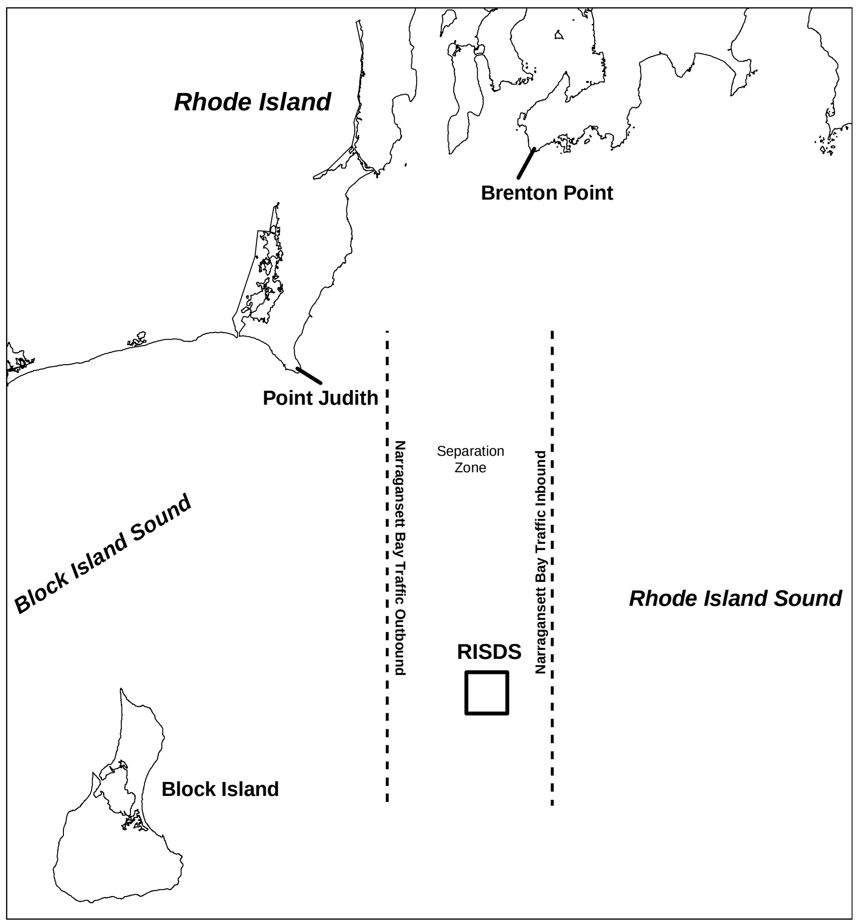
Disposal Plume Tracking and Assessment at the
Rhode Island Sound Disposal Site Spring 2004

Disposal Area Monitoring System DAMOS



D A M O S

DISPOSAL AREA MONITORING SYSTEM

Contribution 166
September 2005

US Army Corps
of Engineers ®
New England District

This report should be cited as:

SAIC. 2005. Disposal Plume Tracking and Assessment at the Rhode Island Sound Disposal Site, Spring 2004. DAMOS Contribution No. 166. US Army Corps of Engineers, New England District, Concord, MA, 184 pp.

REPORT DOCUMENTATION PAGE

form approved
OMB No. 0704-0188

1. AGENCY USE ONLY (LEAVE BLANK)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 2005	FINAL REPORT

4. TITLE AND SUBTITLE
Disposal Plume Tracking and Assessment at the Rhode Island Sound Disposal Site Spring 2004

5. FUNDING NUMBERS

6. AUTHOR(S)
Science Applications International Corporation

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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8. PERFORMING ORGANIZATION REPORT NUMBER
SAIC No. 662

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
US Army Corps of Engineers-New England District
696 Virginia Rd
Concord, MA 01742-2751

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
Contribution No. 166

11. SUPPLEMENTARY NOTES
Available from DAMOS Program Manager, Regulatory Division
USACE-NAE, 696 Virginia Rd, Concord, MA 01742-2751

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT

In accordance with the environmental monitoring plan associated with the Providence River and Harbor Maintenance Dredging Project, the first of two planned sediment plume tracking and assessment surveys was completed over the Rhode Island Sound Disposal Site (RISDS) in April 2004. Survey operations entailed tracking individual sediment plumes generated by the disposal of maintenance material dredged from the Sabin Point Reach of the federal navigational channel. Upon disposal of dredged material at RISDS, oceanographic equipment aboard two survey vessels obtained a variety of measurements related to sediment plume formation and subsequent transport (current speed and direction, physical characteristics of the receiving water, turbidity, etc.) for a period of 3.5 hours following each event. A series of optical and acoustic remote sensors were employed for the collection of digital data, while hydrocasts were obtained for determination of total suspended solids (TSS) concentrations and toxicity.

When initially formed, each plume was characterized as a discrete column of suspended sediment with the size and suspended sediment concentration dependent upon the dimensions of the disposal barge and volume of dredged material disposed. The sediment plumes formed after each disposal event were detectable within the water column both optically and acoustically for a period of three to four hours. The portion of the plume exhibiting the highest concentration of suspended sediments, or centroid, was the primary target of water sampling operations. Although the height of the centroid above the seafloor was a product of oceanographic conditions at the time of the survey, it was often detected at levels 2 to 5 m above the seafloor both immediately following plume formation and for several hours thereafter.

All three plume surveys were conducted during a period of flood tide that varied in duration due to differences in the times of disposal. Water column currents over RISDS displayed minor differences in velocity and direction, with the bulk of the water mass flowing to the west or northwest on each of the three days. As a result, the sediment plumes were transported to the west or northwest in response to the water column currents. In general, turbidity levels decreased rapidly within one hour of disposal through both diffusion and particle settlement. Despite the rapid reduction in suspended particulate matter, each sediment plume remained a distinct feature in the water column and was detectable in both the acoustic backscatter and transmissometer data. Although the data collected as part of this survey suggests the movement of a detectable sediment plume beyond the site boundary is of little environmental significance, it does indicate that refinement of the model calculations used to predict plume behavior at RISDS and subsequent re-distribution of target disposal positions within RISDS could increase plume residence time.

14. SUBJECT TERMS Rhode Island Sound Disposal Site, Dredged Material

15. NUMBER OF TEXT PAGES: 184

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified			

DISPOSAL PLUME TRACKING AND ASSESSMENT
AT THE
RHODE ISLAND SOUND DISPOSAL SITE
SPRING 2004

CONTRIBUTION #166

September 2005

SAIC Report No. 662

Submitted to:

New England District
U.S. Army Corps of Engineers
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EXECUTIVE SUMMARY

In accordance with the environmental monitoring plan associated with the Providence River and Harbor Maintenance Dredging Project, the first of two planned sediment plume tracking and assessment surveys was completed over the Rhode Island Sound Disposal Site (RISDS) in April 2004. The survey effort was sponsored by the Disposal Area Monitoring System (DAMOS) Program, administered by the US Army Corps of Engineers, New England District (NAE). Survey operations over RISDS were completed on 8, 9, and 10 April, tracking individual sediment plumes generated by the disposal of maintenance material dredged from the Sabin Point Reach of the federal navigational channel.

Sediment samples were collected at the dredging site for geotechnical and geochemical characterization during the barge filling process prior to each disposal event. The maintenance material was primarily comprised of silts and clays, and exhibited a water content in excess of 200%. Upon disposal of this material at RISDS, oceanographic equipment aboard two survey vessels obtained a variety of measurements related to sediment plume formation and subsequent transport (current speed and direction, physical characteristics of the receiving water, turbidity, etc.) for a period of 3.5 hours following each event. A series of optical and acoustic remote sensors were employed for the collection of digital data, while hydrocasts were obtained for determination of total suspended solids (TSS) concentrations and toxicity.

A Seabird SBE-32 Carousel System equipped with a conductivity, temperature, and depth (CTD) probe, as well as a series of water sampling bottles, served as the primary instrument on a vessel that continually profiled the water column to measure turbidity. A second vessel was equipped with a downward-looking acoustic Doppler current profiler (ADCP) to examine the relative concentration of entrained sediments within the water column and collect cross-sectional data related to the overall morphology, transport rate, and diffusion of each disposal plume. In addition, a bottom-mounted ADCP mooring and an optical backscatter sensor (OBS) string were deployed in close proximity to the target disposal point to provide information pertaining to movement of the water mass and relative turbidity before and after each disposal event.

Dredged material was placed at Disposal Point B within the northeast quadrant of RISDS on 8 April (Plume 1) and 10 April (Plume 3), and Disposal Point A within the northwest quadrant of the disposal site on 9 April (Plume 2). When initially formed, each plume was characterized as a discrete column of suspended sediment with the size and suspended sediment concentration dependent upon the dimensions of the disposal barge and volume of dredged material disposed. The sediment plumes formed after each disposal event were detectable within the water column both optically and acoustically for a period of three to four hours.

The portion of the plume exhibiting the highest concentration of suspended sediments, or centroid, was the primary target of water sampling operations. Although the height of the centroid above the seafloor was a product of oceanographic conditions at the time of the survey, it was often detected at levels 2 to 5 m above the seafloor both immediately following plume formation and for several hours thereafter. Turbidity measurements made at or near the plume centroid twenty minutes following disposal displayed low light transmittance values at various depth intervals within the water column and TSS concentrations ranging from 24 to 64 $mg \cdot L^{-1}$, strongly contrasting with the ambient seawater, which exhibited background TSS values of 2.0 to 2.9 $mg \cdot L^{-1}$.

All three plume surveys were conducted during a period of flood tide that varied in duration due to differences in the times of disposal. Water column currents over RISDS displayed minor differences in velocity and direction, with the bulk of the water mass flowing to the west or northwest on each of the three days. As a result, the sediment plumes were transported to the west or northwest in response to the water column currents. In general, turbidity levels decreased rapidly within one hour of disposal through both diffusion and particle settlement, exhibiting TSS values $< 10\ mg \cdot L^{-1}$ near the centroid of each plume. Despite the rapid reduction in suspended particulate matter, each sediment plume remained a distinct feature in the water column and was detectable in both the acoustic backscatter and transmissometer data. The influx of ambient seawater and particle settlement over the next 2.5 hours resulted in suspended sediment load reduction near the centroid over time. At 3.5 hours post-placement, the turbidity within the centroid was at or approaching background levels once again.

The sediment plumes tracked during the April 2004 survey operation did leave the confines of the disposal site during the survey, but typically displayed TSS concentrations within the centroid that were comparable to background levels. Residence time within RISDS varied from 75 to 120 minutes, depending upon the target disposal point utilized, as well as the direction and magnitude of water column currents. Although the data collected as part of this survey suggests the movement of a detectable sediment plume beyond the site boundary is of little environmental significance, it does indicate that refinement of the model calculations used to predict plume behavior at RISDS and subsequent re-distribution of target disposal positions within RISDS could increase plume residence time.

Discrete water samples were obtained at or near the plume centroid 40, 60, and 120 minutes post-placement as part of the Plume 1 and 2 surveys for toxicity analysis. After a 96-hour exposure to waters collected from the plume, neither the mysid (*Americamysis bahia)* nor juvenile silverside (*Menidia berylina*) test organisms exhibited a lethal response. This was the anticipated outcome given the source of the sediment (Sabin Point Reach) and the amount of dilution that occurs within the water column during the formation of the sediment plume and its subsequent advection by ambient currents.

1.0 INTRODUCTION

This report presents the results of a marine environmental monitoring survey performed within the Rhode Island Sound Disposal Site (RISDS) as part of the first phase of a sediment plume tracking and assessment study. The information acquired from this survey will be used to estimate sediment plume transport rate, distance, and dilution over time. Furthermore, results from this study will provide information pertaining to the ecological effects of sediment plumes and aid in the future management of dredged material placement at RISDS.

1.1 Background

Dredging activity along the New England coast is overseen by the US Army Corps of Engineers, New England District (NAE). Monitoring of the impacts associated with the subaqueous disposal of sediments dredged from harbors, inlets, and bays in the New England region has been overseen by the Disposal Area Monitoring System (DAMOS). Established in 1977, the goals of the DAMOS program pertain to detailed investigation of dredging and dredged material disposal practices to minimize any adverse physical, chemical, or biological impacts. The activity sponsored by DAMOS helps to ensure that the effects of sediment deposition on the marine environment within pre-defined areas of seafloor are local and temporary. A flexible, tiered management protocol is applied in the long-term monitoring of sediment disposal at ten open-water dredged material disposal sites along the coast of New England (Germano et al. 1994).

Major dredging activity in Rhode Island waters has not occurred in approximately 25 years, since the Providence River and Harbor Navigation Project was completed in 1976. Prior to dredging activities in 1976, the last significant dredging (2,060,000 m^3) occurred in 1971 in the Federal Navigation Channel and resulted in a deepening of the channel from 35 ft Mean Lower Low Water (MLLW) to 40 ft MLLW (USACE 2001). Over the past 20 years, there has been significant shoaling (ranging from 1 to 4 m) of the Providence River shipping channel as a result of sedimentation, thus creating potentially hazardous navigation conditions, restricting access for large vessels in route to the Port of Providence, and reducing the economic value of the Port.

1.2 Providence River Federal Navigation Project

The Providence River comprises the headwaters of Narragansett Bay and is formed by the confluence of the Woonasquatucket and Moshassuck Rivers emanating from northern Rhode Island. Providence River flows through downtown Providence, emptying into Narragansett Bay. The East Passage of Narragansett Bay serves as an integral shipping channel for Rhode Island, with the Providence River and Harbor representing the principal commercial port in Rhode Island. Deep-draft vessel traffic in Providence River and Harbor includes tankers, barges, and general cargo vessels. In particular, Providence Harbor is an unloading point for the region's supply of refined petroleum products, and oil tankers must maintain access to Providence to ensure a steady energy supply for the state (USACE 2001). Furthermore, there are numerous marine terminal facilities within the Port of Providence that serve the commercial fishing and industrial transport fleet.

The Federal Navigation Channel is 16.8 miles long and runs from Providence Harbor following the Providence River south to deeper waters near Prudence Island (USACE 2001; Figure 1-1). Although the channel has an authorized depth of 40 ft and width of 600 ft, shoaling of the channel has resulted in depths as shallow as 30 ft. Shallower depths have forced restrictions on vessel traffic, which could result in both environmental and economic problems. The Providence River and Harbor Maintenance Dredging Project's fundamental purpose is to restore the depth and width of the channel to meet existing economic and safety needs. To fully restore the channel to its authorized dimensions and restore safe navigation requires the removal of approximately 3.3 million cubic meters of sediment and disposing of the material at various subaqueous disposal sites (USACE 2001). Until recently, there was no available ocean disposal site in Rhode Island waters capable of accepting large volumes of dredged material that are determined to be suitable for unconfined open water disposal.

The current Providence River and Harbor Maintenance Dredging Project involves the dredging of approximately 2.1 million cubic meters of suitable maintenance material (material that meets the ocean disposal testing requirements) to be placed at recently selected Rhode Island Sound Disposal Site (RISDS). In conjunction with the federal maintenance project, a small group of private facilities, marine terminals and other facilities may use the active disposal site for additional non-federal maintenance and improvement dredging projects (USACE 2001). An estimated 380,000 m^3 of sediment is expected to be dredged from these smaller projects and deposited at RISDS. In addition, because of the industrialization of Providence Harbor and associated contamination of the in-place sediments, roughly 920,000 m^3 of material is considered unsuitable for unconfined open water disposal. As a result, this material will be placed into a series of Confined Aquatic Disposal (CAD) cells located in the upper portion of the river (Fox Point Reach) in order to isolate the contaminants from the marine environment. To create the CAD cells, an estimated 1.5 million cubic meters of sediment was dredged within Fox Point Reach and deposited at RISDS.

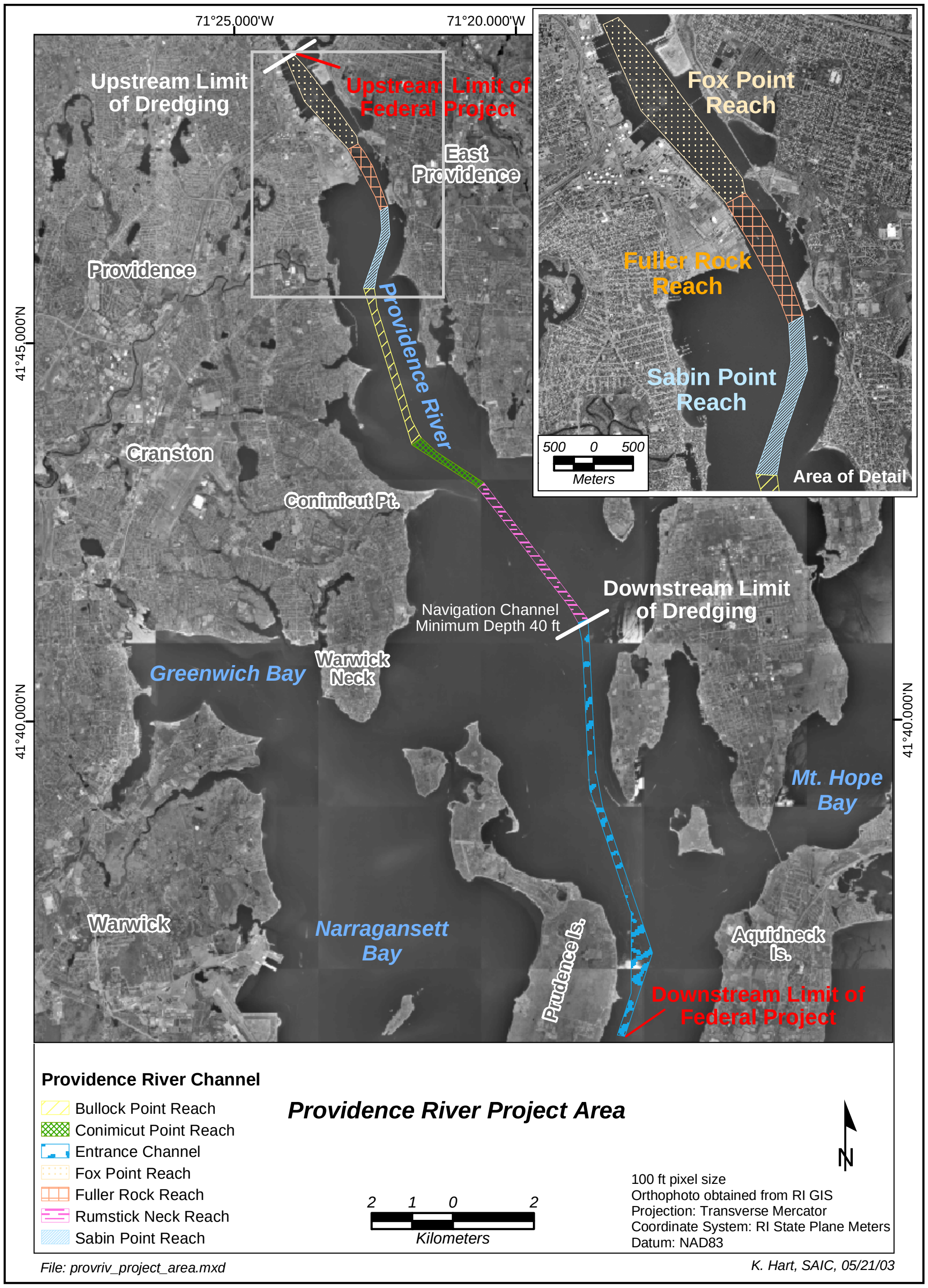


Figure 1-1. Providence River maintenance dredging project area and associated project limits

1.3 Rhode Island Sound Disposal Site

The Rhode Island Sound Disposal Site (RISDS) has been selected for the unconfined disposal of dredged sediments from the Providence River and Harbor Maintenance Dredging Project. The disposal site is defined as an 1800 x 1800 m area of seafloor centered at 41° 13.850´ N, 71° 22.817´ W (NAD 83). The offshore disposal site is located in Rhode Island Sound approximately 31 nmi (58 km) from Providence Harbor and 11 nmi (21 km) south of the entrance of Narragansett Bay (Figure 1-2). RISDS is positioned within the Separation Zone for the Narragansett Bay Inbound and Outbound Traffic Lanes. A detailed, baseline multibeam bathymetric survey encompassing a 4000 x 3800 m area surrounding RISDS was completed in February 2003. Results of the survey confirmed that the disposal site is located in a topographic depression, with water depths ranging from 36 to 39 m. From 13 April 2003 through February 2004, a total estimated volume of 2,825,000 m^3 of dredged material was placed within RISDS. The disposal of material generated from both the federal and non-federal maintenance projects is anticipated to result in a total estimated volume of 3.6 million cubic meters of sediment deposited at RISDS.

1.4 Management Strategy

Dredging in New England waters typically involves the use of a clamshell bucket to extract rock, sand, gravel, mud and clay from the bottom of waterways and transfer the material to barges or on-shore facilities for disposal. The majority of material intended for disposal at the RISDS is fine-grained estuarine sediments (silts) derived from dredging within the lower reaches of the navigation channel (Figure 1-1). However a percentage of the material has been removed from the upper region of the river to create the CAD cells. These sediments consist of basement material that underlies the estuarine deposit and is composed of a mixture of gravel, sand, and clay (glacial till). All sediment excavated as part of the Providence River project was removed by clamshell bucket and transferred to disposal barges with capacities ranging from approximately 4,000 yd^3 (3,000 m^3) to 6,000 yd^3 (4,600 m^3). The material generated from dredging operations has been and will continue to be transported to RISDS by the disposal barges and deposited at various predetermined disposal points within the disposal site. Due to various environmental concerns within the Providence River and Narragansett Bay, the dredging project is subject to a strict schedule, or sequencing, to minimize the overall impact to various biological resources that utilize Narragansett Bay.

A percentage of the sediments located in this area are classified as unsuitable for unconfined open water disposal and require specialized handling techniques for proper

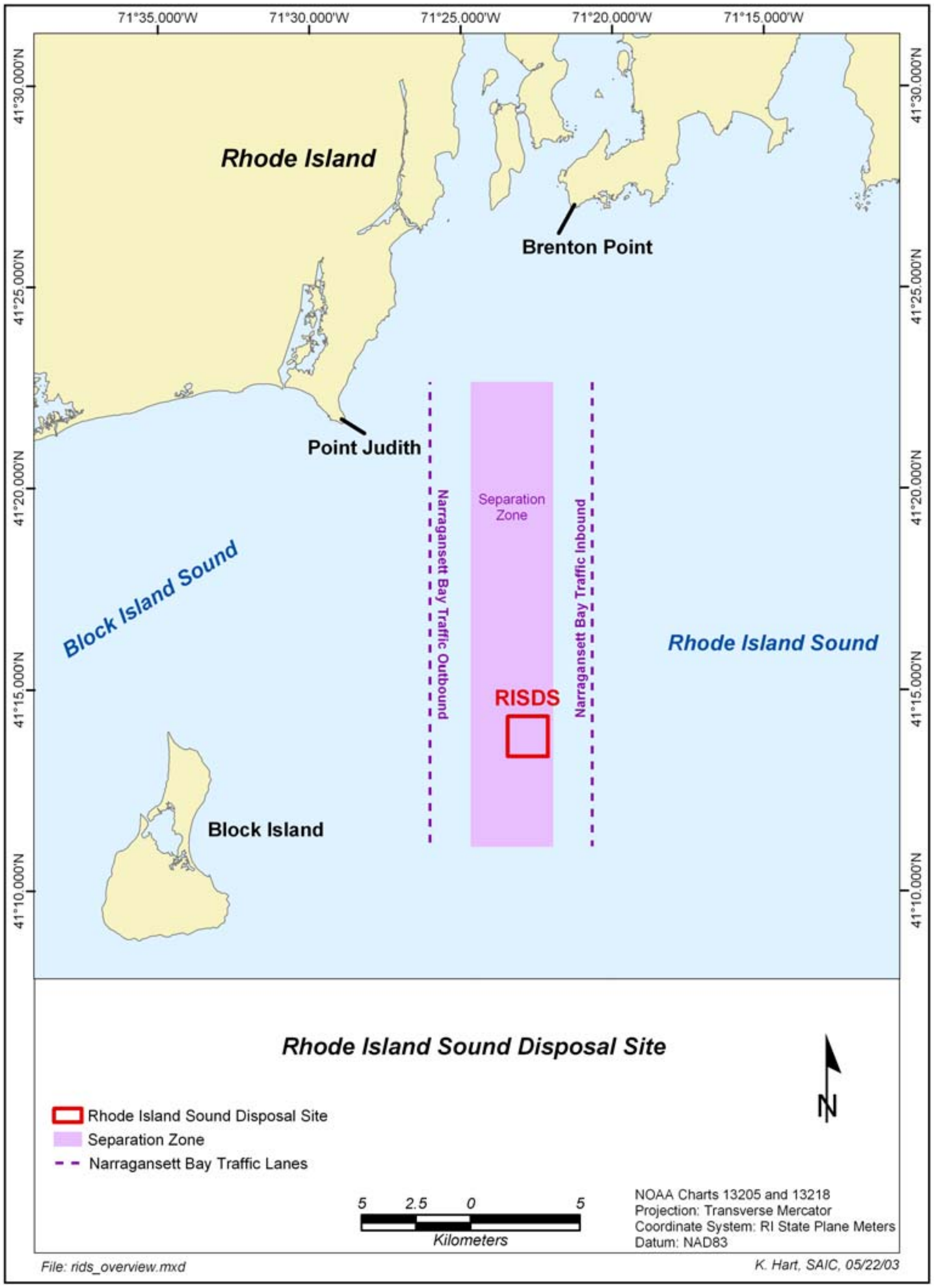


Figure 1-2. Location of the Rhode Island Sound Disposal Site within Rhode Island Sound relative to the coast of southern Rhode Island and adjacent to Block Island (RI).

disposal. Applying the knowledge gained from close monitoring and management of other open water disposal sites in the New England region, it was decided that the volumes of glacial till from the construction of CAD cells could have a beneficial use at RISDS. Because of its physical composition, the mix of glacial till, clay, and sand removed from the river as part of the CAD cell construction process was strategically placed at eleven predetermined disposal points (Targets 1-11) in an effort to form a continuous ridge of sediment along the western boundary of RISDS (Figure 1-3). The development of a containment structure along the western boundary of the disposal site would enhance the containment properties of the open water disposal site and minimize the lateral spread of unconsolidated sediments to be deposited at RISDS during future stages of the project. This western ridge augments a naturally occurring ridge surrounding the remaining sides of a depression located in the southeast corner of the disposal site.

Between February 2003 and February 2004 several post-disposal bathymetric surveys were conducted over the RISDS as part of the disposal site monitoring plan to examine the development of this artificial containment ridge constructed along the western boundary of the disposal site (SAIC 2004a). As of February 2004, an artificial containment cell had been formed at RISDS, essentially increasing the bottom relief of the natural depression to increase its overall capacity from 500,000 m^3 to 2.6 million cubic meters as of February 2004. This enclosed containment structure will continue to be developed as the Providence River dredging project progresses, ultimately minimizing the lateral spread of an estimated 2.1 million cubic meters of unconsolidated sediments to be deposited at RISDS during future stages of the project. As the Providence River maintenance dredging project progressed, the placement of fine-grained estuarine sediments removed from the southern reaches of the Providence River navigation channel were directed to additional target disposal locations within RISDS (Figure 1-3). The actual usage of these points is dependent upon the stage of the tide and likely transport of the sediment plume in the water column.

1.5 Sediment Plume Formation

When a barge load of sediment is deposited at an open-water disposal site, the dredged material goes through multiple phases of descent as it settles to the seafloor: convective descent, dynamic collapse, and passive dispersion (SAIC 1988a; Figure 1-4). Although most of the dredged material released from a disposal barge during open water placement operations travels directly to the bottom through the convective descent phase to form a deposit on the seafloor, each disposal event has the potential of creating a disposal plume comprised of sediments entrained in the water column. Dredged material disposal studies have estimated that 1 to 5% of an individual barge volume placed at an open water disposal site remains entrained within the water column, forming a cloud that may persist

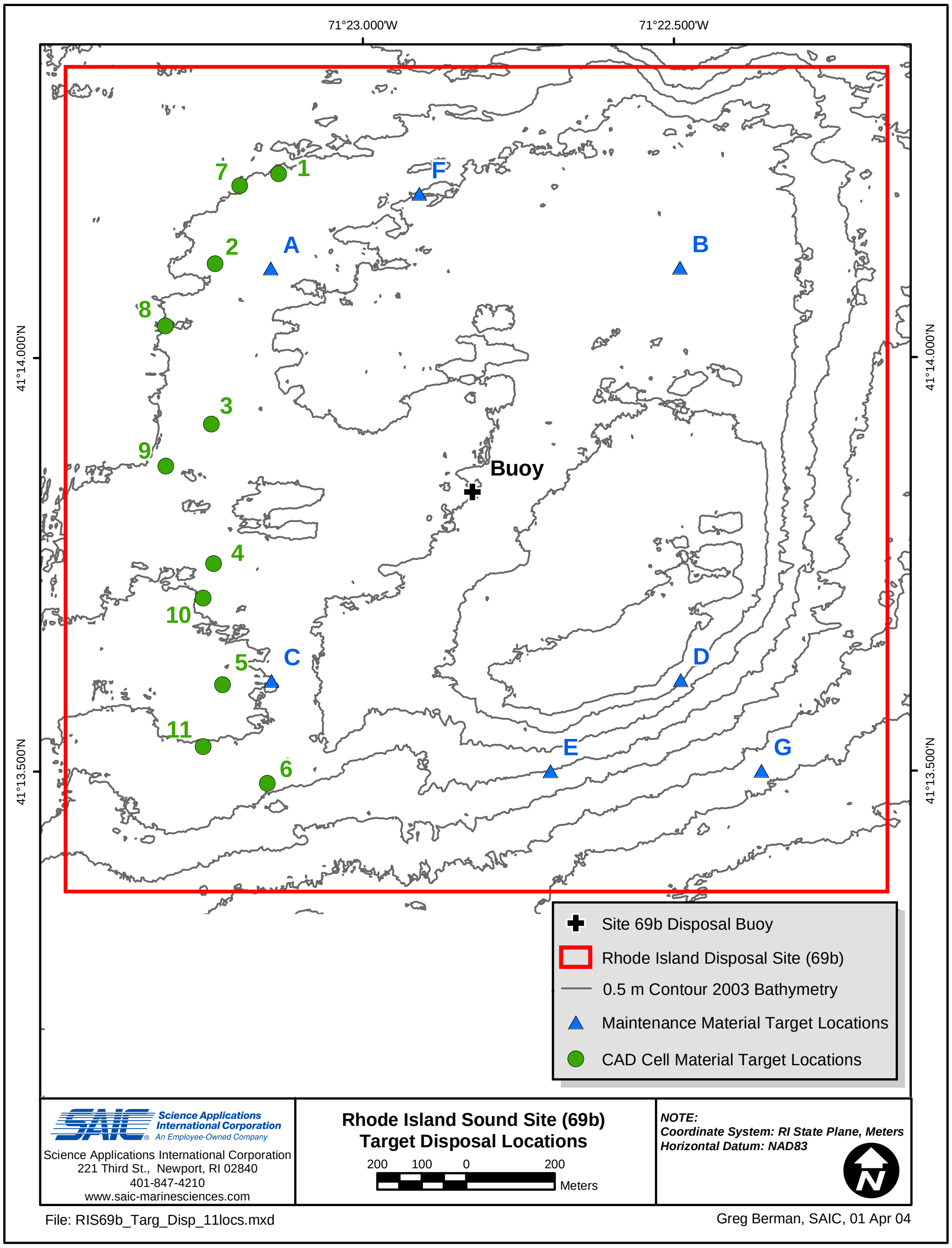


Figure 1-3. Location of the target disposal locations for maintenance material (blue) and CAD cell material (green) relative to the boundaries of RISDS.

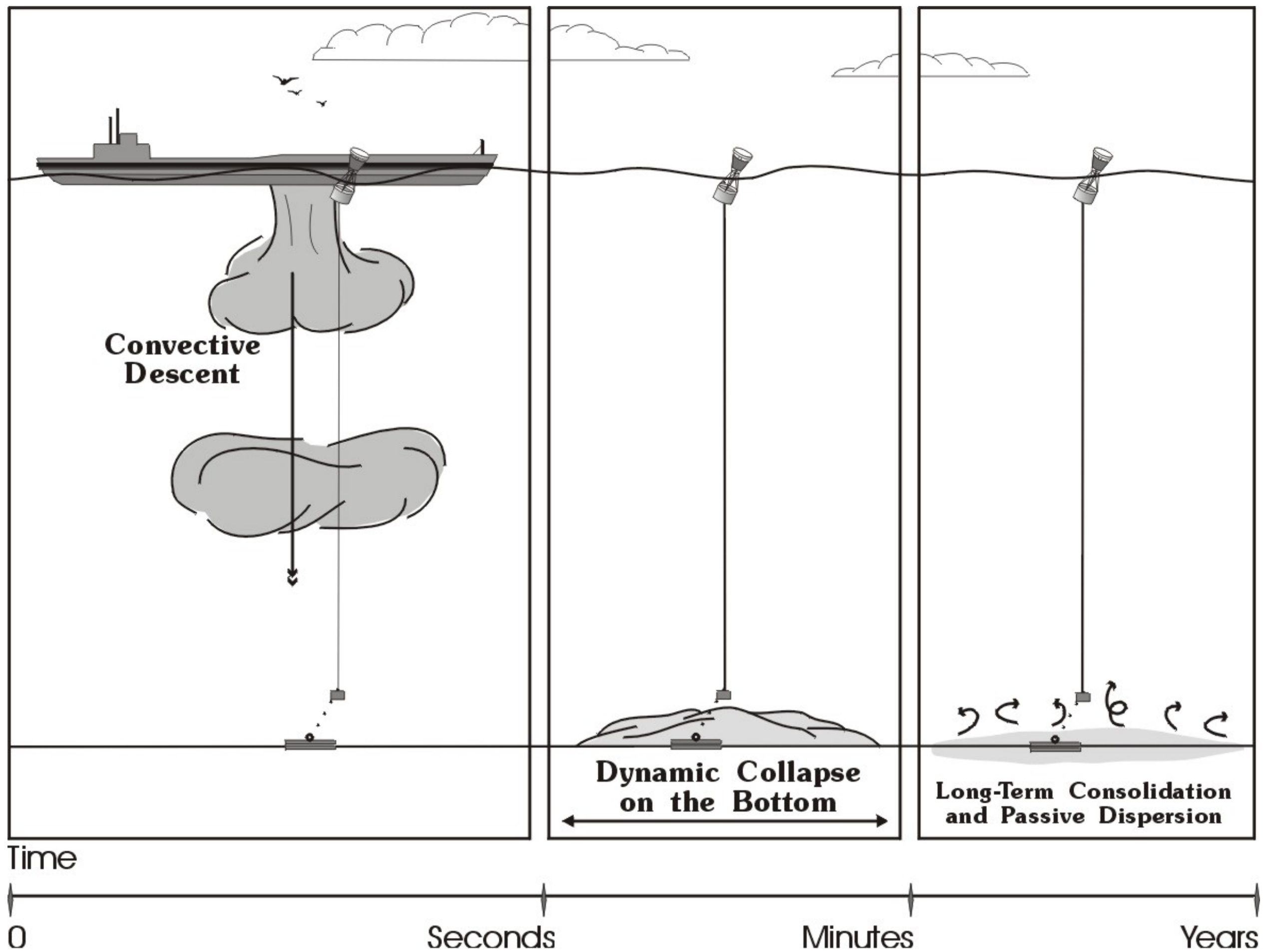


Figure 1-4. Schematic diagram of the three phases of descent encountered during a dredged material disposal event.

at various depth horizons and be advected by the ambient currents (Tavolaro 1984; Truitt 1986). As the sediment mass impacts the seafloor at the end of the convective descent phase, the kinetic energy in the vertical axis is translated to a more horizontal transport. The net result is an annulus of turbidity that travels outward above the seafloor in all directions during the dynamic collapse phase. In addition, the impact of a large volume of material on the seafloor typically induces small-scale resuspension of the upper layer of in-place sediments, which contribute to the turbid, near-bottom plume of suspended sediments originating from the barge. However, as the disposal plume moves with the water mass over time, suspended sediment particles continue to settle to the seafloor and suspended solids concentrations (turbidity) gradually return to background levels as surrounding seawater dilutes the cloud of entrained material.

The behavior and morphology of a disposal plume is the product of the composition of the entrained sediments (typically fine-grained, unconsolidated silts and clays) and the oceanographic conditions at the open-water disposal site at the time of placement, as well several hours after the disposal event. Physical oceanographic studies conducted over RISDS indicated that water column currents generally follow a northwest/southeast direction as the semi-diurnal (twice daily) tide floods and ebbs in the region (USACE 2001). Therefore, individual disposal events are directed to appropriate areas of the disposal site to maximize the time that the suspended sediment plumes will remain within the RISDS boundaries. It has been determined that during a flood tide, water column currents predominantly flow toward the northwest, prompting placement of sediment at predetermined disposal points within southern and eastern quadrants of the disposal site. This would allow for transport of the plume in the northwesterly direction and thus maximize particle settlement within the disposal site boundaries. Alternatively, when the tide is ebbing (flowing in a southeasterly direction), disposal will occur in the northern or western quadrants of RISDS to ensure that the majority of the entrained sediment in the water column settles, and turbidity values return to near-background levels prior to the plume leaving the disposal site boundaries.

Since the disposal operations at RISDS began in April 2003, fine-grained, estuarine maintenance material has been strategically placed at a series of disposal points (Figure 1-3) in order to ensure that the majority of the sediment is contained within the confines of the disposal site, as well as comply with water quality criteria outside the area defined as the “mixing zone”. These disposal points were developed by the NAE in coordination with the Engineering Research, Development Center (ERDC) using Short Term Fate (STFATE) modeling to predict the concentration and morphology of a typical sediment plume. Sediment plumes following release of Providence Harbor dredged sediment at RISDS are generally expected to dissipate within a few hours of the corresponding disposal event.

The US EPA, Region 1 and NAE have an interest in studying the actual morphology of disposal plumes consisting of fine-grained maintenance material dredged from the Providence River and any resuspended material resulting from placement on the seafloor. Determinations of the plume transport rate, distance, and dilution were needed to compare with estimates made by the STFATE model during the evaluation of the project and included within the Final Environmental Impact Statement (FEIS). The focus of the April 2004 field effort described herein was to observe the movement and morphology of sediment plumes and to evaluate short-term impacts with regards to water column turbidity and toxicity. This report documents the findings of the April 2004 survey examining three plumes generated by the disposal of sediment dredged from the Sabin Point Reach of Providence River.

1.6 Survey Objectives and Predictions

As part of the monitoring activities sponsored under DAMOS, SAIC conducted an environmental survey within RISDS. A comprehensive plume tracking survey involving water sampling, turbidity analysis, and plume transport measurements was performed in April 2004. The primary objectives of this survey were to:

1) Track the extent and concentration of the suspended sediment plume during three separate disposal events at RISDS; and

2) Assess the acute toxicity of the sediment plume to marine column organisms.

The April 2004 field effort tested the following predictions:

1) Plume total suspended solids (TSS) concentrations will decrease to 10 $mg \cdot L^{-1}$ or less in the centroid of the plumes within three hours.

2) Water collected from the centroid (most concentrated portion) of the plumes will not exhibit toxicity that is significantly different from background conditions at RISDS within one hour of sediment disposal.

To address the first objective, a variety of vessel-mounted systems, moored sensors, and drifting devices were used to track the plume created by the release of dredged sediment, and to acquire data on turbidity levels within the water column down-current of the disposal operation during the first few hours after material release from the disposal barge. In addition, a water sampling survey was conducted to collect water for total suspended solid (TSS) analysis and water column bioassays.

2.0 METHODS

2.1 Field Operations

The following section provides an overview of the monitoring activities within RISDS in support of the Providence River and Harbor Maintenance Dredging Project. The objective of the April 2004 survey was to track the extent and concentration of the suspended sediment plume during three separate disposal events at RISDS. The three separate plume-tracking events constituted the first of two distinct monitoring events within RISDS. A second plume monitoring survey utilizing identical sampling techniques will be performed during the disposal of material dredged from the Fuller Rock Reach.

The first plume-tracking survey effort was comprised of three consecutive days of sampling to minimize mobilization efforts and potential effects of any temporal changes in water column characteristics (i.e., density stratification), as they would affect the behavior of suspended sediment plumes. Survey operations were conducted aboard the M/V Beavertail and R/V Eastern Surveyor from 8 to 10 April 2004. Field data collection efforts consisted of sediment plume tracking employing acoustic Doppler current profilers (ADCPs), optical backscatter sensors (OBS), a high-resolution Conductivity-Temperature-Depth (CTD) profiling system, a transmissometer, surface and subsurface current drogues, as well as the collection of water samples for total suspended solids (TSS) and toxicity analysis. The plumes generated by the disposal of sediments dredged from the Sabin Point Reach of Providence River were subjected to comprehensive sampling and analysis. Individual barge loads 754 (4,600 m^3), 758 (4,600 m^3), and 763 (3,200 m^3) were periodically sampled during the loading process at the dredging site, and targeted by survey operations at RISDS. Table A-1 in Appendix A provides a summary of the naming convention for the various samples and files generated during the three-day field effort.

The basic plume-tracking program consisted of a two-vessel sampling operation. One vessel (R/V Eastern Surveyor) was primarily responsible for deploying and tracking the current drogues, as well as conducting the periodic water sampling and vertical CTD/transmissometer/OBS profiling operations within the densest portion of the plume. The second vessel (M/V Beavertail) was responsible for conducting the cross-plume and along-plume vessel-mounted ADCP transects to map the track and lateral extent of the plume, as well as deploy and retrieve a bottom-mounted ADCP mooring and OBS sensor string placed in the anticipated path of the sediment cloud. Though the shipboard ADCP data requires post-processing to fully evaluate the track and the extent of the plume, these data, along with the vertical CTD/transmissometer/OBS data, were viewed in real-time to assist with plume location activities and direction of the water sampling operations.

2.2 Barge Sampling

2.2.1 Sampling Design and Field Methods

In coordination with the NAE Project Manager for the Providence River and Harbor Maintenance Dredging Project, a series of dredging/placement events were targeted for monitoring based primarily on the requirement to examine the plumes generated by sediments dredged from specific reaches of the navigational channel. Sediment samples for chemical [trace metals and polycyclic aromatic hydrocarbons (PAHs)] and geotechnical (grain size and moisture content) analyses were collected from the individual barge loads of sediment identified for disposal plume tracking operations at RISDS. Representative sediment sub-samples were obtained from the disposal barges by obtaining discrete samples from the bow and stern of each disposal barge at one-hour intervals during an approximately four-hour barge loading process. The selection of a barge-load for sampling required coordination between SAIC and the on-site NAE Resident Engineer and was primarily dependent on anticipated timing of the barge's arrival at RISDS.

A 0.04 m^2 Van-Veen sediment grab sampler was used to collect sufficient sediment from the barge to enable laboratory bulk chemical and geotechnical analyses. The grab samples were composited to create a single representative sub-sample of the material within the disposal barge. The sediment from each barge was mixed (composited) in a pre-cleaned High Density Polyethylene (HDPE) five-gallon bucket, sub-sampled, placed in a series of pre-cleaned glass jars (500 ml), and stored on ice prior to and during shipment to the analytical laboratory.

2.2.2 Laboratory Analysis Methods

All sediment samples were handled in accordance with recommended procedures in the Inland Testing Manual (EPA/USACE 1998) and delivered to the Woods Hole Group Environmental Laboratories (WHG) in Raynham, Massachusetts as specified by the NAE Project Manager. The samples were analyzed for polycyclic aromatic hydrocarbons (PAHs), and a suite of trace metals including arsenic (As), cadmium (Cd), chromium (Cr), mercury (Hg), lead (Pb), copper (Cu), nickel (Ni), and zinc (Zn). The actual analytical methods employed are summarized in Table 2-1.

Table 2-1. Methods for Chemical Analysis of the 2004 Barge Samples

Subsample	Analysis	Method	Instrumentation
		SW-846 Method* (USEPA 1997)	
All samples	Total Organic Carbon	9060	
All samples	PAHs	3550A/8270	GC/MS
All samples	Trace Metals		
	Arsenic	3051/6020	ICP-MS
	Cadmium	3051/6020	ICP-MS
	Chromium	3051/6020	ICP-MS
	Copper	3051/6020	ICP-MS
	Lead	3051/6020	ICP-MS
	Mercury	NA/7471	CVAA
	Nickel	3051/6020	ICP-MS
	Zinc	3051/6020	ICP-MS

* First value refers to extraction/digestion method, second value refers to analysis method.
PAHs = Polycyclic aromatic hydrocarbons
NA =Not Applicable
GC/MS = Gas Chromatograph/Mass Spectrometry
ICP-MS = Inductively Coupled Plasma Mass Spectrometry
CVAA = Cold Vapor Atomic Absorption

2.2.2.1 Polycyclic Aromatic Hydrocarbons (PAHs)

Sediment Extraction

According to WHG Standard Operating Procedures, the sediment samples were spiked with surrogate compounds, and extracted by pressurized fluid extraction (Dionex Accelerated Solvent Extractor Model 200) using a methylene chloride acetone solvent solution.

Sediment Analysis

The samples were concentrated and then analyzed using a modified version of EPA SW-846 Method 8270 (USEPA 1997). Analysis of PAHs by Gas Chromatography/Mass Spectrometry with Selected Ion Monitoring (Method 8270-PAH-SIM Revision 0; GC/MS-SIM) is a WHG Standard Operating Procedure and a more rigorous method than the Standard Method 8270. The sample extract containing the semi-volatile compounds was injected into a gas chromatograph (GC) with a narrow-bore fused-silica capillary column. The temperature-programmed GC column separated the analytes, which were detected with a mass spectrometer with selected ion monitoring. In this method of analysis, qualitative identifications are confirmed by analyzing standards under the same conditions used for samples and comparing mass spectra and GC retention times. The mass spectra of the target analytes were compared with the electron-impact spectra of authentic standards for identification. Quantification was based on a multi-level initial calibration.

2.2.2.2 Trace Metals

Sediment Digestion

Sediments require acid digestion for extraction and detection of trace metals. The WHG utilized EPA SW-846 Method 3051 (USEPA 1997), which provides a rapid multi-element acid leach of sediments. A representative sample of up to 0.5 g was placed in a fluorocarbon microwave vessel with 10 ml of concentrated nitric acid. The vessel was capped and heated in the laboratory microwave for 10 minutes. The acid digests the sample at high temperatures. After cooling, the vessel contents were filtered, centrifuged, or allowed to settle and then diluted to volume and analyzed.

Sediment Analysis

To determine concentrations of As, Cd, Cr, Pb, Cu, Ni, and Zn, the samples were analyzed using EPA SW-846 Method 6020 (USEPA 1997), involving inductively coupled plasma mass spectrometry (ICP-MS). EPA SW-846 Method 7471 (USEPA 1997) was used to detect Hg levels using cold vapor atomic absorption (CVAA). The Hg was reduced to the elemental state and aerated from solution in a closed system. The mercury vapor passed through a cell positioned in the light path of an atomic absorption spectrometer. Absorbance (peak height) was measured as a function of mercury concentration.

2.2.2.3 Sediment Grain Size, Total Organic Carbon, and Moisture Content

Sediment Grain Size

Grain size analysis was conducted by Applied Marine Sciences (AMS), using American Society for Testing and Materials (ASTM) Method D422. A sieve analysis was performed in which the sample was separated into size fractions (particle size diameters) of greater than 0.0625 mm (sand and gravel), and less than or equal to 0.0625 mm. The wet sieve and dry sieve fractions less than 0.0625 mm (silt and clay) were combined for each sample. The silt and clay fraction was then subdivided using a hydrometer technique, which is based upon differential settling rates of particles. The data on grain size were converted from their respective units to percent of gravel and sand, silt, and clay. For the purpose of this study the following grain size distinction is utilized: gravel (>2.0 mm), coarse sand (0.5 –2.0 mm), medium sand (0.25–0.50 mm), fine sand (0.125–0.25 mm), very fine sand (0.0625–0.125 mm), silt (0.0039–0.0625 mm) and clay (<0.0039 mm).

Water Content

In conjunction with sediment grain size analyses, water content was determined using ASTM Method D2216. This method defines water content as the ratio of the mass of water contained in the pore spaces of soil or rock material to the solid mass of particles in that material, and expresses it as a percent. Since this represents the ratio of water to sediment particles, values in excess of 100% are common.

2.3 Navigation and Survey Control

During field operations conducted in April 2004, both survey vessels were equipped with Trimble DSM212L Differential Global Positioning System (DGPS) receivers to provide precise navigation data. Because of its proximity to the survey area, the U.S. Coast Guard differential beacon broadcasting from Moriches, NY (293 kHz) was used for generating the real-time differential corrections for the DGPS positions. During survey operations, the vessel-based navigation system output real-time navigation data at a rate of once per second to an accuracy of ±3 m in the horizontal control of North American Datum of 1983 (NAD 83-Latitude and Longitude). Prior to departure from the dock on each field survey day, the proper operation of the navigation system was confirmed by comparing the output DGPS position with the known position of a point on the dock.

In addition, the navigation systems on both vessels utilized Coastal Oceanographic's HYPACK® Max survey and data acquisition software to provide the real-time data display and logging of the vessel position and depth sounding data. Prior to field operations, HYPACK® Max was used to define a State Plane grid (Rhode Island State Plane Coordinates) around the survey area and to establish the planned survey lines that would be occupied by the roving vessel with the downward-looking ADCP. During the survey operations, the incoming navigation data were translated into state plane coordinates, time-tagged, and stored within HYPACK® Max. Depending on the type of field operations being conducted, the real-time navigation information was displayed in a variety of user-defined modes within HYPACK® Max.

2.4 Water Column Properties (Plume Tracking)

2.4.1 Turbidity

Using various types of monitoring equipment and survey techniques, the centroid of each sediment plume was identified and water samples were collected to determine the suspended solids concentration and toxicity within the densest portion of the plume following the three dredged material placement events monitored.

2.4.1.1 Real-time CTD Profiles

A Seabird Electronics SBE-19® conductivity-temperature-depth (CTD) profiler integrated with a Wet-Labs C-Star, 25 cm path length transmissometer, and a Seapoint optical backscatter (OBS) sensor were mounted within a Seabird (Model SBE-32) Carousel Water Sampler to collect and display vertical profiles of the water column in real-time, and thus aid decisions on the timing and depth of discrete water sample collection (Figure 2-1). The SBE-32 Carousel unit was controlled by a Seabird SBE-33 deck unit to facilitate the transmission of real-time CTD data and serve as the triggering mechanism for individual water sampling bottles. The CTD profiling system provided real-time display of sensor depth and water column properties (e.g., turbidity, salinity, density, etc.) to facilitate quality control and assurance that monitoring objectives were being met. Real-time

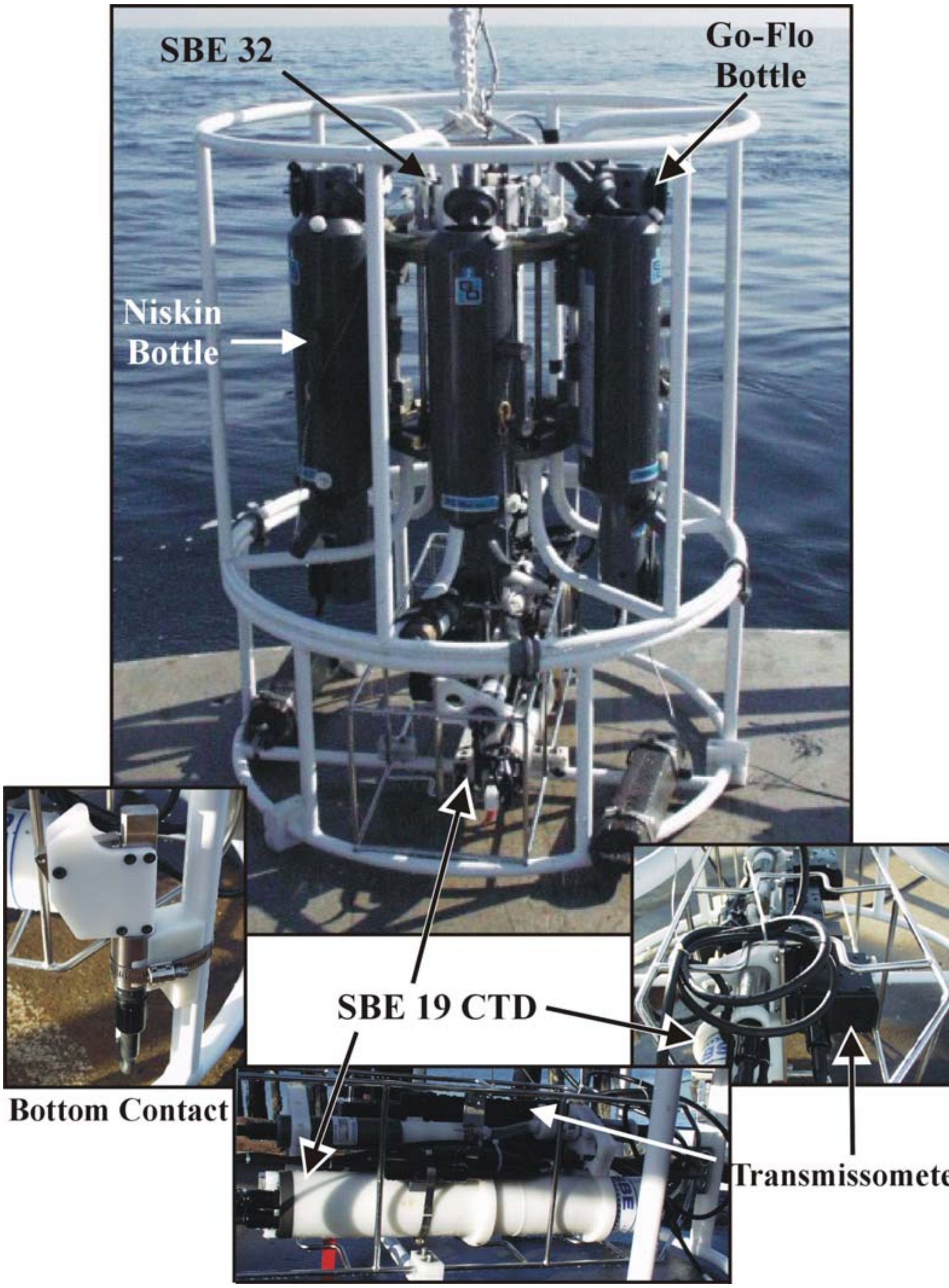


Figure 2-1. Photograph of the Seabird (Model SBE-32) Carousel Water Sampler used for plume tracking and water quality monitoring.

viewing of the vertical distribution of turbidity concentration allowed careful selection of the optimum depth for collection of discrete water samples. The real-time data provided by the transmissometer were used to determine the depth, thickness, and maximum turbidity at the centroid of the plume.

The CTD profiling system was also equipped with a bottom-contact switch, which was attached to a small weight suspended approximately 3 m below the level of the water sampling bottles on the Carousel. During each lowering, the CTD descent rate was initially about 0.5 $m \cdot s^{-1}$, but was decreased to approximately 0.1 $m \cdot s^{-1}$ within the lower 5 m of the water column. When the small weight that was suspended beneath the CTD touched the seafloor, this contact was indicated on the real-time display and the CTD operator immediately directed the winch operator to stop the winch. This procedure prevented the CTD from making contact with the seafloor, and thus eliminated unwanted resuspension of bottom sediment, as this would have created a plume of suspended ambient sediment that would have interfered with measuring the dredged material plume.

The CTD/transmissometer, in conjunction with the towed ADCP and current-following drogues was used to locate, delineate, and track the plumes associated with the release of dredged material from the barge. The water column profiling surveys followed the plume as it traveled with the ambient currents during the three and one-half hours after each placement event. Water column turbidity measurements were monitored continuously and the centroid of the plume was identified using the Wet-Labs optical beam transmissometer (660 nm wavelength), which measured the amount of light transmitted through the seawater over the 25 cm path length of the instrument. A low value of measured light transmittance represented a relatively high concentration of suspended particulate matter (turbidity) in the water column. Because the main focus of the plume monitoring study was to track the movement and temporal evolution of the suspended sediment plume after release of dredged material from the barge, emphasis was placed on the real-time assessment of numerous vertical profiles of turbidity (percent light transmittance).

2.4.1.2 Total Suspended Solids (TSS)

Sampling Design and Field Methods

Water samples were collected during the monitoring operations to facilitate post-survey analysis of total suspended solids (TSS) concentration. In addition to the in-situ measurement capabilities of the CTD profiling system, the electronics of the CTD were interfaced to the Seabird Carousel Water Sampling device for collection of discrete water samples. The Carousel was equipped with six 5-liter Niskin and two 2.5-liter GO-FLO water-sampling bottles to allow hydrocasts concurrent with the real-time vertical CTD profiles. Water samples were collected at various times during the disposal operation to monitor temporal variations in TSS concentration at predetermined, downstream sampling locations and at various positions in the water column (e.g., surface, mid-depth, and near-bottom). During water sample collection, the Carousel and CTD were lowered and raised (yo-yoed) in the water column for continuous monitoring of turbidity. As discussed above, the Carousel unit was controlled by a Seabird SBE-33 deck unit to facilitate the transmission of real-time CTD data and serve as the triggering unit for the water sampling bottles.

Individual Niskin-type sampling bottles were located approximately 1 m above the transmissometer and fired at predetermined time intervals to collect water samples for post-survey laboratory analysis of TSS. Water samples were collected for TSS measurement within the densest portion of the plume at 10, 20, 40, 60, 90, 120, 150, and 210 minutes after the placement event (Table 2-2). At each sampling time, three separate 1 liter samples (triplicates) were drawn from a single Niskin bottle. The bottom contact switch on the Carousel unit ensured that the lowest water sample was obtained approximately 3 m above the seafloor to prevent localized sediment resuspension caused by the CTD/Carousel unit touching bottom. The vertical CTD profile data gave the on-board scientist the ability to view, in real-time, the turbidity profile and then select the optimum depth for water sample collection (at the depth of highest turbidity in the vertical profile). Horizontal positioning of the CTD survey vessel in the right spatial location within the plume was based upon: 1) real-time assessment of drogue tracks, and 2) constant communication with the roving vessel with the downward-looking ADCP (backscatter profiler).

A total of 81 water samples (27 samples for three individual events) for TSS analysis were acquired during the survey operations. In addition, at least three background samples were collected prior to the placement event within 5 m of the seafloor. Samples obtained during the first two days of the survey (S1D1 and S1D2) were associated with plumes from dredged material released from a 6,000 yd^3 capacity barge (loads 754 and 758). The last day of water sampling (S1D3) was associated with the plume resulting from dredged material released from a smaller 4,000 yd^3 capacity barge (Load 763). A naming convention for the RISDS water samples was established prior to survey activities and can be found in Appendix A. The TSS results were compared with concurrent, co-located, in-situ measurements of turbidity acquired by the transmissometer and OBS sensors integrated into the CTD vertical profiling system.

Laboratory Analysis Methods

Standard chain of custody protocols were followed during the water sampling

Table 2-2.

Sampling Scheme for the Collection of Water Samples as part of Plume Monitoring Operations over RISDS

* **T0**	Background
T1	**10 min**
T2	**20 min**
***T3**	**40 min**
***T4**	**60 min**
T5	**90 min**
***T6**	**120 min**
T7	**150 min**
T8	**210 min**

* Toxicity Samples (collected on 8 April and 9 April 2004 only)

operations and shipment operations. Following the survey, the discrete 1 liter water samples were shipped to Aquatec Biological Sciences, Inc. in Williston, VT for TSS analysis. Sample replicates were obtained at several of the sampling stations to provide quality assurance checks for the TSS laboratory results. To determine TSS concentration, the samples were analyzed using Standard Method 2540 D (Total Suspended Solids Dried at 103°C – 105°C). All samples were stored refrigerated until the time of analysis. Just prior to analysis, samples were warmed to room temperature and then shaken vigorously to suspend particulate material immediately before decanting a measured sub-sample for analysis. Environmental Express ProWeigh™ pre-weighed and pre-rinsed 47 mm diameter filters (Manufacturer's Lot #s 345123CS and 345312GG) were used for the total suspended solids analyses. The QC sample (Samples 26939 and 26944) was a Certified ULTRAcheck™ standard obtained from Fisher Scientific (Manufacturer's Lot # 72670). The reference value for this standard was 116 $mg \cdot L^{-1} \pm 8$ $mg \cdot L^{-1}$ (108-124 $mg \cdot L^{-1}$).

2.4.1.3 Moored OBS Arrays

In addition to the real-time turbidity profiling conducted at RISDS aboard the CTD survey vessel, an in-line, vertical mooring with three Seapoint optical backscatter (OBS) sensors (Seapoint Inc. Turbidity Meters) was used to monitor in-situ turbidity levels within the water column at a fixed location near the disposal location. The OBS mooring was deployed prior to the targeted dredged material placement event, down-current of the disposal operation, and in the projected path of the plume to monitor suspended sediment concentrations in the mid-depth and near-bottom levels (see Figures 2-2 through 2-4 for mooring deployment locations on the three consecutive monitoring days). The individual OBS sensors were positioned at depths of 13, 18, and 32 m on the mooring and interfaced with a single Dryden R2 data logger. Based on water depths at the mooring deployment locations, the deepest OBS sensors ranged from approximately 2 to 4 m above the seafloor, in an attempt to monitor turbidity in the near-bottom plume as it passed the mooring. The three-sensor OBS mooring was retrieved at the end of each survey day and redeployed the following day prior to disposal operations.

The OBS sensors measured the amount of emitted (infrared) light that is reflected back to the sensor. The higher reflection values equated to a greater quantity of suspended particulate material in the volume of water being measured. The R2 data logger acquired turbidity data from each sensor at 10-second intervals throughout the deployment periods. The OBS data presented in this report are stated in terms of Formazin Turbidity Units (FTUs), which provide a relative measure of suspended particulate matter.

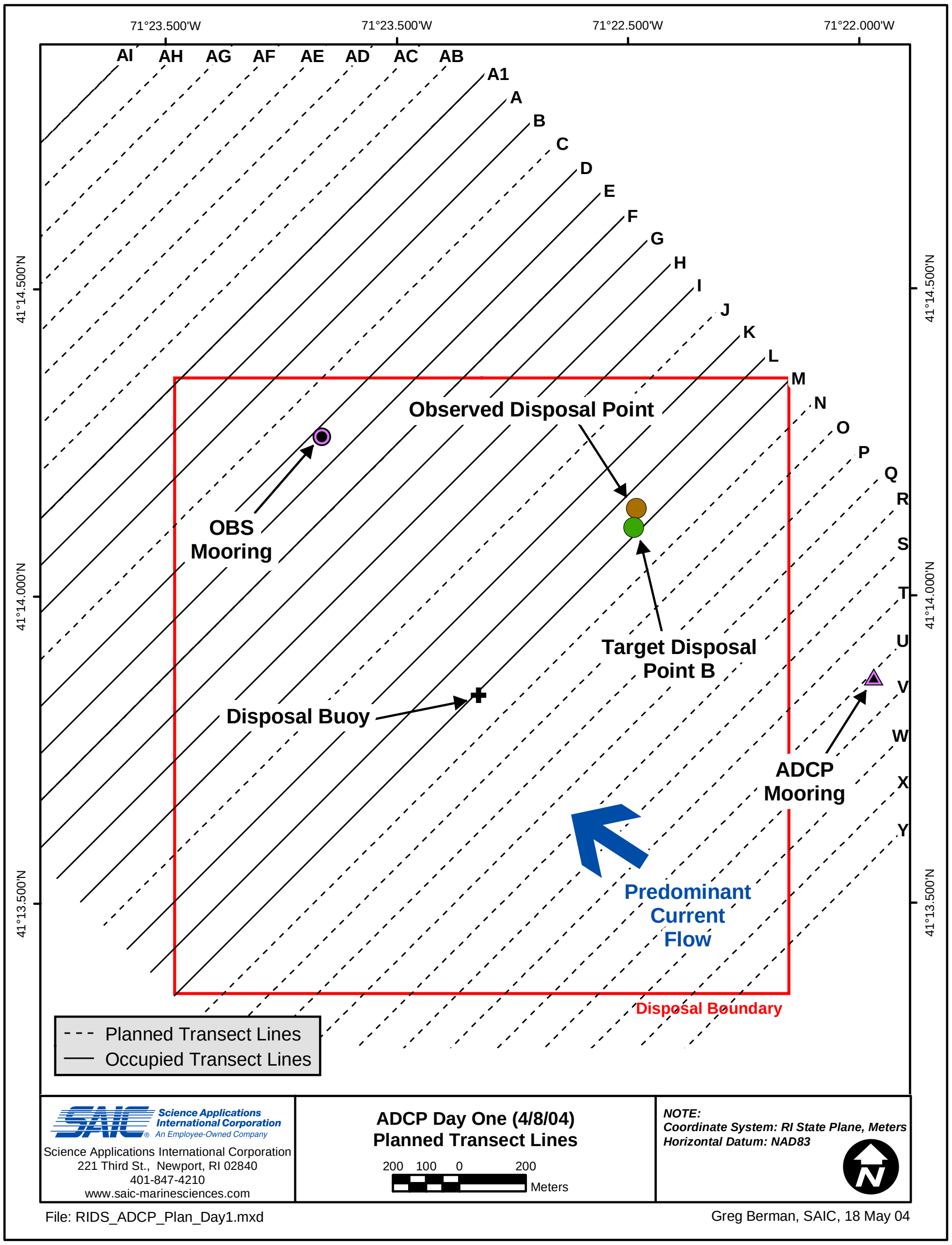


Figure 2-2. Survey track lines for acoustic monitoring of suspended sediment occupied as part of the Plume 1 monitoring event during the RISDS plume survey. Solid lines represent survey lines that were occupied during the course of the survey day, while dashed lines represent those that were pre-established but not occupied.

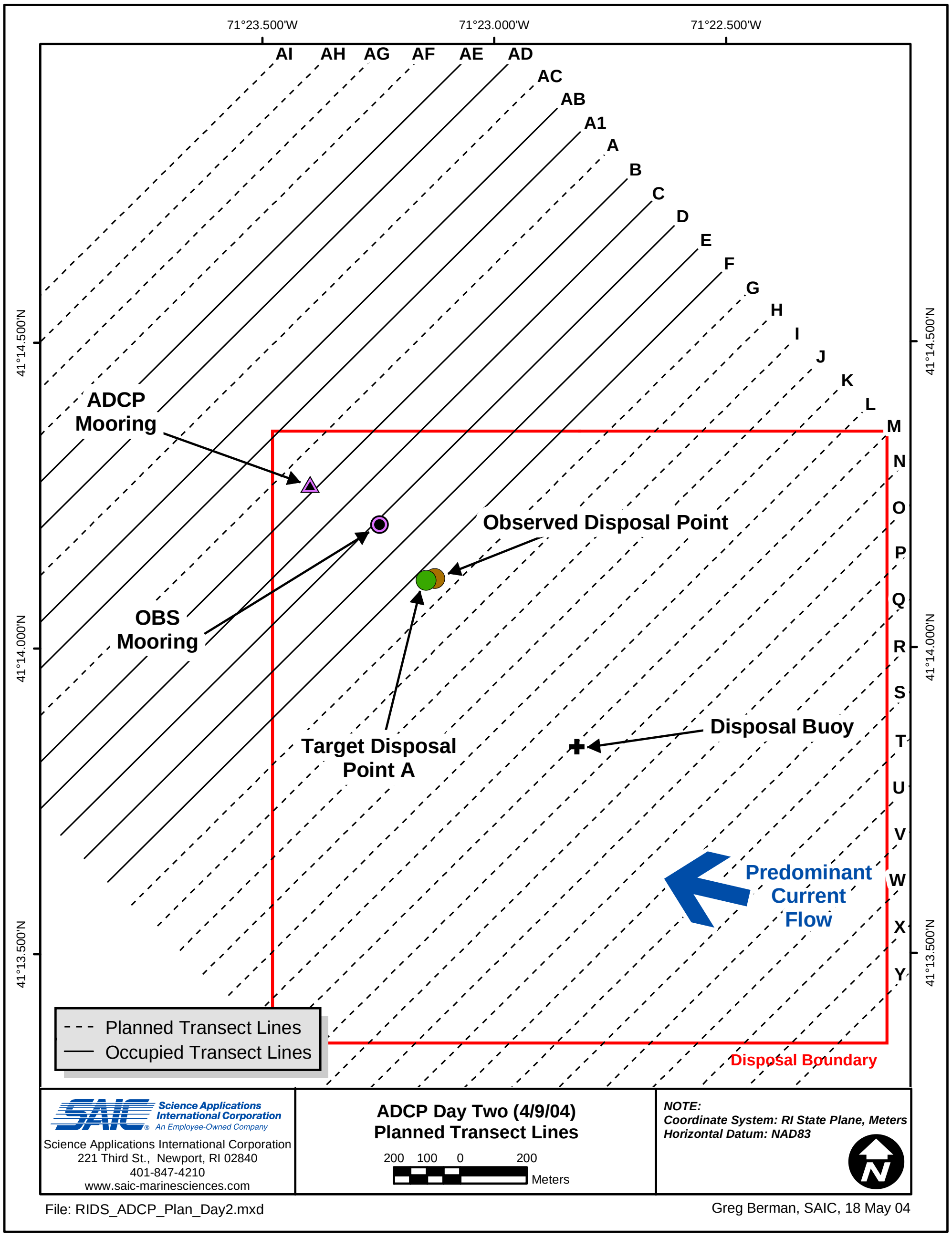


Figure 2-3. Survey track lines for acoustic monitoring of suspended sediment occupied as part of the Plume 2 monitoring event during the RISDS plume survey. Solid lines represent survey lines that were occupied during the course of the survey day, while dashed lines represent those that were pre-established but not occupied.

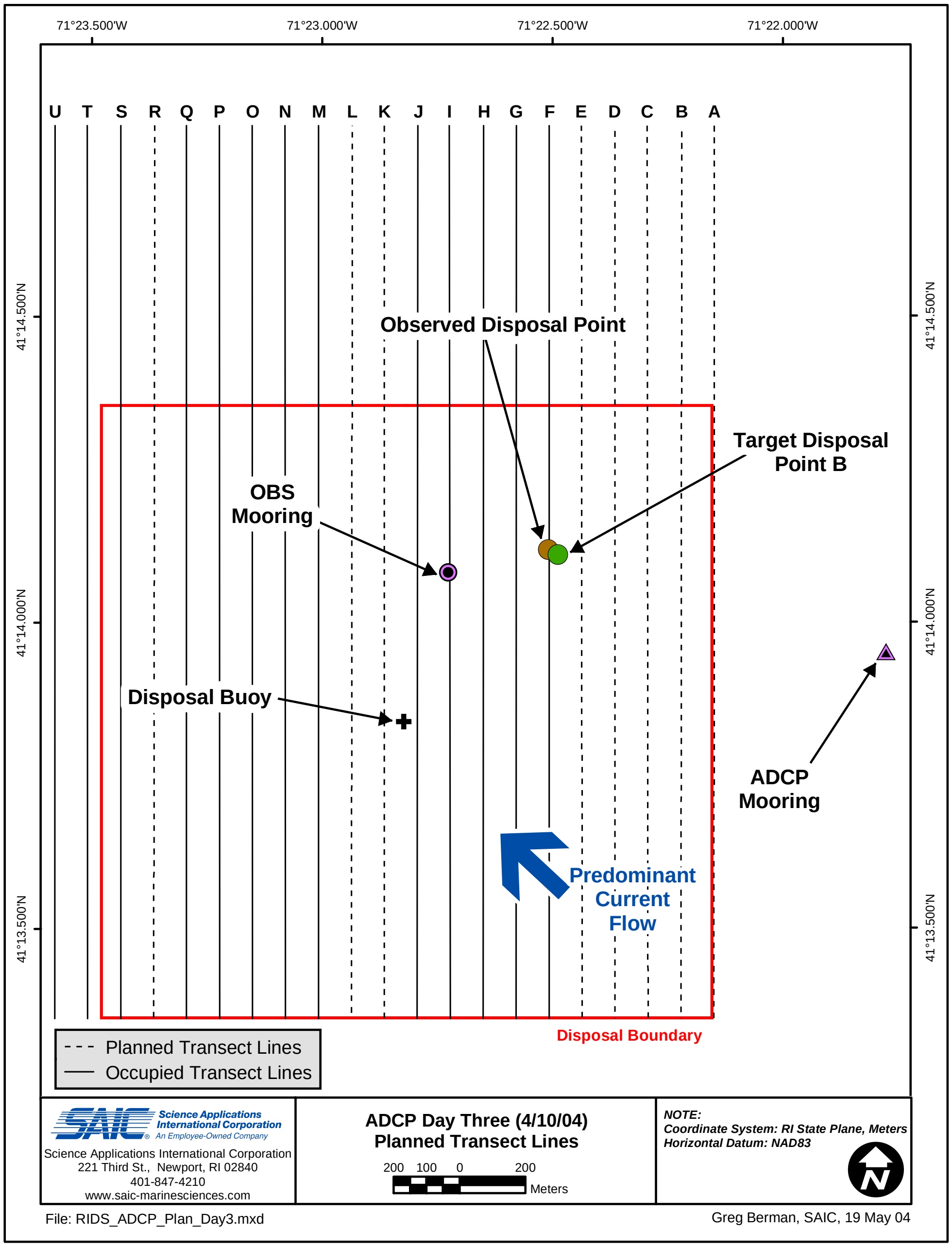


Figure 2-4. Survey track lines for acoustic monitoring of suspended sediment occupied as part of the Plume 3 monitoring event during the RISDS plume survey. Solid lines represent survey lines that were occupied during the course of the survey day, while dashed lines represent those that were pre-established but not occupied.

2.4.1.4 Acoustic Backscatter

Using the principles of Doppler shift, acoustic Doppler current profilers (ADCPs) are designed to determine current speed and direction within various levels or bins within the water column based on the movement of suspended particulates. In order to track the movement of each of the RISDS sediment plumes and document changes in their morphology, the ADCPs used in this study were primarily deployed to log the echo intensity or strength of each acoustic return to estimate the amount of particulate matter in the water column. Commonly referred to as acoustic backscatter, the intensity of the acoustic return would provide a relative measurement of the turbidity within various depth levels. Underway ADCP surveys were conducted on each of the three plume survey days with the ultimate goal of characterizing the transport and dispersion of sediment plumes in the water column associated with the placement of dredged material at RISDS.

In addition to detecting the entrained sediment particles composing the plume, the acoustic pulses of the ADCP also identified other acoustic reflectors within the water column that influenced plume morphology. Many of these acoustic reflectors were associated with the mechanics of the disposal event (i.e., propeller wash from the tug boat, release of air/gas bubbles from the sediment matrix, etc.) and dissipated over time. However, the ADCP returns were also affected by changes in seawater density within the water column, as sharp, small-scale vertical density interfaces appeared to be significant reflectors within the acoustic record. The seawater density gradient was a function of the physical properties of the water column during the April survey and likely remained relatively consistent throughout each survey day.

Underway, in-situ measurements of acoustic backscatter and horizontal currents were acquired throughout the water column using vessel-mounted ADCPs on a second survey vessel. Two independent downward-looking, vessel-mounted ADCPs (600 kHz and 1200 kHz) were used to acquire detailed information on real-time currents (speed and direction) and echo intensity (relative backscatter) in the water column. These current data were used in real-time to assess vertical differences in velocity and direction in the water column currents and also to monitor the changes in plume morphology in both time and space.

The primary underway ADCP was a 600 kHz Broadband system, which provided data for the entire water column. This lower-frequency system was optimal for identifying the boundaries of the plume and centroid of maximum sediment concentration within the first two hours of each survey operation. A second, higher-frequency, 1200 kHz Broadband system also was used to acquire data on plume characteristics. The higher-frequency ADCP was used to locate the centroid and guide the water sampling operations during the final stages of the plume-tracking operation when suspended sediment concentrations were relatively low. The data collected on each survey day were used to illustrate: 1) the patterns in backscatter intensity along discrete transect lines and 2) characteristic flow patterns recorded during the surveys, providing insight to the overall morphology of each plume. On each day, data were collected prior to the disposal event to characterize background or reference profiles for backscatter intensity, as well as ambient currents throughout the water column.

Prior to the RISDS plume monitoring survey effort, a series of predetermined survey lines spaced at 100 m intervals was established over the disposal site to facilitate collecting cross-sectional data of the moving sediment plume (Figures 2-2 through 2-4). Multiple survey line files were constructed over the disposal site, with lines oriented in various directions (north-south, east-west, northeast-southwest, and northwest-southeast). Upon review of the water column current data obtained by the vessel-mounted ADCP prior to a disposal event, a file offering lines running perpendicular to the anticipated direction of plume transport was selected for each survey day. Based on the information obtained prior to disposal events, the survey lines oriented northeast-southwest were occupied on 8 and 9 April, while lines oriented north-south were occupied by the underway ADCP vessel on 10 April (Figures 2-2 through 2-4).

2.4.2 Acute Toxicity Testing

2.4.2.1 Sampling Design and Field Methods

Concurrent with the collection of samples for TSS determination, water samples were collected to assess acute toxicity within the mixing zone at RISDS during two of the three survey days. A pair of 2.5 liter General Oceanics GO-FLO water sampling bottles was used to obtain toxicity samples. Toxicity samples were obtained prior to dredged material placement, as well as 40, 60, and 120 minutes after the placement event (Table 2-2). Four liters of water were obtained at each time interval and composited in a single cubitainer. Because these samples are time sensitive (36-hour holding time), they were sent to the Aquatec Biological Sciences immediately following each survey day. The water samples were tested using the methodology outlined in the Inland Testing Manual (EPA/USACE 1998).

2.4.2.2 Laboratory Analysis Methods

Aquatec Biological Sciences conducted 96-hour water column toxicity tests with mysids (*Americamysis bahia*) and juvenile silversides (*Menidia berylina*). These tests were conducted with five replicates of 100% field samples with no dilution. Standard measurements including survival and water quality conditions were made at 24-hour intervals and were reported to SAIC. Water quality monitoring included temperature (measured daily), as well as pH, dissolved oxygen, and salinity (measured at the beginning and end of the test run). Rations of brine shrimp (*Artemia nauplii*) were fed daily to the mysids and at the test mid-point (48 hours) to silversides.

2.4.3 Water Column Currents

Moored current meter and tide records that were available from past measurements at RISDS were used to predict local tidal currents for the days of plume-tracking operations. This information was useful for predicting tidal flow direction and amplitude in the lower water column, as well as developing preliminary sampling plans (e.g., survey transects). In addition, the plume survey activity also included the use of bottom-mounted acoustic Doppler current profilers (ADCPs) to measure water column currents, as well as the use of current-following subsurface drogues and Davis surface drifters.

2.4.3.1 Acoustic Doppler Current Profilers (ADCPs)

In addition to the vessel-mounted ADCPs, SAIC deployed two upward-looking ADCPs moored on a single bottom mount during the monitoring project. The array supported a 1200 kHz and a 300 kHz ADCP, and was deployed in close proximity to the work site prior to beginning the plume-tracking operation. The ADCPs were left undisturbed until the plume monitoring operation for each day was complete. The actual placement locations were based on known current patterns, probable disposal locations, and the amount of disposal activity anticipated for each survey day. On 8 and 10 April (Plumes 1 and 3) the ADCP mooring was positioned outside the eastern boundary of RISDS, upstream of the target disposal location. On 9 April (Plume 2), this near-field ADCP array was deployed within the northwestern quadrant of RISDS in the expected downstream path of the disposal plume (Figures 2-2 through 2-4).

Additionally, high-resolution multibeam bathymetric data from the February 2003 baseline survey for RISDS (Site 69b; SAIC 2004a) was available to the survey team for planning of mooring deployment locations and consideration of bottom topography.

The temporal sampling objective required rapid (i.e., 1 Hz) sampling by the ADCPs to acquire high resolution data pertaining to near-bottom currents (and potentially turbidity) during the relatively brief placement events in order to acquire high-resolution data on plume characteristics during the first 3 to 4 hours following material placement. In addition, the data from the ADCPs were used to generate an accurate plot of both the current direction and velocity at different levels in the water column throughout each deployment period. The instruments were configured to acquire 40 vertical bins of velocity data, each bin 0.5 m in height, and with each measurement representing the velocity at the center of the corresponding vertical bin. The instruments computed an average north-south and east-west current velocity for each bin at six-minute intervals. The ADCP current velocity data were later processed to provide the six-minute averaged current magnitude and direction at each depth level. In addition, echo intensity readings were evaluated to provide additional information on the concentration of particulate matter in the overlying water.

2.4.3.2 Current-Following Drogues

In addition to the moored and underway ADCPs, surface and subsurface (mid-water and deep-water) current drogues also were used to determine the general speed and direction of horizontal currents at the dredged material disposal location and thus aid in tracking the suspended sediment plumes. Two current-following "holey-sock" drogues were deployed and visually tracked during disposal operations at RISDS to obtain real-time information on horizontal currents at two depths in the water column. These drogues were constructed of a 4.9 m long by 0.6 m diameter cylindrical shape that was made of nylon material and attached to a small surface buoy by a small-diameter, nylon line (Figure 2-5). For each deployment, one mid-depth drogue (18 m) and one near-bottom drogue (32 m, roughly 5 m above the bottom) were deployed as a pair and tethered to the surface buoys to facilitate real-time tracking of the lateral movement of the plumes located at mid-depth and/or near-bottom levels. In addition, a single Davis-style surface drifter was deployed at the start of each plume monitoring event. This drifter remained within the surface waters (1 m) providing an indication of flow within the upper layer. The surface drifter, mid-depth drogue, and deep-water drogue provided a real-time indication of difference in current velocity and direction within the water column.

Following deployment, the near-bottom and mid-depth drogues served as reference points for the position of the disposal plume. Accurate DGPS positions of each drogue were obtained at roughly 15-minute intervals as the water-following drogues were transported away from the initial placement site by currents. In addition, the majority of the CTD/transmissometer/OBS profiles and hydrocasts used to quantify water column turbidity were collected in close proximity to either the mid-depth or near-bottom drogue. To obtain drogue positions, the survey vessel would stop alongside the surface buoy of the drogue and the DGPS position of the vessel (and adjacent drifter) would be recorded by the navigation system used for the water quality monitoring operations. The drogue number, time, and DGPS positions were recorded by the onboard SAIC navigator.

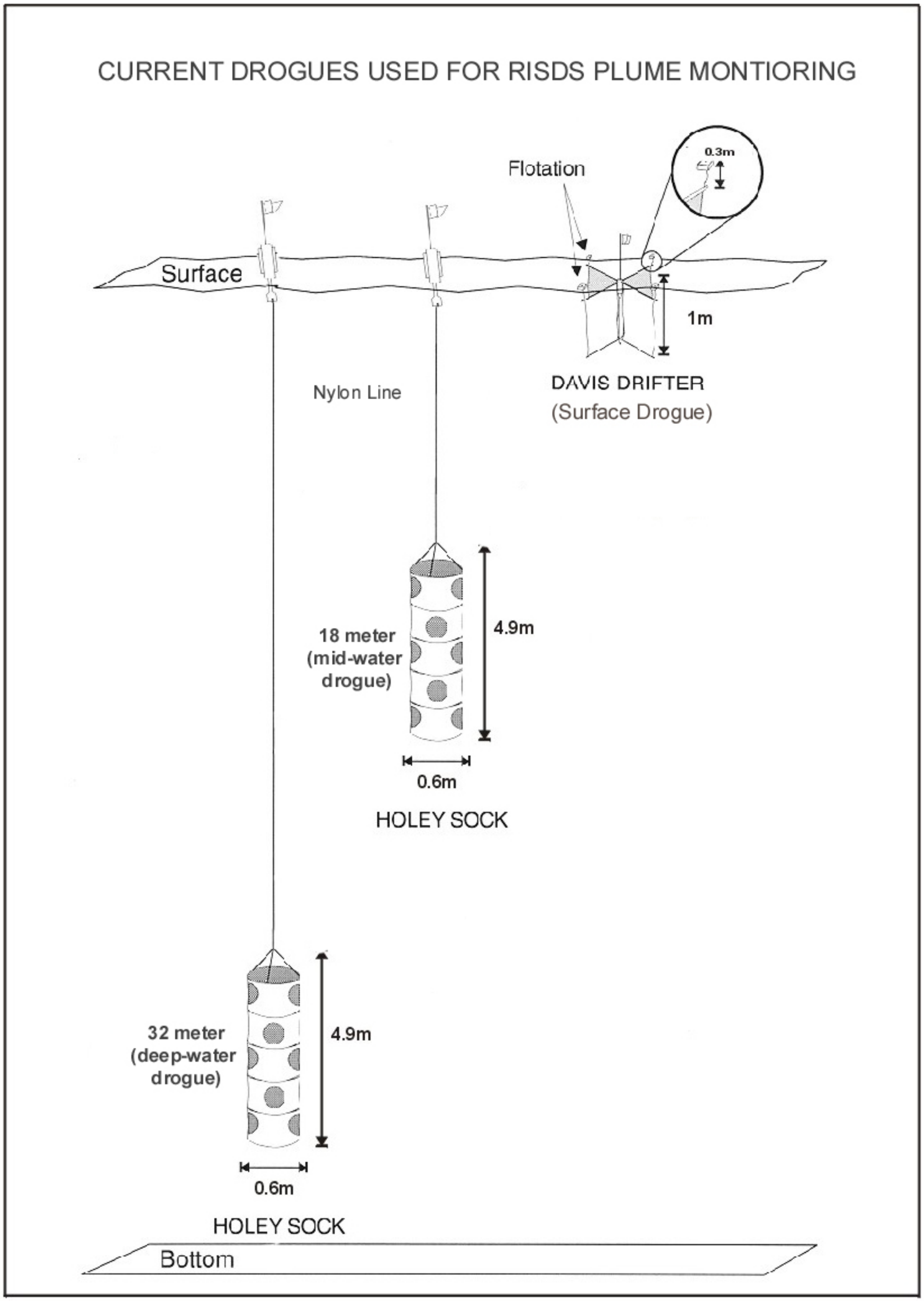


Figure 2-5. Drawing of holey sock drogues and Davis drifter used for real-time assistance with tracking plume advection at mid-water, deep-water, and surface levels.

3.0 RESULTS

3.1 Disposal Barge Sampling

3.1.1 Sediment Chemistry

A composite sediment sample was collected from each disposal barge that was tracked as part of the plume monitoring operation and analyzed for trace metals and PAHs. The samples were obtained during the dredging and barge filling process in Sabin Point Reach the evening prior to each survey effort. The analytical results for samples labeled S1D1, S1D2, and S1D3 were compared to the analytical results for material collected from Station I during the pre-dredging sediment characterization in 1992 and 1994. A summary of those findings are presented in Section 5.7 of this document.

Results indicated detections for all trace metals analyzed (Table 3-1). Comparison of the three individual barge samples indicated consistent metal concentrations, with metals detected in all samples and standard deviations ranging from 6 to 19% of the means. For the PAH compounds, standard deviations for the three samples from each sampling event were slightly greater than for the metals, and ranged between 13 and 28% of the mean for the Sabin Point samples, with the exception of naphthalene (65% of the mean). The only analyte not detected in all three barge samples was acenaphthene, which was present at levels above the detection threshold (12 μg/kg) in two of the three samples analyzed.

The metal concentrations were evaluated using comparison to ecological screening benchmarks (Table 3-1, Buchman 1999). Detected metal concentrations would generally be considered low with maximum concentrations greater than the most conservative NOAA Effects Range-Low (ER-L) benchmark, but less than or comparable to the Probable Effects Level (PEL) benchmark. Mean concentrations of arsenic, cadmium, chromium, nickel, and zinc exceeded the ER-L roughly by a factor of two. These would be considered relatively low concentrations given that the ER-Ls are viewed as very conservative benchmarks, and comparison to benchmarks for ecological risk assessments are generally conducted as an order of magnitude comparison. Only copper, lead, and zinc exceeded the PEL benchmarks, with relatively small exceedances for lead and zinc.

Copper concentrations posed an exception, with concentrations that ranged from 290-350 mg/kg, and exceeded the ER-L (34 mg/kg), PEL (108 mg/kg), and Effects Range-Medium (ER-M; 270 mg/kg) benchmarks. The mean copper concentration exceeded the ER-L by a factor of 9.4 and the ER-M by a factor of 1.2.

Table 3-1. Sediment Chemistry Results for the Dredged Material Removed from Sabin Point Reach

Analyte	Dry Weight	Barge Sample Results					NOAA Screening Benchmarks		
		Min	Max	Mean	St Dev	Stdev as % of mean	ER-L[1]	PEL[1]	ER-M[1]
Metals									
Arsenic	mg/kg	13.0	15.0	14.3	1.2	8.1	8.2	41.6	70.0
Cadmium	mg/kg	1.9	2.2	2.0	0.2	7.5	1.2	4.2	9.6
Chromium	mg/kg	140	170	157	15	9.8	81	160	370
Copper	mg/kg	290	350	320	30	9.4	34	108	270
Lead	mg/kg	120	140	130	10	7.7	47	112	218
Mercury	mg/kg	0.5	0.8	0.7	0.1	18.5	0.15	0.70	0.71
Nickel	mg/kg	34	40	37	3	8.2	20.9	42.8	51.6
Zinc	mg/kg	260	290	273	15	5.6	150	271	410
PAHs									
Naphthalene	µg/kg	51.0	150.0	85.7	55.8	65.1	160	391	2100
Acenaphthylene	µg/kg	29.0	41.0	33.7	6.4	19.1	44	128	640
Acenaphthene	µg/kg	ND	12.0	11.0	1.4	12.9	16	89	500
Fluorene	µg/kg	20.0	28.0	24.0	4.0	16.7	19	144	540
Phenanthrene	µg/kg	110.0	160.0	130.0	26.5	20.4	240	544	1500
Anthracene	µg/kg	41.0	58.0	46.7	9.8	21.0	85	245	1100
Fluoranthene	µg/kg	230.0	350.0	270.0	69.3	25.7	600	1494	5100
Pyrene	µg/kg	220.0	330.0	260.0	60.8	23.4	665	1398	2600
Benz[a]anthracene	µg/kg	92.0	130.0	106.3	20.6	19.4	261	693	1600
Chrysene	µg/kg	120.0	180.0	143.3	32.1	22.4	384	846	2800
Benzo[b]fluoranthene	µg/kg	130.0	200.0	156.7	37.9	24.2		1800*	
Benzo[k]fluoranthene	µg/kg	120.0	190.0	143.3	40.4	28.2		1800*	
Benzo[a]pyrene	µg/kg	140.0	200.0	160.0	34.6	21.7	430	763	1600
Indeno[1,2,3-cd]pyrene	µg/kg	110.0	150.0	123.3	23.1	18.7		600*	
Dibenz[a,h]anthracene	µg/kg	27.0	43.0	33.3	8.5	25.5	63	135	260
Benzo[g,h,i]perylene	µg/kg	120.0	170.0	136.7	28.9	21.1		670*	
Inorganics									
Solids, Percent	%	30.0	34.0	32.3	2.1	6.4			

1- ER-L = Effects Range-Low, PEL = Probable Effects Level, ER-M = Effects Range-Medium, from Buchman, 1999

* No ER-L, PEL, or ER-M available; value shown is Apparent Effects Threshold, AET. (From MacDonald, 1994)

For PAHs, mean concentrations as well as the maximum concentration from the three barge samples were lower than the conservative ER-L benchmark for all compounds except fluorene. Fluorene concentrations exhibited a mean of 24 μg/kg, and a maximum concentration of 28 μg/kg, that slightly exceeded the ER-L, 19 μg/kg, but were well below the PEL, 144 μg/kg. Compounds for which an ER-L, PEL, and ER-M value are not available include benzo(b)fluoranthene, benzo(k)fluoranthene, indeno(1,2,3-cd)pyrene, and benzo(g,h,i)perylene. Comparisons to Apparent Effects Thresholds (AETs) that are available for these compounds (MacDonald 1994; Buchman 1999; indicated with an asterisk in the PEL column in Table 3-1) indicated mean concentrations well below those benchmarks.

3.1.2 Geotechnical Characterization

During the evening prior to each offshore placement event, sediment grab samples were collected hourly from both the bow and stern of the barge carrying the load to be subjected to monitoring at RISDS and composited during the filling process. A summary of the sediment grain size results associated with the barge sediment sampling data is provided in Table 3-2.

The sediment collected from Load 754 that would form the first plume formed on 8 April was predominantly fine-grained (88.9%) with a small fraction of sand (11.1%). The fine-grained component was comprised of 49% clay and 39.9% silt, while the 11% sand fraction contained fine (7.5%), medium (3.5%), and trace amount of coarse (0.1%) sand. Total solids composed 28% of the sample collected from Load 754. Water content (ratio of water to sediment particles) within the barge sample was 261%. This relatively high water content value within barge sediments was analogous to water content of in-situ material sampled during the 1992 and 1994 sediment characterization effort. Relative to the remainder of the study, this first barge composite sample displayed the highest water content of the three barges sampled.

Similar to the effort described for Load 754 described above, sediment grab samples were collected from GLLD Barge 63 (Load 758) and composited during the filling process prior to the 9 April disposal event. A summary of the grain size results associated with the barge sediment sampling data is also provided in Table 3-2. Once again, the sediment collected was predominantly fine-grained with a slightly lower sand content relative to the previous load sampled. Silt comprised 43.3% of the sample, while clay-sized grains made up 48%. The 8.7% sand fraction was predominantly fine-grained (7.7%), with only 1% of the total sample classified as medium-grained sand. Total solids composed 32% of the sample collected from Load 758, while water content was 217%, noticeably lower than that of the previous barge load of material tracked as part of the first plume monitoring survey.

Table 3-2. Barge Sampling Sediment Grain Size Results

Sample	% Cobble	% Gravel	% Sand			% Fines		% Water Content	% Total Solids
			Coarse	Medium	Fine	Silt	Clay		
S1D1	0.00	0.00	0.11	3.53	7.46	39.90	49.00	261	28
S1D2	0.00	0.00	0.00	0.98	7.72	43.30	48.00	217	32
S1D3	0.00	0.00	0.03	0.16	4.42	46.39	49.00	205	33
S1D3 replicate	0.00	0.00	0.03	0.16	4.39	46.42	49.00	205	33

The sediment sample collected from GLLD Barge 402 (Load 763) prior to the 10 April disposal event was predominantly fine-grained sediment with a small fraction of sand (4.6%); no cobble or gravel was present in any of the samples (Table 3-2). The fine-grained material was comprised of 49% clay and 46.4% silt. Total solids within the sample were 33%, while water content was 205%, suggesting slightly less incorporation of water in the excavated material relative to the previous two barge loads sampled.

3.2 Disposal Plume Monitoring

3.2.1 Plume 1

The first day of the plume survey operations occurred on 8 April 2004, in association with the sediment plume generated by the disposal of 4,600 m^3 of maintenance material dredged from Sabin Point Reach and placed at Point B within RISDS. Load 754 was deposited by a split-hull barge in the northeastern quadrant of the disposal site at 13:09 universal time coordinated (UTC; four hours ahead of local daylight time; Figure 3-1). Comprehensive plume tracking and water sampling was performed using two survey vessels for 3.5 hours immediately following the disposal event. Based on the water level data from the National Oceanographic and Atmospheric Administration (NOAA) tide station in Newport, RI (Station 8452660), corrected to the tide zone encompassing RISDS, this disposal event occurred during the final stages of a flood tide (Figure 3-1). The plume monitoring activity continued through the early stages of the ebb tide, concluding just prior to 17:00 UTC. During this time period, the net transport of the sediment plume was to the northwest as described in further detail below.

3.2.1.1 Water Column Currents

The Davis-type surface drifter, as well as the mid- and deep-water, current-following drogues were deployed immediately following the disposal event and left free to drift with the ambient currents for the duration of the 3.5-hour survey. All three drogues drifted in a northwesterly direction in response to water column currents (Figure 3-2). The average speed of the surface water was determined to be 13 $cm \cdot s^{-1}$ based on the deployment and recovery position of the Davis drifter and the total elapsed time. The lower portion of the water column displayed an overall average speed of 11 $cm \cdot s^{-1}$, based on the information from the positional fixes for both the mid- and deep-water drogues at deployment and recovery (Table 3-3). These data illustrate that the water column had minimal vertical differences in velocity and direction in horizontal currents during this survey period.

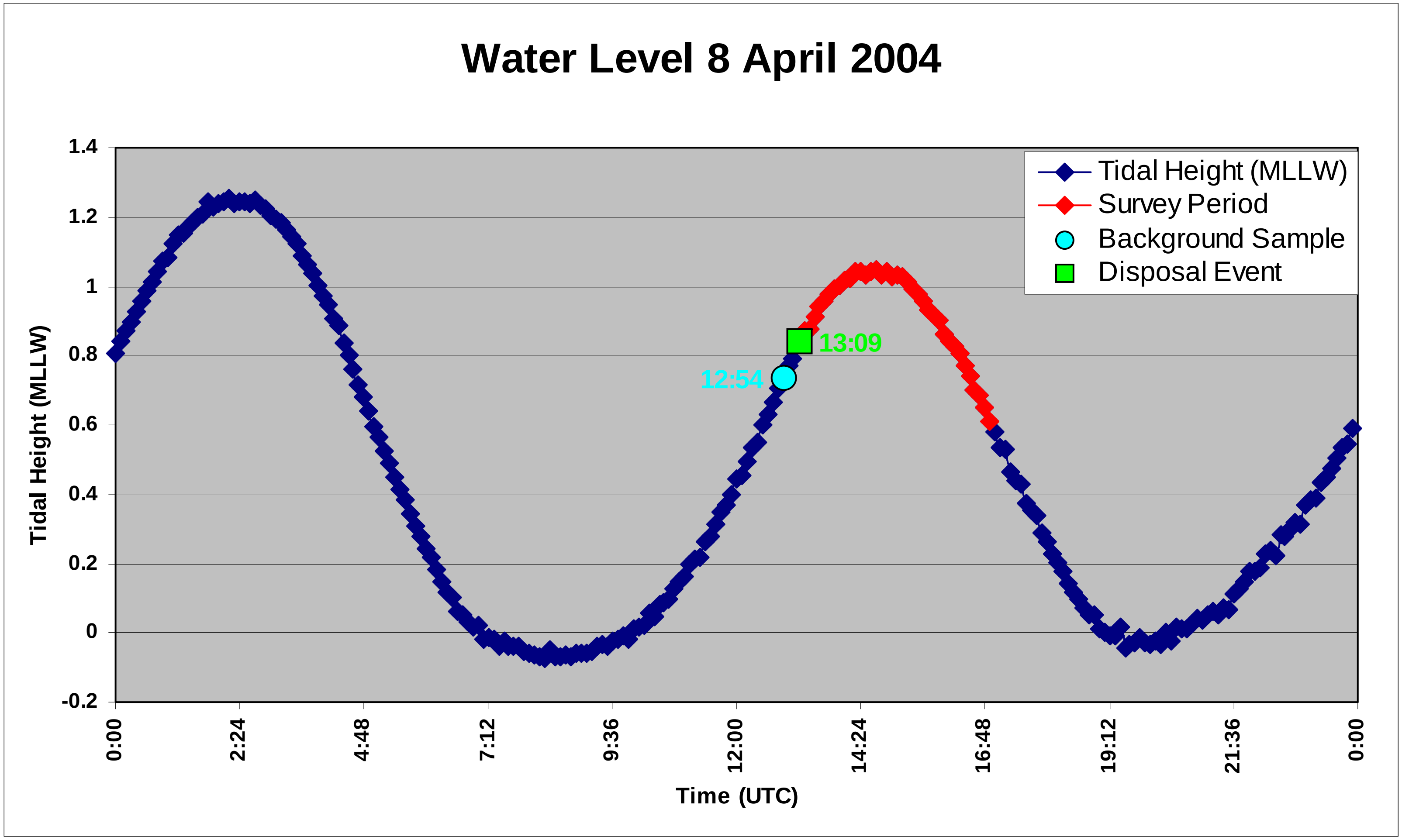


Figure 3-1. Water level data from the NOAA tide station in Newport, RI, corrected to the tide zone encompassing RISDS for 8 April 2004. The Background Sample and the Disposal Event are shown in comparison to the tidal stage.

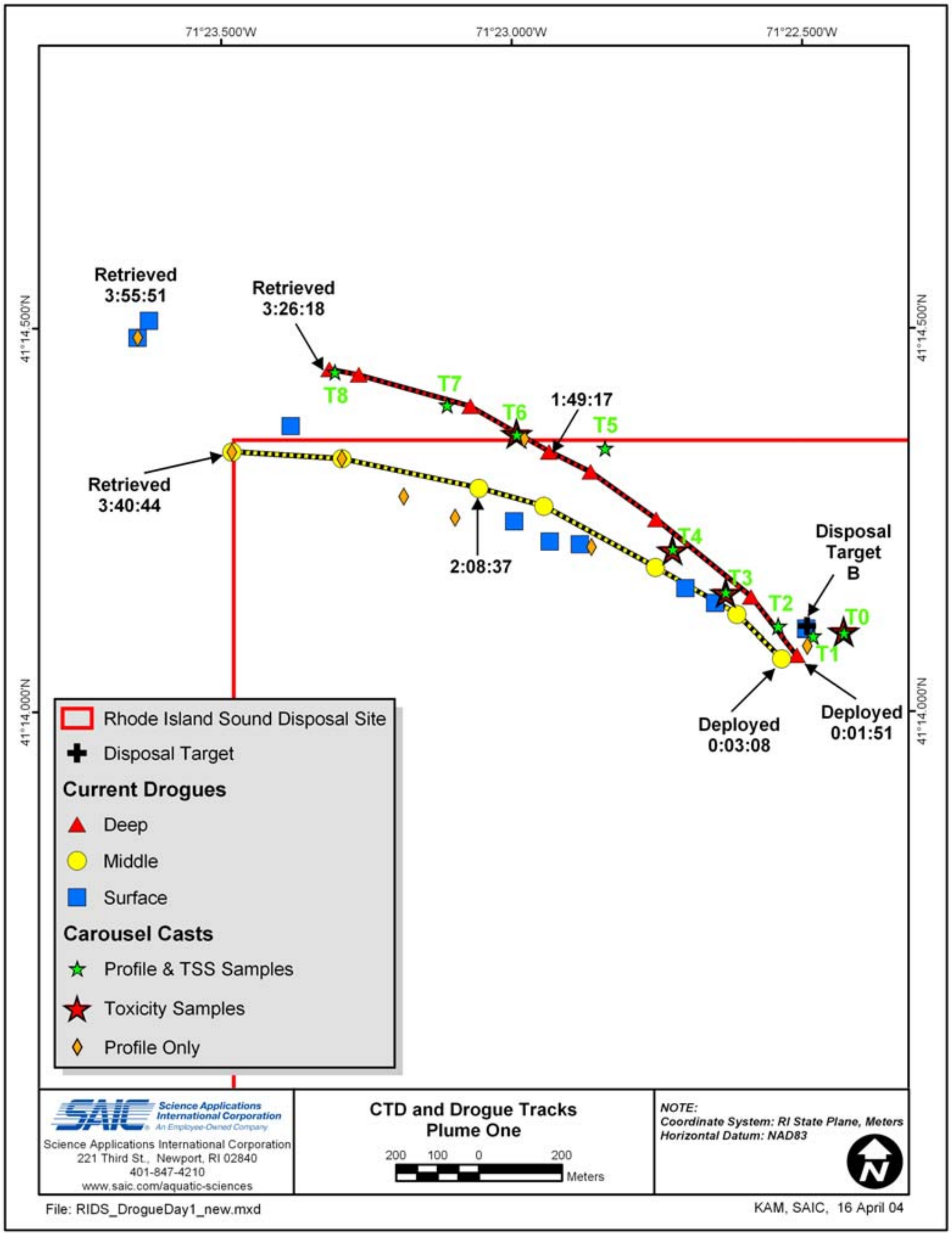


Figure 3-2. Map indicating current drogue trajectories and CTD cast locations during the tracking of Plume 1. Locations of water samples are also shown. Times represent elapsed time since disposal operations.

Table 3-3. Summary of Drift Statistics for Current Drogues Deployed during the RISDS Plume Monitoring Survey

		Drogue Depth meters	Deployment Time UTC	Retrieval Time UTC	Elapsed Time HH:MM:SS	Distance Traveled meters	Average Speed	Average Direction
8 April (Day 1)	Surface	1	13:11:31	17:06:43	3:55:12	1775.70	13 cm/s	NW
	Mid	18	13:14:00	16:51:36	3:37:36	1426.53	11 cm/s	NW
	Deep	32	13:12:43	16:37:10	3:24:27	1328.48	11 cm/s	NW
9 April (Day 2)	Surface	1	13:20:26	17:20:13	3:59:47	470.62	3 cm/s	NNW
	Mid	18	13:19:04	16:57:17	3:38:13	1755.04	13 cm/s	WNW
	Deep	32	13:19:13	16:54:23	3:35:10	1713.45	13 cm/s	WNW
10 April (Day 3)	Surface	1	14:21:32	15:24:11	1:02:39	270.00	7 cm/s	SE
	Mid	18	14:21:08	17:23:03	3:01:55	1341.62	12 cm/s	NW
	Deep	32	14:21:21	17:35:23	3:14:02	1055.66	9 cm/s	NW

The bottom-mounted ADCP records for Plume 1 (8 April) provided additional information on currents within RISDS during the plume monitoring event. Overall, the time-series of six-minute averaged ADCP current data agreed well with the drogue and drifter data. The moored ADCP data indicated that water column currents averaged over the survey time period flowed predominantly to the northwest, with speeds ranging from a minimum of near 0 $cm \cdot s^{-1}$ to a maximum of 21 $cm \cdot s^{-1}$ (Figure 3-3). These averaged data also demonstrate that currents in the upper 18 m of the water column were somewhat stronger than within the lower half of the water column, and that current direction was consistent throughout the water column.

Comparisons between the current record generated by the bottom-mounted ADCP and water level data corrected for RISDS suggests the disposal event occurred during a period of flooding tide and relatively high current flow (13:09 UTC), but approximately 1.5 hours before the peak flow (14:30 UTC; Figure 3-4). These comparisons also indicate that maximum current velocities were detected over RISDS when water levels were at their highest (Mean Lower High Water; see Figure 3-1) during the Plume 1 survey. Current velocities remained elevated ($>$10 cm) at the surface, mid-depth, and near-bottom during a period of slack tide, then displayed a gradual decrease as water levels at RISDS began to fall due to the ebbing tide (Figure 3-4).

The current data showed coherent flow in the water column to the northwest (velocities exceeding 10 $cm \cdot s^{-1}$) for approximately 2.5 hours before current velocities decreased. Despite the transition to ebb tide and decreasing water levels, the direction of flow remained consistent at the surface mid-depth, and near bottom until approximately 16:00 UTC when the flow direction rotated counterclockwise through the west and southwest directions approximately one hour into the ebb tide and one hour prior to the end of the survey (Figure 3-4). This change in current direction was first detected near-bottom at approximately 16:00 UTC (3 hours post-placement); one hour after water levels began decreasing locally (Figure 3-5). Within 10 minutes, a similar response was detected at mid-depth, with current speeds decreasing and the direction rotating to the west, southwest, and then south (Figure 3-5). Although current velocity in the near-surface waters did decrease somewhat from approximately 16:40 UTC to the end of the survey, the direction of flow remained northwesterly.

The vessel-mounted ADCP data collected for Plume 1 (8 April) agreed with the observations of the bottom-mounted instruments and current-following drogues. The vessel-mounted ADCPs detected flow to the west-northwest over most of the survey period, with average speeds ranging between 10 and 15 $cm \cdot s^{-1}$. Toward the end of the survey day, water column current velocities were somewhat weaker ($<$10 $cm \cdot s^{-1}$) flowing in a more westerly direction.

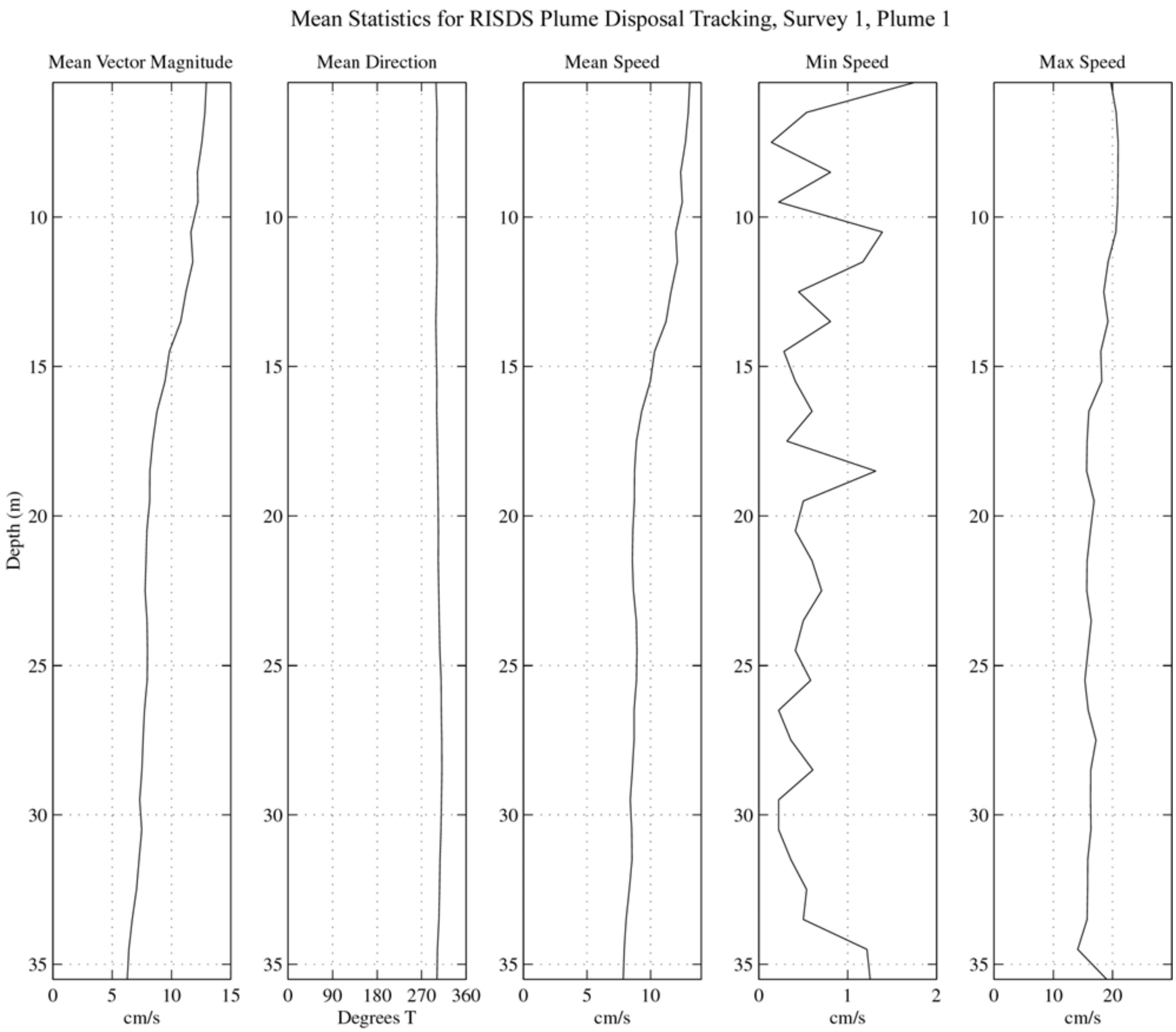


Figure 3-3. Statistics of moored current meter data collected on site during Plume 1 disposal monitoring activities. Current meter deployed for extent of survey period (3.5 hours). Parameters plotted include mean vector magnitude, mean vector direction, mean speed (regardless of direction), minimum speed and maximum speed.

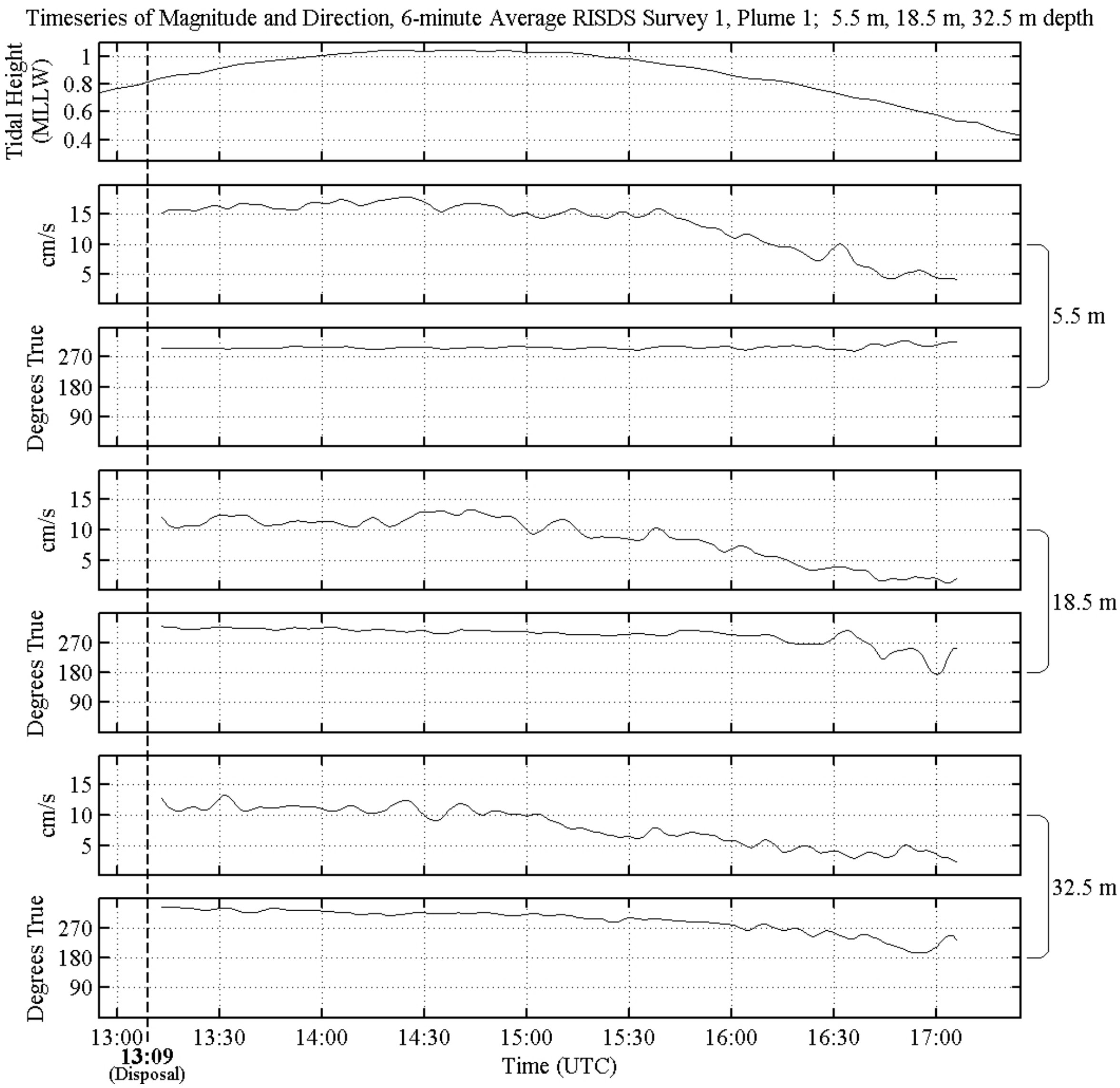


Figure 3-4. Time-series (UTC) plot of current magnitude and direction during Plume 1 at the near-surface level (~5 m; top two panels) and the two selected drogue depth levels of ~18 m (middle two panels) and ~32 m depth (bottom two panels). Currents were sampled at one-minute intervals, and filtered with six-minute Low Pass Filter (LPF) to reduce high-frequency noise. Dashed line (13:09) represents the start of barge disposal.

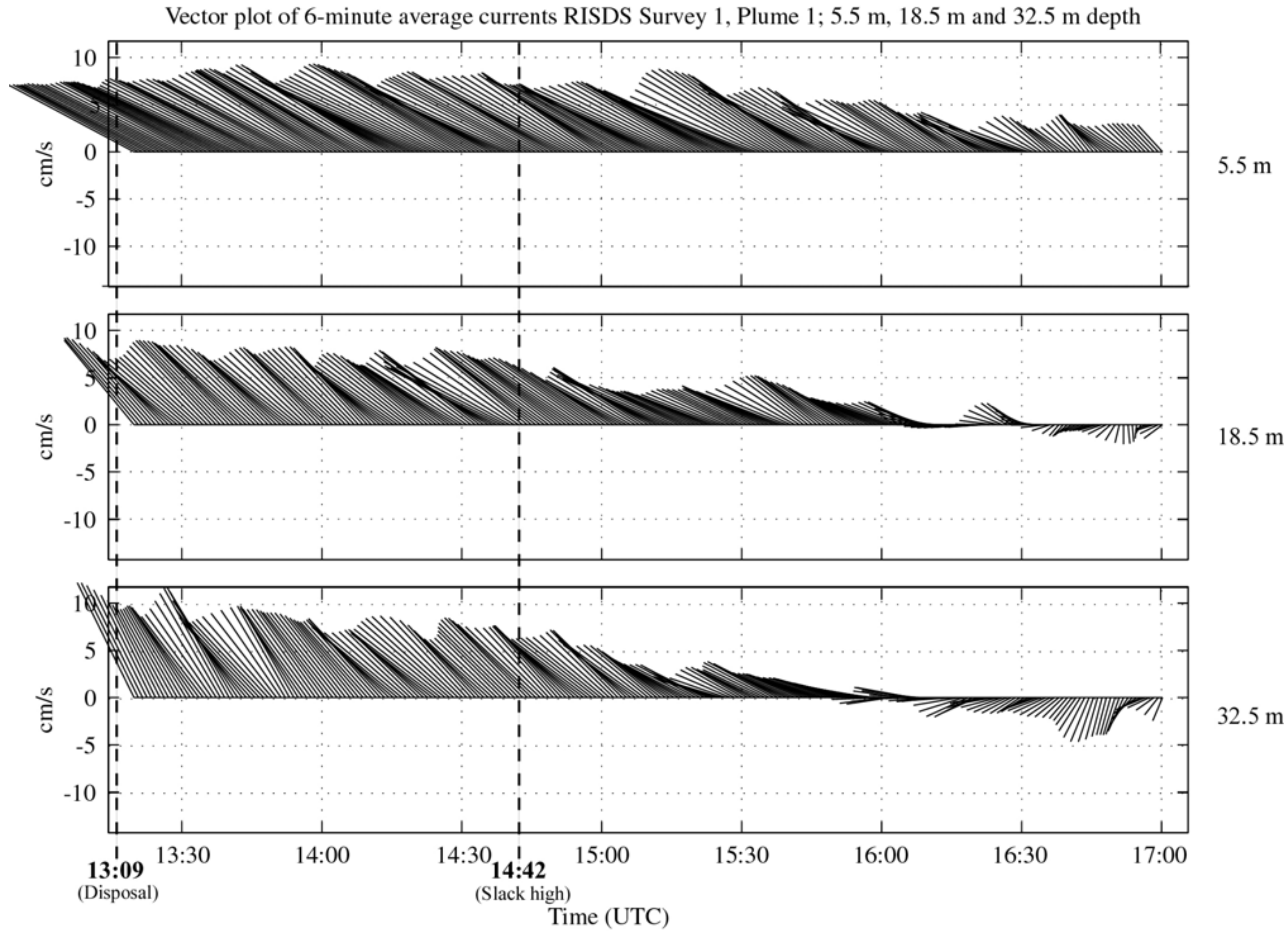


Figure 3-5. Time-series (UTC) plot of current vectors (six-minute low pass filtered) during Plume 1 at the near-surface level (~ 5 m; top panel), as well as the two selected drogue depth levels of ~ 18 m (middle panel) and ~ 32 m (bottom panel). Dashed lines represent time of disposal (13:09) and slack high tide (14:42).

3.2.1.2 CTD/Transmissometer Profiles

As part of the plume monitoring operations for Load 754, a total of 16 CTD profiles were acquired within and adjacent to RISDS during the 3.5-hour monitoring period. Background water samples (T0) were collected 5 m above the seafloor (at 33 m depth) prior to disposal operations in the vicinity of the targeted disposal location (Figure 3-2). The term "background" represented local water column conditions (e.g., temperature, salinity, density, light transmission, etc.) prior to disposal. In general, salinity and percent transmittance were relatively constant versus depth. Percent transmittance remained constant at approximately 81%, while salinity was consistently 32.7 PSU for the background profile (Figure 3-6). However, both density and temperature displayed noticeable changes with depth. Density increased gradually from the surface to 20 m (26.02 to 26.06 sigma-t), then remained near constant at 26.06 sigma-t to the bottom. Temperature decreased minimally (3.6 to 3.4°C) from the surface to approximately 10 m depth then remained nearly constant within the lower portion of the water column. The slight pycnocline that existed between the surface and 20 m depth was mostly a result of temperature decreasing with depth.

As the disposal barge approached the target disposal location, the CTD sampling vessel positioned itself immediately astern. Once the dredged material was released from the split-hull barge, the draft of the barge decreased by more than 3 m and a surface plume was evident in close proximity. Visual observations revealed that the barge was mostly empty within 30 seconds of opening, and the dredged material descended through the water column. Within the first ten minutes following the disposal event, the surface plume remained limited in area and situated at the disposal location.

The first sampling interval (T1) occurred eight minutes after the disposal event at a position having a water depth of 38 m. A CTD profile conducted in close proximity to the deep-water (32 m) drogue displayed the presence of suspended sediment plumes at mid-depth and near the bottom (Figure 3-7). The entrained sediments at mid-depth were clearly evident from the very low light transmittance values (2 to 10%) between water depths of 15 and 20 m. A water sample for TSS analysis was collected within the plume at a depth of 16.7 m as part of the upcast. However, as depicted in Figure 3-7, this sample was not collected within the most turbid layer (centroid) of the plume. A highly turbid, near-bottom layer was also present in the lower 5 m of the water column with a constant percent transmission of 0% (Figure 3-7).

The lack of a strong surface plume during the T1 profile was apparently a result of the CTD survey vessel not being positioned exactly over the centroid of the plume. The

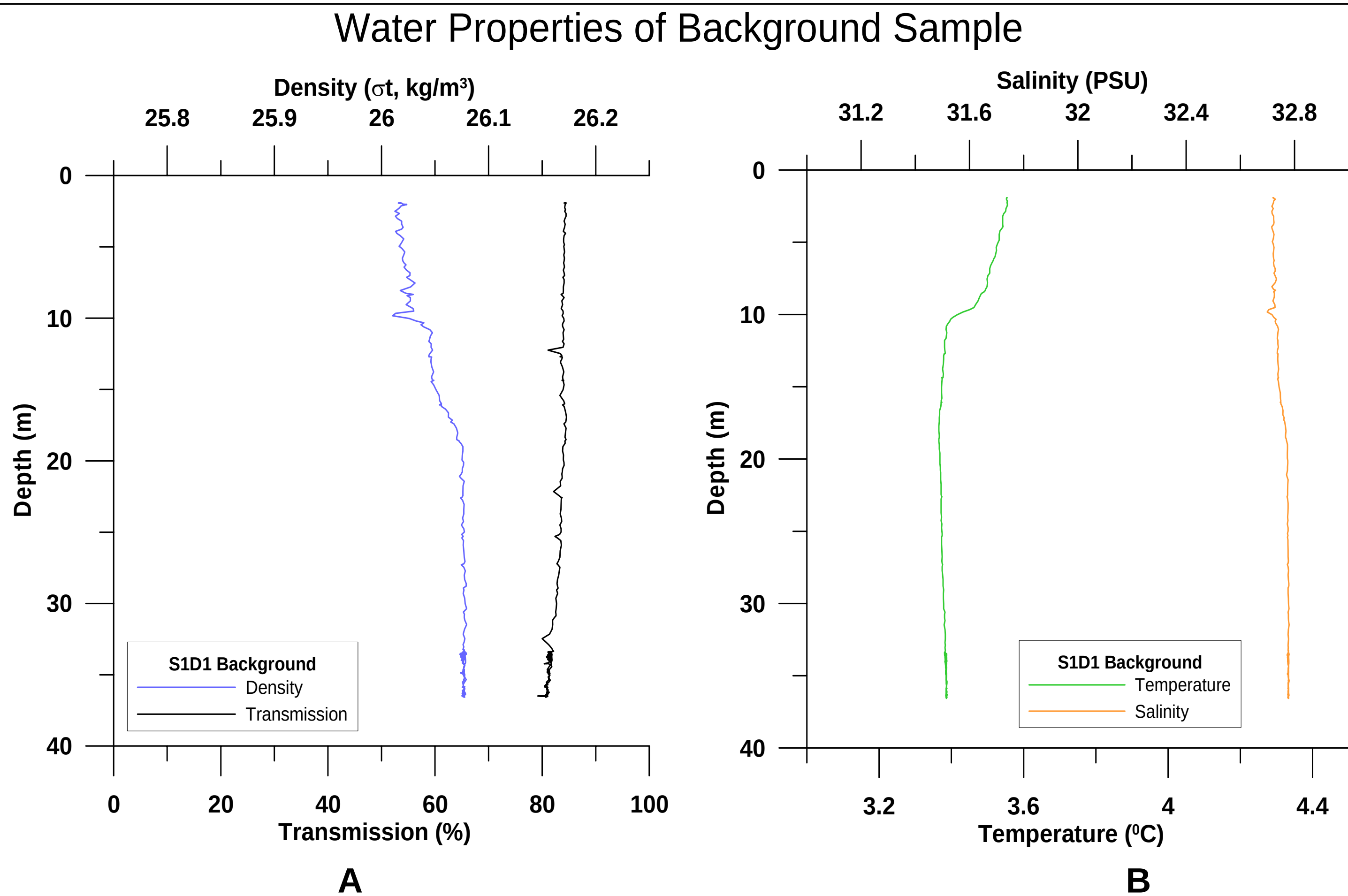


Figure 3-6. Profile plots of percent light transmission and seawater density versus depth (A) and temperature and salinity versus depth (B) acquired during the CTD background sample interval for Plume 1. Data are from the downcast profile only.

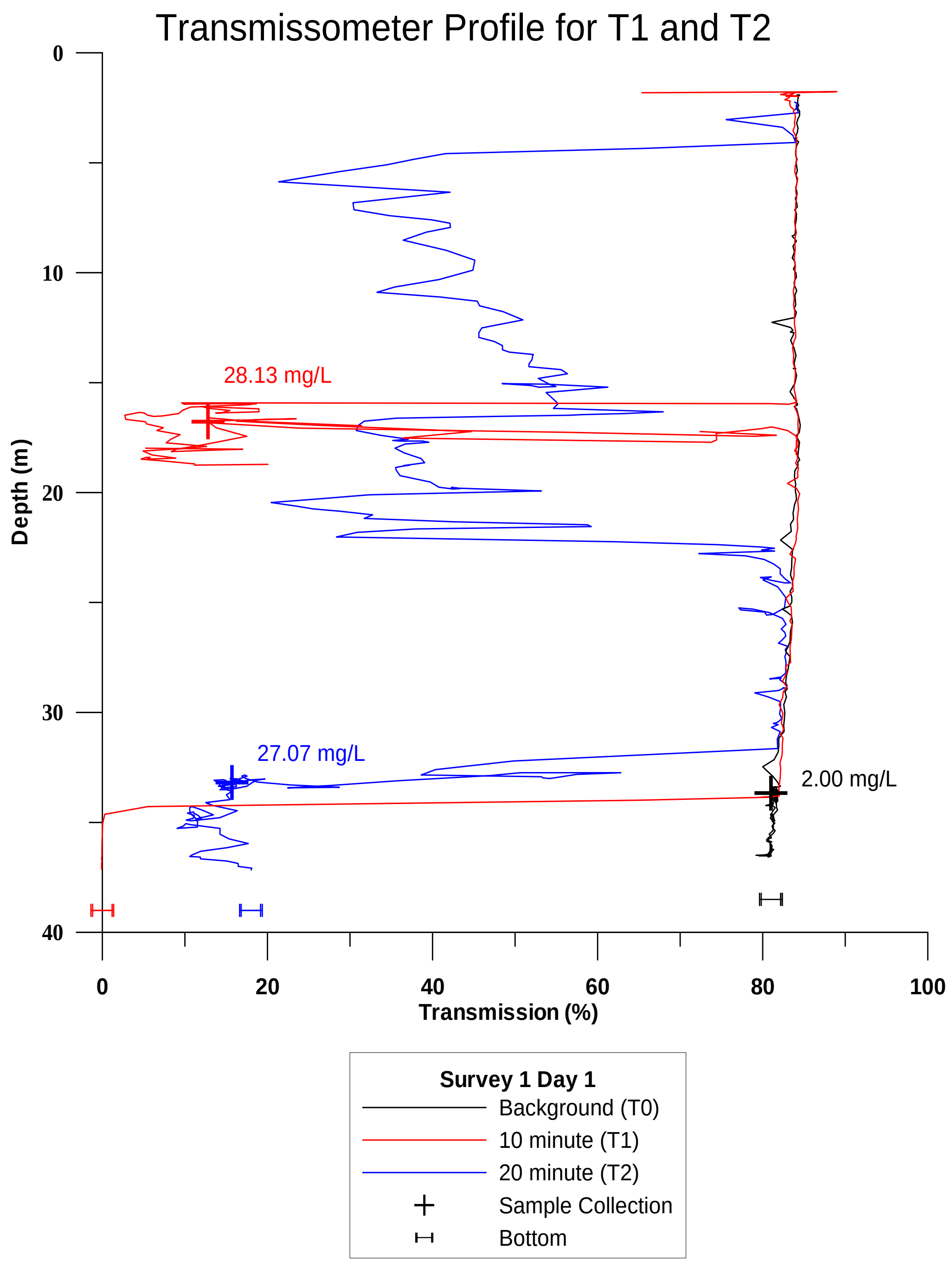


Figure 3-7. Profile plot of percent light transmission and sensor depth acquired during CTD sample intervals T1 and T2 for Plume 1. Locations of water sample collections within the plume are also shown.

CTD profile acquired during T1 sampling was representative of the outer edges of the plume, where the water column was less turbid than in the centroid.

At the 20-minute sampling interval (T2), a vertical CTD profile was collected near the deep-water drogue (Figure 3-2). The transmissometer data showed two layers of turbid water separated by a 10 m layer having background turbidity levels (Figure 3-7). The upper plume extended from approximately 5 m to 23 m depth, and was composed of sediments that were entrained within the water column during the convective descent. Percent transmission values in this upper plume ranged from 70 to 20%, with the highest turbidity values identified at approximately 6 and 20 m water depth (Figure 3-7). Transmittance levels representative of background were observed from 24 to 33 m depth. The near-bottom plume was initially detected at a depth of 33 m and extended to the seafloor (38 m depth). This turbid layer displayed somewhat higher turbidity than the shallower plume, with an average light transmittance of 15%, compared to the sub-surface plume having a transmittance of 20%. A water sample was collected for total suspended solids concentration within the near-bottom plume at a depth of 33 m. It is theorized that similar plume morphology would have been found at the ten-minute sampling interval (T1), if the actual centroid of the plume had been sampled.

The CTD profile at the 40-minute sampling interval (T3) was collected in proximity to the deep-water drogue (32 m; Figure 3-2). In general, the transmissometer profile provided evidence of particle settlement within the upper water column portion of the plume when compared to the 20-minute sampling interval. Light transmission values were 10 to 15 transmission units higher in the upper 23 m of the water column indicating a relative reduction in turbidity (Figure 3-8), assuming that the same portion of the plume had been sampled at both T2 and T3. In addition, the transmittance values showed a noticeable decrease between 23 and 30 m water depth, suggesting that near-bottom turbidity increased as the entrained sediment particles gradually settled through the water column towards the seafloor.

Transmittance values of the plume in the upper half of the water column ranged from 67 to 33%. The lowest transmission values (averaging 35%; and most turbid) were collected from 15 to 25 m water depth, while the high transmittance levels (70 to 80%) persisted within the 27 to 35 m depth range. The near-bottom portion of the plume continued to be visible from a depth of 35 m to the seafloor (38 m). This near-bottom plume continued to display the highest turbidity, corresponding with the lowest transmittance values (approximately 27%). Water samples for both TSS and toxicity analysis were collected in the 3 m thick layer of concentrated turbidity at a depth of 36.6 m during the upcast (Figure 3-8).

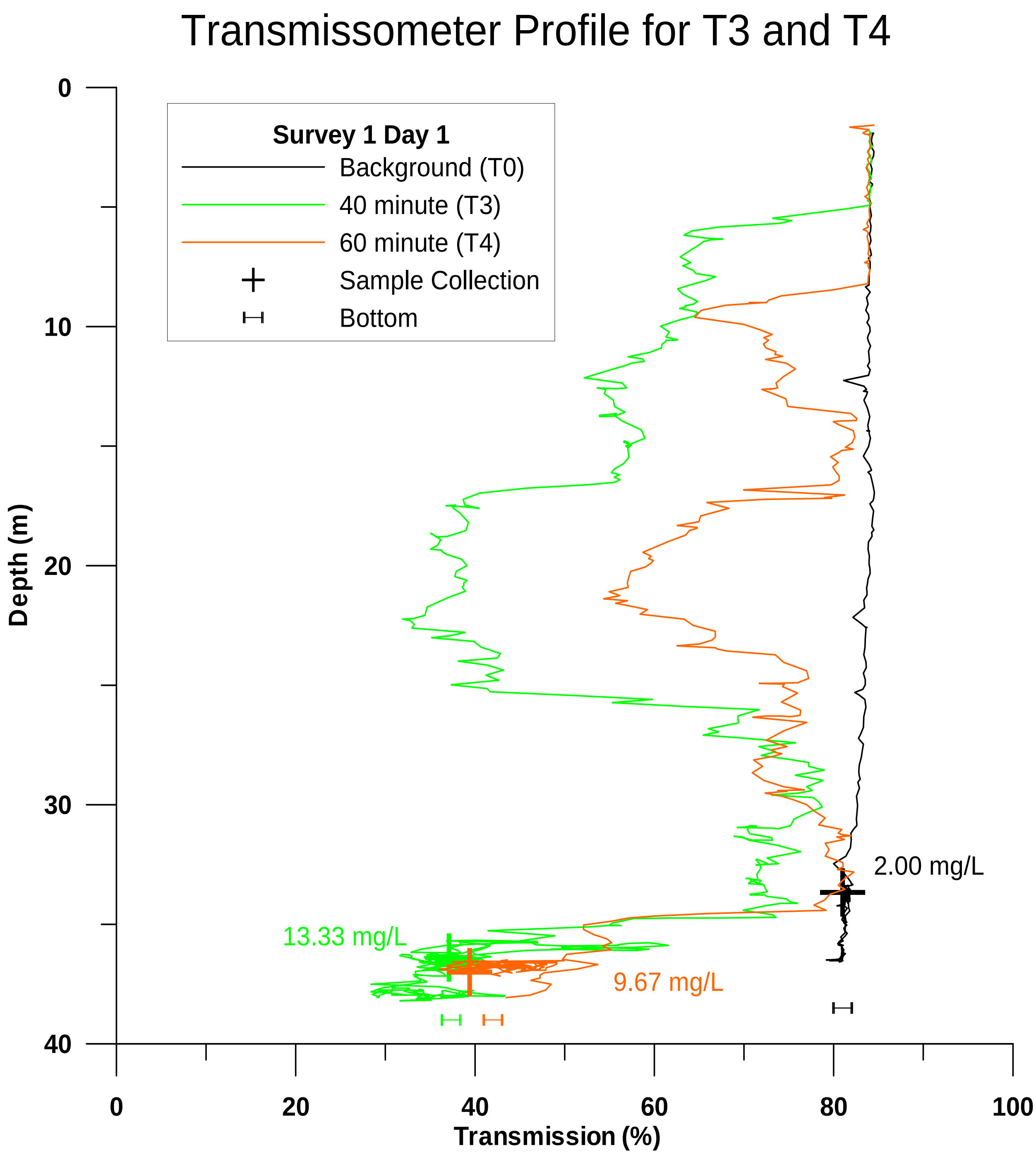


Figure 3-8. Profile plot of percent light transmission and sensor depth acquired during CTD sample intervals T3 and T4 for Plume 1. Locations of water sample collections within the plume are also shown.

The T4 profile was acquired 60 minutes after the disposal event and adjacent to the deep-water drogue (Figure 3-2). This CTD profile showed signs of both settlement and dispersion of suspended sediments throughout the water column, as substantial increases in percent light transmission (indicative of decreasing turbidity) relative to earlier profiles were detected. In the T4 profile, the turbidity of the surface waters had returned to background levels, with the first sign of plume sediments observed at a water depth of 9 m, compared to 5 m during the 40-minute profile (Figure 3-8). This finding provides evidence of either particle settlement or sufficient differences in velocity and direction in water column currents to separate the top of the plume from the mid-water portion. The transmittance values began to decrease below the 9 m depth horizon, indicating increasing turbidity and detection of the sub-surface plume sediments. From approximately 13 to 17 m, the transmittance values within the plume approached background levels. Below a depth of 18 m, transmittance once again decreased, which indicated the presence of a turbid layer at mid-depth. The lowest transmittance value of the mid-depth plume (55%) occurred at a depth of 22 m, representing the highest turbidity in this portion of the plume.

Light transmission approached background levels at 32 m then decreased sharply near the bottom. With values ranging from 55 to 39%, the near-bottom plume had lower transmittance compared to both the sub-surface (65%) and mid-depth (55%) plumes. Water samples were collected at the 60-minute sampling interval at a depth of 37 m within the near-bottom portion of the plume.

Prior to the 90-minute sampling interval (T5), a supplemental CTD profile was obtained in close proximity to the mid-water (18 m) drogue to determine whether the plume centroid may have been displaced from the deep-water drogue (32 m; Figure 3-2). The light transmission data from this profile indicated the presence of plume sediments at a water depth of 5 to 10 m, as well as at mid-depth (16 to 19 m), and near-bottom (32 m to the seafloor; Figure 3-9). Although entrained sediments were found within three layers of the water column, the relatively high transmittance values and the water depths at which the plume sediments were detected suggest the plume centroid was not located at the mid-water drogue.

At the 90-minute sampling interval (T5), a CTD profile acquired adjacent to the deep drogue displayed portions of the plume at mid depth and below. The first substantial increase in turbidity occurred at a depth of 16 m (Figure 3-9), illustrating that entrained sediments were present at mid-depth. However, the lowest observed transmissometer reading within this portion of the plume was 56% before briefly returning to near background levels (81%) at a depth of 22.5 m. These findings indicated the presence of a distinct turbidity layer 6.5 m thick at mid-depth. Background turbidity levels were

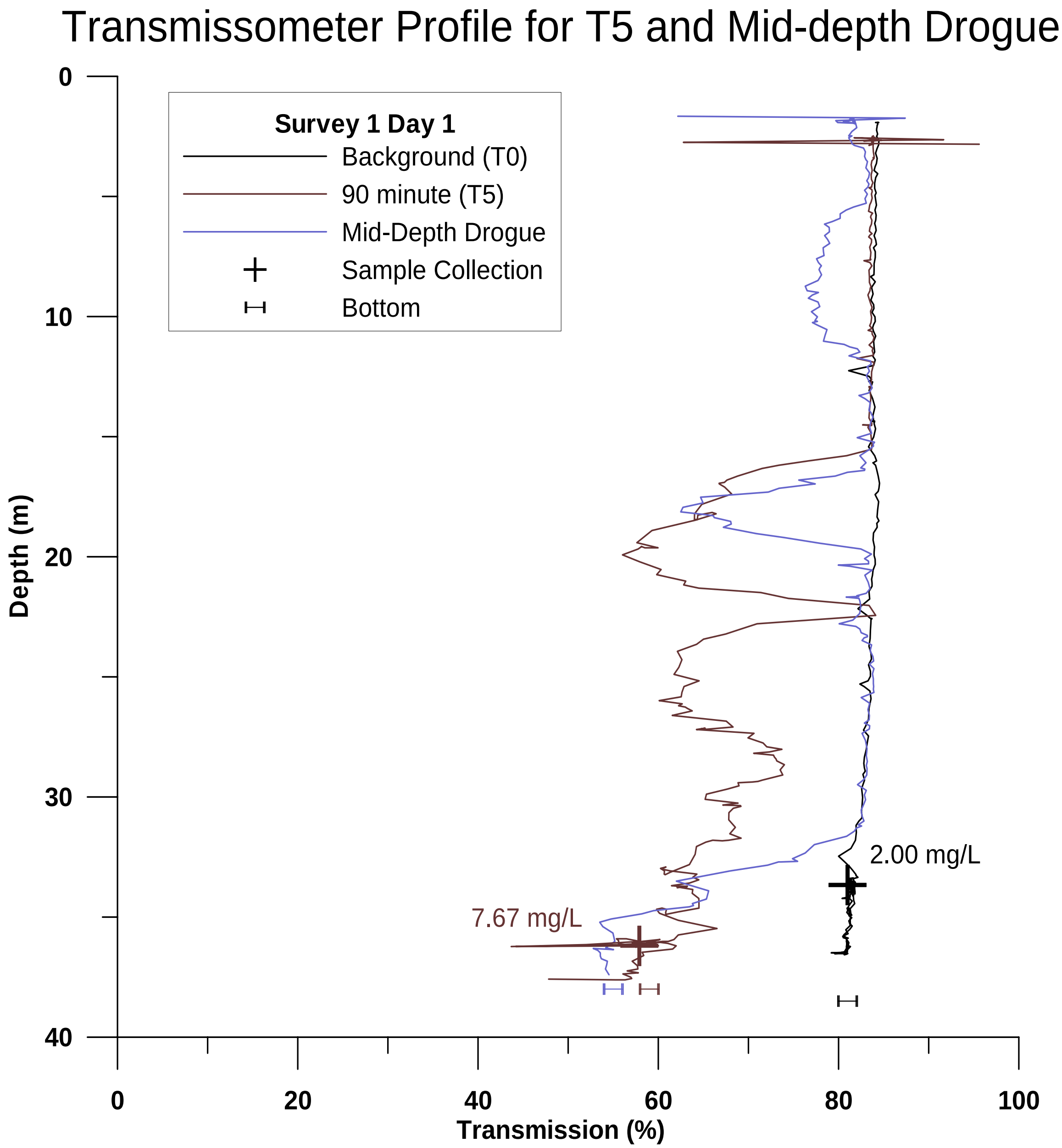


Figure 3-9. Profile plot of percent light transmission and sensor depth acquired during CTD sample interval T5 and the mid-depth drogue for Plume 1. Locations of water sample collections within the plume are also shown.

detected at a water depth of 23 m, but generally increased with depth to 28 m. The lower 10 m of the CTD profile showed increasing turbidity with depth until a maximum was detected at 36 m. The 90-minute (T5) water sample was collected within this near-bottom plume at 36 m, corresponding with a transmissometer reading of 56% (Figure 3-9).

In comparison to the T5 profile, the CTD profile at the T6 interval displayed a more vertically coherent sediment plume, suggesting sediment dispersion and/or dilution (Figure 3-10). The T6 profile was obtained in very close proximity to the deep-water drogue position 120 minutes after the disposal event (Figure 3-2). From a depth of 5 to 12 m, a layer of turbidity was encountered with a minimum light transmittance reading of 70%. Background transmission levels (81%) were encountered between water depths of 12 to 16 m. Below 16 m, a continuous plume was present, extending to the seafloor. The majority of the plume displayed a transmittance of approximately 68%, though the most turbid portion (4 m above the seafloor) revealed a transmittance of 62% (Figure 3-10). Comparing data from T6 with those of prior profiles, suggests the increase in transmittance (decrease in turbidity) over time was likely due to lateral spreading and settling of the suspended sediments in the water column. The water samples at this interval (T6) were collected 4 m above the seafloor within the most turbid portion of the plume.

The CTD profiles acquired at 150 (T7) and 210 minutes (T8) were both collected in proximity to the deep-water drogue. Both profiles were remarkably similar in transmittance characteristics with clear water from the surface to about 17 m depth, then a nearly constant-turbidity plume extending from about 20 m depth to the seafloor (Figure 3-11). Plume sediments had been advected away in the upper water column and/or had settled to deeper layers of the water column. Below 17 m, turbidity levels maintained a relatively consistent transmittance level (65%) to the seafloor at both times (T7 and T8). At T7 and T8, water samples were acquired at approximately the same depth (36 m) and transmittance value (65%).

3.2.1.3 Total Suspended Solids (TSS) Results from Water Samples

A summary of the TSS results associated with the water sampling data for the Plume 1 survey and the associated background samples is presented in Table 3-4. The replicate background samples (S1D1_T0) were obtained approximately 15 minutes prior to the disposal event at RISDS and displayed an average TSS value of 2 $mg \cdot L^{-1}$. The background sample was collected approximately 5 m above the seafloor, while the majority of the TSS samples obtained within the plume were collected 2 to 4 m above the seafloor where the plume centroid was believed to be situated. The location of each TSS sample within the water column during the plume monitoring surveys was based on real-time

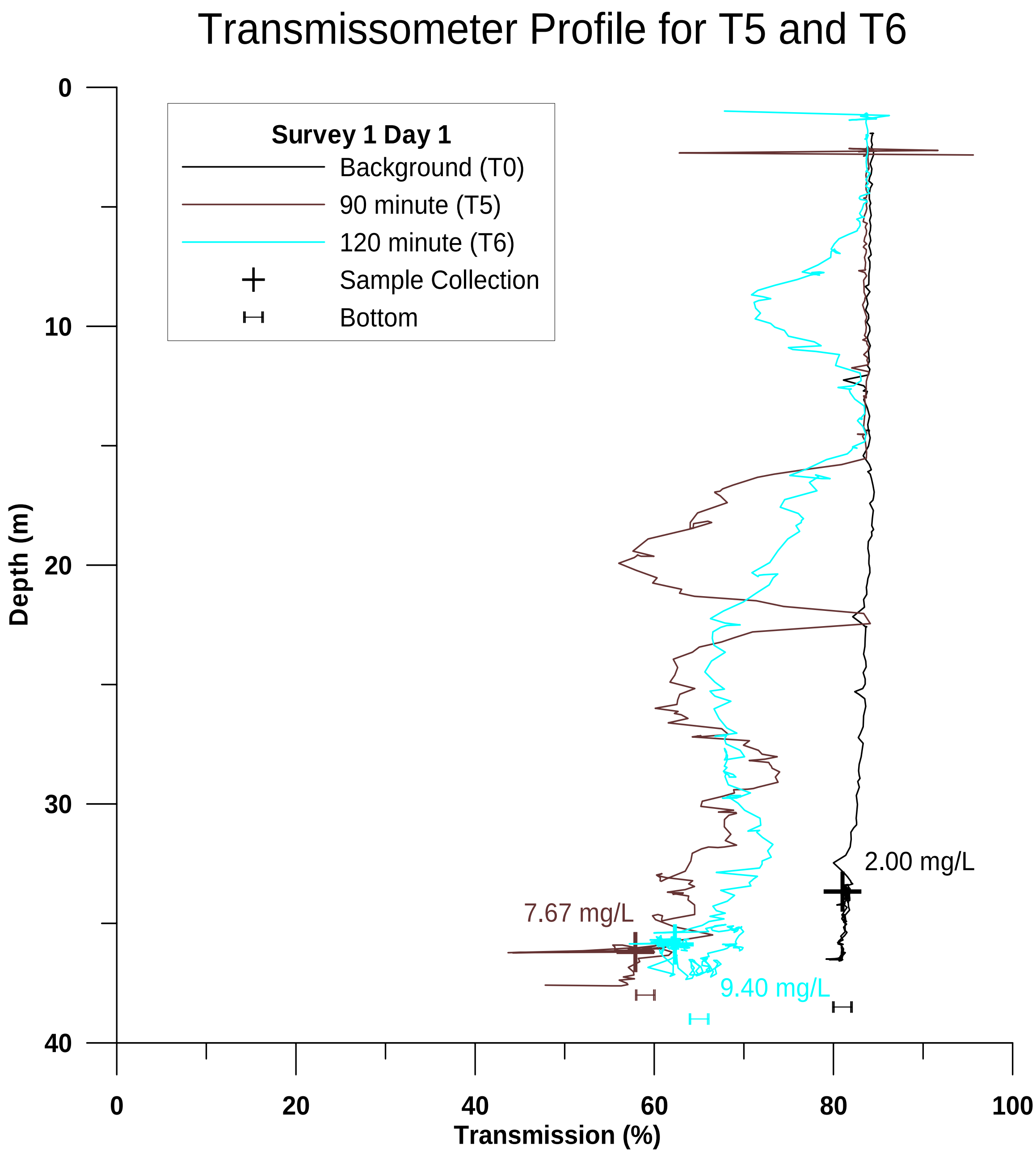


Figure 3-10. Profile plot of percent light transmission and sensor depth acquired during CTD sample intervals T5 and T6 for Plume 1. Locations of water sample collections within the plume are also shown.

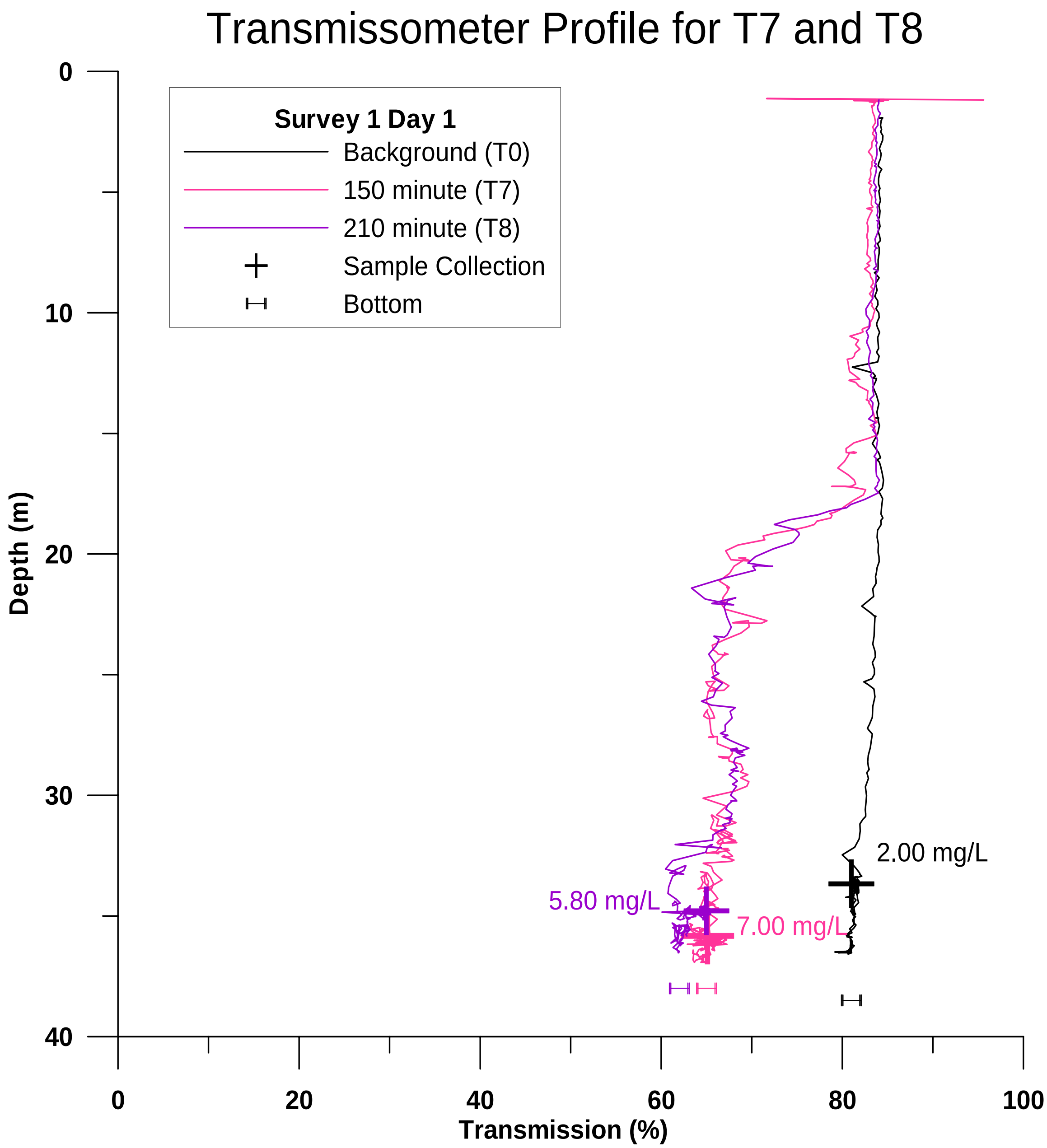


Figure 3-11. Profile plot of percent light transmission and sensor depth acquired during CTD sample intervals T7 and T8 for Plume 1. Locations of water sample collections within the plume are also shown.

Table 3-4. Results of Total Suspended Solids (TSS) Analysis from Discrete Water Samples Collected during CTD Profiling Operations during Survey Day 1 (Plume 1)*

Sample ID	Time (min)	Elapsed Time (hr:min)	Depth (m)	Transmittance (%)	OBS (FTU)	TSS (mg/L)				
						A	B	C	Avg	STDev
S1D1_T0	0	0:00	34	81.44	9.77	2.2	2.6	1.2	2.0	0.72
S1D1_T1	10	0:08	17	12.82	20.15	31.6	28.4	24.4	28.1	3.61
S1D1_T2	20	0:17	33	15.76	21.98	28.0	27.6	25.6	27.1	1.29
S1D1_T3	40	0:35	37	37.30	14.65	14.0	11.6	14.4	13.3	1.51
S1D1_T4	60	0:58	37	39.44	14.04	8.4	9.4	11.2	9.7	1.42
S1D1_T5	90	1:33	36	58.00	12.21	9.2	5.8	8.0	7.7	1.72
S1D1_T6	120	1:57	36	62.34	11.60	10.6	11.0	6.6	9.4	2.43
S1D1_T7	150	2:31	36	65.11	10.99	11.0	5.4	4.6	7.0	3.49
S1D1_T8	210	3:29	35	65.09	11.60	4.6	4.4	8.4	5.8	2.25

* plume tracked from the disposal of material from a 6,000 yd^3 capacity split-hull disposal barge

observations of transmissometer data and generally corresponded to the depth level of greatest turbidity.

At approximately ten minutes after the disposal event, the average TSS concentration near the plume center was 28.1 mg·L^{-1} (Figure 3-7; Table 3-4). As anticipated, this sample (S1D1_T1) had the highest reported average TSS concentration observed during the first plume monitoring event. The water sample for TSS was collected at a depth of 16.8 m within an isolated layer of turbid water at mid-depth. The rapid and significant increase in turbidity suggested this layer represented the most concentrated portion of the sediment plume. However, the vertical transmissometer profiles obtained at the T2 interval and during the remainder of the survey day indicated a substantially higher TSS concentration existed at the center of the plume. As a result, it is theorized that, although the T1 water sample was obtained within the plume, it was likely collected outside the centroid for Plume 1.

The TSS sample collected at the T2 interval was obtained approximately 4 m above the seafloor, with turbidity remaining relatively high 20 minutes after the disposal event (27.1 mg·L^{-1}; Figure 3-7: Table 3-4). TSS values decreased substantially for the remainder of the sampling intervals, approaching background levels in Sample S1D1_T8 (5.9 mg·L^{-1}) collected 210 minutes after the disposal event. Although the turbidity levels generally decreased with time during the course of the 3.5-hour survey, a noticeable increase in the average TSS concentration (approximately 2 mg·L^{-1}) was observed between the T5 (90 minutes) and the T6 (120 minute) sample intervals. Since the TSS samples for intervals T2 through T8 were all collected within near-bottom portion of the plume, the relatively low value at T5 could have been a result of sampling outside of the plume centroid, and/or a result of settling of fine-grained sediment through the water column.

3.2.1.4 ADCP Backscatter from Underway Profiling

In order to best characterize the morphology of a sediment plume in the water column, a determination of background acoustic backscatter was required to remove the impacts of particulate matter in the ambient water column on the acoustic record. In each case, a band of higher backscatter intensity was recorded at mid water column levels prior to the placement of dredged material at RISDS. For Plume 1, background backscatter ranged from acoustic counts of 65 to 90, with values steadily increasing from a depth of 3 m to a depth of 17 to 18 m (mid depth), then decreasing to approximately 70 in the near bottom depth horizons (Figure 3-12). Although these results suggest the presence of a significant turbidity layer in the water column prior to dredged material disposal activity, there was no corresponding deflection in the transmissometer record during background water column profiles. Based upon the findings of similar surveys conducted in support of

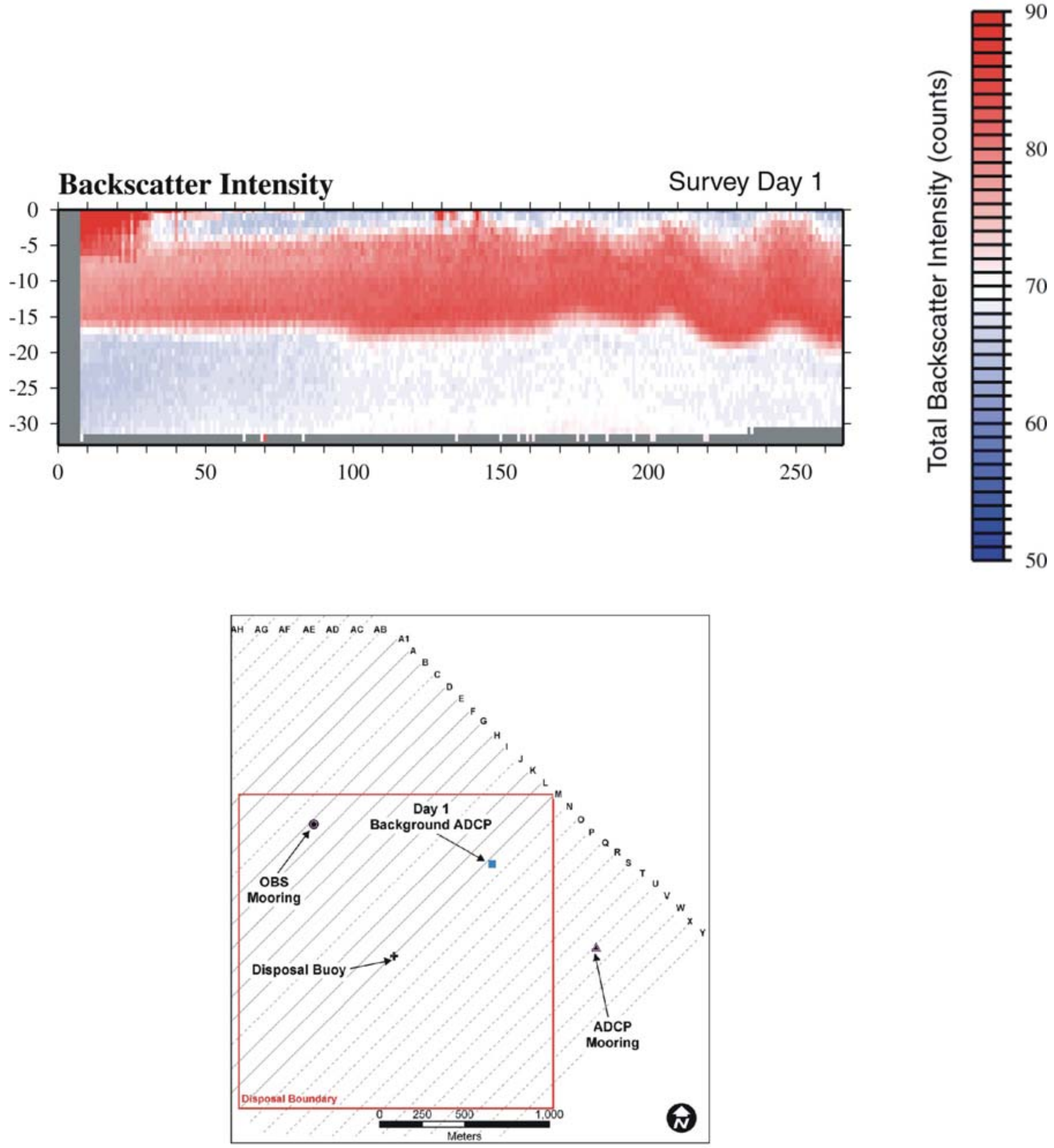


Figure 3-12. Profile plot of raw ADCP backscatter data collected on 8 April 2004 (Plume 1) to characterize background conditions at RISDS.

turbidity monitoring, it was theorized that the banding effect was driven by changes in seawater density within the mid-water column. Small-scale, but sharp vertical density gradients may have acted as significant reflectors of the acoustic signal transmitted by the ADCP, and the strong signal returns associated with variability in the acoustic properties within the water column were indistinguishable from the returns associated with suspended particulate matter (Flagg and Smith 1989).

Figures 3-13 through 3-18 show the variation in water column backscatter intensity above background within the individual transect lines occupied over RISDS for the duration of the Plume 1 survey. Based on the water column density artifact discussed above, these data are considered valid for near-surface and near-bottom depth levels. The raw backscatter signal has been removed in these cross-sections, but the effects of the strong acoustic signature associated with the water column density gradient tend to obscure the morphology of the sediment plume at mid depth.

During the first 15 minutes following the Plume 1 disposal event, a large (20 count), broad signal was recorded on survey Line M centered on the observed disposal point. Based on the acoustic backscatter data, the sediment plume extended from the surface to the seafloor, with entrained sediments acoustically detectable over a 260 m portion of the initial 430 m long cross-section, with the highest sediment concentrations detected over a 70 m segment in close proximity to the observed disposal point (Figure 3-13A). The data collected along Lines L and K indicated a general reduction in plume intensity as these cross-sections were completed at the leading (northwestern) edge of the plume, ahead of the centroid (Figures 3-13B and C).

The first three transects (Lines M, L, and K) were complete within 32 minutes of the disposal event, then re-occupied to evaluate the changes in plume morphology due to dispersion, settlement, and advection by the ambient currents. On the second sampling of Line M (Line M2), there was no acoustically detectable surface backscatter signal and the deeper expression of the plume was both weaker (15 counts) and narrower, indicating a substantial reduction in the presence of the plume within the acoustic data along this transect relative to the first pass (Figure 3-14A). The second passes conducted on Lines L and K showed a double peaked signal at depth (10 and 15 counts) and two weak near-surface signals that were displaced to the south relative to those at depth, suggesting some differences in velocity and direction in the water column currents (Figures 3-14B and C).

In general, the second occupation of Lines M, L, and K indicate a substantial reduction in the intensity and overall size of the sediment plume relative to the first pass (Figures 3-13 and 3-14). This reduction in the acoustic return 40 to 50 minutes post-placement could be attributable to rapid settlement of particles and/or advection from the

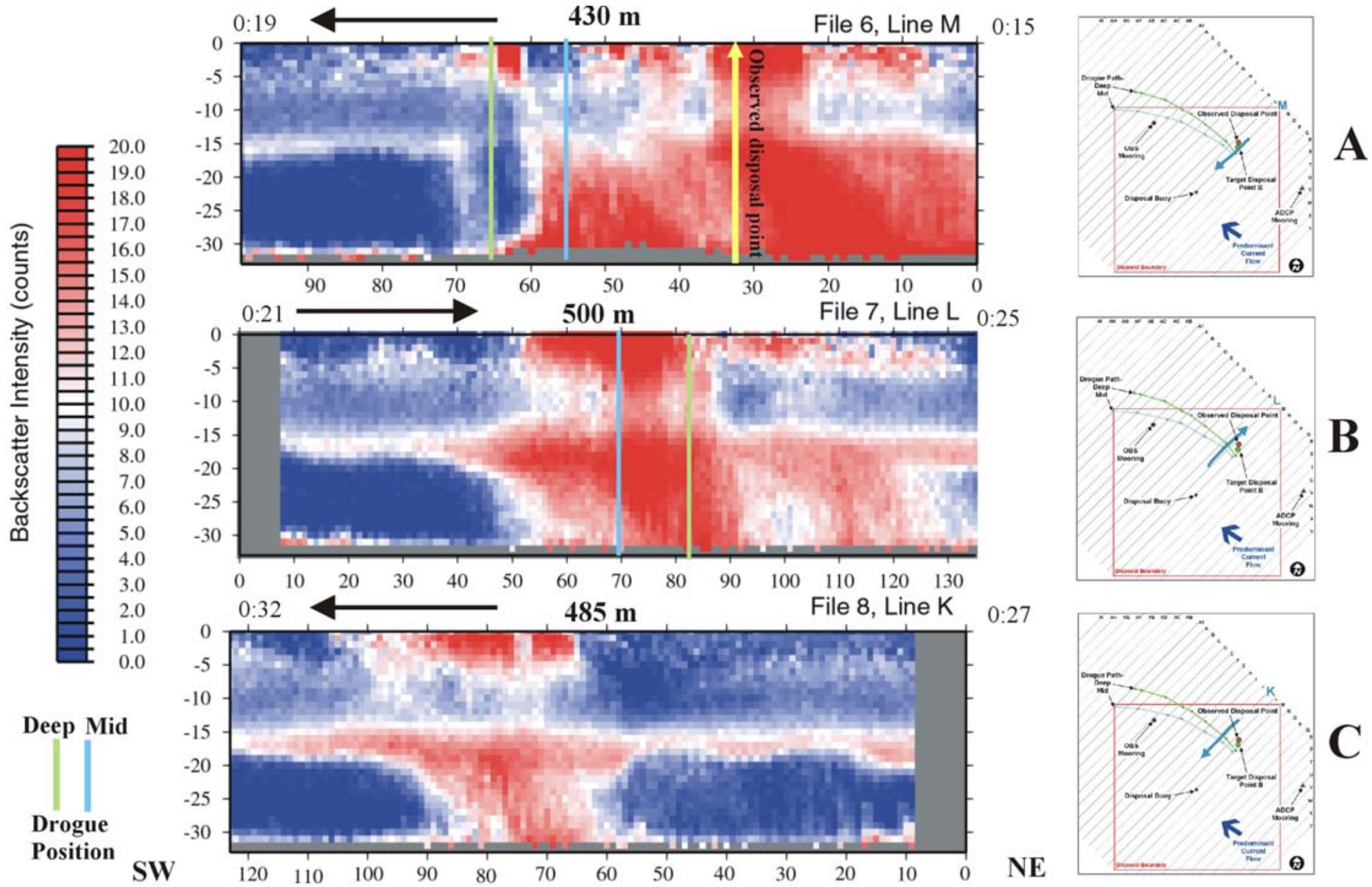


Figure 3-13. Profile plots of data collected from ADCP transects M, L, and K on 8 April 2004 (Plume 1) displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to illustrate plume morphology 15 to 32 minutes after the dredged material disposal event at Point B.

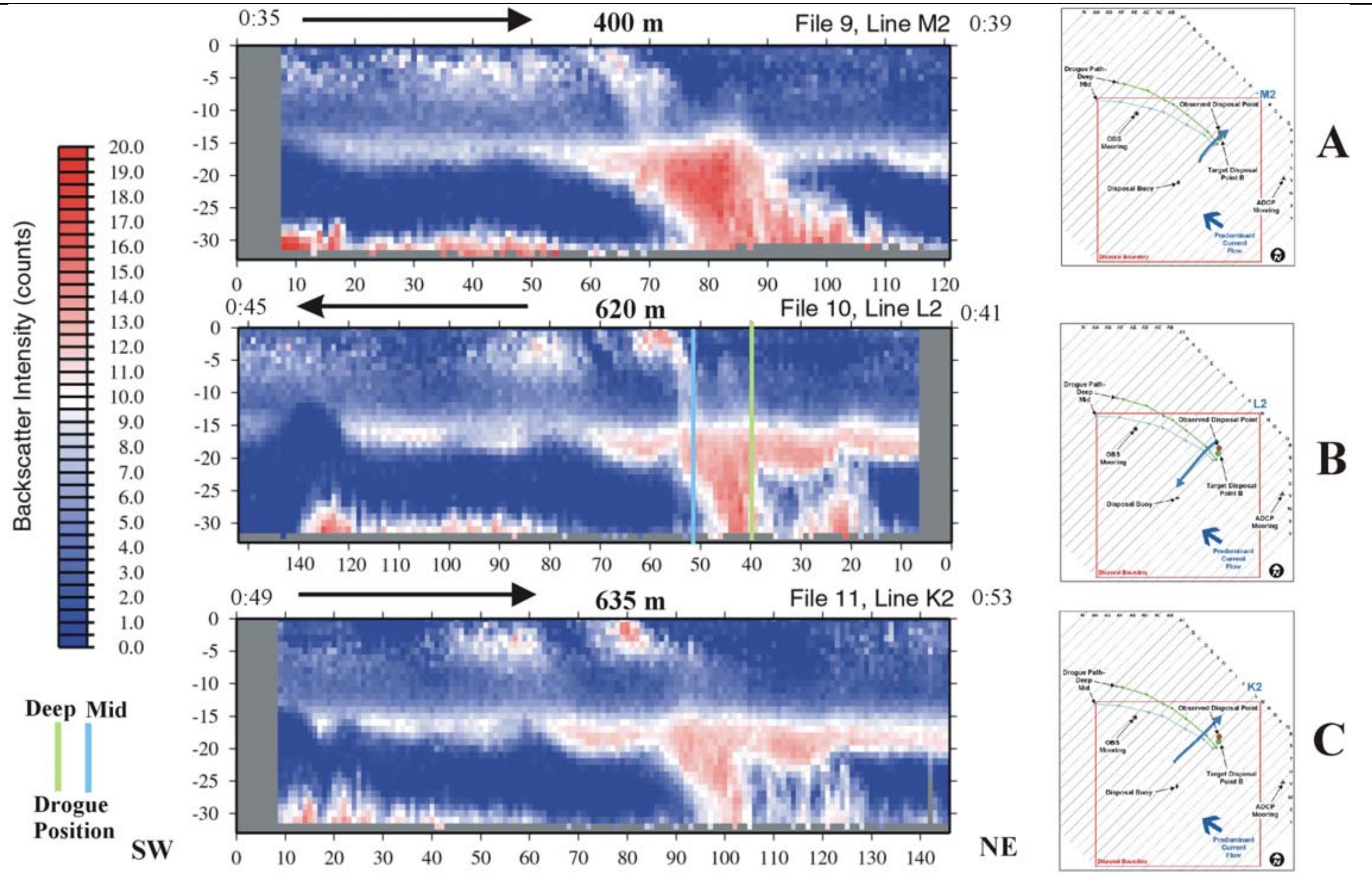


Figure 3-14. Profile plots of data collected from ADCP transects M2, L2, and K2 on 8 April 2004 (Plume 1) displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to illustrate plume morphology 35 to 53 minutes after the dredged material disposal event at Point B.

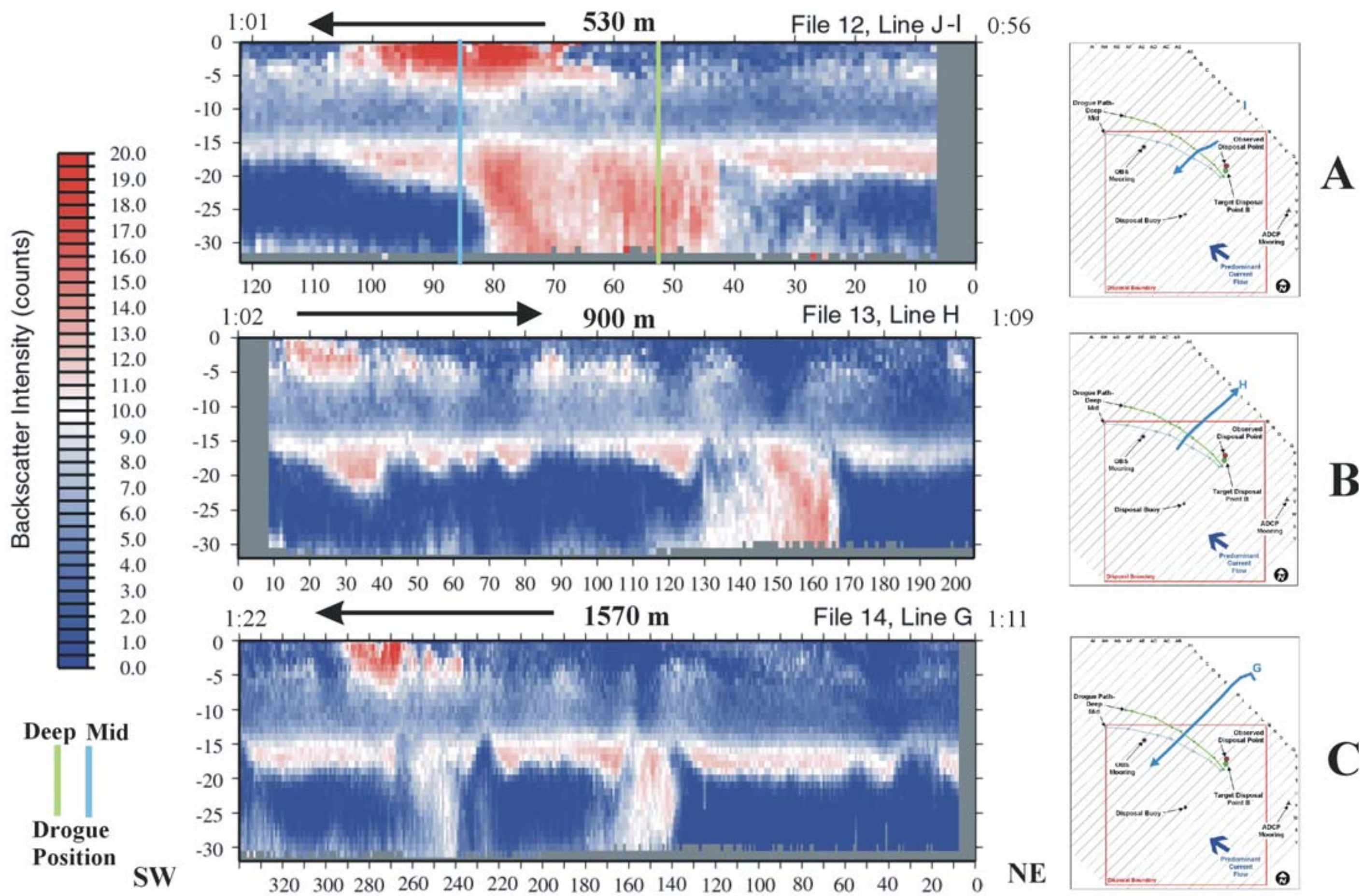


Figure 3-15. Profile plots of data collected from ADCP transects J, H, and G on 8 April 2004 (Plume 1) displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to illustrate plume morphology 56 to 82 minutes after the dredged material disposal event at Point B.

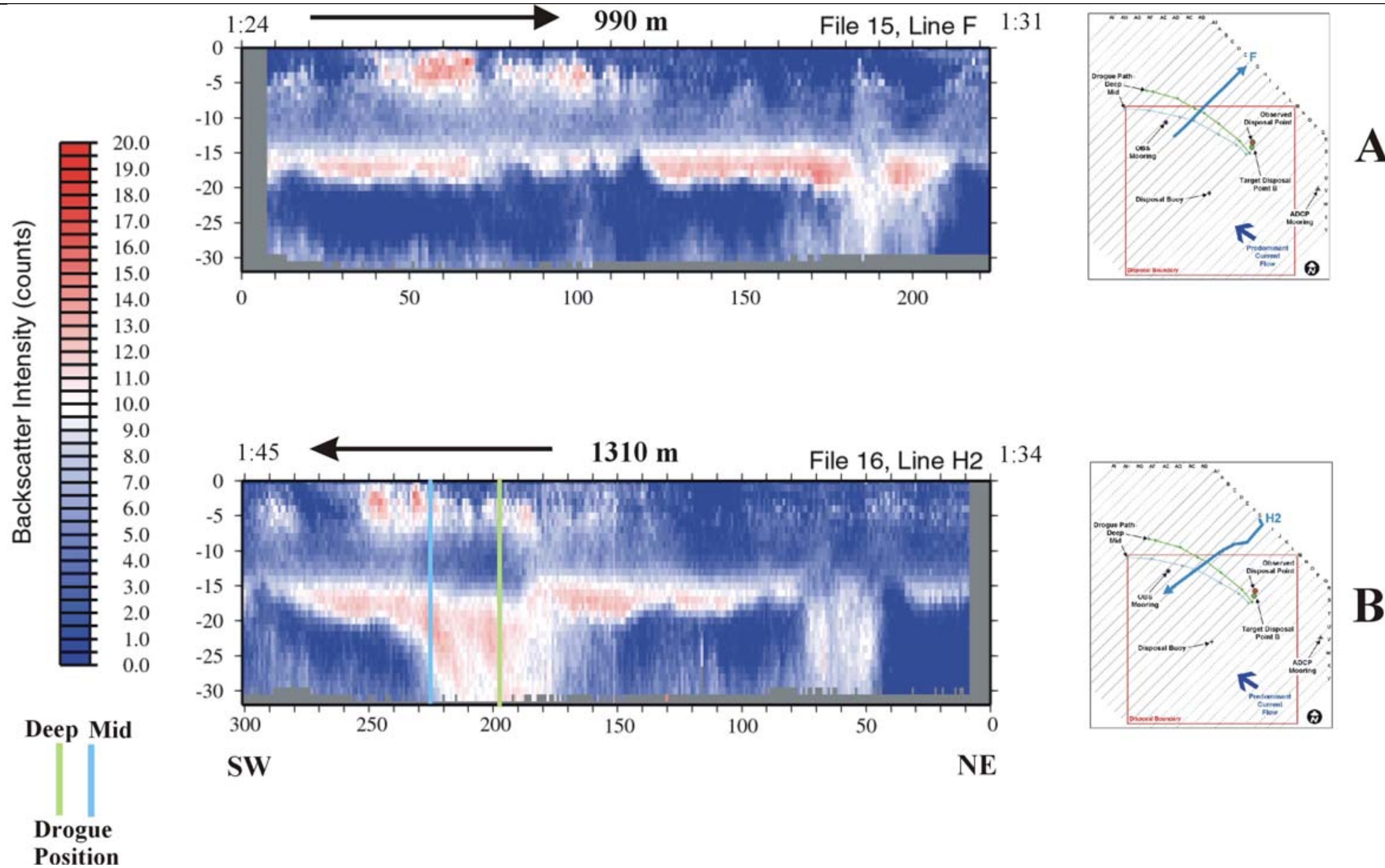


Figure 3-16. Profile plots of data collected from ADCP transects F and H2 on 8 April 2004 (Plume 1) displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to illustrate plume morphology 84 to 105 minutes after the dredged material disposal event at Point B.

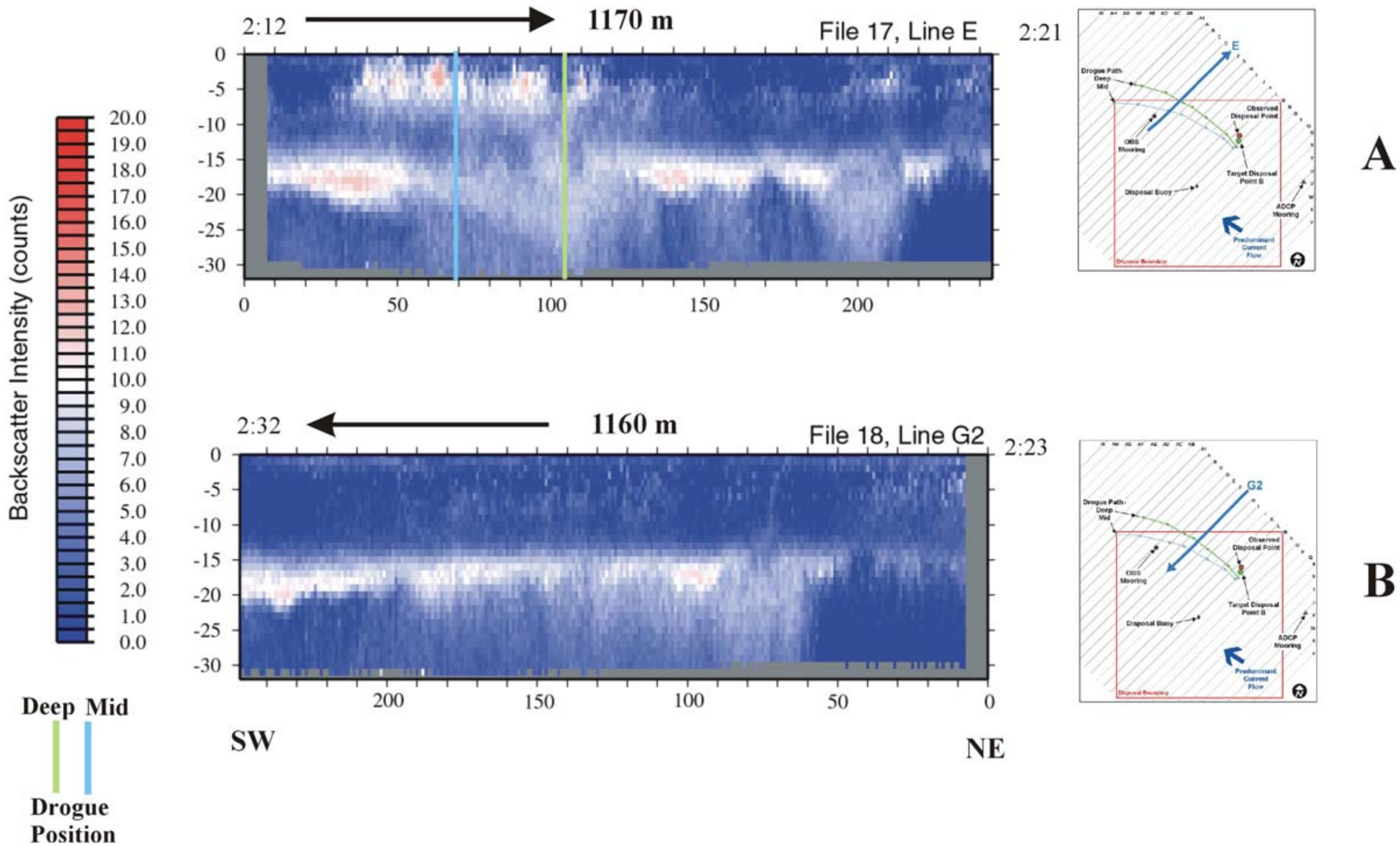


Figure 3-17. Profile plots of data collected from ADCP transects E and G2 on 8 April 2004 (Plume 1) displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to illustrate plume morphology 132 to 152 minutes after the dredged material disposal event at Point B.

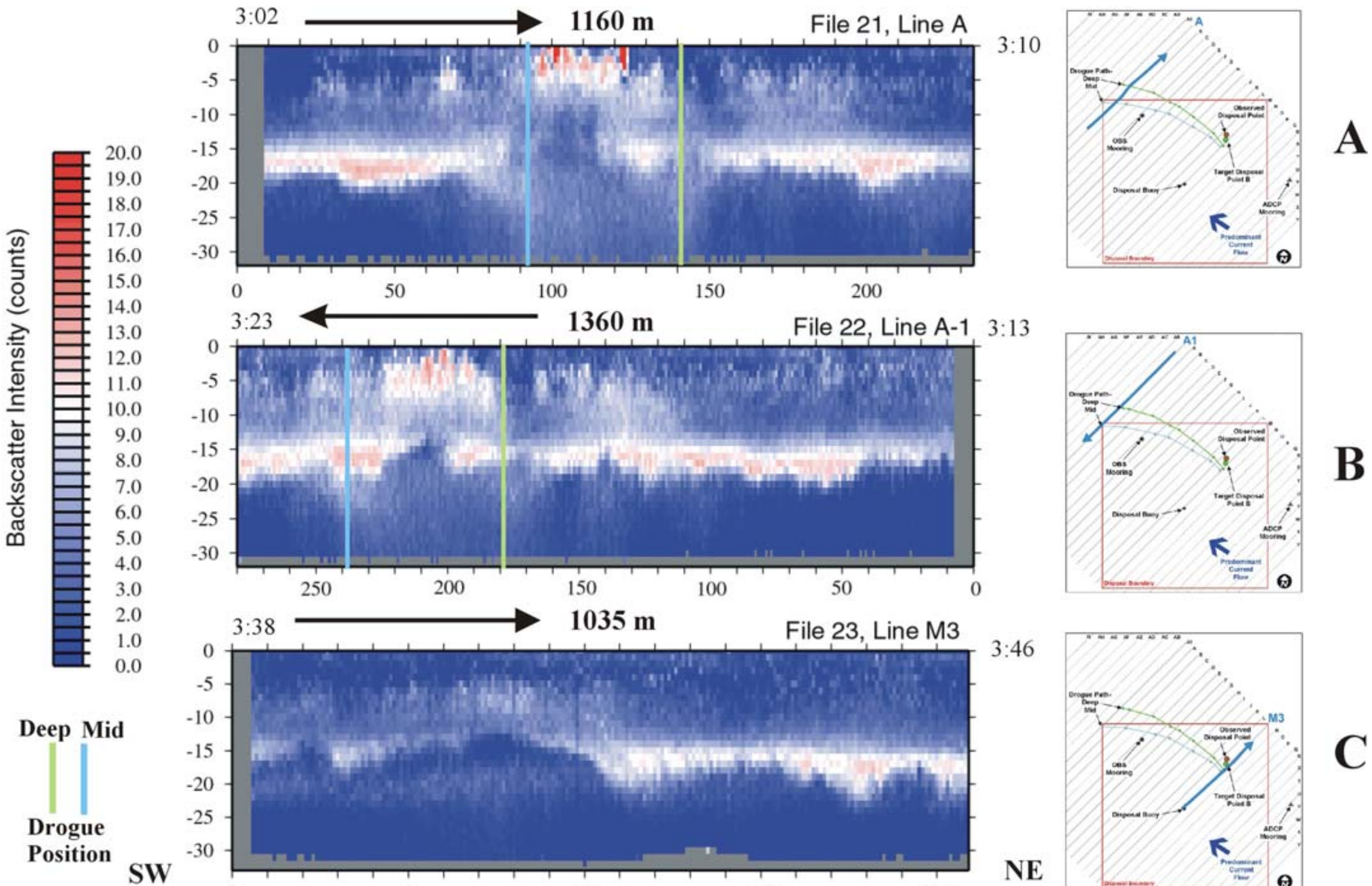


Figure 3-18. Profile plots of data collected from ADCP transects A, A-1 and H2 on 8 April 2004 (Plume 1) displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to illustrate plume morphology 182 to 226 minutes after the dredged material disposal event at Point B.

disposal point. However, another contributing factor to this reduction in plume intensity would be the decrease in the amount of gas bubbles and turbulence in the water column. Much of the gas that was entrained within the water column as bubbles during the disposal event would have risen to the surface within 40 minutes. Furthermore, the turbulencegenerated in the water column by the disposal of estuarine sediments at a marine site (i.e., mixing driven by density, salinity, and temperature contrast) would have subsided within that timeframe as well.

The center of the plume was reacquired on Line J where a broad (15 to 18 count) signal was recorded in the near-bottom waters, with an equally strong signal offset to the south in the surface waters (Figure 3-15A). The surface and deep signals were weaker and farther offset in the record from Line H. On lines G and H, two 15 count signals were seen in the deeper waters with a single weaker surface signal (Figure 3-15B and C). The remaining transect lines that were acquired from roughly 1.5 to 3 hours after the disposal event (Figures 3-16 through 3-18) showed a broad, relatively weak (<12 counts) elevation in backscatter intensity over background, that was essentially limited to the lower portion of the water column. A consistent correlation was noted between the areas displaying elevated backscatter intensity and the position of the mid-water and deep-water drogues. Possible surface expressions of the remnant plume were recorded in the southern and central portions of lines B and A approximately three hours after the initial disposal event.

3.2.1.5 Water Column Optical Backscatter from Moored Array

As part of the Plume 1 survey, the OBS sensor mooring was placed approximately 950 m west-northwest of the observed disposal position (Figure 2-2). The record presented in Figure 3-19 begins at its deployment time of 15:11 (approximately two hours after the disposal event). The delay in deployment was necessary to determine the direction and rate of plume transport, as well as select the optimal position to capture the leading edge, core and trailing edge of the sediment plume. The data collected at 10-second intervals showed low levels of background turbidity in the upper and middle water column (13 m and 18 m) with values averaging 2 FTU during the first 40 minutes of the record (Figure 3-19). A noticeable and sustained increase in suspended sediment concentrations was detected at 15:51 UTC, and higher concentrations persisted for approximately 20 minutes before returning to background levels once again (Figure 3-19).

The information collected by the near-bottom OBS sensor (32 m) displayed relatively high and quite variable turbidity levels for the duration of the 8 April deployment (0 to 30 FTU), which did not agree with data provided by the 13 m and 18 m OBS sensors. Despite great variability, a general trend of higher turbidity was observed for the near-bottom sensor. The record for the near-bottom sensor suggested that it was located in a

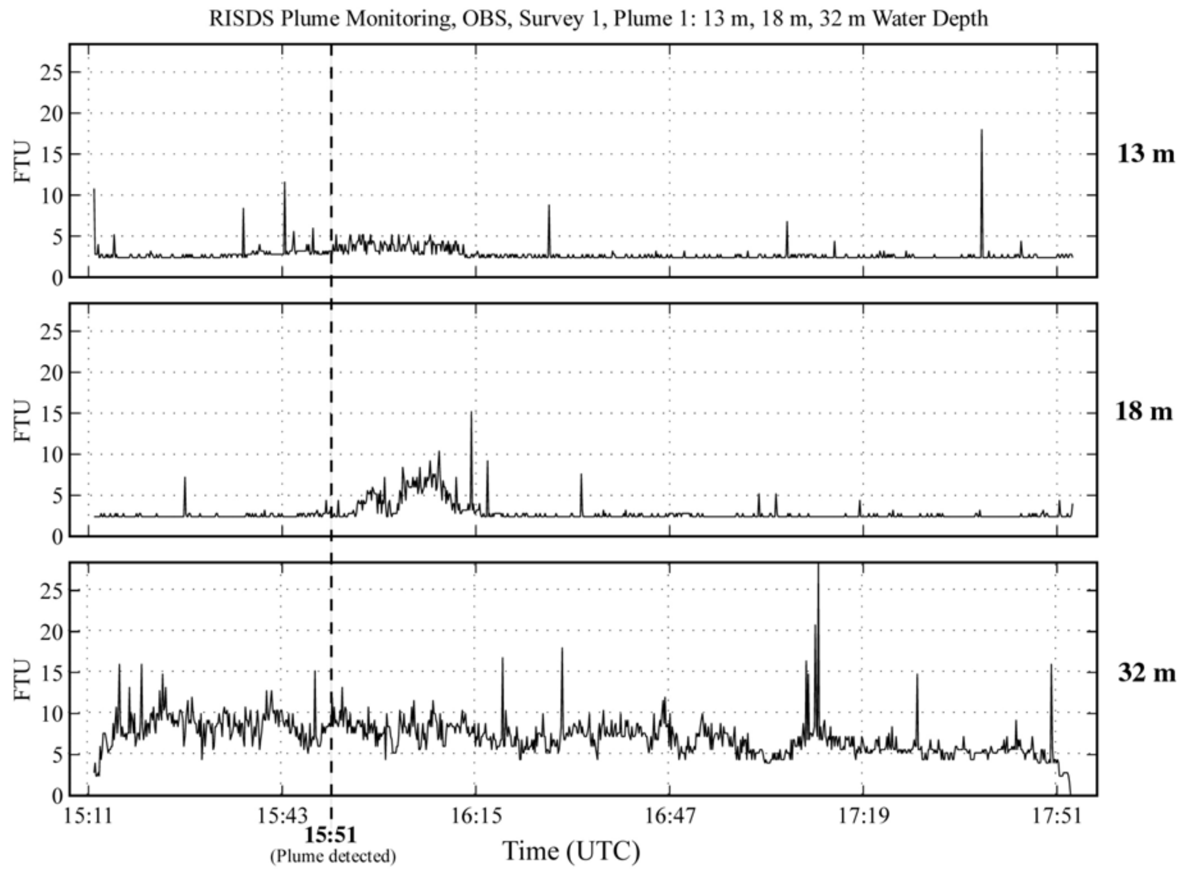


Figure 3-19. Time-series (UTC) plot of OBS data collected on 8 April 2004 (Plume 1) from three levels in the water column (13 m, 18 m, and 32 m), displaying changes in turbidity (FTU) over time resulting from sediment plume passage. Dashed line (15:51) represents an increase in suspended sediment, indicating the possible of the leading edge of the plume.

layer of turbid water near-bottom for the 2.5-hour deployment period or failed to equilibrate upon deployment and provided artificially high turbidity values. Comparisons with the background transmissometer data showed no signs of increased turbidity at 32 m depth that would be a basis for the high OBS readings. Therefore, the data provided by the near-bottom sensor were considered invalid for this survey day.

The data from the upper and middle water column sensors suggest the leading edge of the sediment plume passed by the OBS mooring position approximately 162 minutes after the disposal event at 13:09 UTC. The plume was first detected by the sensor at 13 m depth at 15:51 UTC, and again at a depth of 18 m four minutes later (15:55 UTC). Given the distance from the initial disposal point (950 m), the sediment plume was transported at an average rate of 9.8 $cm \cdot s^{-1}$, generally equivalent to the mean current speed calculated from the bottom mounted ADCP mooring (Figure 3-3). The OBS readings from the sensor located in 13 m of water displayed only a minor increase in turbidity over background with readings approaching 5 FTU detected in that depth interval for 20 minutes while the plume passed. The duration of the plume passage was similar at the 18 m depth interval. However, the concentration of entrained sediments was likely somewhat higher in the deeper portion of the water column, as OBS readings above 5 FTU were common. In addition, there appeared to be a short period of time (2 to 3 minutes) when turbidity levels at the 18 m depth interval returned to near background levels before increasing to levels above 5 FTU once again (Figure 3-19). This suggests two distinct pulses of turbid water passed by the mooring position within the 20-minute period.

3.2.1.6 Toxicity of Water Samples

A summary of the toxicity results associated with the water sampling data for the Plume 1 is provided in Table 3-5A. Mysids and silversides exhibited no lethal responses to any of the water samples from the first plume tracking series. Mean responses for all samples, from T0 to T6 (120 minutes) were greater than 90% survival, and all QA/QC requirements for successful conduct of the tests were met.

3.2.2 Plume 2

The second day of the plume survey operations occurred on 9 April 2004, and followed the sediment plume generated by the disposal of 4,600 m^3 of maintenance material dredged from Sabin Point Reach and placed at Point A, located in the northwestern quadrant of RISDS (Figure 1-3). Load 758 was deposited by a split-hull barge in the northwestern quadrant of RISDS at 13:19 UTC. Similar to the Plume 1 survey, comprehensive tracking and sampling was performed for 3.5 hours immediately

Table 3-5a. Toxicity Results from Discrete Water Samples Collected during CTD Profiling Operations conducted at RISDS on 8 April 2004 (Plume 1)

Sample	Time Interval	Mysid % Survival	Silverside % Survival
Control		98	98
S1D1-TOX	Background	100	100
S1D1-T3X	40 min	98	96
S1D1-T4X	60 min	100	100
S1D1-T6X	120 min	100	96

Table 3-5b. Toxicity Results from Discrete Water Samples Collected during CTD Profiling Operations conducted at RISDS on 9 April 2004 (Plume 2)

Sample	Time Interval	Mysid % Survival	Silverside % Survival
Control		100	98
S1D2-TOX	Background	100	84
S1D2-T3X	40 min	100	90
S1D2-T4X	60 min	96	94
S1D2-T6X	120 min	100	92

following the event. Based on the water level data corrected to the local tide zone, this disposal event occurred during a mid-flood tide (Figure 3-20). The plume monitoring survey activity continued through the remainder of the flood, during a short period of slack tide (no change in water level; 15:18 to 15:30 UTC) and through the early stages of an ebb tide (decreasing water levels), concluding at approximately 17:00 UTC. Within this time period, the net transport of the sediment plume was to the west-northwest as described in further detail below.

3.2.2.1 Water Column Currents

Similar to the preceding day, the surface drifter, mid-water and deep-water current following drogues were deployed immediately following the disposal event and allowed to drift with ambient currents for the duration of the survey activities. The Davis surface drifter displayed a much slower speed than the mid and deep-water drogues with a calculated average of 3 $cm \cdot s^{-1}$ (Table 3-3). The surface drifter displayed a more north-northwest direction of travel, but remained within the general vicinity of the dredged material disposal site (Figure 3-21). Although relatively light (<6 $m \cdot s^{-1}$), the surface winds for that day were emanating from the north and northwest, in opposition to the currents. This suggests the currents in the surface waters (1 m) were affected even by the minor wind stress and resulting small waves. Furthermore, wind forces on the drifter's flag may also have affected motion.

An average speed of 13 $cm \cdot s^{-1}$ was calculated for both the mid and deep-water drogues for Plume 2 monitoring survey (Table 3-3). For the first two hours of the survey both the mid and deep-water drogues tracked relatively close to each other. However, towards the end of the plume tracking, the deep-water drogue had displayed a more northerly track, ending approximately 175 m to the north of the mid-water drogue (Figure 3-21).

In agreement with the information provided by the current-following drogues, the bottom mounted ADCP record for Plume 2 indicated that the water column currents flowed predominantly to the west-northwest during the plume monitoring event, with speeds ranging from a minimum of near 0 $cm \cdot s^{-1}$ to a maximum of 25 $cm \cdot s^{-1}$ (Figure 3-22). Although fairly weak at all levels of the water column, the six-minute averaged data showed some noticeable differences in flow direction and intensity between the surface, mid-water and near-bottom currents just prior to the disposal event, indicative of minor differences in velocity and direction within the water column (Figures 3-23 and 3-24). Near-bottom currents remained relatively consistent in both direction and velocity for the entire ADCP record, while both the near-surface and mid-water column currents exhibited some variability.

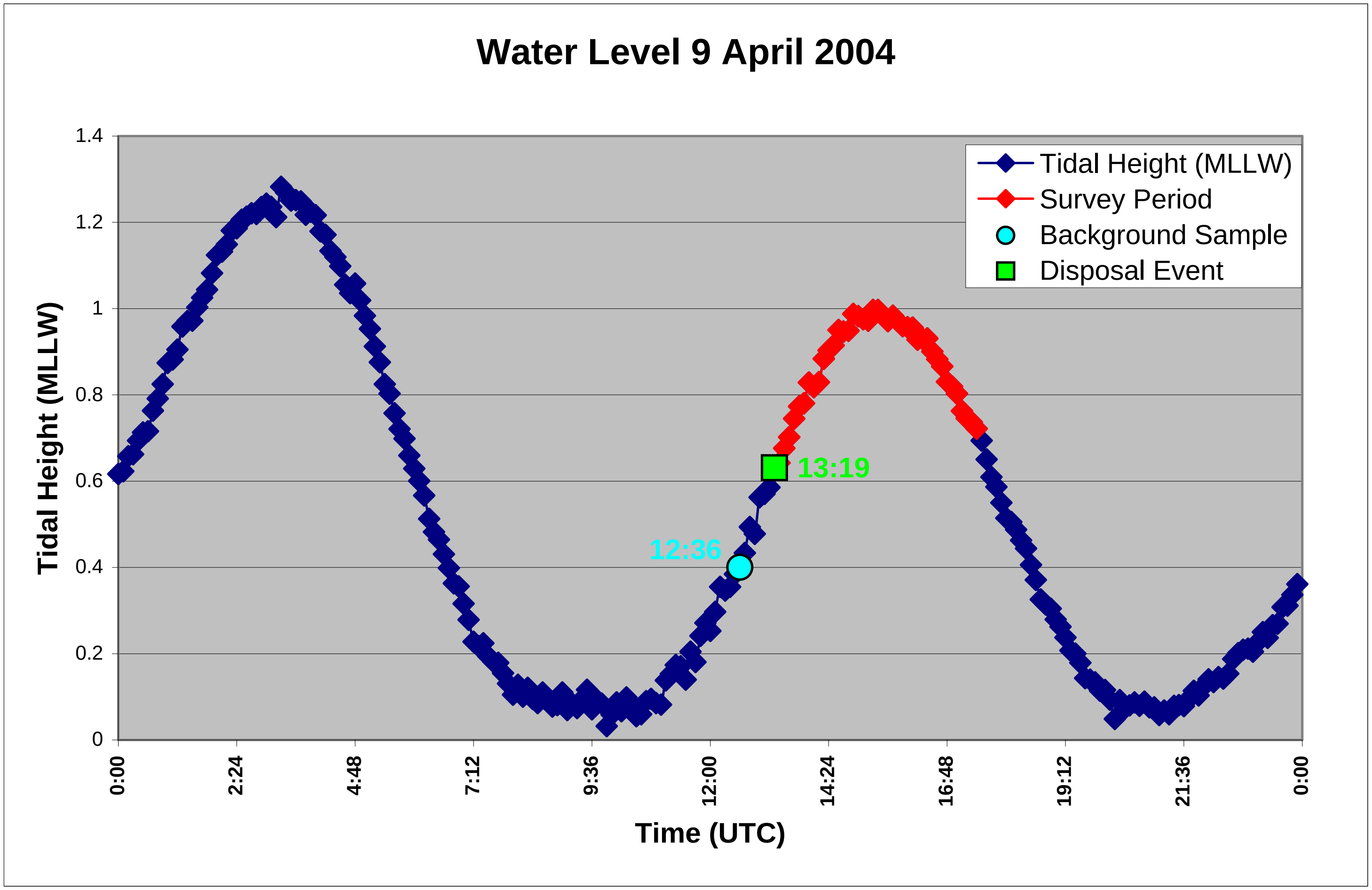


Figure 3-20. Water level data from the NOAA tide station in Newport, RI, corrected to the tide zone encompassing RISDS for 9 April 2004. The Background Sample and the Disposal Event are shown in comparison to the tidal stage.

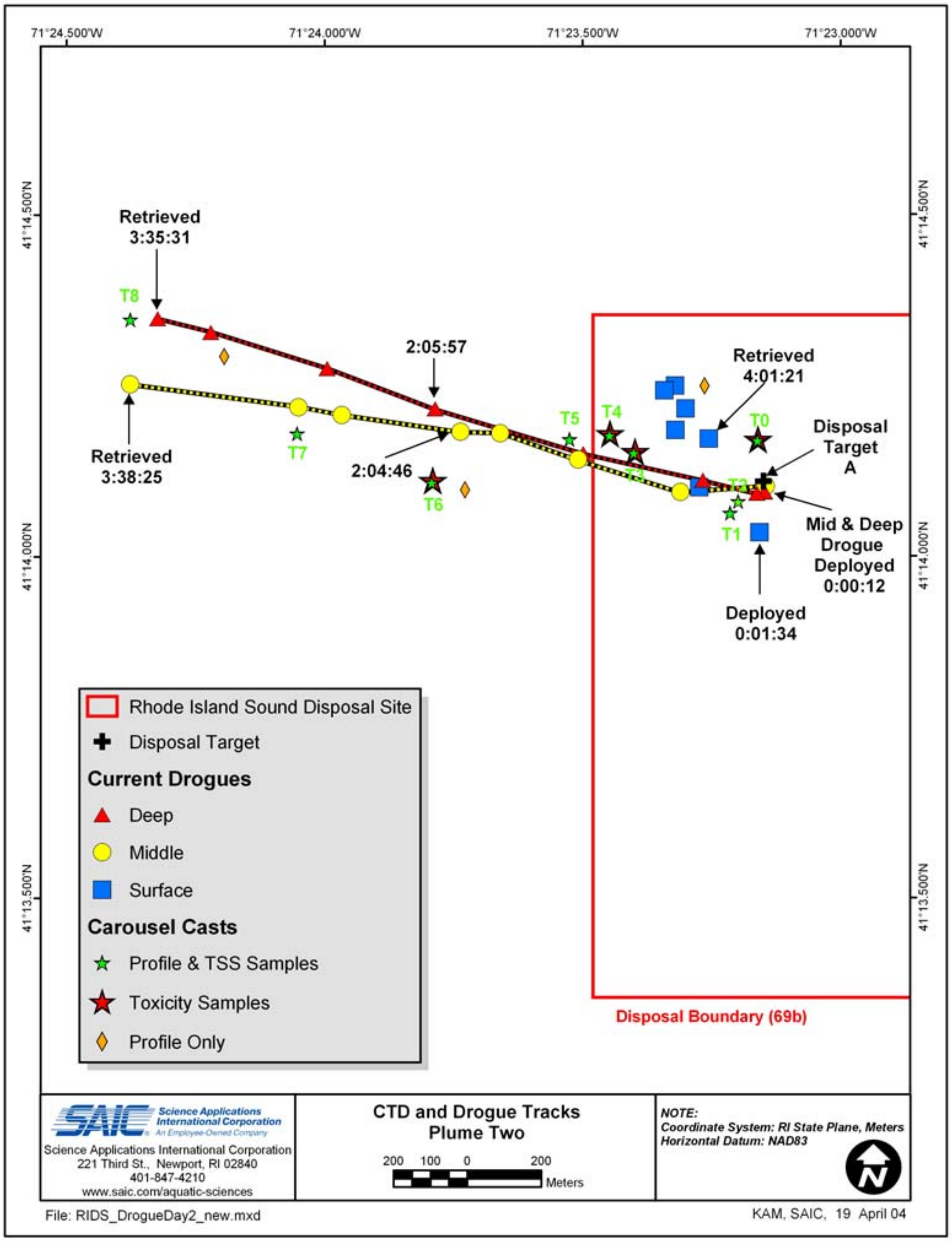


Figure 3-21. Map indicating current drogue trajectories and CTD cast locations during the tracking of Plume 2. Locations of water samples are also shown. Times represent elapsed time since disposal operations.

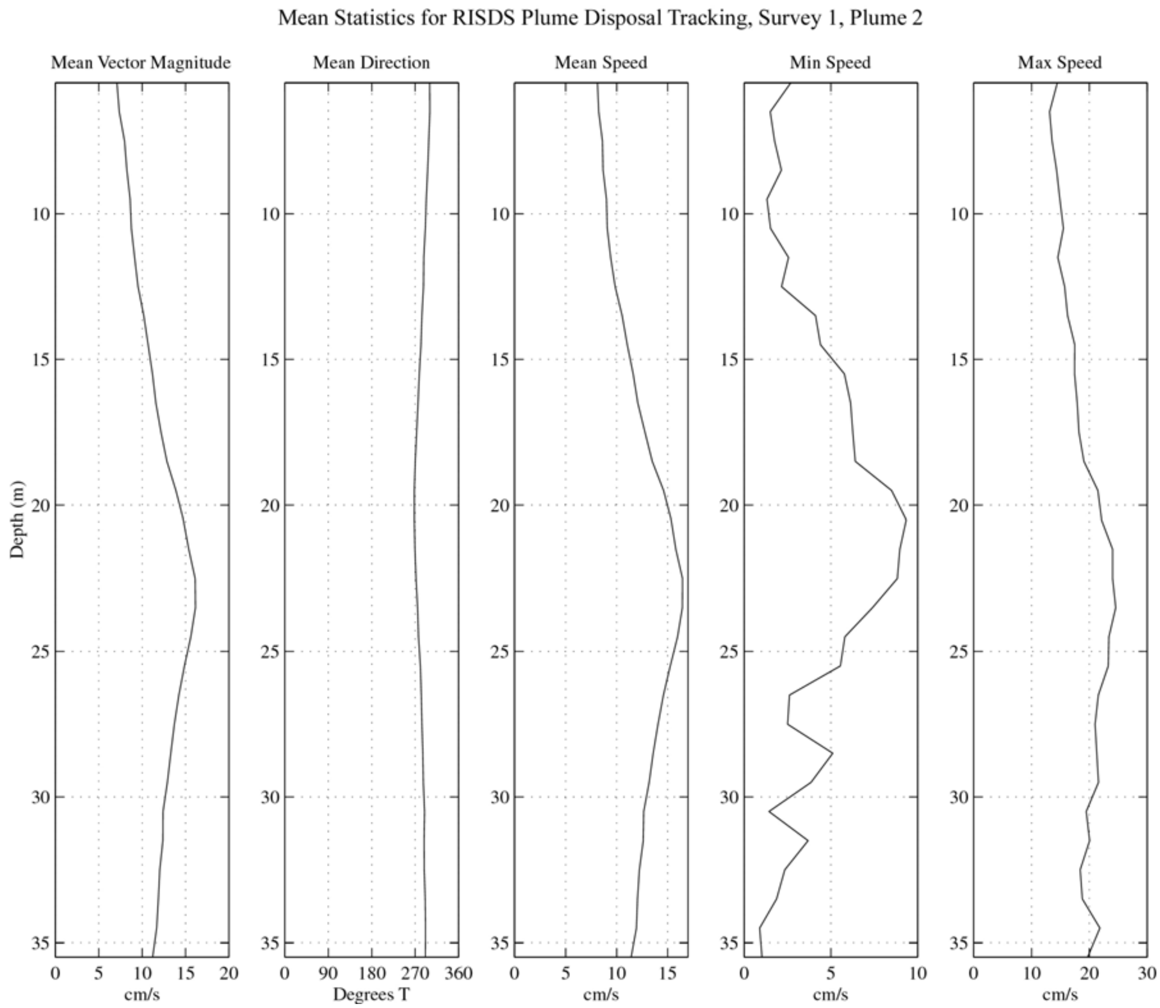


Figure 3-22. Statistics of moored current meter data collected on site during Plume 2 disposal monitoring activities. Current meter deployed for extent of survey period (3.5 hours). Parameters plotted include mean vector magnitude, mean vector direction, mean speed (regardless of direction), minimum speed and maximum speed.

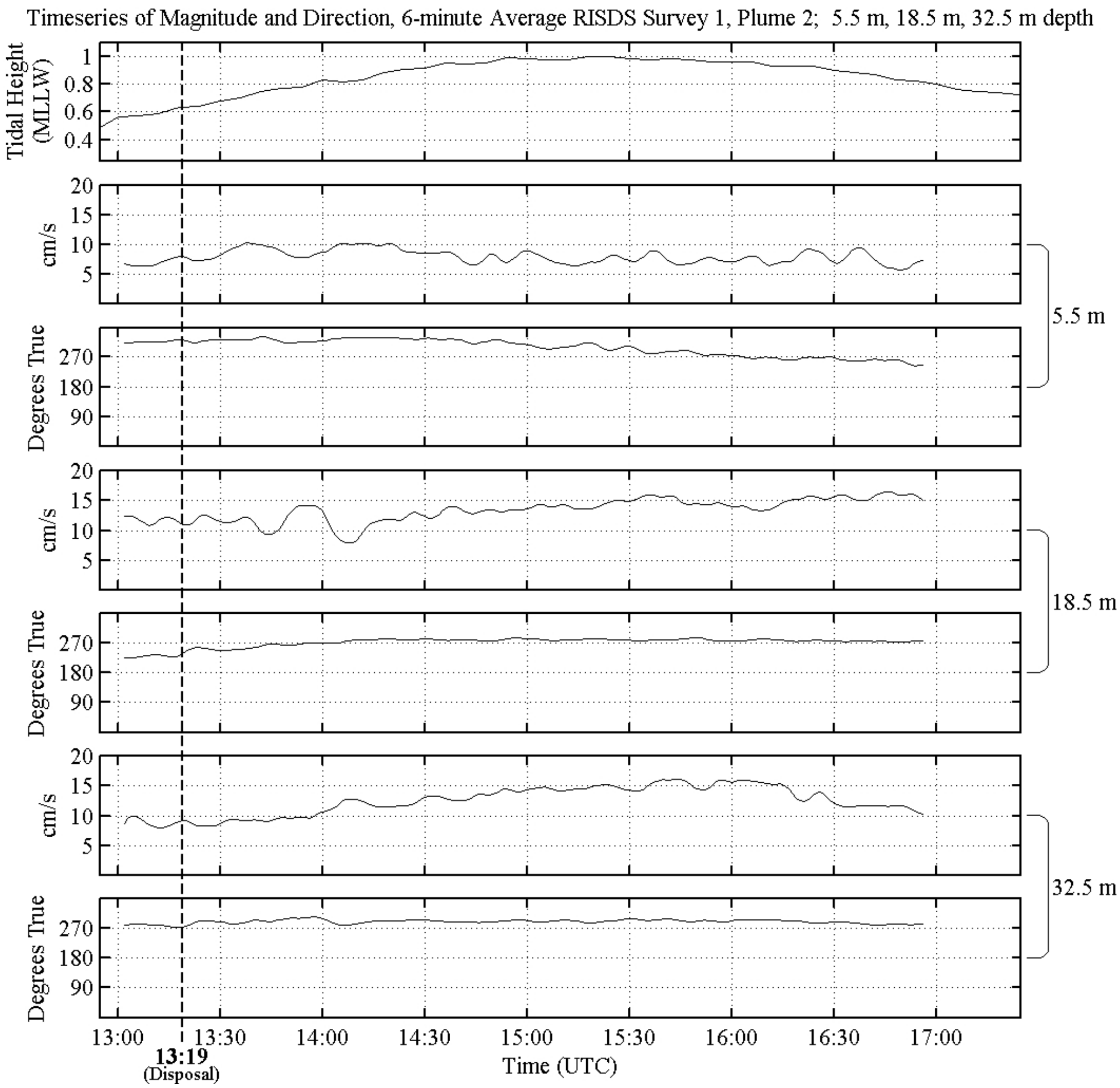


Figure 3-23. Time-series (UTC) plot of current magnitude and direction during Plume 2 at the near-surface level (~5.5 m; top two panels) and the two selected drogue depth levels of ~18 m (middle two panels) and ~32 m depth (bottom two panels). Currents were sampled at 1 minute intervals, and filtered with six minute Low Pass Filter (LPF) to reduce high-frequency noise. Dashed line (13:19) represents barge disposal time.

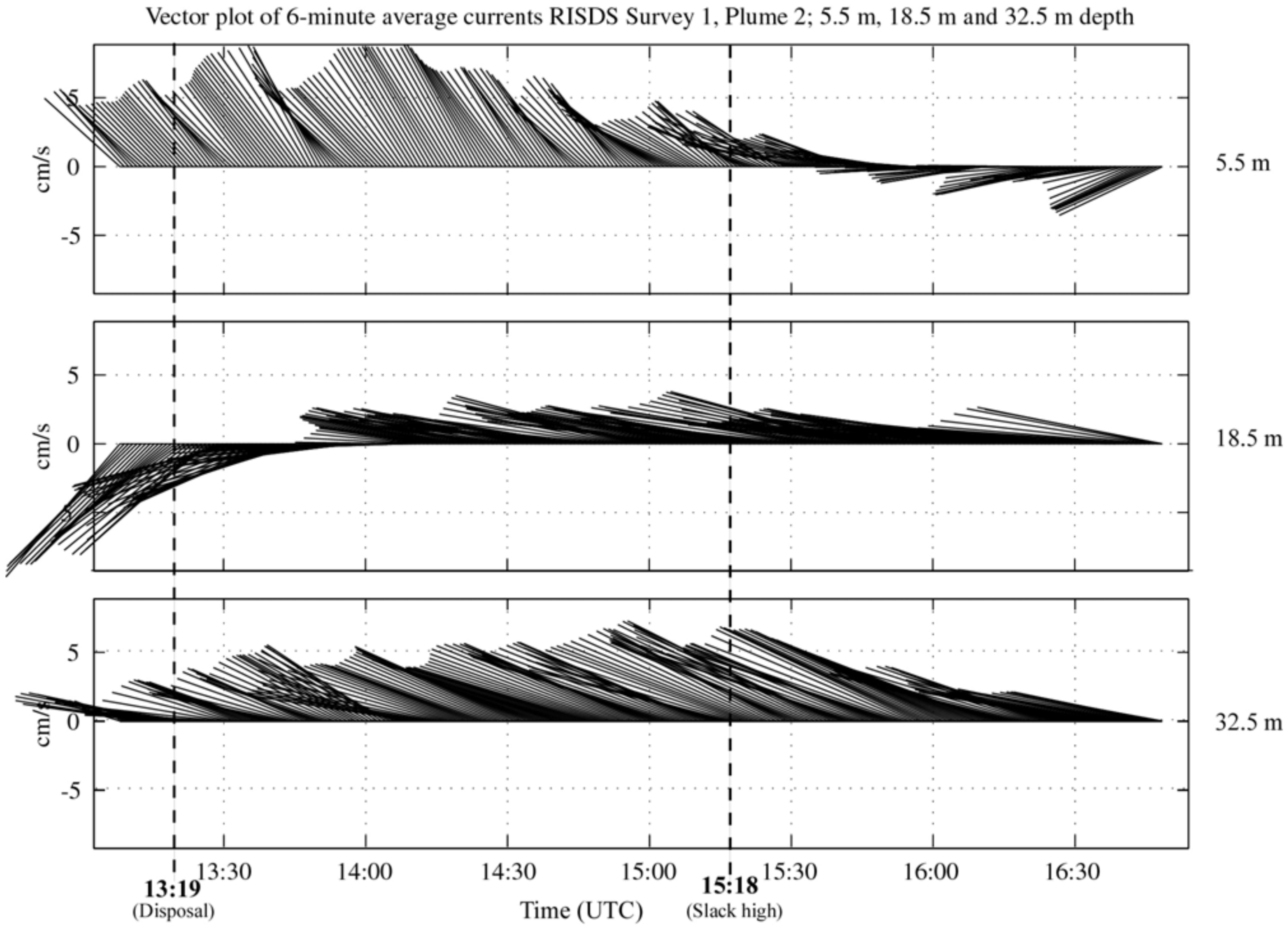


Figure 3-24. Time-series (UTC) plot of current vectors (six-minute LPF) during Plume 2 at the near-surface level (5.5 m; top panel) and the two selected drogue depth levels of ~18 m (middle panel) and ~32 m depth (bottom panel). Dashed line (13:09) represents barge disposal time.

Comparisons between the current record generated by the bottom-mounted ADCP and water level data corrected for RISDS suggests the disposal event once again occurred during a period of flooding tide and relatively high current flow (13:19 UTC), but approximately 2.5 hours before the peak flow (15:40 UTC; Figure 3-23). Similar to the Plume 1 findings, maximum current velocities were detected over RISDS when water levels were at their highest (Mean Lower High Water; see Figure 3-23) during the Plume 2 survey. Current velocities at mid-depth and near bottom remained elevated (>10 cm·s^{-1}) for the duration of the survey, regardless of the tidal stage. However, the near surface currents, which appeared generally weak throughout the deployment period (<10 cm·s^{-1}), displayed a minor decrease in velocity as water levels reached the highest level in the cycle. Surface currents then rotated to the south and west and oscillated between 5 and 10 cm·s^{-1} as the ebb tide prompted water levels to decrease (Figure 3-23).

At the time of disposal (13:19 UTC), surface and near-bottom currents were relatively weak (5 to 10 cm·s^{-1}) and flowing in a northwesterly to westerly direction. During this same time period, mid-water currents were somewhat stronger, but flowing more to the southwest at an average speed of 12 cm·s^{-1}. Between 14:00 and 17:00 UTC, water column current flow remained generally west to northwest with the mid-water and near-bottom current displaying stronger flow and maintaining velocities of 12 to 17 cm·s^{-1} for the remainder of the deployment (Figure 3-24). In general, the currents in the depth horizon between 20 and 25 m were the strongest and most significant factor affecting plume morphology (Figure 3-22). The vessel mounted ADCP data collected on 9 April (Plume 2) displayed similar results when compared to the bottom mounted instruments, with more variability in flow structures relative to the first survey day. Flow magnitudes were generally 10 to 15 cm·s^{-1} over most of the survey with flow ranging from west-northwest to more north- northwesterly directions. Towards the end of the survey (approximately 17:00 UTC), two maximum instantaneous current velocities (>20 cm·s^{-1}) were seen at mid-depth and flow was uniformly to the west-northwest.

3.2.2.2 CTD/Transmissometer Profiles

A total of 13 CTD profiles were acquired within and adjacent to RISDS during the plume tracking survey associated with Load 758. Background water samples (T0) were collected approximately 5 m above the seafloor surface at a depth of 31 m prior to the disposal event in close proximity to the target disposal location (Point A). Figure 3-25 presents background profiles of the physical properties of the water column prior to dredged material deposition. As depth increased, salinity and percent transmittance showed minimal change in the water column. Percent light transmission remained relatively constant throughout the profile at approximately 82%, while salinity values were consistently 32.7 PSU.

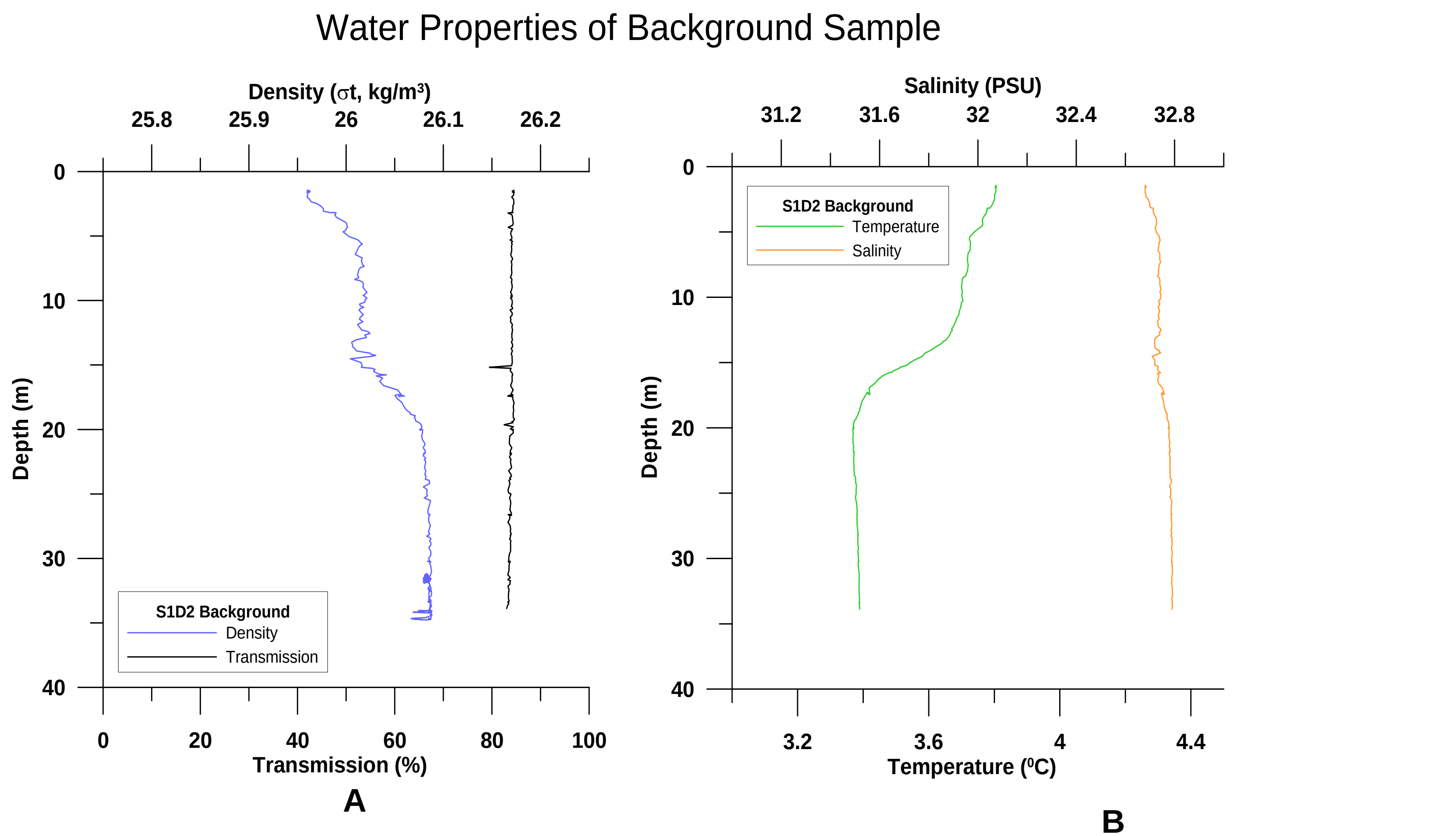


Figure 3-25. Profile plots of percent light transmission and seawater density versus depth (A) and temperature and salinity versus depth (B) acquired during the CTD background sample interval for Plume 2. Data are from the downcast profile only.

Seawater density appeared to be primarily a function of temperature, both changing moderately with depth. Although water temperature decreased minimally between the sea surface to 15 m depth, a rapid decrease was detected at a thermocline between depths of 15 to 18 m, before becoming a consistent 3.4° C below 20 m. Displaying an inverse relationship to temperature, seawater density increased from the surface to 15 m depth (25.95 to 26.02 sigma-t). A sharp increase in density was detected between 15 to 18 m, with density values becoming a constant 26.07 (sigma-t) below 20 m (Figure 3-25). The presence of a slight thermocline and corresponding pycnocline provided an indication of weak stratification in the water column. As a result, these conditions had the potential to affect settlement and dispersion of the sediment plume during the 3.5-hour monitoring period.

The Plume 2 disposal barge approached Disposal Point A from the north, slowed and released its load at 13:19 UTC. Once again, the CTD sampling vessel positioned itself immediately astern of the disposal barge during the disposal event. The barge was mostly empty within 30 seconds of opening, with the majority of the sediment falling through the water column to form a deposit on the seafloor. Visual observations revealed that the surface plume remained limited in area and in close proximity to the disposal location.

Monitoring of the sediment plume began several minutes after the disposal barge deposited its load at Point A, with the T1 profile and water samples collected 10 minutesafter disposal. The CTD profile displayed low transmittance levels throughout the water column, suggesting that the first samples were collected at or near the centroid of the concentrated sediment plume (Figure 3-26). Percent light transmittance decreased from background levels (82%) to approximately 30 to 35% below 5 m water depth. At the 15 m depth horizon, a 1 m layer of relatively clear water was detected, with light transmittance values approaching background levels, but turbidity increased sharply again at a depth of approximately 16 m prompting a corresponding decrease in transmittance. Below 16 m depth, a relatively constant light transmittance of 10% was recorded until the downcast was stopped 1 to 2 m above the seafloor. Water samples for TSS analysis were collected in the near-bottom portion of the plume at a depth of 31 m during the upcast.

The 20-minute (T2) CTD profile was collected in the vicinity of the deep-water drogue and produced a transmittance profile displaying three distinct layers of entrained sediment from the plume (Figure 3-26). The near-surface portion of the plume was visible from the water surface to a depth of 18 m, with transmittance levels ranging from 25 to 40%. Low turbidity levels, analogous to background, were detected at mid-depth (18 to 22 m), but a distinct trend of increasing suspended sediment concentrations with depth was detected between 22 m and 27 m. With a minimum light transmittance of 25%, this mid-depth portion of the sediment plume appeared to be slightly more turbid than that detected

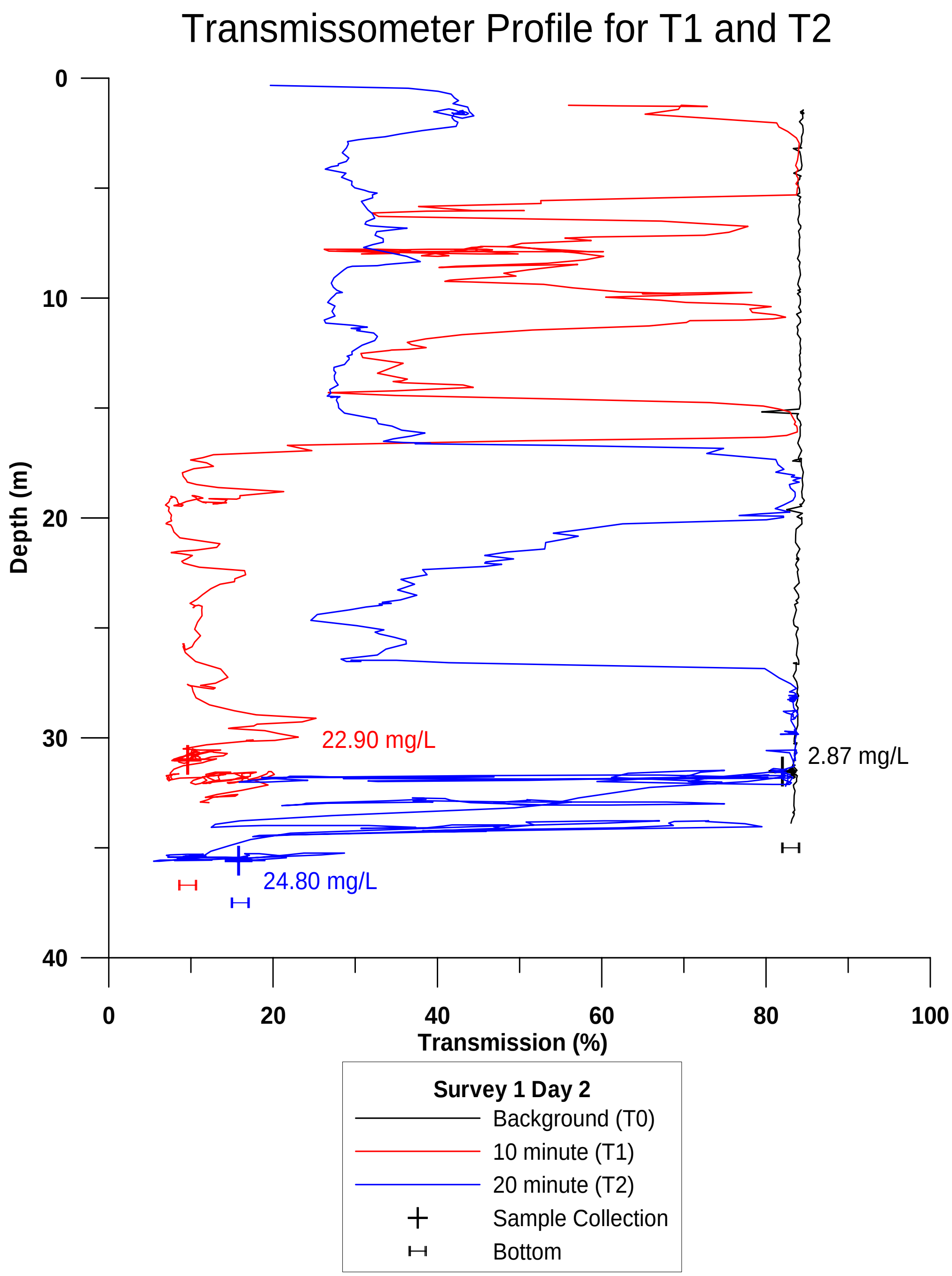


Figure 3-26. Profile plot of percent light transmission and sensor depth acquired during CTD sample intervals T1 and T2 during Plume 2. Locations of water sample collections within the plume are also shown.

closer to the surface. At a depth of 27 m, transmittance levels rapidly increased to near background levels (81%), with relatively clear water detected for 4 to 5 m within the profile. Evidence of a third discrete layer of a turbid near-bottom plume was visible at a depth of 31 m, as transmittance levels fell to nearly 5%, indicating that this near-bottom layer was the most turbid of the three layers observed. Water samples were collected for TSS during the upcast at a depth of 35.5 m within the near-bottom plume, corresponding to a transmittance level of 16.7%.

Prior to the 40-minute sample interval (T3), a supplemental CTD profile (Cast C) was collected in close proximity to the Davis drifter to verify the absence of a surface plume and to confirm that the plume centroid was located at the deep-water drogue location. A substantial increase in turbidity over background levels was detected in the water column between the depths of 8 and 20 m (Figure 3-27). At a depth of 21 m, light transmission data suggested water column turbidity decreased to near background conditions (82%). This layer of clear water extended down to approximately 13 m to a depth of 34 m before turbidity levels increased once again. A near-bottom turbidity layer was visible in the profile from a depth of 34 m to the seafloor (Figure 3-27). Although the transmittance data from this profile displayed a lower percentage of light transmission within this near-bottom layer, the readings were not indicative of a sediment plume centroid.

Following the completion of Cast C, the survey vessel was repositioned between the deep-water drogue and the Davis drifter in an attempt to locate the plume centroid and collect the T3 profile and water samples (Figure 3-27). The T3 (40-minute) sample was obtained approximately 15 minutes after the desired sample time (55 minutes post disposal). The transmissometer data from the CTD profile indicated a portion of the water column with increased turbidity levels existed between depths of 7 and 24 m. At 7 m, transmittance levels decreased with depth from background levels (82%) to a minimum of 56% (Figure 3-27). These reduced transmittance levels were observed throughout the upper portion of the water column to a depth of 24 m, where background levels were once again detected. Below 27 m, transmittance decreased with depth to the seafloor, representing the near-bottom portion of the sediment plume, with a minimum transmittance of 55%. The T3 water samples were collected at the depth of 34 m, within the centroid of the plume.

The T4 profile was obtained near the deep-water drogue, which was approximately 75 m to the northwest of the T3 sample (Figure 3-21). Due to the delay in collecting the 40-minute interval samples (T3), the 60-minute sampling interval (T4) was also delayed to approximately 70 minutes post disposal. Comparisons between the T3 and T4 transmissometer profiles indicated the presence of similar sediment concentrations and

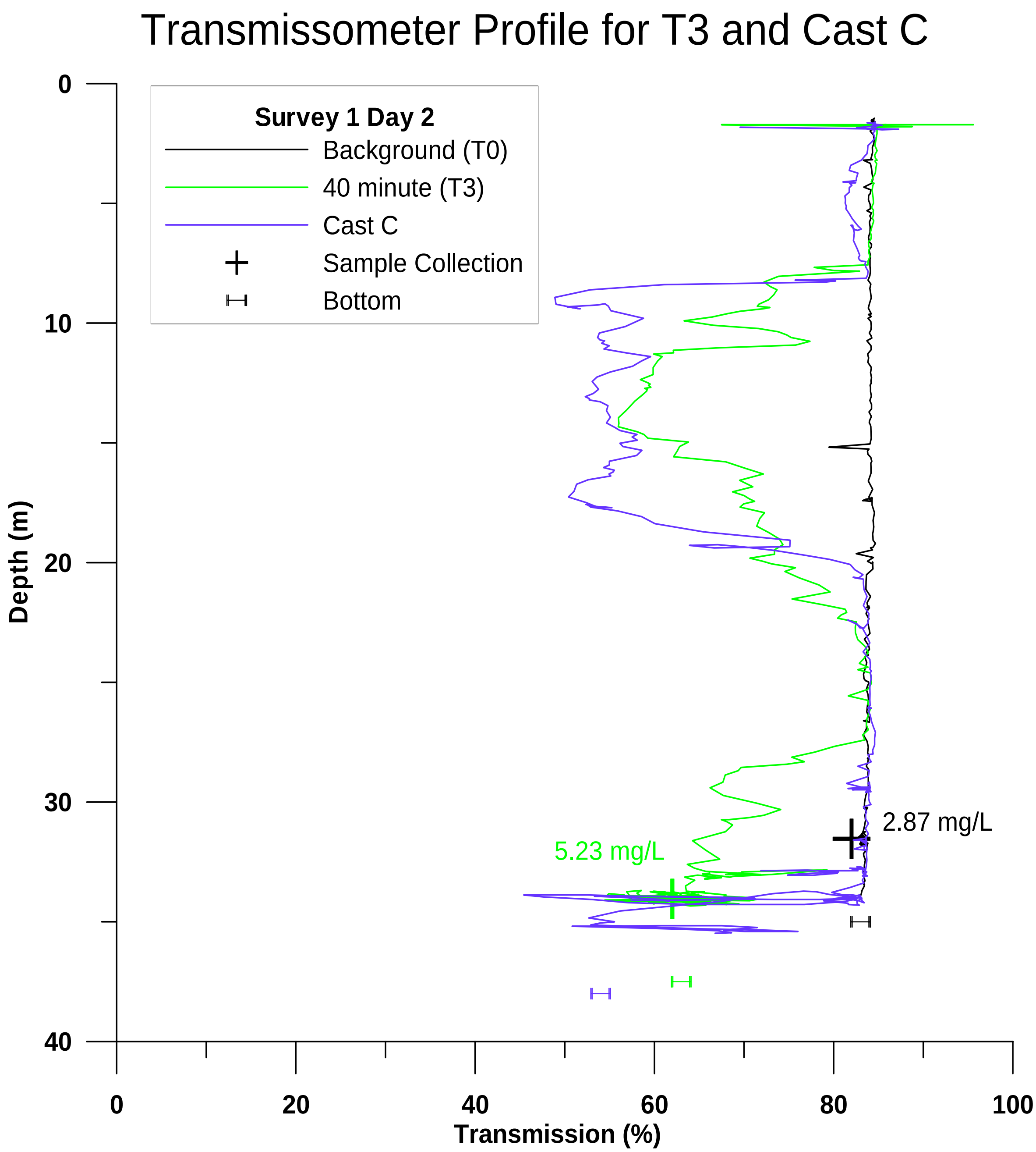


Figure 3-27. Profile plot of percent light transmission and sensor depth acquired during CTD sample interval T3 and Cast C for Plume 2. Locations of water sample collections within the plume are also shown.

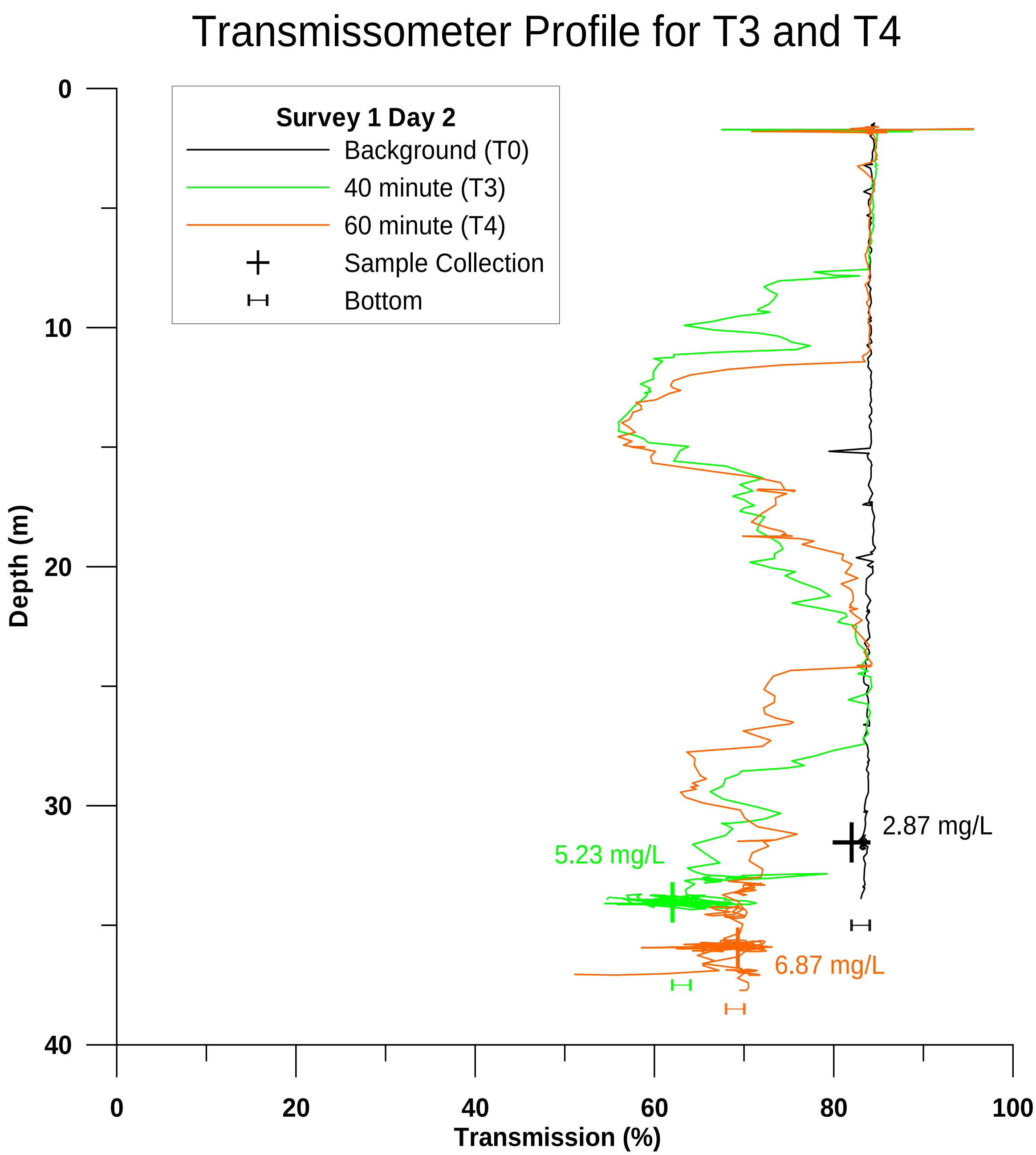


Figure 3-28. Profile plot of percent light transmission and sensor depth acquired during CTD sample intervals T3 and T4 for Plume 2. Locations of water sample collections within the plume are also shown.

plume morphology, as well as a suggested particle settlement from the upper water column (Figure 3-28).

For the T4 profile, the first reduction in transmittance below background levels was noted at a depth of 12 m, compared to 7 m in the 40-minute profile (T3), suggesting plume morphology was changing as sediment settled from the near-surface to deeper intervals. This mid-depth plume persisted from 12 m to a depth of 20 m, then gradually dissipated to background levels between 20 and 24 m. Below 24 m, transmittance values decreased once again, representing the near-bottom portion of the sediment plume. The depth interval between 24 m and the seafloor exhibited a minimum transmittance value of approximately 50%, but remained predominantly between 60 and 65%. The 60-minute interval (T4) water sample was collected at a depth of 35 m, within the near-bottom plume.

Transmissometer profiles for both the 90 (T5) and 120 (T6) minute sampling intervals were very similar, with signs of particle settlement and dispersion apparent in both records (Figure 3-29). The most significant difference between the two profiles occurred in the upper portion of the water column. The 90-minute profile showed a decrease in light transmittance at 11 m, while the 120-minute profile did not display the initial decrease beyond background levels until 15 m, suggesting continued settlement of suspended particles in the upper portion of the water column. Below 20 m, both profiles appeared very similar with respect to the intensity of light transmission, with values remaining close to 65% in the near-bottom plume and minimum transmission values of 63% for both sample intervals. The 90-minute interval water sample was collected at a depth of 33.8 m, while the 120-minute water sample was collected at a slightly deeper depth of 36 m.

The transmissometer profile for the 150-minute sampling interval (T7) indicated the first noticeable decrease in transmittance occurred at a depth of 17 m (Figure 3-30), similar to the 120-minute sampling interval. Percent light transmittance values then steadily decreased with depth throughout the majority of the profile, eventually reaching a minimum of 70% at a depth of 32 m (approximately 6 m above the seafloor). Turbidity appeared to decrease slightly as the transmissometer was lowered to a position 1 m above the bottom, with transmittance values remaining at 75% for the remainder of the downcast. Water samples for TSS analysis were collected at a depth of 31.3 m during the corresponding upcast Similar to profiles obtained at the 90 and 120-minute sampling intervals, the final transmittance profile obtained 210 minutes (T8) after disposal operations at a location west of the deep-water drogue, indicated a distinct increase in turbidity at a depth of 15 m (Figure 3-30). This strong turbidity layer within the water column was approximately 3 m in thickness, as transmittance readings returned to near background levels at a depth of 18 m. Showing similar structure to the profiles conducted at the T6 interval (120 minutes post placement), a second layer of higher turbidity water was

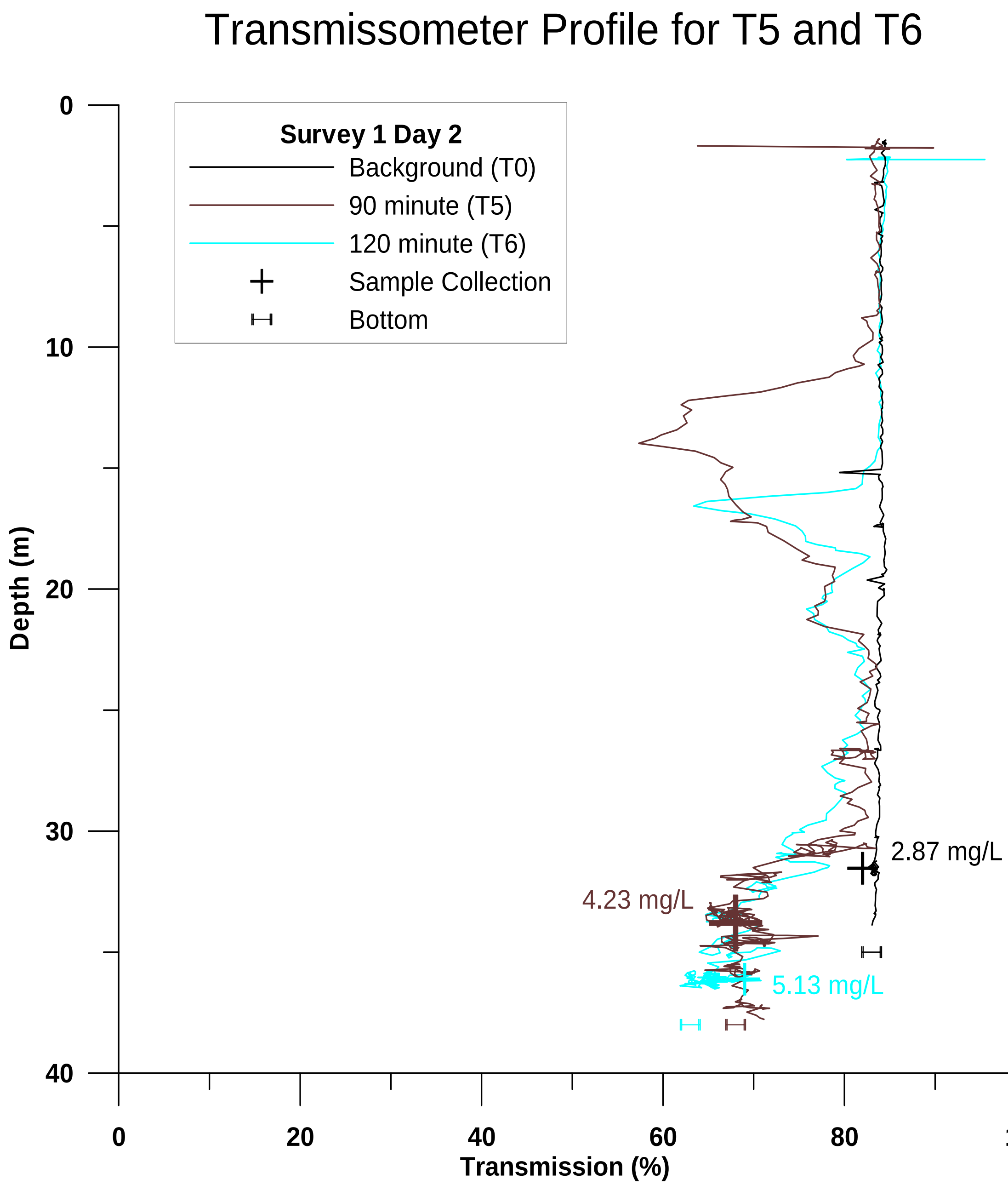


Figure 3-29. Profile plot of percent light transmission and sensor depth acquired during CTD sample intervals T5 and T6 for Plume 2. Locations of water sample collections within the plume are also shown.

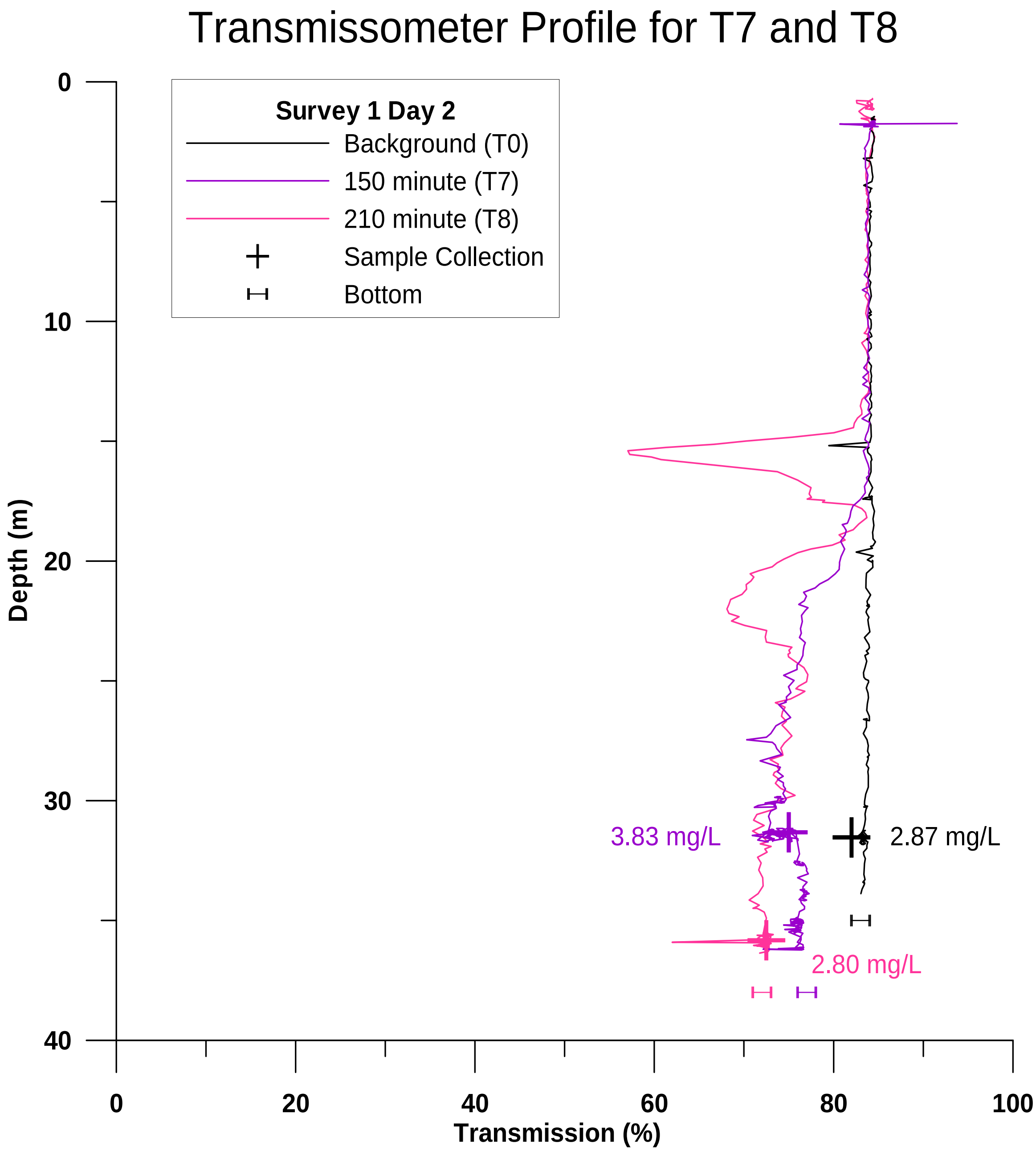


Figure 3-30. Profile plot of percent light transmission and sensor depth acquired during CTD sample intervals T7 and T8 for Plume 2. Locations of water sample collections within the plume are also shown.

Table 3-6. Results of Total Suspended Solids (TSS) Analysis from Discrete Water Samples Collected during CTD Profiling Operations as part of Survey Day 2 (Plume 2)*

Sample ID	Time (min)	Elapsed Time (hr:min)	Depth (m)	Transmittance (%)	OBS (FTU)	TSS (mg/L)				
						A	B	C	Avg	STDev
S1D2_T0	0	0:00	32	82.53	9.16	3.9	1.7	3.0	2.9	1.11
S1D2_T1	10	0:14	31	9.59	25.03	24.7	22.0	22.0	22.9	1.56
S1D2_T2	20	0:25	36	16.75	22.59	22.4	26.0	26.0	24.8	2.08
S1D2_T3	40	0:55	34	62.03	11.60	6.0	5.1	4.6	5.2	0.71
S1D2_T4	60	1:09	36	69.33	10.99	6.6	9.7	4.3	6.9	2.71
S1D2_T5	90	1:28	34	68.24	10.38	5.1	4.0	3.6	4.2	0.78
S1D2_T6	120	1:58	36	69.99	10.99	3.6	6.7	5.1	5.1	1.55
S1D2_T7	150	2:31	36	72.51	10.99	6.3	2.5	2.7	3.8	2.14
S1D2_T8	210	3:29	31	75.04	10.38	1.9	5.1	1.4	2.8	2.01

* plume tracked from the disposal of material from a 6,000 yd^3 capacity split-hull disposal barge

encountered between 20 and 23 m depth. The transmittance values briefly fell below 70% at a depth of 22 m then became relatively consistent, ranging from 72 to 76% for the remainder of the profile. Water samples for TSS analysis were collected at a depth of 37 m, approximately 2 m above the seafloor.

3.2.2.3 Total Suspended Solids (TSS) Results from Water Samples

A summary of the TSS results including background water samples associated with the water sampling data for Plume 2 is provided in Table 3-6. The background samples for the second plume tracking event (S1D2_T0) were obtained prior to disposal operations and revealed a relatively low average TSS value of 2.9 $mg \cdot L^{-1}$. Based on real-time transmissometer data, TSS samples were generally taken 3 to 4 m above the seafloor where it appeared the plume centroid was located. In order to ensure the centroid of the plume was targeted by the water sampler, additional CTD casts away from the current-following drogue positions were obtained, sometimes delaying the targeted time for collecting the sample (i.e., 15 minute delay for the 40 minute sample interval).

The average TSS value at the first sample interval (S1D2_T1) after disposal operations was 22.9 $mg \cdot L^{-1}$, collected from a water depth of 31 m. There was a slight increase in suspended sediment load detected between the 10 and 20 minute samples as a TSS value of 24.8 $mg \cdot L^{-1}$ was obtained for the S1D2_T2 sample (collected from a depth of 35.6 m) suggesting a small increase in suspended sediment within the lower portion of the water column (Table 3-6). Percent transmission of light values (obtained in real-time from the transmissometer) were quite low (10 to 40%) in the early stages of the plume monitoring event, correlating with the higher TSS concentrations. Nearly 55 minutes after the dredged material disposal event (T3 sample), TSS values decreased considerably to an average value of 5.2 $mg \cdot L^{-1}$ and remained low for the duration of the survey. This is likely the result of the sediment plume becoming less concentrated as material settled to the seafloor. The final TSS samples, collected approximately 3.5 hours after the disposal event, showed average turbidity at background (2.8 $mg \cdot L^{-1}$) levels. However, a relatively high standard deviation value of (2.0) is indicative of a substantial amount of variability in the triplicate samples taken from the single Niskin bottle.

Similar to Plume 1, a slight increase in TSS values (approximately 1 $mg \cdot L^{-1}$) was observed at both the 60 (T4) and 120-minute (T6) sample intervals, in comparison to the 40 (T3) and 90-minute (T5) intervals (Table 3-6). Replicate TSS values were more variable at the 60-minute sample interval resulting in the highest standard deviation value for the Plume 2 TSS data set (2.7). The minor increases noted at T4 and T6 could be a function of particulate settling within the water column (settlement delay of fine-grained sediment at a moderate density layer in the water column) or simply represent spatial variability in plume characteristics.

3.2.2.4 ADCP Backscatter

Similar to the Plume 1 survey operation, ADCP data were collected to determine background acoustic characteristics of the ambient water column prior to the 9 April (Plume 2) disposal event. These data were then subtracted out of subsequent survey records to determine the impacts of suspended particulate matter from the disposal plume on total suspended load. The most significant mid-level acoustic backscatter intensity band (background) was seen on 9 April (Plume 2), within a 10 to 12 m layer in the mid water column (Figure 3-31). The highest backscatter values reached 85 counts and appeared as a distinct maximum relative to values of 65 to 70 counts within shallower and deeper portions of the water column. Once again, the lack of ambient turbidity (as confirmed by the background transmissometer profile) within this layer suggests that it was an artifact of the water column density gradient that essentially negates the use of acoustic backscatter data within the depth interval between 5 and 20 m.

Figures 3-32 through 3-38 show the variation in water column backscatter intensity above background within the individual transect lines occupied over RISDS for the duration of the Plume 2 survey. Due to the predominant west-northwest current flow over RISDS at the time of the survey, a series of northeast-southwest trending transects were occupied as part of the Plume 2 survey operation (Figure 3-31). Based on the water column density artifact discussed above, these ADCP data are considered valid for near-surface and near-bottom depth levels only.

The first ADCP data were collected along a 550 m segment of Line F and captured conditions in the water column within the first seven minutes after the dredged material disposal event at Point A (Figure 3-32A). As anticipated, this ADCP record displayed the most intense acoustic signal detected during the day, with residual backscatter in excess of 20 counts in close proximity to the current-following drogues. The initial morphology of the plume in the surface water was distinguishable as an area of approximately 195 m wide, while the elevated backscatter counts at depth suggest the near-bottom portion of the plume was nearly 350 m wide. Although a residual backscatter signal was present in the mid-water column (5 to 20 m), determining the true plume morphology was problematic due to the effects of the acoustic artifact in the background ADCP record.

Survey Lines E and D were both completed within 20 minutes of the disposal event and appeared to capture the leading edge of the sediment plume at the surface, as well as at depth (Figures 3-32B and C). Residual acoustic backscatter suggested that the sediment

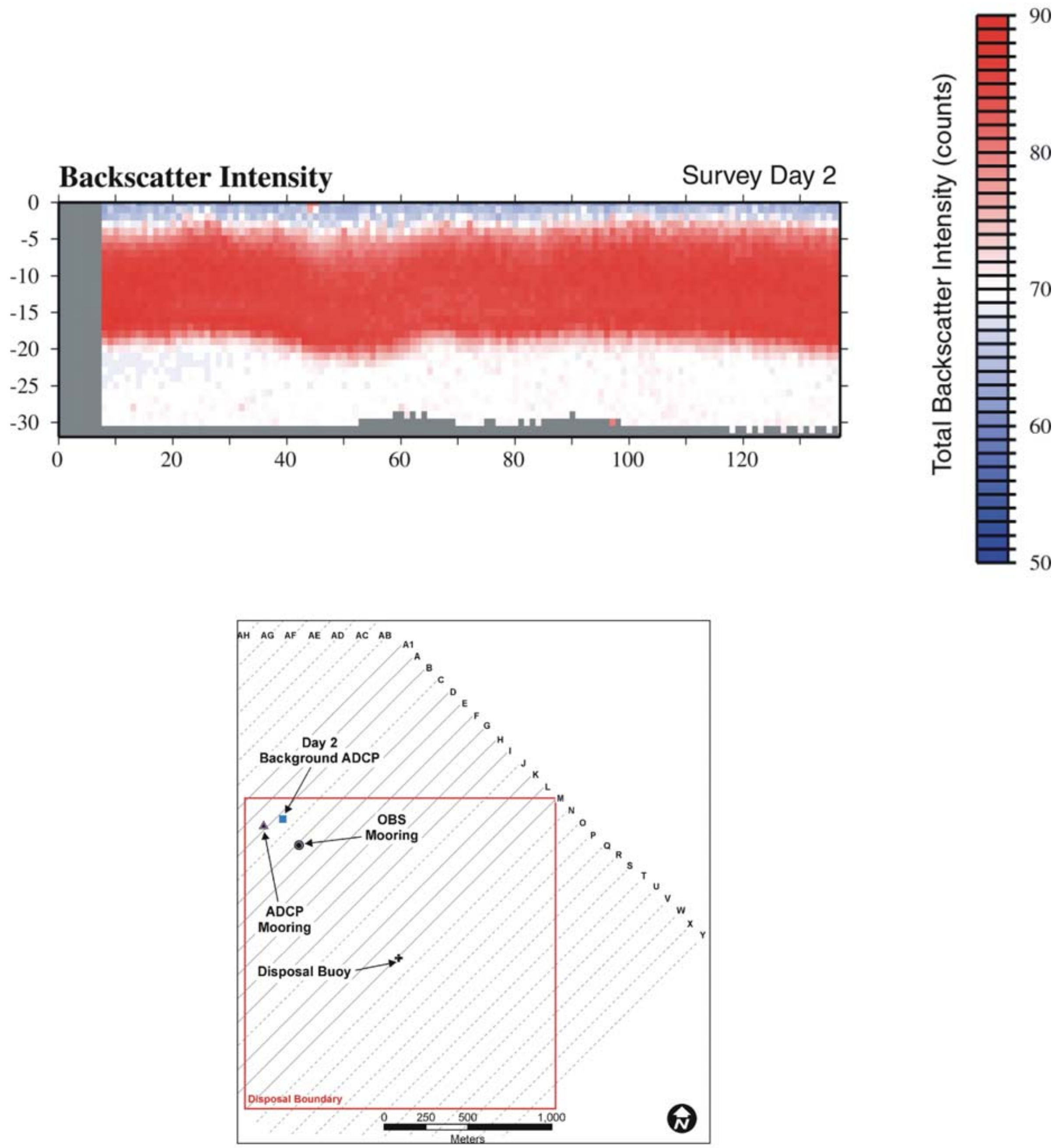


Figure 3-31. Profile plot of raw ADCP backscatter data collected on 9 April 2004 (Plume 2) to characterize background conditions at RISDS.

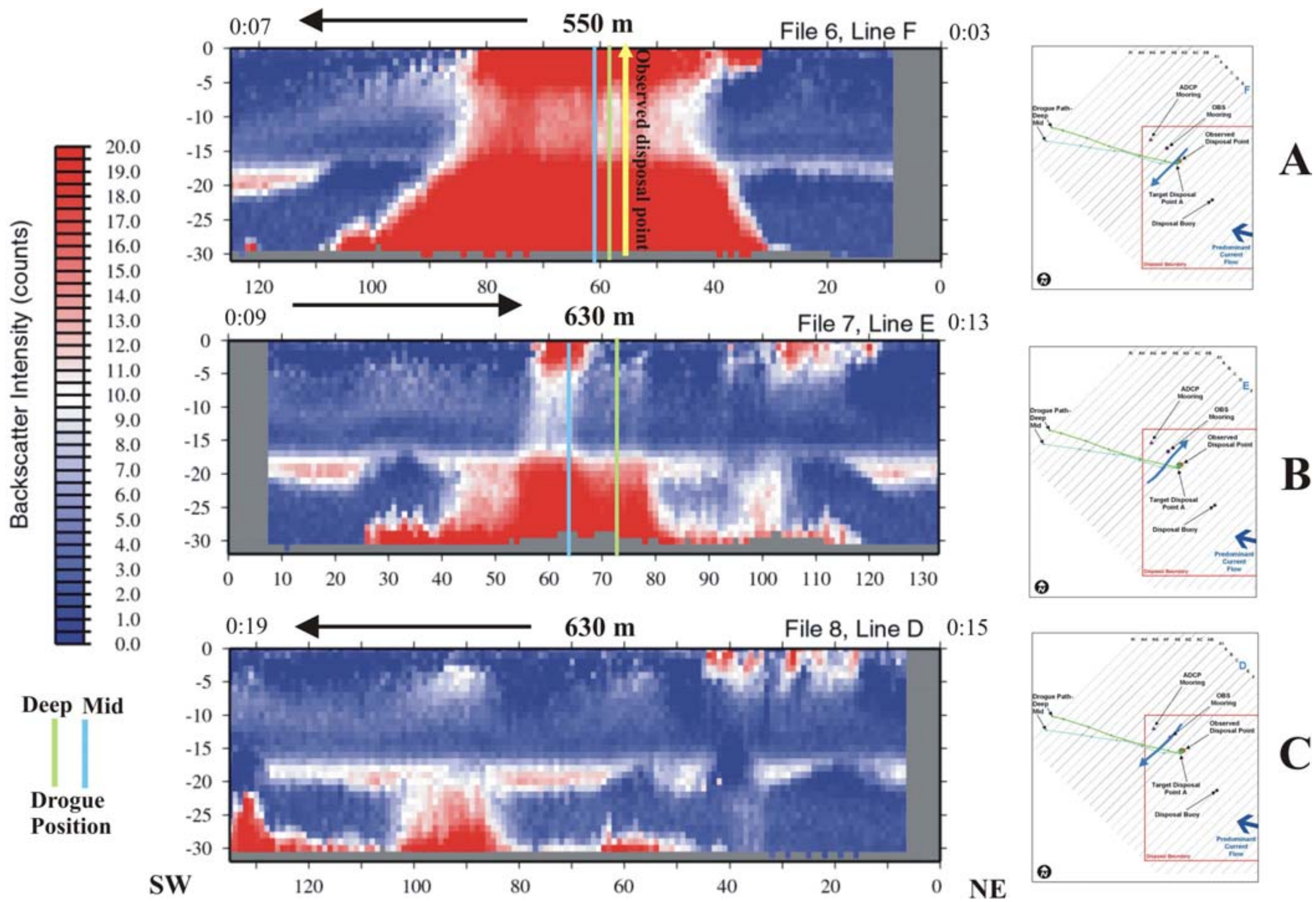


Figure 3-32. Profile plots of data collected from ADCP transects F, E, and D on 9 April 2004 (Plume 2) displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to illustrate plume morphology 3 to 19 minutes after the dredged material disposal event at Point A.

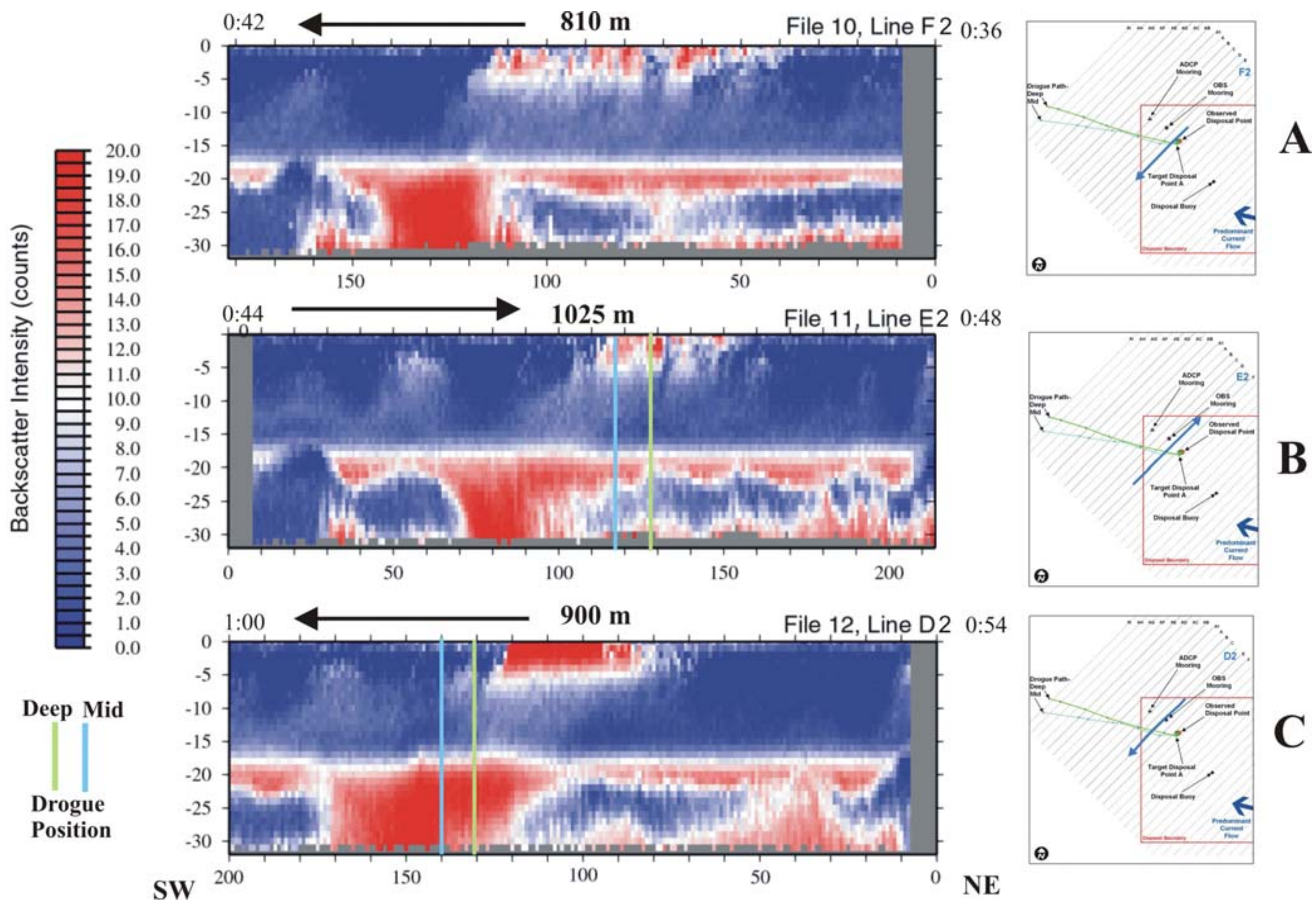


Figure 3-33. Profile plots of data collected from ADCP transects F2, E2, and D2 on 9 April 2004 (Plume 2) displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to illustrate plume morphology 36 to 60 minutes after the dredged material disposal event at Point A.

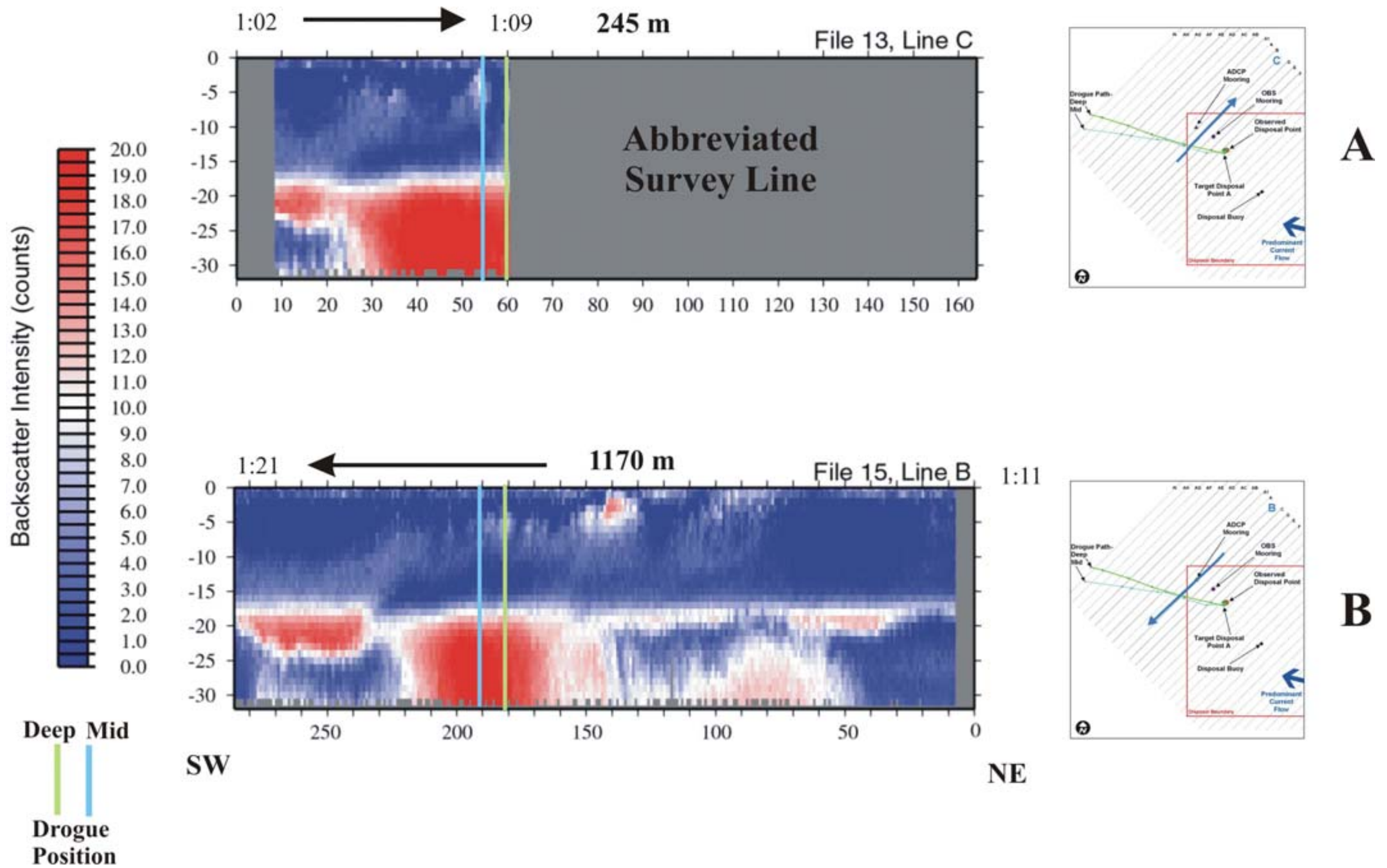


Figure 3-34. Profile plots of data collected from ADCP transects C and B on 9 April 2004 (Plume 2) displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to illustrate plume morphology 62 to 81 minutes after the dredged material disposal event at Point A.

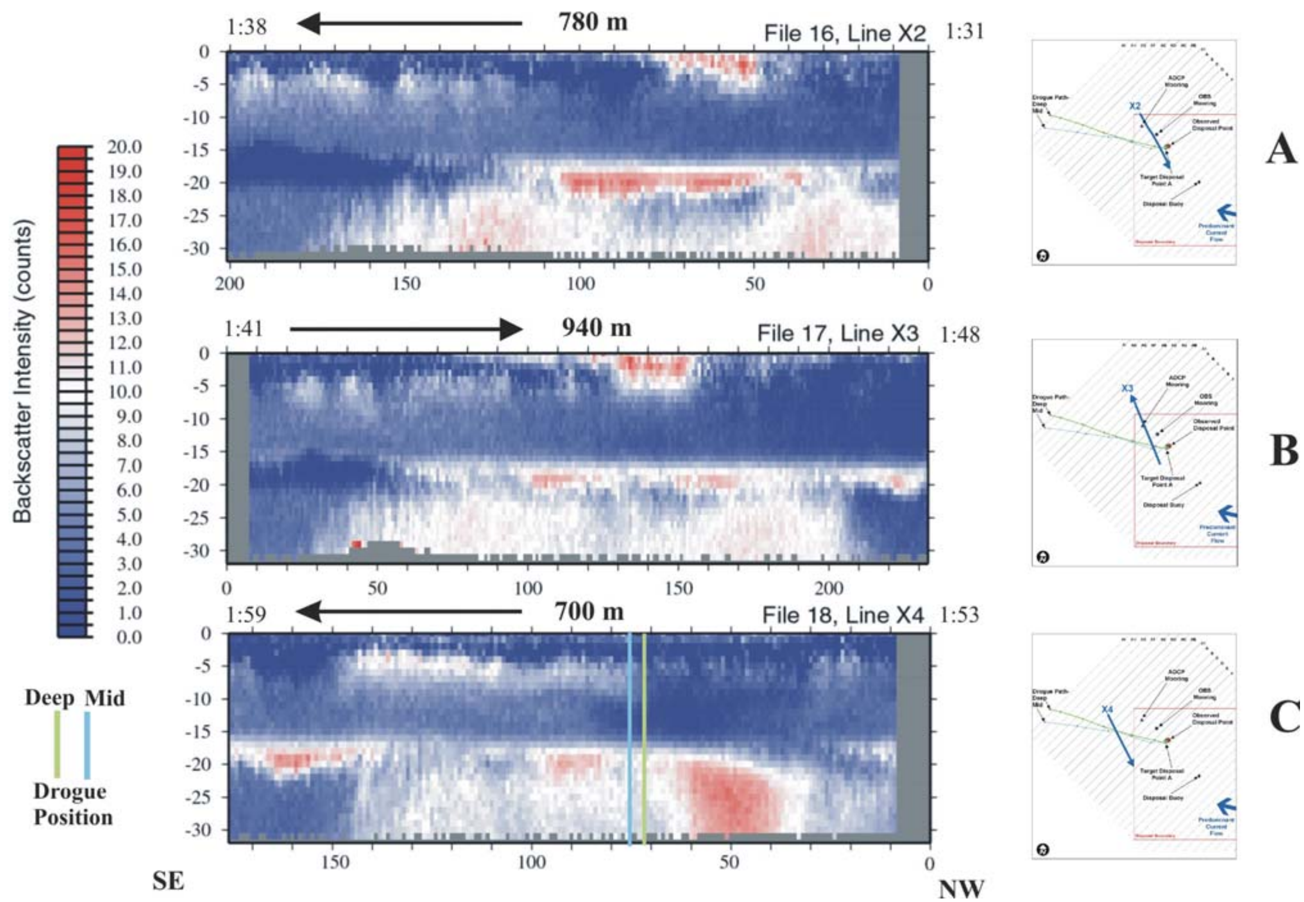


Figure 3-35. Profile plots of data collected from ADCP transects X2, X3, and X4 (northwest-southeast orientation) on 9 April 2004 (Plume 2) displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to illustrate plume morphology 91 to 119 minutes after the dredged material disposal event at Point A.

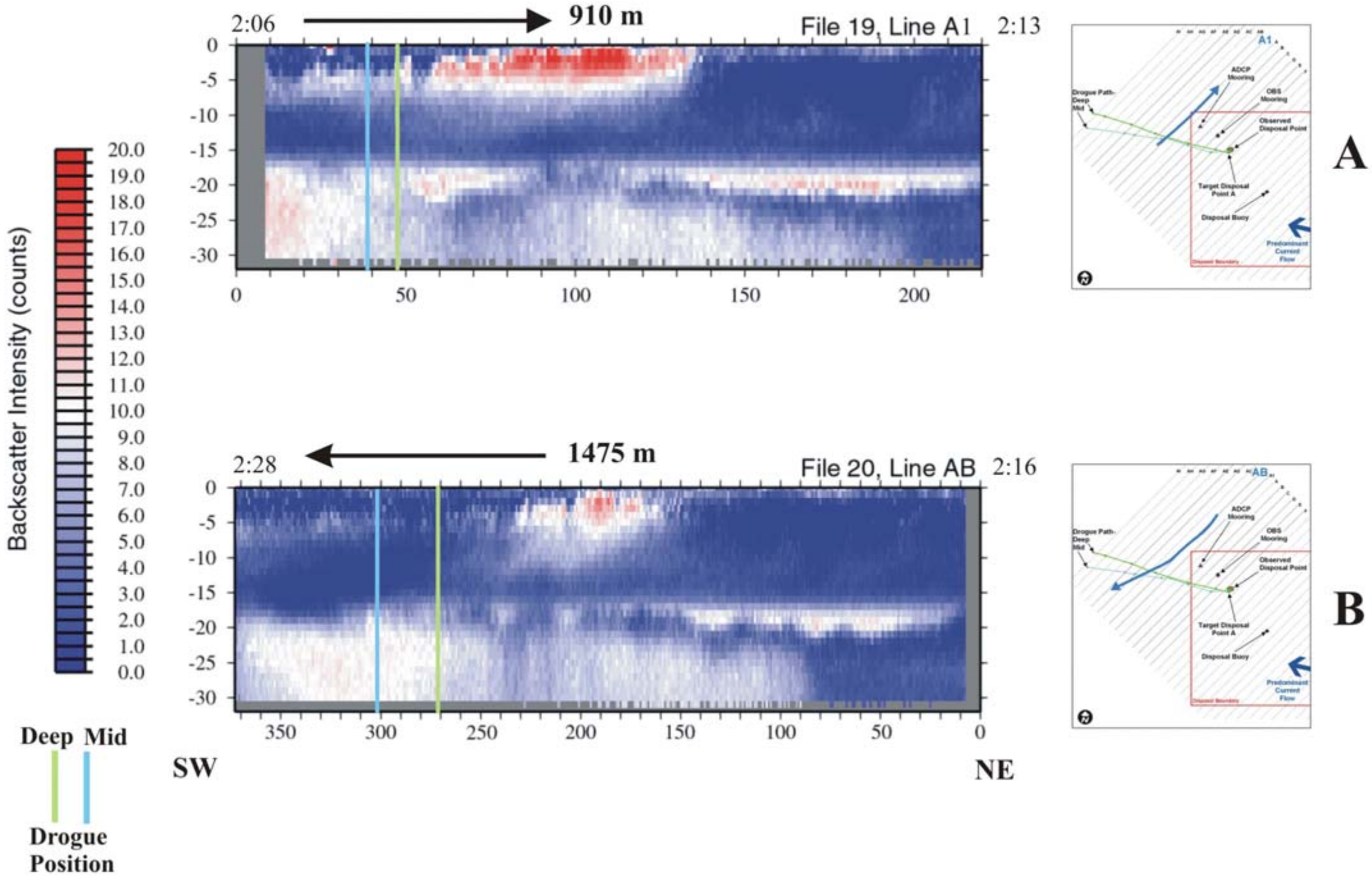


Figure 3-36. Profile plots of data collected from ADCP transects A1 and AB (northeast-southwest orientation) on 9 April 2004 (Plume 2) displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to illustrate plume morphology 126 to 148 minutes after the dredged material disposal event at Point A.

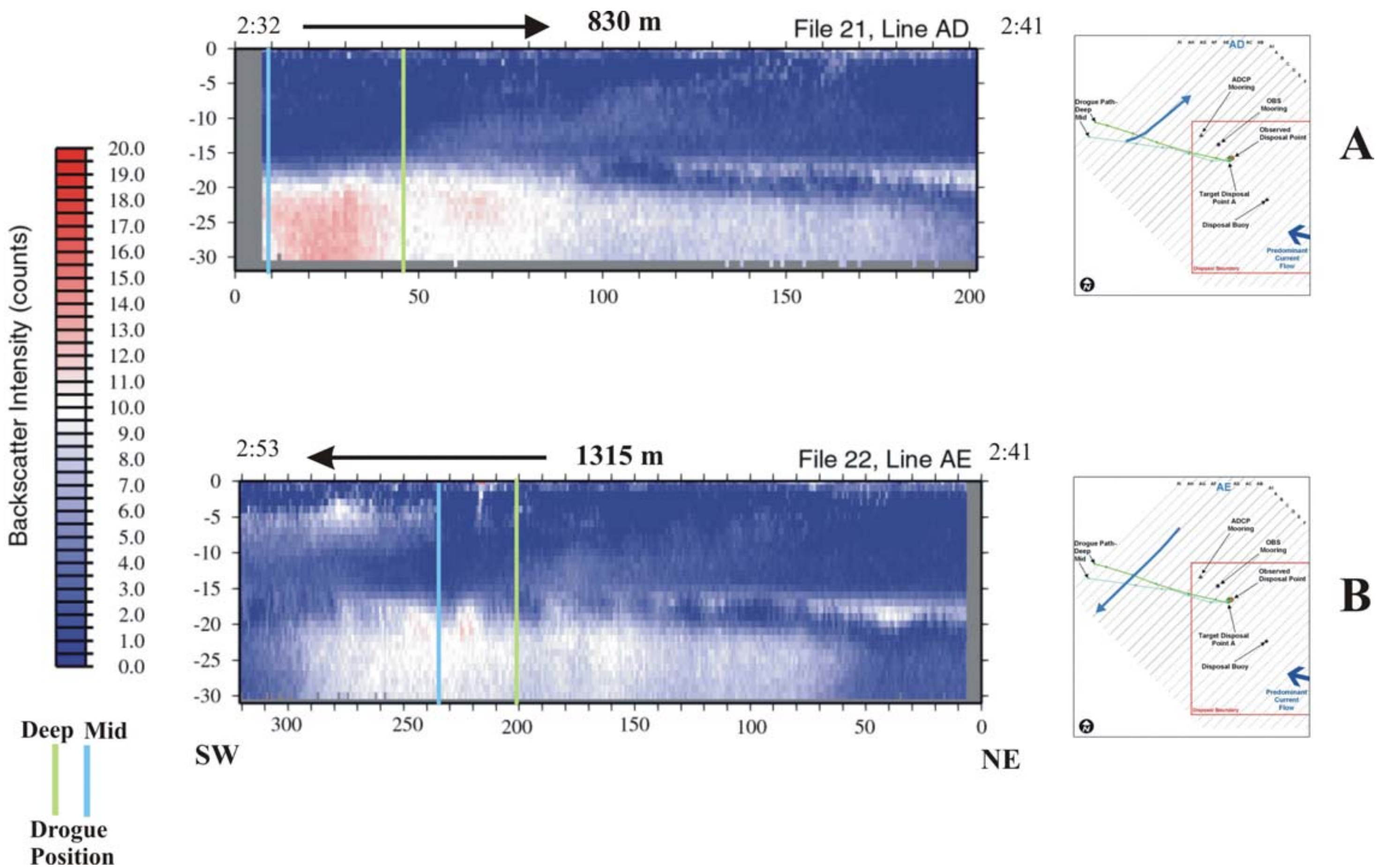


Figure 3-37. Profile plots of data collected from ADCP transects AD and AE on 9 April 2004 (Plume 2) displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to illustrate plume morphology 152 to 173 minutes after the dredged material disposal event at Point A.

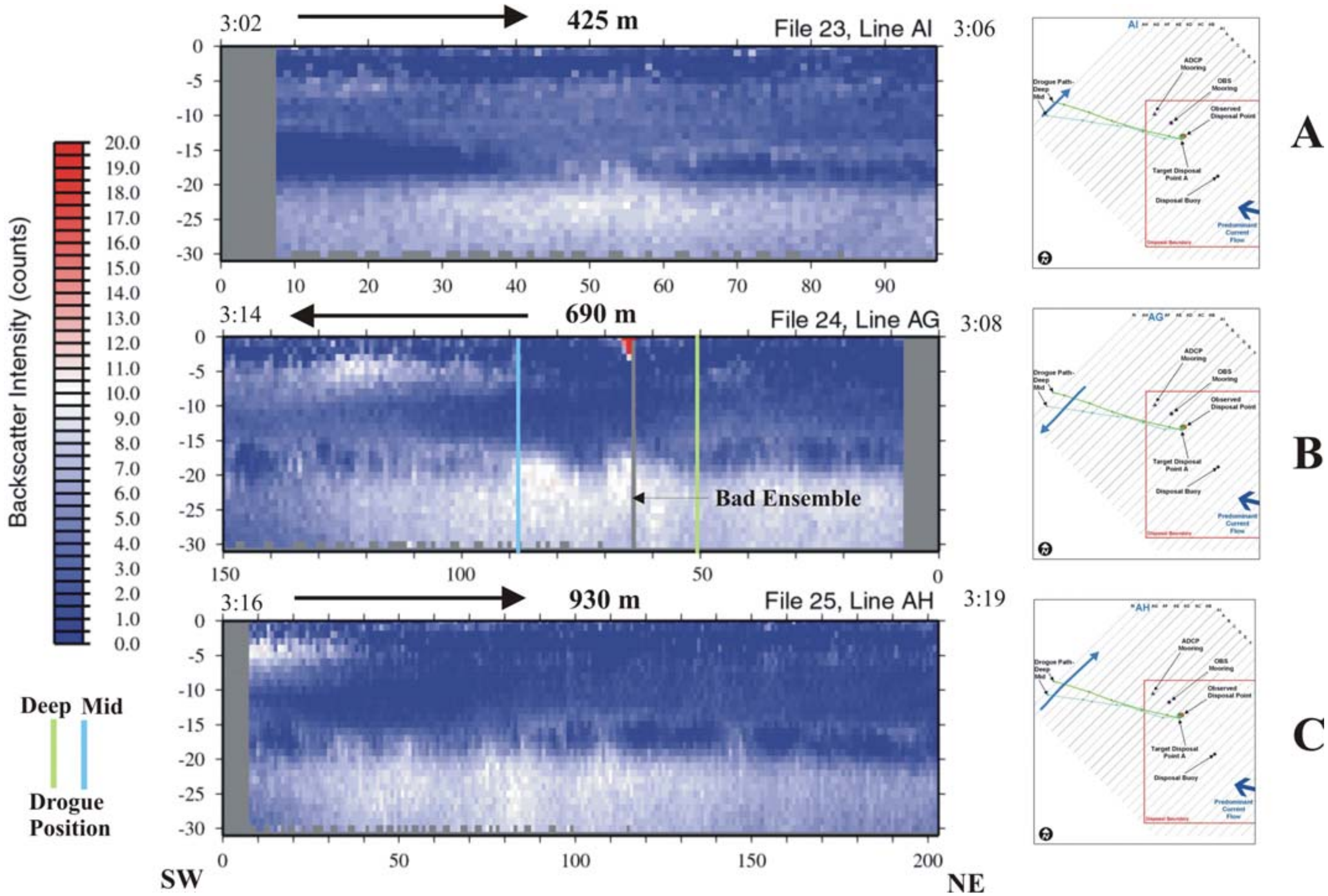


Figure 3-38. Profile plots of data collected from ADCP transects AI, AG, and AH on 9 April 2004 (Plume 2) displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to illustrate plume morphology 182 to 199 minutes after the dredged material disposal event at Point A.

plume appeared more concentrated and covered a wider area in the bottom waters along both survey lines, relative to the signal detected in the surface water. Lines F, E, and D were reoccupied after the initial sampling runs, with the data providing insight on the morphology of the sediment plume from 36 minutes to one hour after the disposal event (Figure 3-33). A characteristic pattern emerged in all three records, with a linear feature visible in the water column at a depth of 20 m (likely the product of the mid-depth backscatter artifact) and strong acoustic returns in the deeper portion of the water column representing the near-bottom portion of the sediment plume.

A lower intensity, yet substantial acoustic return was also noted along the seafloor within each survey line approximately 500 m northeast of the concentrated plume. Line D2 provided the best representation of this secondary feature, which may be the result of a small sediment deposit that occurred moments before the major disposal event, or some other seafloor disturbance associated dredged material placement operation. In addition, the data from Line D2 showed a concentrated cloud of turbidity in the surface waters much closer to the near-bottom portion of the disposal plume being tracked via current following drogues, representing the surface expression of the main sediment plume (Figure 3-33C).

Valid acoustic data were collected along the first 245 m of Line C only (Figure 3-34A). The acoustic returns suggested a fairly concentrated sediment plume at depth within the abbreviated record. Similar morphology was noted in the data collected along Line B approximately 120 minutes after the disposal event, as the near-bottom plume was detectable in close proximity to the drogue positions (Figure 3-34B). As detected along Lines D2, E2, and F2, a secondary pulse of turbid water was noted to the northeast of the primary, near-bottom sediment plume.

Upon completion of Line B, a series of three survey lines (Lines X2, X3, and X4) were run in a northwest-southeast orientation, essentially bisecting the projected plume track at a 45° angle (Figure 3-35). At 1.5 to 1.75 hours after disposal, data from Lines X2 and X3 displayed the trailing edge of the plume, with relatively weak acoustic backscatter signals (10 to 15 counts over background) detected in close proximity to Disposal Point A. Once again, two distinct patches of turbidity were detected in the bottom waters along both lines. The patch located toward the southeast ends of Lines X2 and X3 likely represented the trailing edge of the primary disposal plume, while the patches detected nearer the northwest ends were attributable to the secondary pulse of turbidity (Figures 3-35A and B). Due to its location, Line X4 was completed closer to the plume centroid, relative to Lines X2 and X3 (Figure 3-35C). Higher acoustic backscatter results (15 to 18 counts) were detected near the center of the disposal plume feature, suggesting higher suspended sediment concentrations were present on Line X4 than those encountered in Lines X2 and X3.

Lines A1 through AH were added to the original survey grid to account for the transport of the disposal plume beyond the western boundary of the disposal site. Lines A1 and AB were occupied approximately 2 hours post-disposal and showed a substantial acoustic signal in the surface waters to a depth of 5 m (Figure 3-36). The data from Line A1 indicated the strongest signal existed in the surface waters near the northwest corner of RISDS, likely attributable to plume sediments being advected from Disposal Point A by near-surface currents (Figure 3-36A). In addition, the acoustic data collected over Line A1 also provided insight into the position of the near-bottom portion of the sediment plume, as backscatter intensities 10 to 15 counts above background were detected near the start of the survey line (Figure 3-36A). The information collected over Line AB, completed immediately after A1, showed similar plume morphology with somewhat lower backscatter values. These findings suggest that acoustic data collected over Line AB 140 minutes after the disposal event characterized the leading edge of the sediment plume.

Line AD, completed 2.5 hours post-disposal, provided the last acoustic evidence of a concentrated plume centroid within the disposal plume, while the remaining lines covered during the late stages of the survey show a very broad, weak signal in the deeper portion of the water column (Figures 3-37 and 3-38). A maximum residual backscatter value of 15 counts was detected between the positions of the mid-water and deep drogues, indicative of turbid water. The backscatter values decreased with distance from the drogue positions, but were detected at levels approaching 10 counts above background approximately 750 m northeast of the centroid (Figure 3-37A).

3.2.2.5 Water Column Optical Backscatter from Moored Array

As part of the Plume 2 survey, the OBS sensor mooring was placed approximately 200 m northwest of the observed disposal position (Figure 2-3). The data collected at a 10-second interval showed low levels of background turbidity in the upper, middle, and lower levels of the water column (13, 18, and 32 m depth), with values averaging 2 FTU during the first 90 minutes of the record. A noticeable increase in suspended sediment concentrations was first detected in the bottom waters at 14:03 UTC (44 minutes post-disposal), and persisted for approximately 83 minutes before returning to background levels (Figure 3-39). The near-bottom sensor detected these elevated optical backscatter levels (5 to 10 FTU), while the mid-and upper-water column sensors displayed no appreciable change in turbidity values over the course of the five-hour deployment.

The low backscatter values in the upper portion of the water column suggested the surface and mid-water column remained clear while an isolated patch of turbid water passed by the OBS sensor located in the lower portion of the water column. Based on the west-northwest trajectory of the drogues from the initial disposal location, it is likely that the primary disposal plume was advected west-northwest by ambient water column currents, but remained south of the OBS mooring. The signal detected by the near-bottom sensor was likely the result of the passage of the secondary patch of turbidity that was detected in the underway ADCP acoustic backscatter data presented in Section 3.2.2.4.

This secondary pulse of turbidity was first detected by the near-bottom sensor (32 m depth) at 14:03 UTC. The distance from the initial disposal point (Disposal Point A) was 200 m, suggesting an average transport rate of approximately 7.6 $cm \cdot s^{-1}$. This calculated rate of transport was comparable to the mean current speed measured at the 32 m depth interval within the first 40 minutes of the current meter record (Figure 3-23).

3.2.2.6 Toxicity of Water Samples

A summary of the toxicity results associated with the water sampling data for Plume 2 is provided in Table 3-5b (Samples S1D2-X). As in the first plume tracking event, mysids and silversides exhibited no lethal responses to any of the water samples collected during the second day of sampling. Mean responses for all samples, from T0 to T6 were greater than 90% survival with the exception of the silversides (Menidia) in the T0 sample, where mean survival was 84%. No post-disposal samples exhibited toxicity, and all QA/QC requirements for successful conduct of the tests were met. Hence, it can be concluded that the single slight deviation below 90% survival within the background water sample was inconsistent with all other responses and does not alter the conclusion that no toxicity related to dredged material disposal occurred.

3.2.3 Plume 3

The third day of the plume survey operations occurred on 10 April 2004, in association with the sediment plume generated by the disposal of 3,200 m^3 of maintenance material dredged from Sabin Point Reach and placed at Point B within RISDS. Load 763 was deposited by a split-hull barge in the northeastern quadrant of RISDS at 14:19 UTC. The barge used to transport the sediment to RISDS during the third monitoring event was smaller in volume and overall dimensions (4,000 yd^3) relative to the previous two days when 6,000 yd^3 barges were employed for transport and disposal. Based on the water level data corrected to the local tide zone, this disposal event occurred during a mid-flood tide (Figure 3-40). The plume monitoring survey activity continued through the remainder of the flood, during a period of slack tide (little to no change in water level; 16:30 to 17:48 UTC) and through a brief period of ebb tide (decreasing water levels), concluding at approximately 18:00 UTC. Within this time period, the net transport of the sediment plume was to the west-northwest by the water column currents as explained below.

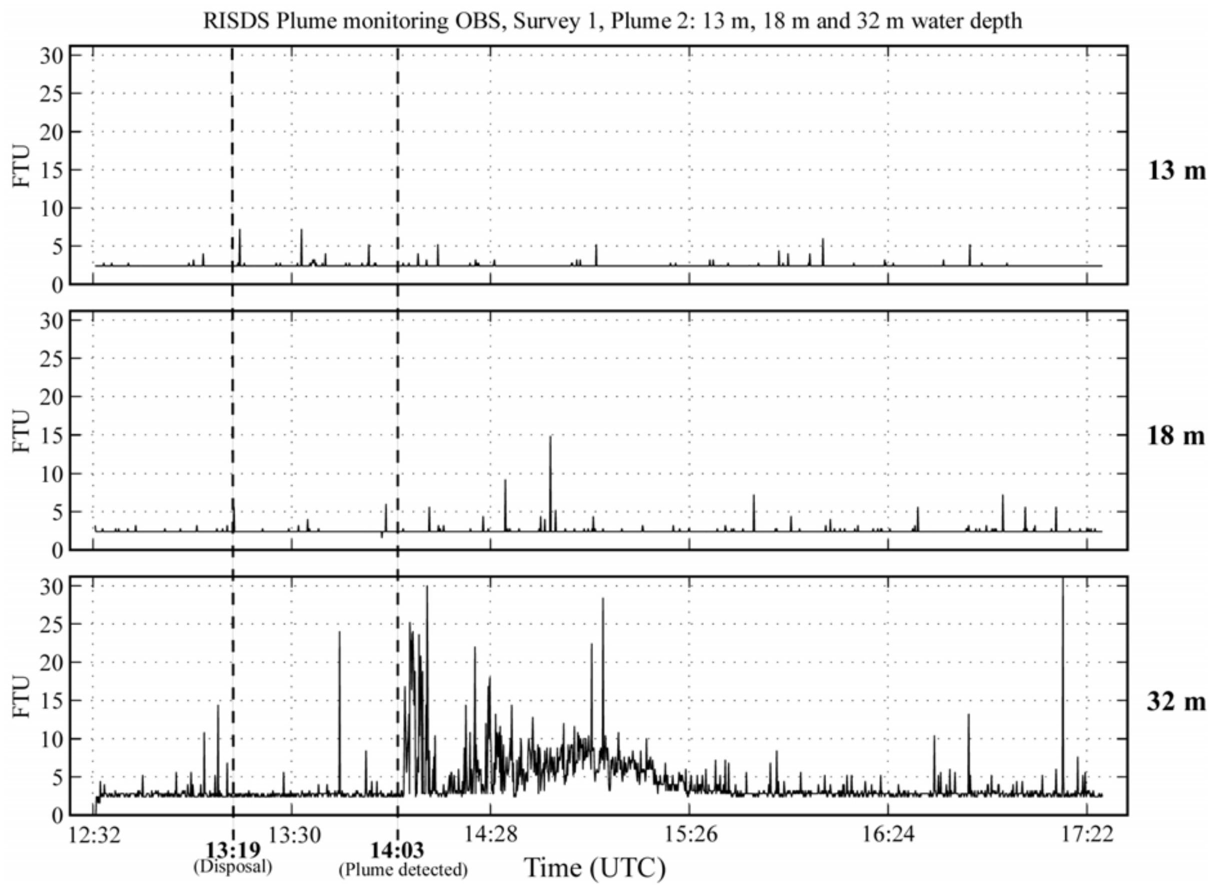


Figure 3-39. Time-series (UTC) plot of OBS data collected on 9 April 2004 (Plume 2) from three levels in the water column (13 m, 18 m, and 32 m), displaying changes in turbidity (FTU) over time resulting from sediment plume passage. Dashed lines represent barge disposal time (13:19) and an increase in suspended sediment (14:03), indicating the possible of the leading edge of the plume.

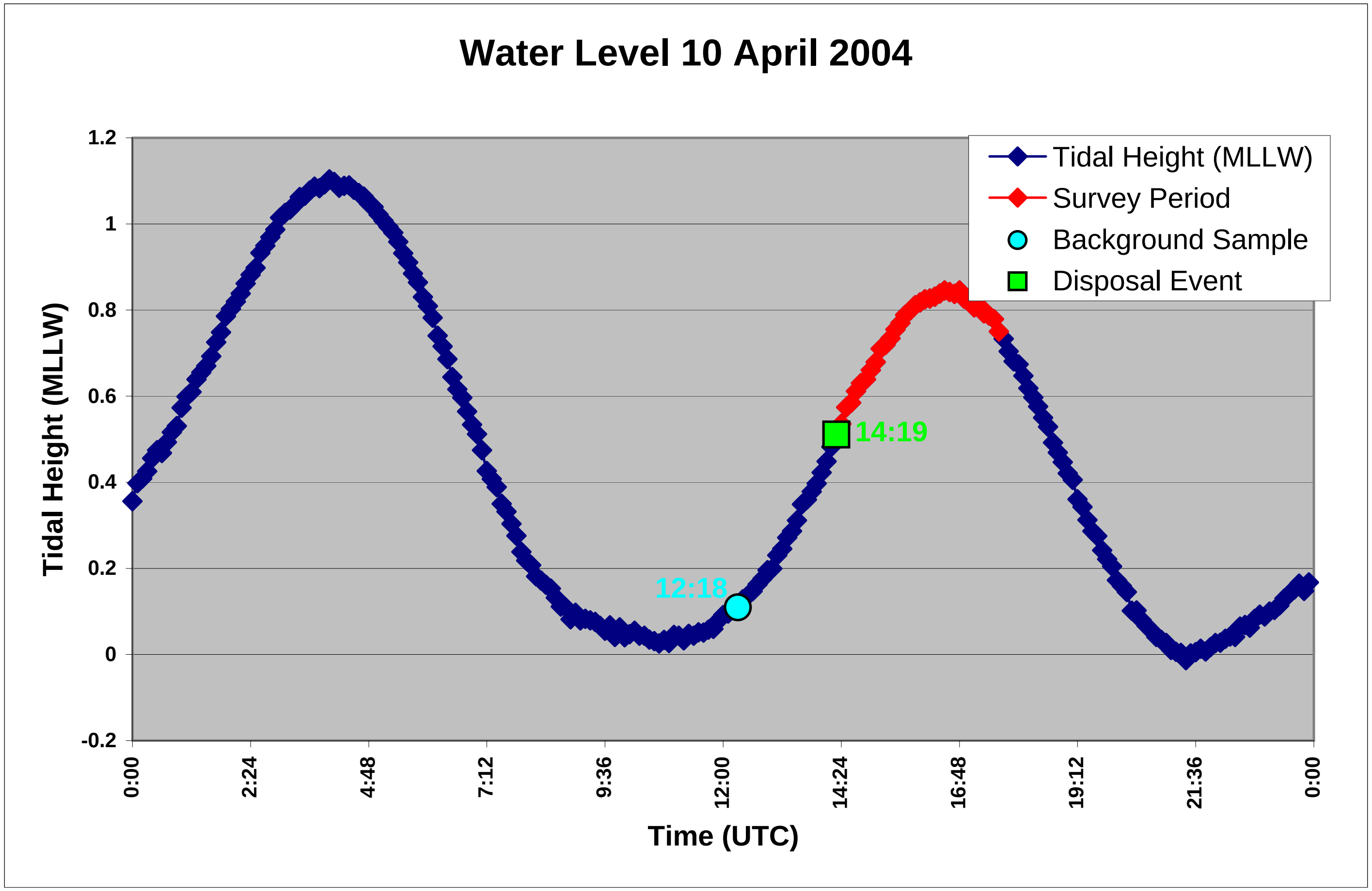


Figure 3-40. Water level data from the NOAA tide station in Newport, RI, corrected to the tide zone encompassing RISDS for 10 April 2004. The Background Sample and the Disposal Event are shown in comparison to the tidal stage.

3.2.3.1 Water Column Currents

All three drogues (mid-water, deep-water, and surface) were deployed following the release of dredged material by the disposal barge. Both mid (18 m) and deep-water (32 m) drogues indicated water column current flow in a northwesterly direction (Figure 3-41). The Davis drifter was deployed at the same location as the mid and deep-water drogue immediately following disposal operations. However, the drifter traveled 270 meters to the southeast within one hour (7 $cm \cdot s^{-1}$) before being recovered. The mid and deep-water drogues were tracked for over three hours.

Of the three consecutive days that disposal plume monitoring operations were conducted, the effects of meteorological conditions (sea state, wind speed, and direction) on currents (surface and water column) at RISDS were most pronounced on 10 April (Plume 3). Steady winds from the west and southwest, with speeds ranging from 5 to 8 $m \cdot s^{-1}$ (prior to and during the survey period), generated surface waves approaching1.5 m in height within the survey area. In response to this meteorological forcing during the flood tide, the velocity of the surface currents was weak (<5 $cm \cdot s^{-1}$) and deflected to the south (Figure 3-42). The transport of the surface drogue to the southeast at an average velocity of 7 $cm \cdot s^{-1}$ was likely attributed to the minimal southerly current flow, as well as the effects of short period surface waves generated by the sustained westerly winds (Table 3-3). The data collected by the bottom mounted ADCPs indicated that meteorology had affected both the speed and direction of the surface currents to an approximate water depth of 7 m (Figure 3-42).

Net transport of both the mid and deep-water current drogues was primarily to the northwest, as anticipated during a flood tide. An average speed of 12 $cm \cdot s^{-1}$ was calculated for the mid-water drogue, while the deep-water drogues displayed a speed of 9 $cm \cdot s^{-1}$ (Table 3-3). Similar to the results for the Plume 2 survey, it appeared the deep-water drogue had taken a more northerly track, suggesting that small-scale differences in velocity and direction existed in the lower portion of the water column (Figure 3-41). The bottom mounted ADCP record for Plume 3 confirmed the results from the drogue deployments, displaying currents at 18.5 m water depth approximately 5 $cm \cdot s^{-1}$ stronger in comparison to the near-bottom flow (32.5 m water depth) for the duration of the deployment (Figure 3-40).

Comparisons between the current record generated by the bottom-mounted ADCP and water level data corrected for RISDS suggests the disposal event occurred at mid flood with weak and variable currents existing in surface waters due to meteorological effects and moderate to strong currents at depth (14:19 UTC). Current velocities at mid-depth and near bottom were in excess of 10 $cm \cdot s^{-1}$ at the time of disposal in response to the influx of

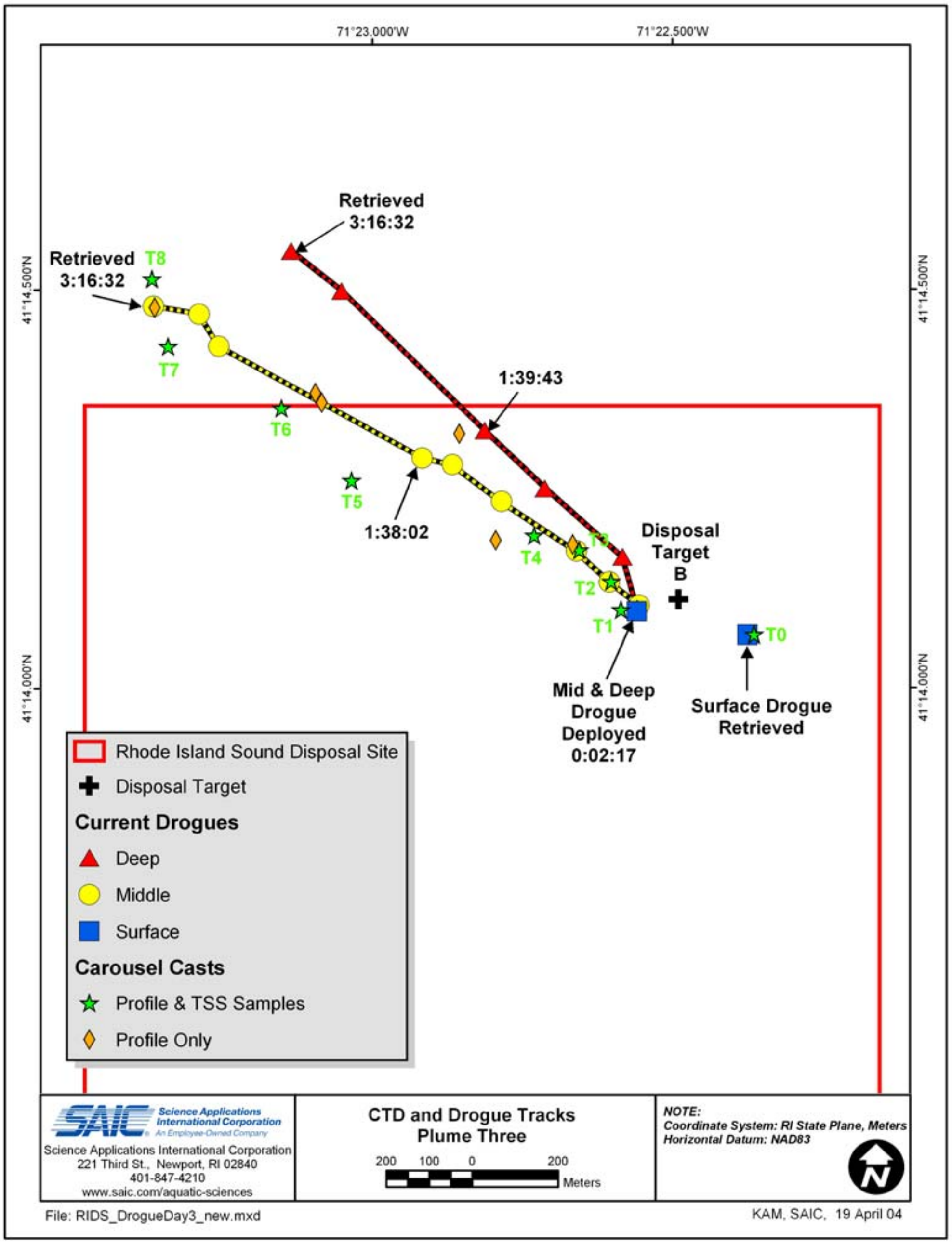


Figure 3-41. Map indicating current drogue trajectories and CTD cast locations during the tracking of Plume 3. Locations of water samples are also shown. Times represent elapsed time since disposal operations.

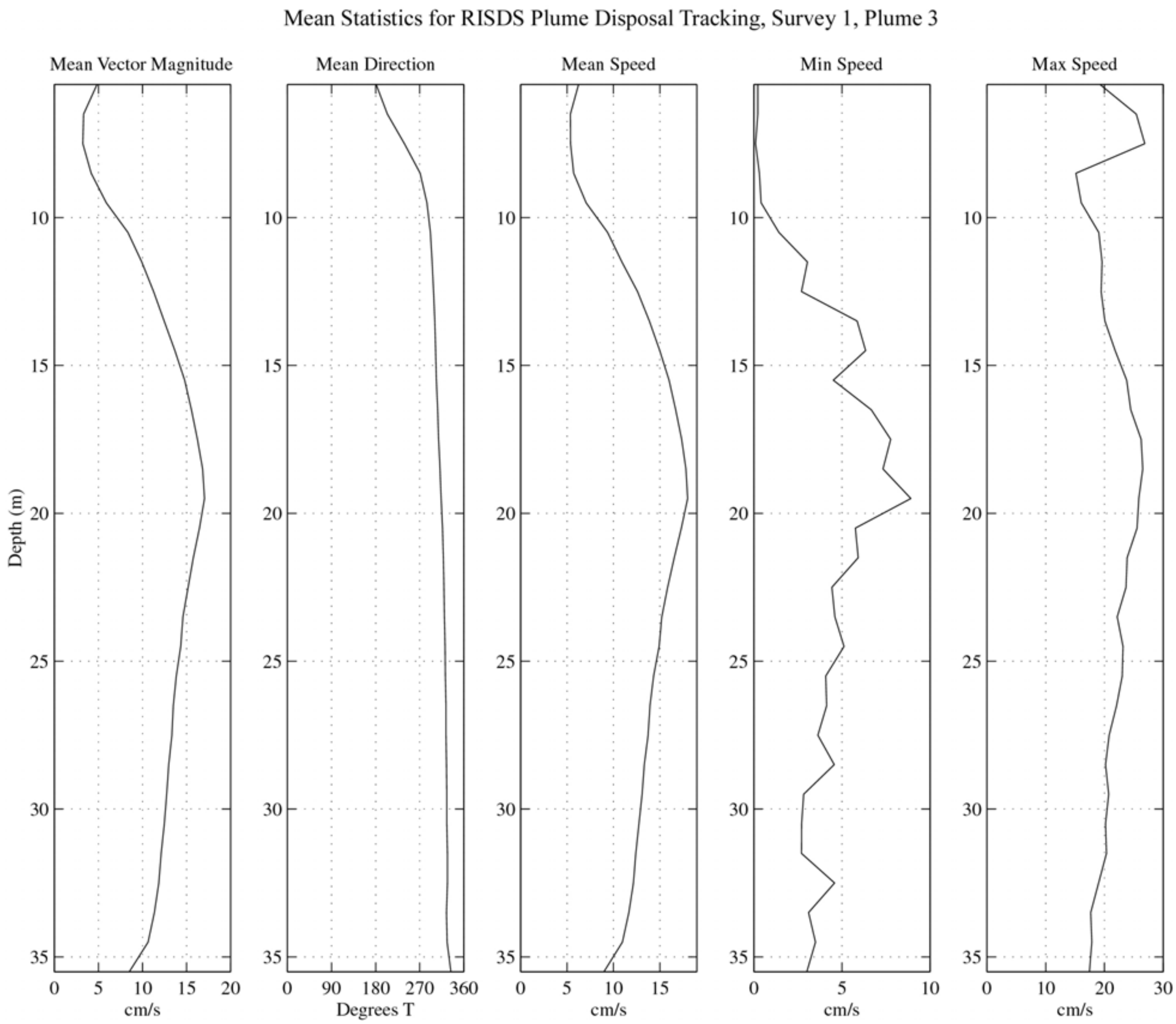


Figure 3-42. Statistics of moored current meter data collected on site during Plume 3 disposal monitoring activities. Current meter deployed for extent of the survey period (3.5 hours). Parameters plotted include mean vector magnitude, mean vector direction, mean speed (regardless of direction), minimum speed and maximum speed.

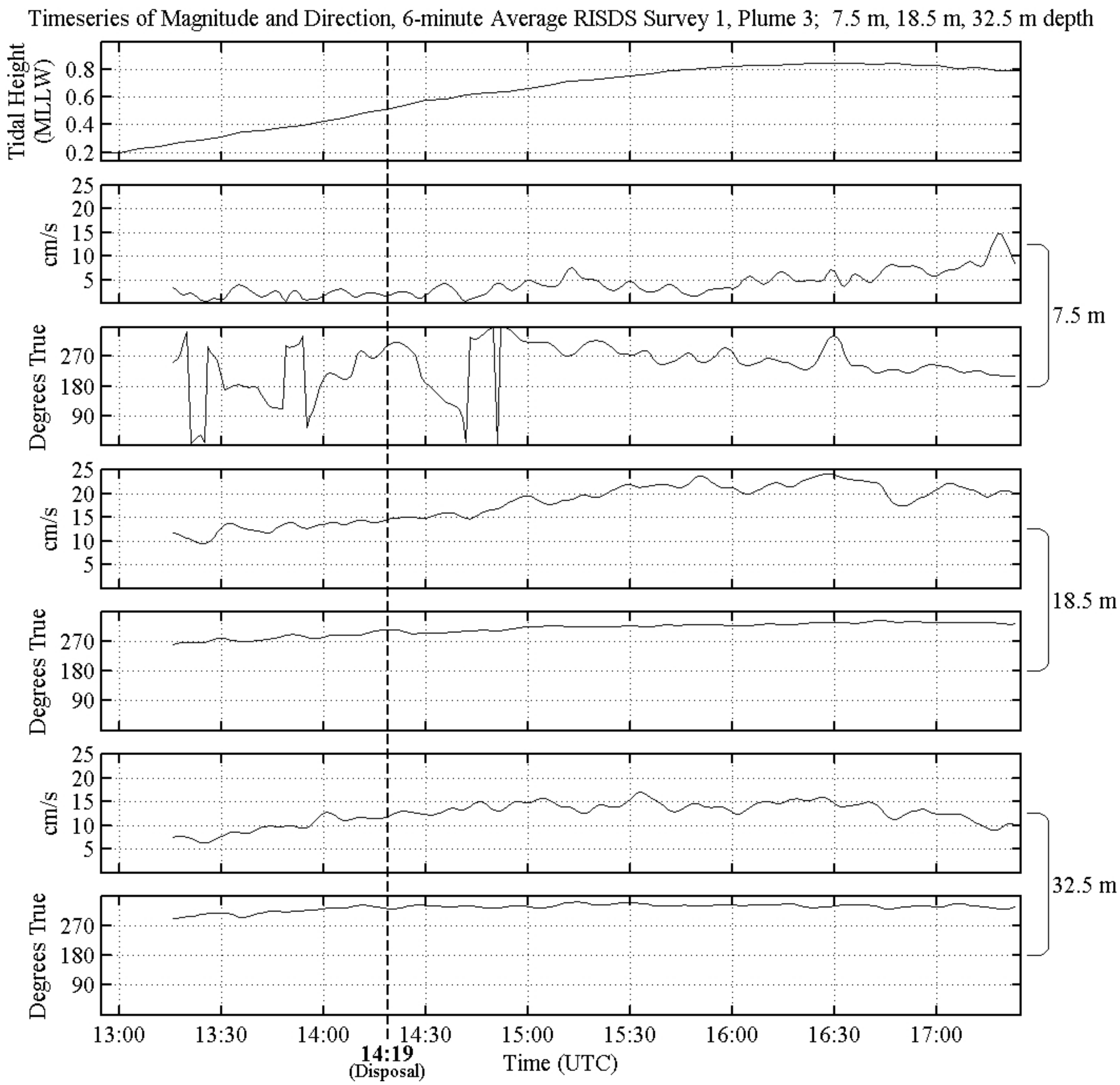


Figure 3-43. Time-series (UTC) plot of current magnitude and direction during Plume 3 at the near-surface level (top two panels) and the two selected drogue depth levels of ~18m (middle two panels) and ~32m depth (bottom two panels). Currents were sampled at 1min intervals, and filtered with 6-min Low Pass Filter (LPF) to reduce high-frequency noise. Dashed line (14:19) represents barge disposal time.

water associated with the flood tide. Velocities at these depth levels continued to increase throughout the flood tide with peak flow detected at the time of high tide (16:30 UTC; Mean Lower High Water; see Figure 3-43) similar to the previous plume monitoring surveys.

Near-bottom and mid-water currents displayed a west or northwest flow for the entire ADCP record, remaining relatively strong and consistent in both speed and direction from 15:00 UTC through 17:10. Speeds in excess of 20 $cm \cdot s^{-1}$ were recorded in the mid-water at the same depth horizon as the mid-water drogue (18 m; Figure 3-44). At approximately 17:10 UTC, which corresponded to the early stages of ebb tide (reduction in water levels), current speeds began to diminish but continued to flow in a northwesterly direction. In general, the currents in the depth horizon between 16 and 22 m were the strongest and most significant factor affecting plume morphology.

The vessel-mounted ADCP data corresponded to the information extracted from the bottom mounted unit, as well as the surface drifter and drogues. The shipboard instruments indicated flow was initially to the south at 10 $cm \cdot s^{-1}$, with the prevailing winds promoting a strong difference in velocity and direction in the water column. The upper 5 m of the water column was flowing in a south-southwesterly direction at 5 to 15 $cm \cdot s^{-1}$. The deeper portions of the water column (>10 m) moved uniformly to the northwest at 15 to 25 $cm \cdot s^{-1}$, with larger flow magnitudes occurring towards the end of the survey.

3.2.3.2 CTD/Transmissometer Profiles

On the third day of plume tracking and assessment, 16 CTD profiles were obtained within and adjacent to the disposal site. Background water properties and samples (T0) were collected 5 m above the seafloor (34 m) prior to disposal operations in the vicinity of the disposal location. Figure 3-45 presents profiles of the physical properties of the water column prior to the dredged material disposal event. As depths increased, salinity and percent transmittance showed minimal vertical stratification, but both density and temperature exhibited change with depth. Light transmittance remained relatively constant at approximately 83%, while salinity showed a slight increase at approximately 5 m depth, after which remaining relatively consistent at 32.8 PSU. Temperature decreased from 4.3°C at a depth of 5 m to 3.4° C at a depth of 20 m, remaining constant below 20 m. Corresponding to the change in water temperature, seawater density displayed a notable change within the 5 to 20 m depth range, increasing from 25.8 sigma-t near the surface to 26.1 sigma-t at a depth of 20 m, then becoming consistent below a depth of 20 m. As a result, this stratification may have corresponded with a difference in current velocity and direction and affected the dispersion of plume sediments over the 3.5-hour tracking period.

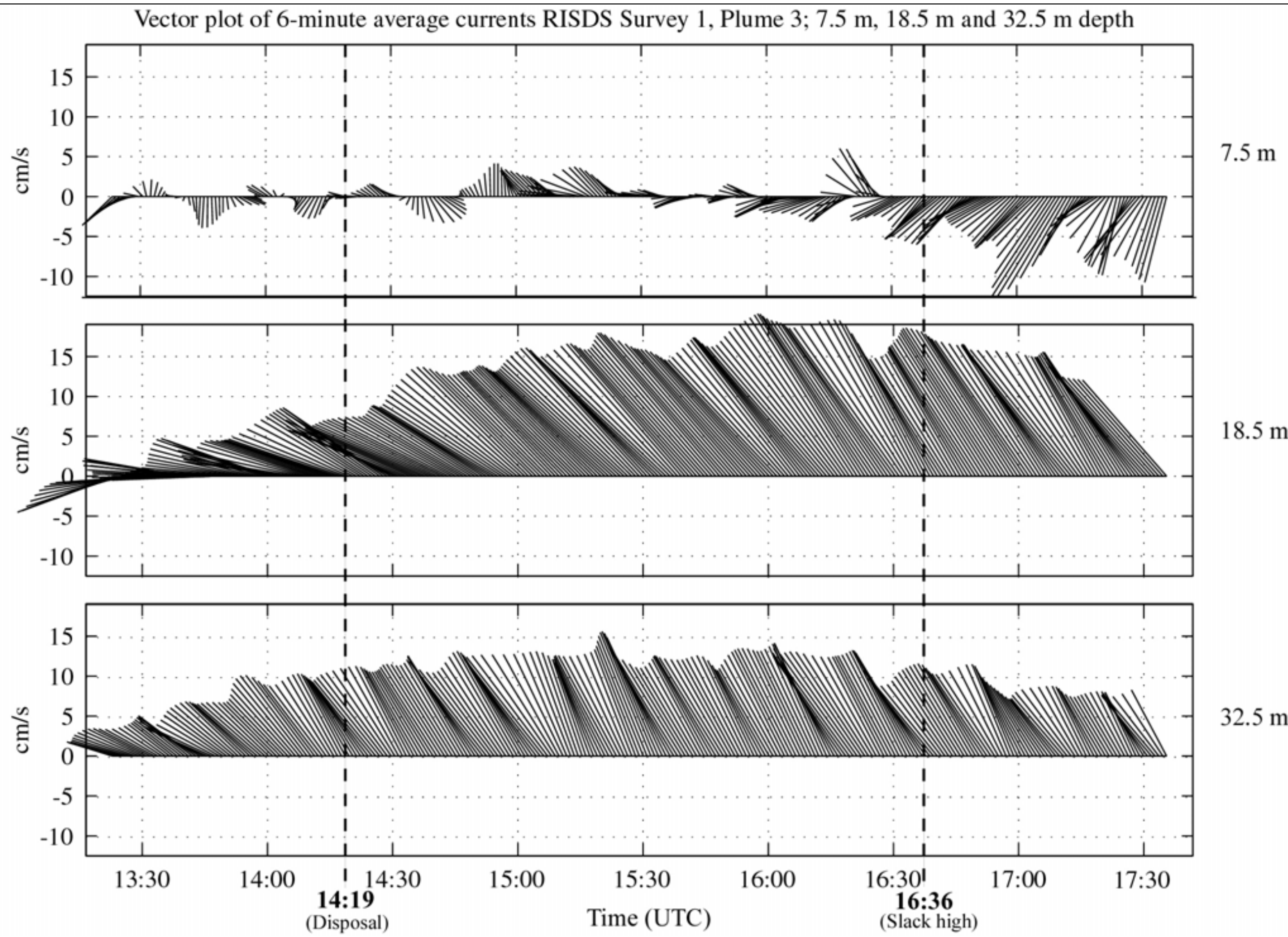


Figure 3-44. Time-series (UTC) plot of current vectors (6-min LPF) during Plume 3 at the near-surface level (7.5 m; top panel) and the two selected drogue depth levels of ~18m (middle panel) and ~32m depth (bottom panel). Dashed lines represent the time of barge disposal (14:19) and the slack high tide (16:36).

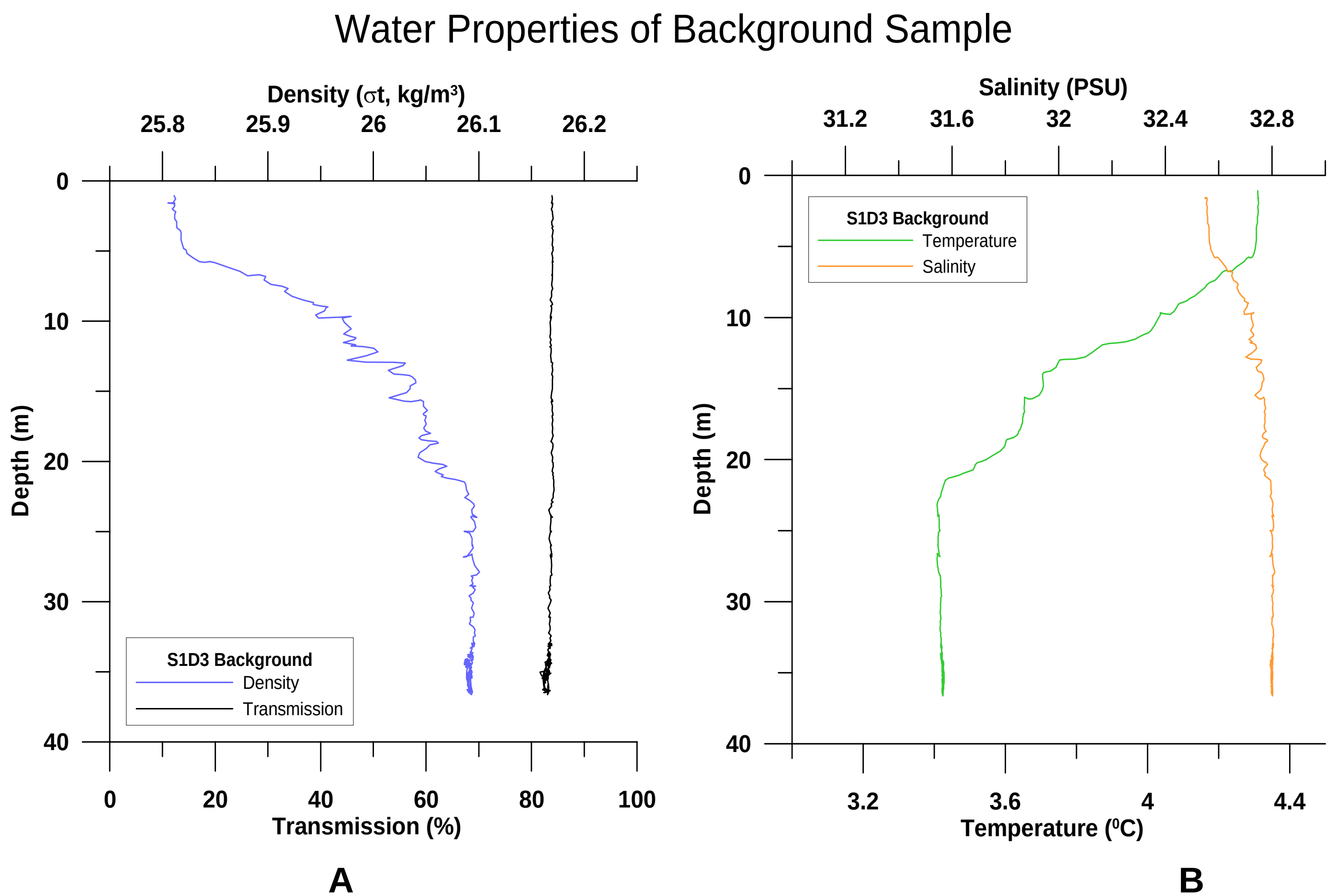


Figure 3-45. Profile plots of percent light transmission and seawater density versus depth (A) and temperature and salinity versus depth (B) acquired during the CTD background sample interval for Plume 3. Data are from the downcast profile only.

The disposal barge approached Disposal Point B from the north, slowed and released its load at 14:19 UTC. As with the two prior survey days, the CTD sampling vessel positioned itself immediately astern of the disposal barge during the disposal event. The barge emptied 10-15 seconds after opening, with the majority of the sediment falling through the water column to form a deposit on the seafloor. The maintenance material that was entrained in the water column formed a sediment plume at the surface that extended down to the seafloor. Visual observations revealed a substantial surface plume that was apparent in close proximity to the disposal location.

Ten minutes after the disposal event, plume monitoring began with a CTD cast between the drogue locations (T1 profile and water sample). The transmissometer profile displayed a substantial amount of turbidity over background conditions with percent transmittance near zero in the upper water column at the centroid (Figure 3-46). From a depth of 5 m to the seafloor, a continual plume was observed with minimum transmittance values of near zero to a maximum transmittance value of 50%. The water sample for TSS analysis was collected at a depth of 33.2 m. Due to variations in plume morphology close to the seafloor, the water sample was not collected at the most turbid portion of the plume, but was still collected within the plume.

The 20-minute sampling interval (T2) profile was collected in proximity to both the mid-depth and deep-water drogues. The transmissometer profile detected a small layer of turbid water with a minimum transmittance of approximately 55% at 6 m that extend down to a depth of 10 m (Figure 3-46). From 10 m to approximately 20 m, background transmittance levels were observed. Below 20 m, transmittance decreased rapidly with a range from near zero to 40%, indicating the presence of highly turbid water at depth. The T2 water sample was collected for TSS in this near-bottom portion of the disposal plume at a depth of 33.6 m (transmittance 4.5%).

Information provided by the roving ADCP vessel, approximately 30 minutes into the monitoring survey, indicated that the most turbid portion of the plume was located in proximity to the mid-water drogue and a CTD cast was subsequently obtained at this location to confirm this finding (Figure 3-41). Based on the results of the CTD data, the T3 (40-minute) water samples were collected in proximity to the mid-water drogue at a depth horizon corresponding to the plume centroid. The transmittance profile showed light transmittance at background levels to a depth of 15 m, after which transmittance decreased in response to increasing turbidity, eventually approaching zero transmittance at a depth of 32 m (Figure 3-47). The T3 water samples were collected at a depth of 32 m during the upcast; transmittance levels of 4.4% were recorded at this depth interval at the time the hydrocast was collected. Overall, the transmissometer detected much higher levels of light transmittance (lower turbidity) in the upper 15 m water column, relative to depths below

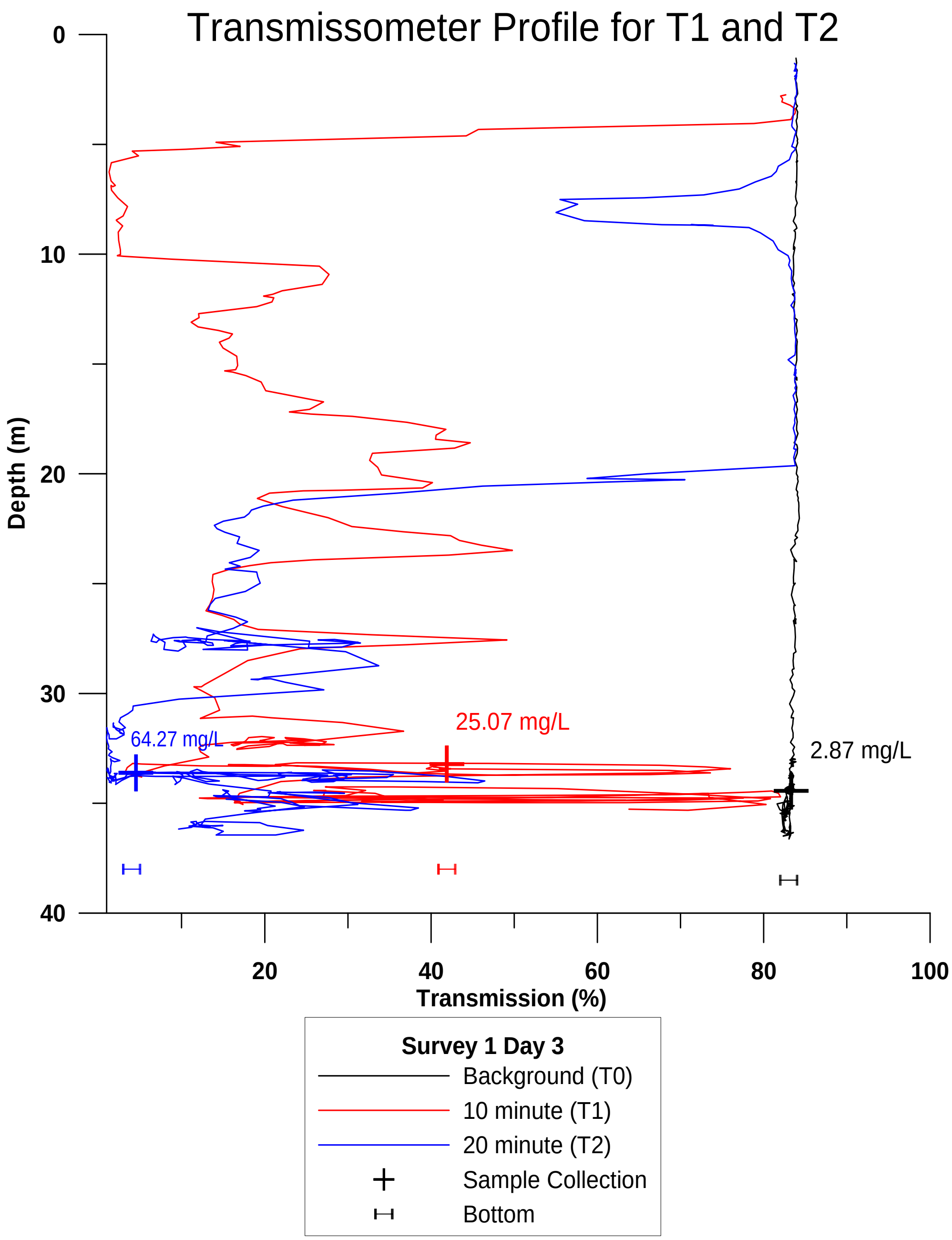


Figure 3-46. Profile plot of percent light transmission and sensor depth acquired during CTD sample intervals T1 and T2 during Plume 3. Locations of water sample collections within the plume are also shown.

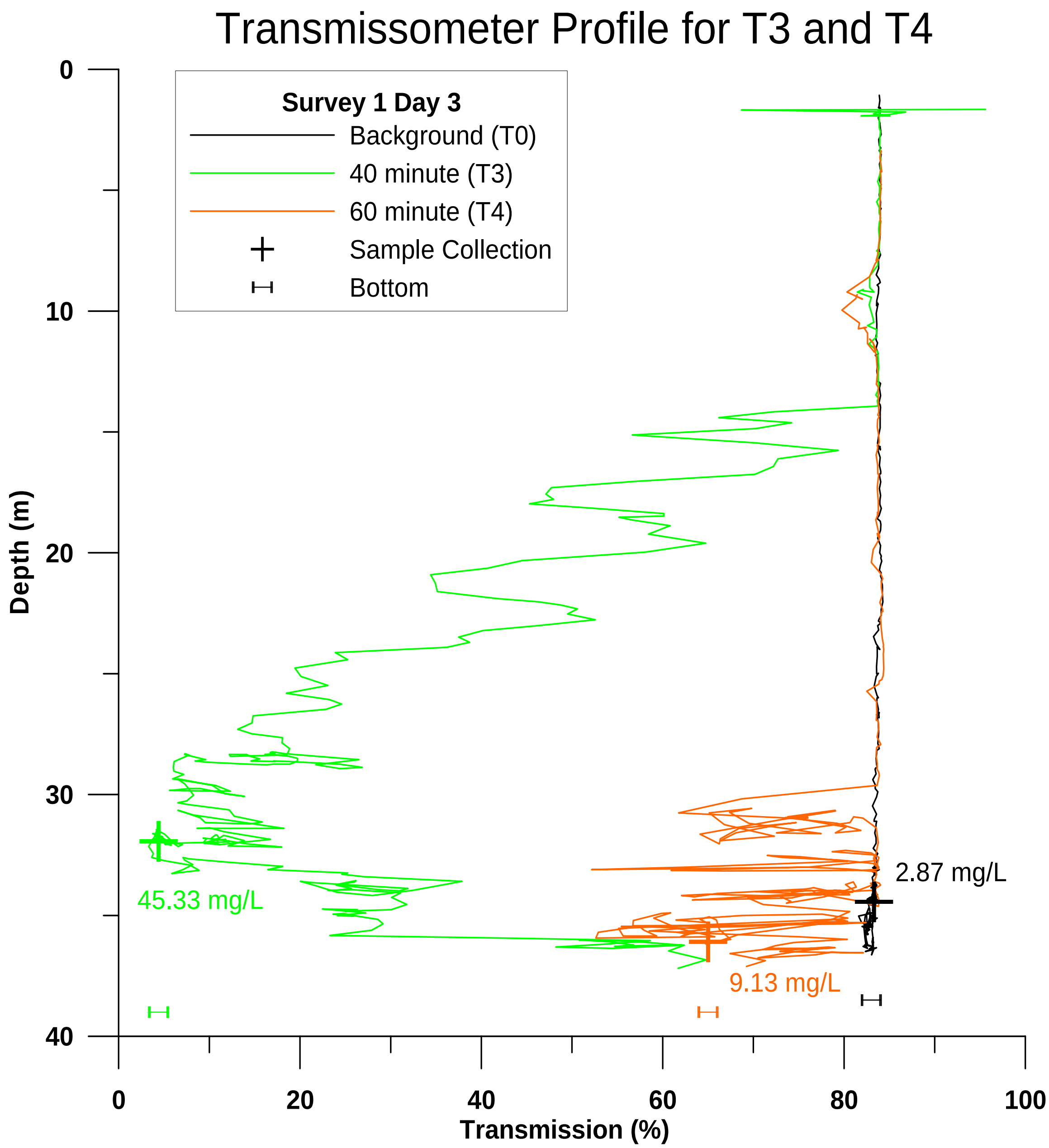


Figure 3-47. Profile plot of percent light transmission and sensor depth acquired during CTD sample intervals T3 and T4 for Plume 3. Locations of water sample collections within the plume are also shown.

15 m, suggesting a substantial difference in velocity and direction in the water column and/or particle settling.

At the 60-minute sample interval (T4), a CTD profile was collected near the mid-water drogue (Figure 3-41). The transmittance profile reflected background levels of transmittance (83%) to a depth of approximately 7 m, where transmittance decreased slightly, eventually returning to background levels at a depth of 12 m (Figure 3-47). At the 30 m depth horizon, transmittance levels reached the lowest levels at approximately 53% in response to increasing turbidity. Water samples for T4 were collected at a depth of 35.8 m (transmittance 68%). Due to the lack of sub-surface and mid-depth plumes and the low intensity of the near-bottom plume, it appeared that the plume centroid was no longer located at the position of the mid-depth drogue at this time interval.

Following the T4 profile, several supplemental CTD casts were performed in close proximity to the current-following drogues, as well as various distance offsets to locate the centroid of the plume. The 90-minute (T5) CTD profile and corresponding water samples were collected approximately 150 m southwest of the mid-depth drogue position (Figure 3-41). The CTD data showed the presence of background transmittance levels to a depth of 12 m, where a mid-depth pulse of turbidity, likely related to the sediment plume, was present (Figure 3-48). Below 12 m, transmittance levels decreased with depth to approximately 60% at 15 m (indicating an increase in turbidity), then increased to near background levels for the next 7 to 8 m. At a depth of 25 m, the near-bottom portion of the disposal plume was detected as a steady increase in turbidity (decreasing transmittance) with depth. The lowest level of transmittance observed in the near-bottom portion of the plume was 54.7% at a depth of 31.6 m; the T5 water samples were collect at this location during the upcast.

At the 120-minute sampling interval (T6), the vessel monitoring real-time ADCP data directed the water sampling vessel to the approximate plume centroid, independent of the position of the current-following drogues (Figure 3-41). Here, the transmissometer profile displayed background levels of light transmittance occurring to a depth of 25 m. Below 25 m, percent light transmittance decreased to a minimum value of 65%. The T6 water samples were collected at a depth of 32 m (transmittance 71%).

The 150-minute profile (T7) was captured to the southwest of the mid-water drogue at a location directed by the ADCP vessel, while the 210-minute interval (T8) was collected in proximity to the mid-water drogue. Though the two profiles were obtained in different locations, the plume morphology remained similar over time. Both profiles indicated background levels of transmittance to a depth of 23 m, and both decreased

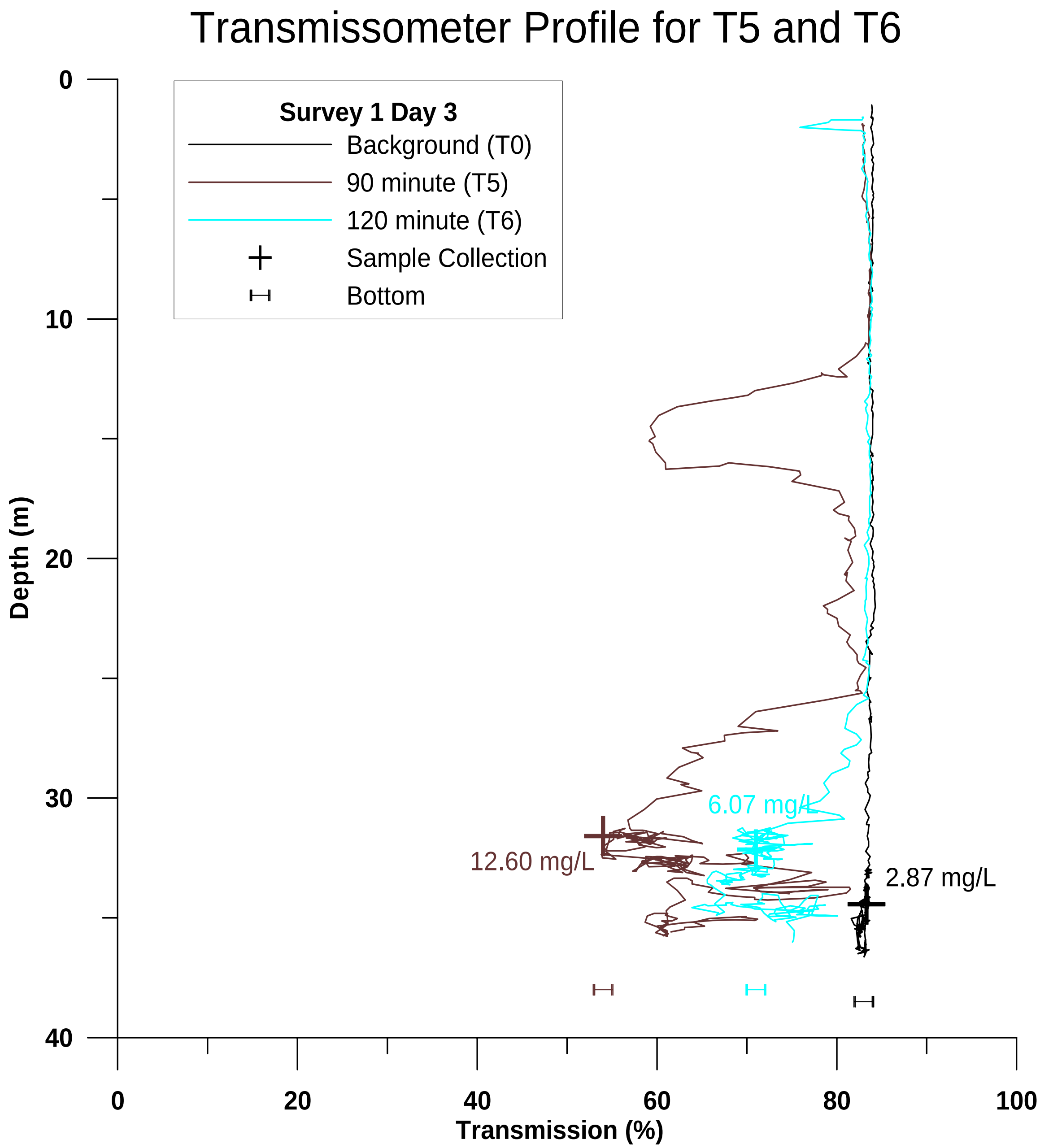


Figure 3-48. Profile plot of percent light transmission and sensor depth acquired during CTD sample intervals T5 and T6 for Plume 3. Locations of water sample collections within the plume are also shown.

similarly with depth indicating the presence of a near-bottom turbidity plume (Figure 3-49). Light transmission values for both intervals ultimately reached a minimum of 75%. The water samples for each interval were collected at different depths within the near-bottom portion of the plume; the 150-minute interval sample was collected at 35 m, while the 210-minute interval sample was collected at 31 m.

3.2.3.3 Total Suspended Solids (TSS) Results from Water Samples

A summary of the TSS results associated with the water sampling data for the Plume 3 survey is provided in Table 3-7. The background samples for the third plume tracking survey were obtained prior to disposal operations and are also summarized in Table 3-7. The background TSS samples for Plume 3 were similar to the values reported from both Plumes 1 and 2, with a relatively low average value of 2.9 $mg \cdot L^{-1}$. Plume TSS samples were generally collected approximately 3 to 4 m above the seafloor within the apparent plume centroid.

TSS values reflected a strong increase in turbidity over the next few sample intervals (T1 through T3). In general, the higher TSS values observed at the 20 and 40 minute (T2 and T3) sample intervals corresponded to the lowest percent transmission of light recorded in the CTD profiles. A value of 25.1 $mg \cdot L^{-1}$ (S1D3_T1) was reported ten minutes after plume tracking commenced, but the highest TSS value corresponded to the samples collected 20 minutes after disposal operations (S1D3_T2; average of 64.3 $mg \cdot L^{-1}$) at a depth of 33.6 m. The substantially higher result in suspended sediment in the lower portions of the water column suggests that the T2 water samples had been obtained closer to the actual centroid of the plume in comparison to the T1 samples. The TSS concentrations remained relatively high for the T3 sample interval (40 minutes), with a reported average value of 45.3 $mg \cdot L^{-1}$. Values decreased significantly for the remaining sample intervals, ultimately returning to near background levels (2.9 $mg \cdot L^{-1}$) nearly four hours after disposal operations.

Similar to the data collected for Plumes 1 and 2, there was a slight increase (approximately 3 $mg \cdot L^{-1}$) in TSS at the 90-minute sample interval (T5; average of 12.6 $mg \cdot L^{-1}$) followed by a trend of decreasing turbidity for the remaining samples. However, replicate sample data displayed more variability (standard deviation of 6.5 $mg \cdot L^{-1}$) at the time of the observed increase (T5 sample interval). As previously observed during the tracking of both Plumes 1 and 2, the increase in TSS concentration from the 60-minutesample to the 90-minute sample may be a function of a density layer within the water column affecting settlement of entrained sediment particles.

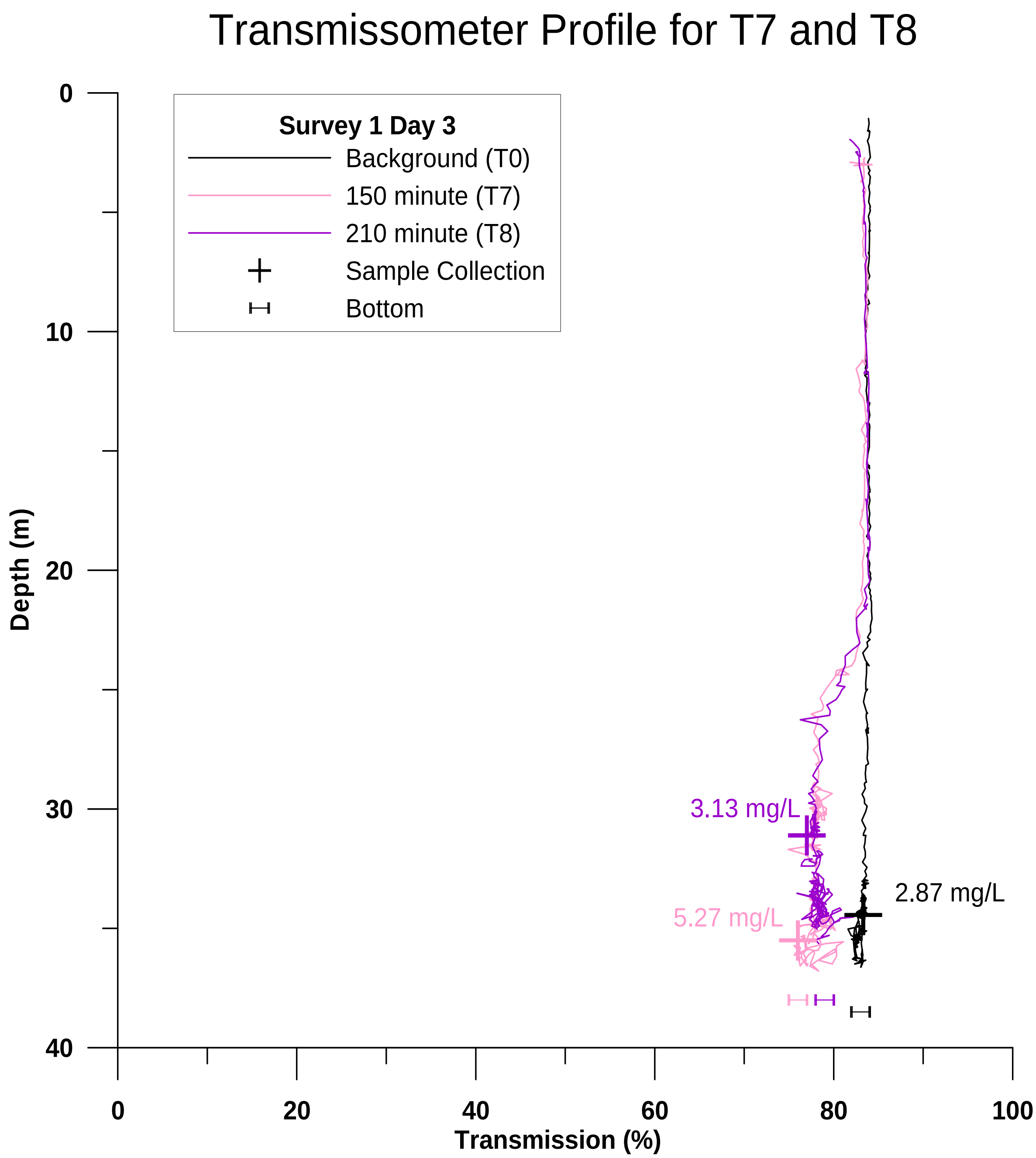


Figure 3-49. Profile plot of percent light transmission and sensor depth acquired during CTD sample intervals T7 and T8 for Plume 3. Locations of water sample collections within the plume are also shown.

Table 3-7. Results of Total Suspended Solids (TSS) Analysis from Discrete Water Samples Collected during CTD Profiling Operations as part of Survey Day 3 (Plume 3)*

Sample ID	Time (min)	Elapsed Time (hr:min)	Depth (m)	Transmittance (%)	OBS (FTU)	TSS (mg/L)				
						A	B	C	Avg	STDev
S1D3_T0	0	0:00	34	83.31	9.16	2.4	2.8	3.4	2.9	0.50
S1D3_T1	10	0:12	33	42.00	14.04	27.2	27.6	20.4	25.1	4.05
S1D3_T2	20	0:24	34	4.52	20.15	64.8	65.2	62.8	64.3	1.29
S1D3_T3	40	0:38	32	4.43	33.58	51.2	44.0	40.8	45.3	5.33
S1D3_T4	60	1:03	36	68.31	10.38	2.6	18.0	6.8	9.1	7.96
S1D3_T5	90	1:32	32	54.70	12.82	19.6	11.4	6.8	12.6	6.48
S1D3_T6	120	2:01	32	71.20	10.38	4.4	10.2	3.6	6.1	3.60
S1D3_T7	150	2:39	36	76.75	9.77	6.8	5.6	3.4	5.3	1.72
S1D3_T8	210	3:31	31	77.65	9.77	4.0	2.6	2.8	3.1	0.76

* plume tracked from the disposal of material from a 4,000 yd^3 capacity split-hull disposal barge

3.2.3.4 ADCP Backscatter from Underway Profiling

The ADCP background data collected over RISDS prior to the Plume 3 disposal event provided insight into the acoustic properties of the ambient water column. Similar to the previous datasets, the acoustic backscatter was removed from the survey records obtained over the course of the Plume 3 survey day to isolate the acoustic signature of the suspended particulate matter associated with the disposal plume from Load 763. In contrast to the Plume 1 and 2 surveys, the raw backscatter intensity data for Plume 3 displayed only a minor increase in acoustic backscatter intensity at mid depth. The highestbackscatter values reached 75 counts at a depth horizon of 12 to 15 m (Figure 3-50). The transition between depth horizons showing the minimum backscatter intensity value (65 counts) to the maximum value (75 counts) was relatively gradual, failing to generate the strong banding effect noted in the baseline records acquired on the previous survey days. As a result, the artifacts associated with the density gradient in the water column were minor, which provided more useful data within the mid-water column, relative to the datasets for the Plume 1 and 2 surveys.

A set of north-south oriented survey lines was utilized to monitor plume migration during the Plume 3 survey. Line F, located closest to the disposal point was occupied immediately after the dredged material disposal event. Acoustic backscatter data were collected over a 540 m segment of Line F within five minutes of the deposition of dredged material. Residual backscatter values in excess of 20 counts were detected throughout the water column and centered at the actual disposal location (Figure 3-51A). Based on the acoustic data obtained by the shipboard ADCP, the near-surface expression of the disposal plume was approximately 160 m wide, while the near-bottom portion of the sediment plume measured 290 m.

Upon the completion of Line F, the ADCP vessel transited north along Line G, which was established approximately 100 m west of the observed disposal point (Figure 2-4). The acoustic backscatter data indicated the existence of a secondary, concentrated area of turbidity in the surface waters south of the primary sediment plume feature (Figure 3-51B). This feature extended approximately 240 m south of the primary plume feature and appeared to be limited to the depth horizon between 0 and 15 m. Based upon the approach of the disposal barge, as well as course after the disposal event, this secondary plume feature was likely composed of both sediments washed from the open disposal barge as it transited south immediately following the disposal event (and formation of the primary plume) as well as the turbulence and cavitation in the near surface layers from the propeller wash of the tug boat. The presence of this secondary feature in the upper portion of the water column tended to correlate with the visual observations of increased turbidity at the surface reported in Section 3.2.3.2 above.

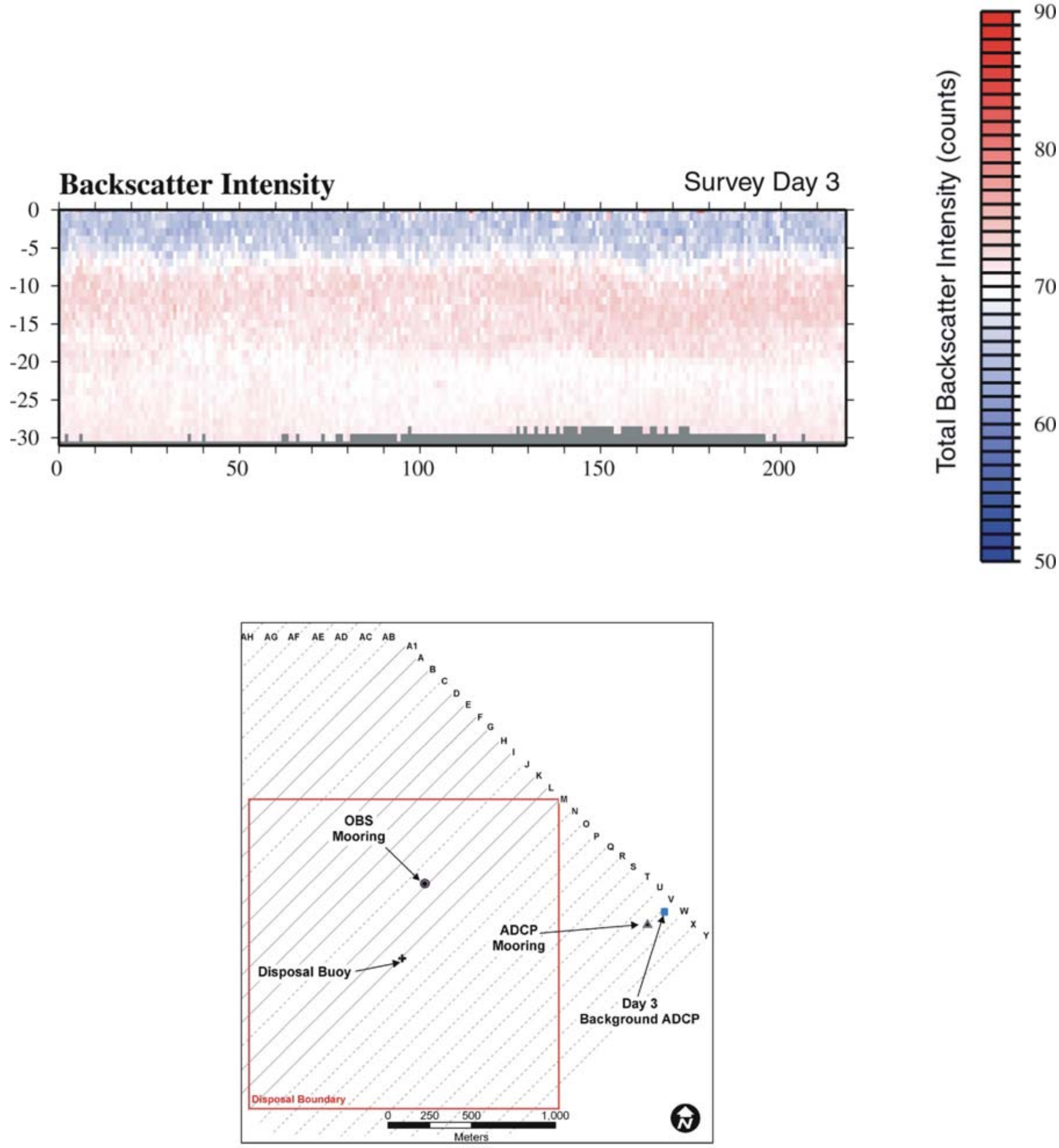


Figure 3-50. Profile plot of raw ADCP backscatter data collected on 10 April 2004 (Plume 3) to characterize background conditions at RISDS.

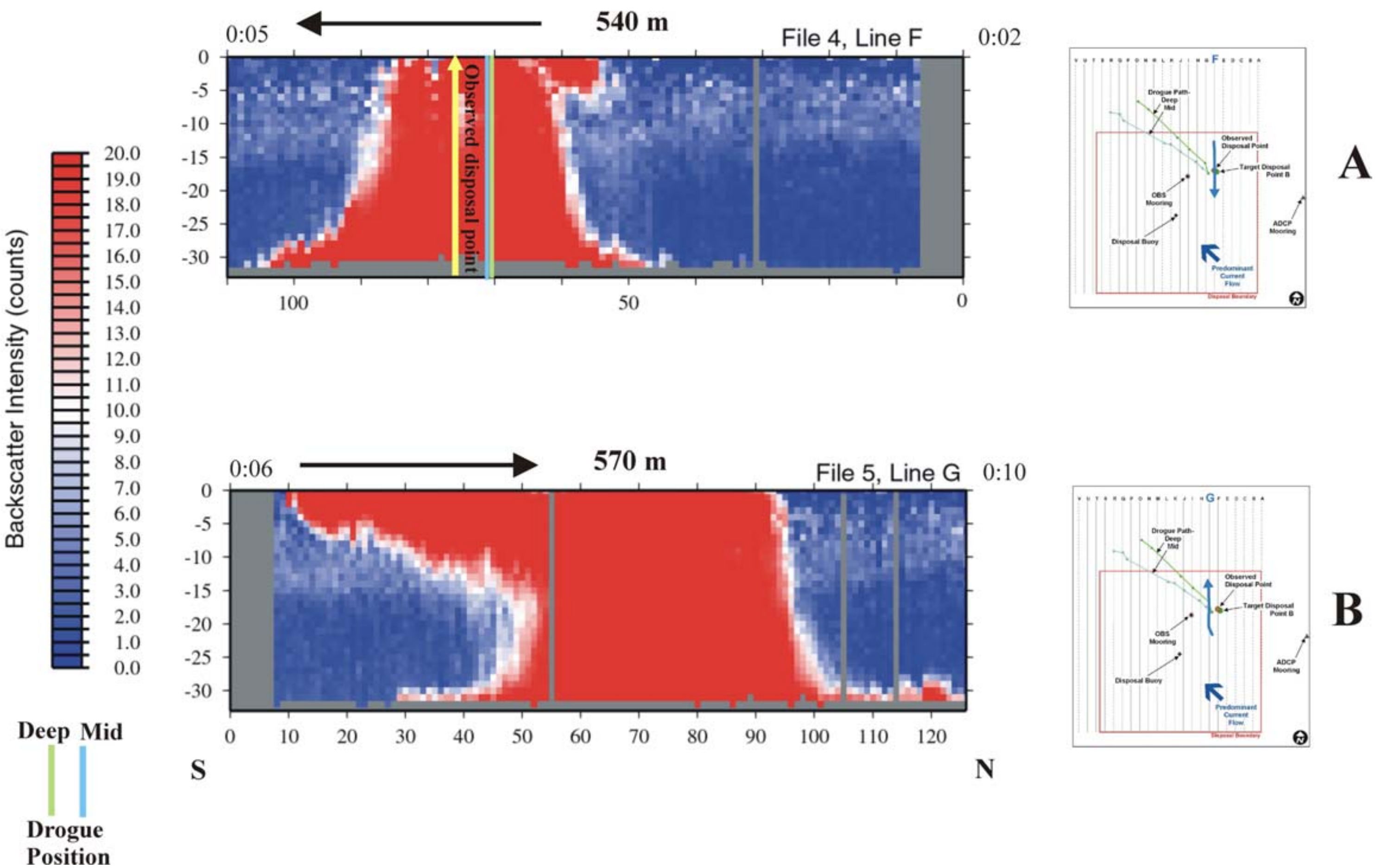


Figure 3-51. Profile plots of data collected from ADCP transects F and G on 10 April 2004 (Plume 3) displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to illustrate plume morphology 2 to 10 minutes after the dredged material disposal event at Point B.

Acoustic backscatter data from Lines H and I provided further insight into the morphology of both the primary and secondary plume features (Figure 3-52). At 17 minutes post disposal, there appeared to be two distinct plumes in the water column approximately 200 m west of the observed disposal point (Figure 3-52A). Residual backscatter values approaching 20 counts and elevated turbidity levels were detected in the surface, mid, and bottom waters, suggesting two distinct sediment deposits were released from the barge during the 10 April disposal event. The overall size and morphology of both plumes detected in Line H indicated a substantial amount of material was released at the observed disposal point during the initial deposit, as well as during the secondary release that occurred 100 to 200 m to the southwest of the observed disposal point noted in Figure 2-4. The data collected along Line I tended to support this finding as the acoustic signal from the primary plume (located to the north) decreased in size and intensity with distance away from the initial disposal point, while the signal from the secondary plume (located to the south) remained relatively strong (Figure 3-52B).

Survey Lines F and G (located near and 100 m west of the observed disposal point, respectively) were reoccupied approximately 30 to 40 minutes post-placement. Data collected along both lines (Lines F2 and G2) displayed residual backscatter from the surface to an approximate depth of 5 m in the water column, as well as near-bottom (depths of 27 m and below; Figure 3-53). Although the majority of the plume material that had occupied the mid-water column had apparently been advected to the west and north by ambient currents, the sediments entrained near the surface remained in close proximity to the observed disposal point. In addition, this turbidity layer appears to have been advected to the south of the initial disposal point, likely due to the weak surface currents and meteorological forcing associated with the strong northwest winds.

A relatively strong, near-surface turbidity layer also was detected along Lines H2 and I2, as well as the trailing edge of the mid-water and near-bottom portions of the primary sediment plume. In contrast to Lines F2 and G2, a 1 to 3 m layer of clear water appeared to exist at the surface along both lines, with a strong increase in acoustic backscatter detected at approximately 3 m depth (Figure 3-54 A and B). Once again, this finding can likely be attributed to the effects of the northwest wind on surface currents, preventing the northwestward migration of the plume sediments entrained within the surface layer. Lines H2 and I2 also displayed a relatively coherent primary sediment plume in the mid-water column and near bottom, as well as the remnants of the secondary sediment plume that existed as a near bottom layer of turbid water south of the primary plume feature.

At nearly 1.75 hours post-placement, Line Q, situated approximately 1,100 m west of the observed disposal point, was surveyed. The acoustic backscatter data along this line showed a single plume feature residing in the mid-water column and along the seafloor with

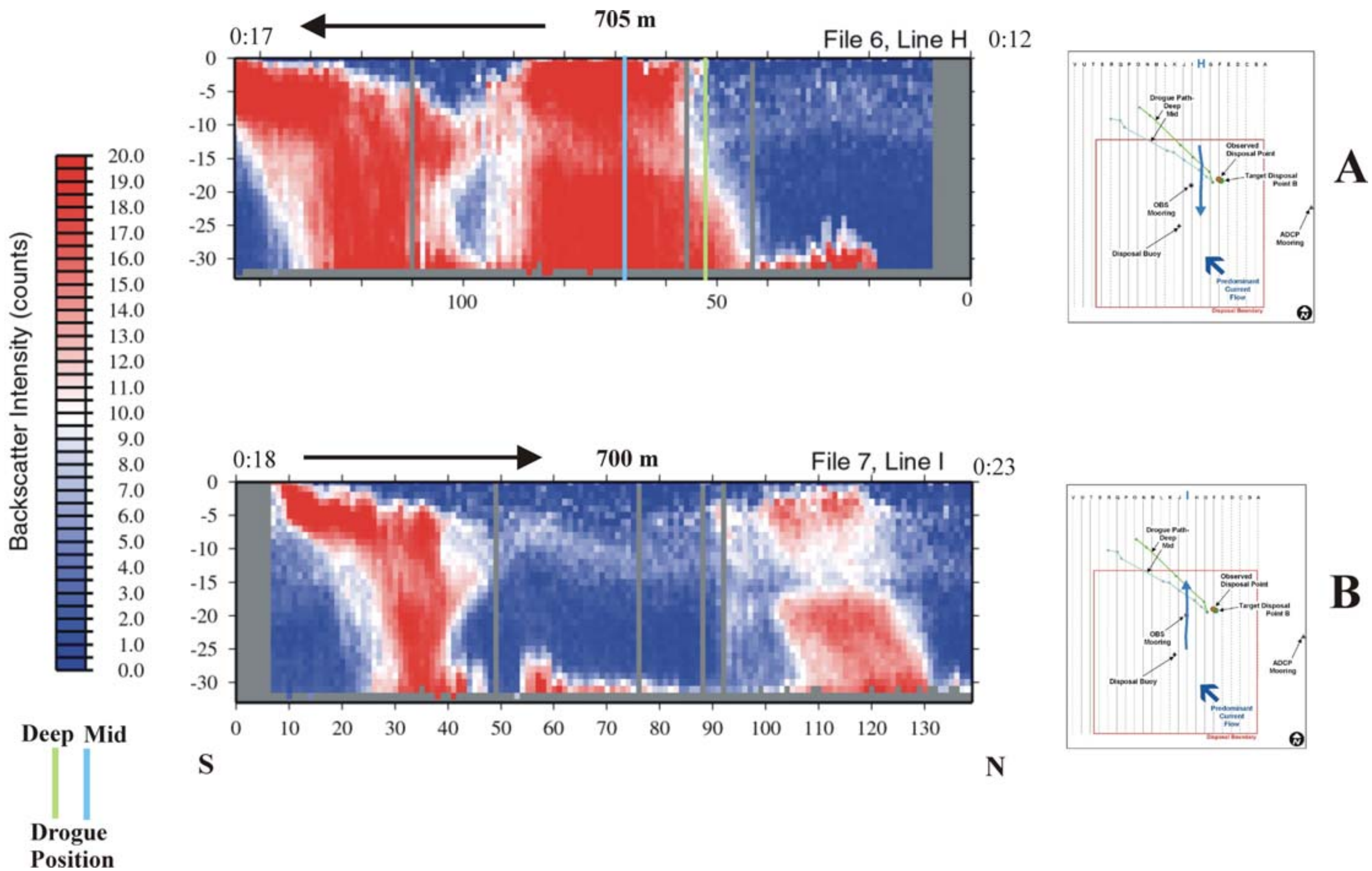


Figure 3-52. Profile plots of data collected from ADCP transects H and I on 10 April 2004 (Plume 3) displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to illustrate plume morphology 12 to 23 minutes after the dredged material disposal event at Point B.

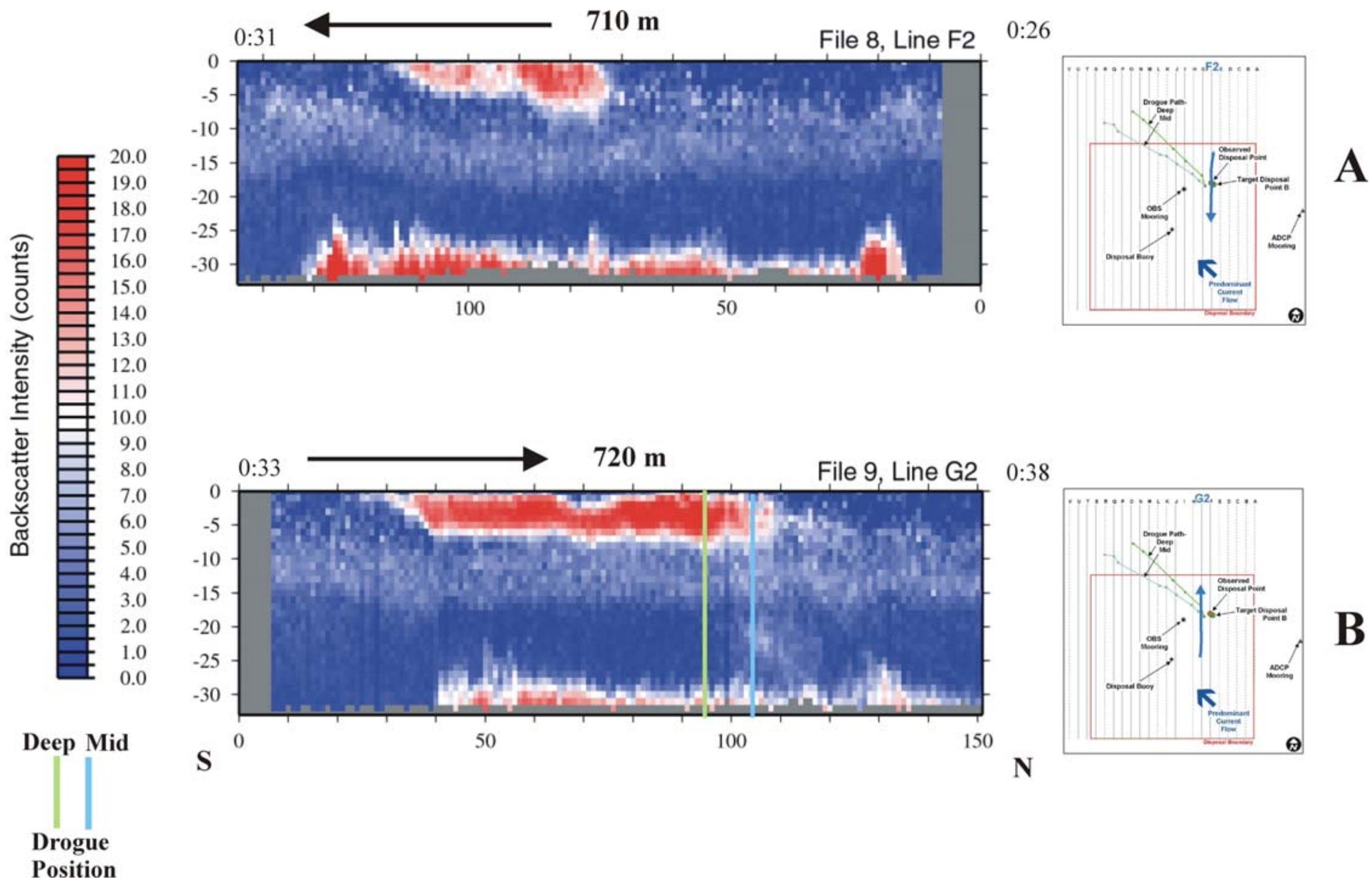


Figure 3-53. Profile plots of data collected from ADCP transects F2 and G2 on 10 April 2004 (Plume 3) displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to illustrate plume morphology 26 to 38 minutes after the dredged material disposal event at Point B.

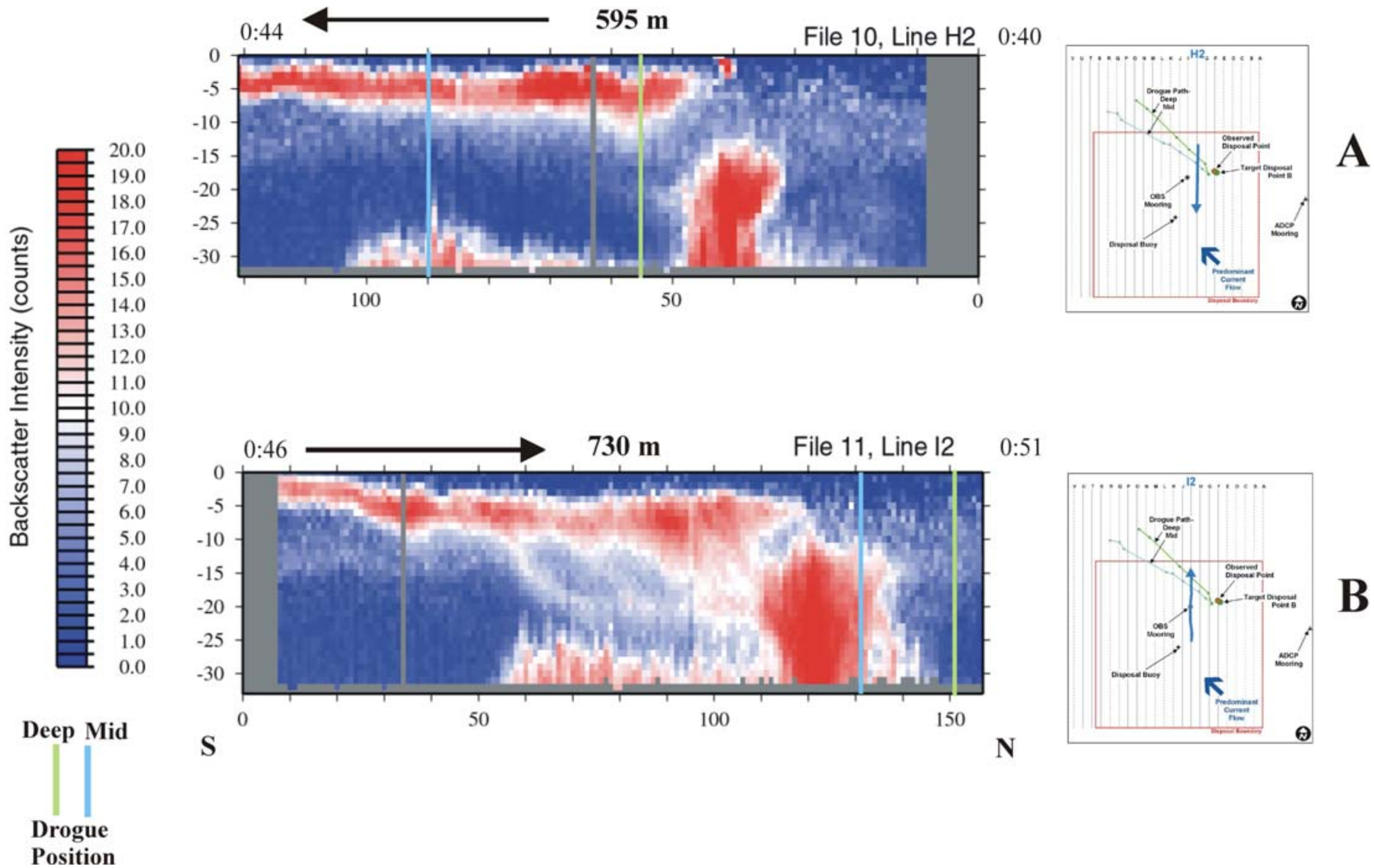


Figure 3-54. Profile plots of data collected from ADCP transects H2 and I2 on 10 April 2004 (Plume 3) displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to illustrate plume morphology 40 to 51 minutes after the dredged material disposal event at Point B.

a maximum backscatter intensity of approximately 17 counts at its core (Figure 3-55A). This relatively compact sediment cloud was detected due west of the observed disposal point and south of the anticipated plume track. As a result, this turbidity feature could represent a lobate extension of the leading primary plume or remnants of the secondary plume that was formed by a second sediment release southwest of the initial disposal point.

Survey Lines P, O, and N were surveyed after Line Q to provided insight into the relative turbidity and morphology of the remainder of the sediment plume. Data from all three lines indicated the presence of a single plume feature changing in size and residual backscatter intensity as distance from the initial disposal point decreased. The cross-section of the sediment plume detected along Line P was approximately 530 m along the north-south axis, with a significant percentage of the plume residing in the mid-water column (Figure 3-55B). Completed nearly two hours post-placement, the data from Line O provided a substantial amount of detail for the center of the plume, showing residual backscatter values approaching 18 counts and the bulk of the entrained sediments located south of the mid-water drogue track (Figure 3-56A). Line N illustrated the less coherent trailing edge of the sediment plume as the morphology and backscatter intensity suggest both diffusion/dilution of the sediment plume and settlement of entrained particles.

The remaining survey lines (Lines S, T, U, S2 and T2) chronicle the time period between two and three hours post-disposal. The data indicated a detectable sediment plume existed in the lower portion of the water column for at least three hours following the disposal event. Residual backscatter intensities ranging between 12 and 15 counts were detected at the centroid (or core) of the plume (Figures 3-57 and 3-58). The morphology of the plume showed little variability over time as it was advected to the west and northwest by water column currents. The lack of major changes in backscatter suggested the sediment plume maintained its integrity three hours after disposal, with minimal reduction in turbidity realized through particle settlement. As a result, the sediment plume from this disposal event would likely exist in the form of a finite sediment cloud in the mid to lower water column and remain acoustically detectable for several more hours (4 to 6 hours post-disposal).

3.2.3.5 Water Column Optical Backscatter from Moored Array

As part of the Plume 3 survey, the OBS sensor mooring was placed approximately 300 m west-southwest of the observed disposal position (Figure 2-4). The data collected at 10-second intervals showed low levels of background turbidity in the middle, and lower levels of the water column (13, 18, and 32 m depth), with values averaging 2 FTU during the 2.5 hours immediately following the mooring deployment at 14:19 UTC. A sharp

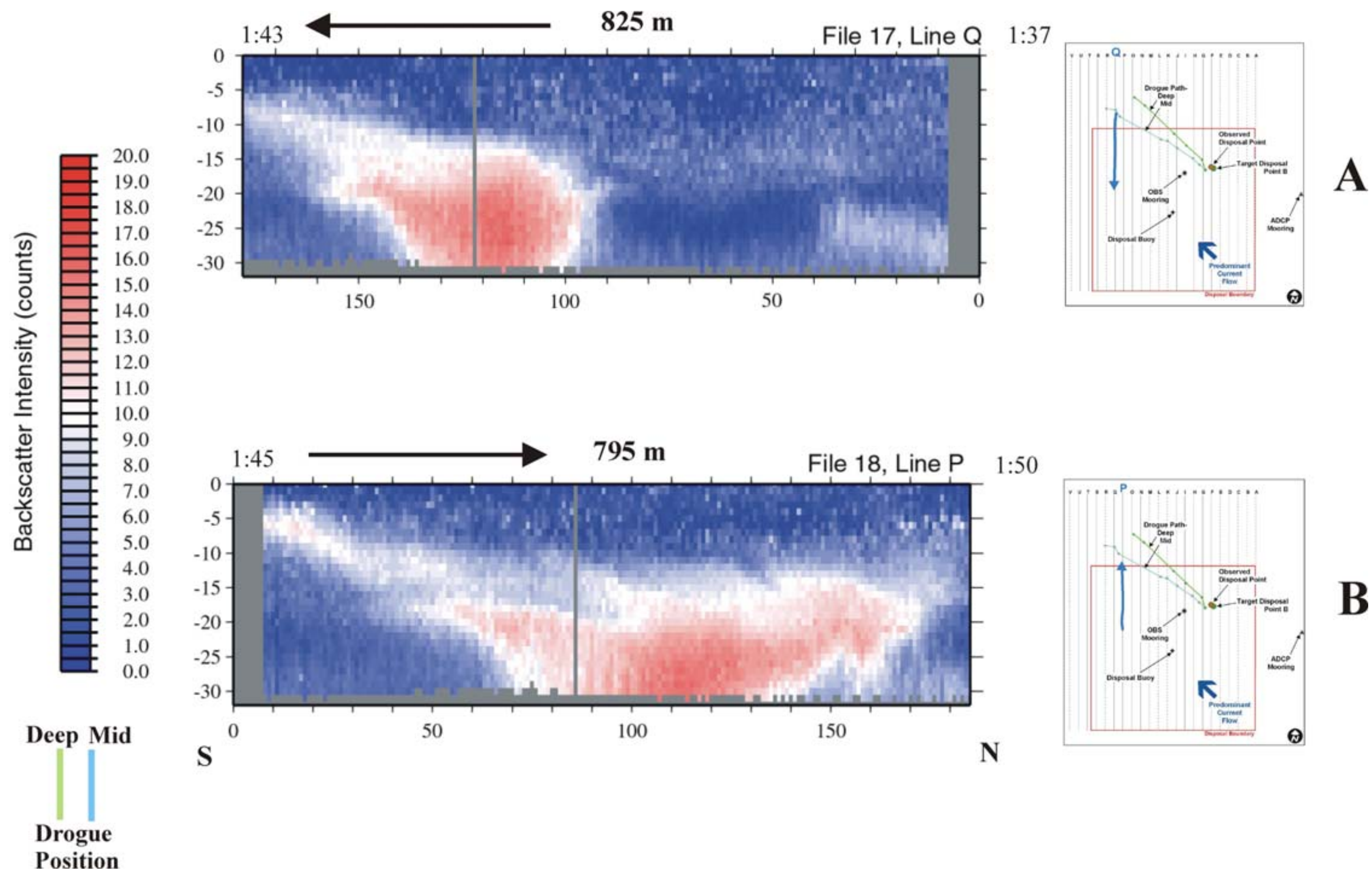


Figure 3-55. Profile plots of data collected from ADCP transects Q and P on 10 April 2004 (Plume 3) displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to illustrate plume morphology 97 to 110 minutes after the dredged material disposal event at Point B.

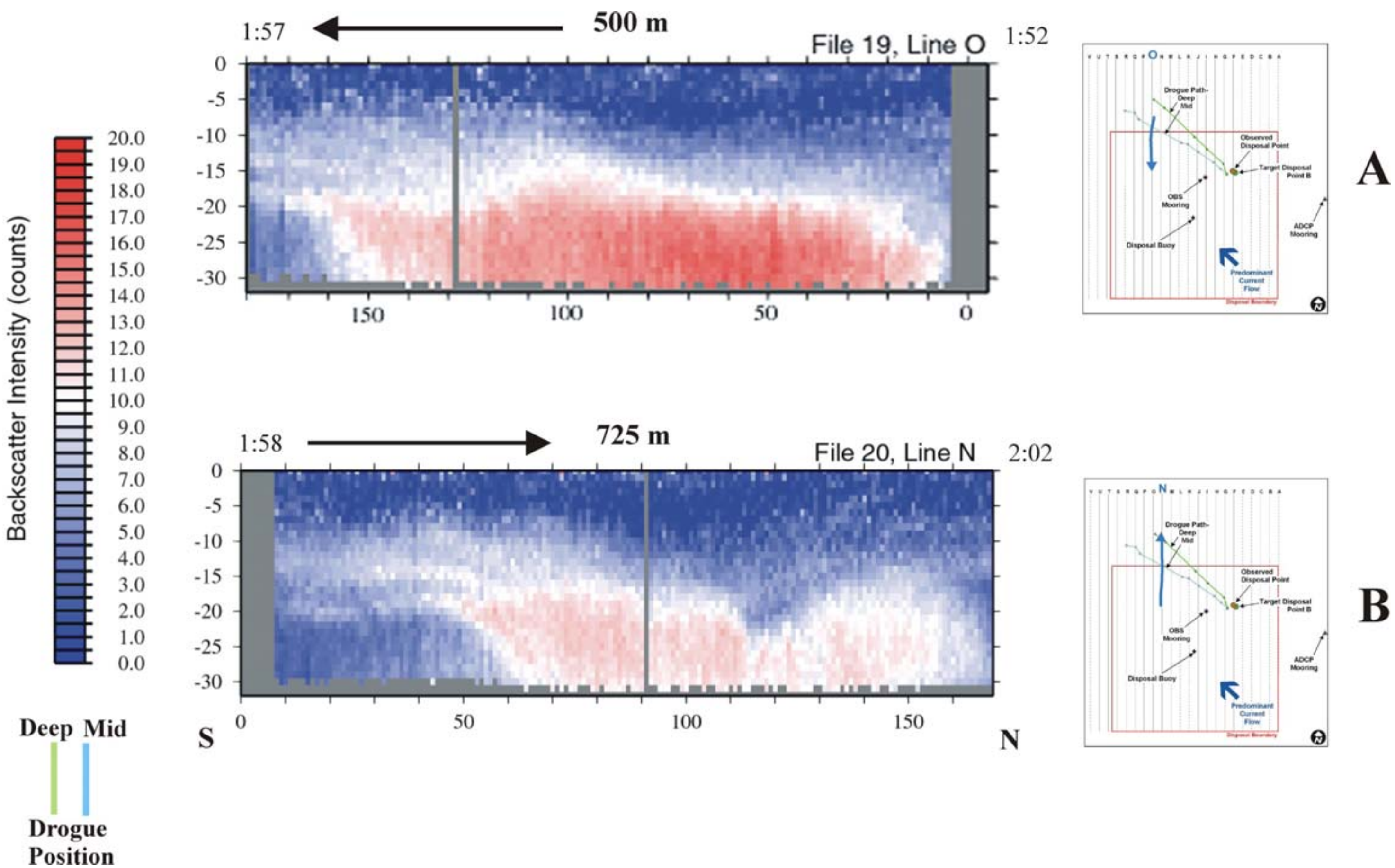


Figure 3-56. Profile plots of data collected from ADCP transects O and N on 10 April 2004 (Plume 3) displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to illustrate plume morphology 112 to 122 minutes after the dredged material disposal event at Point B.

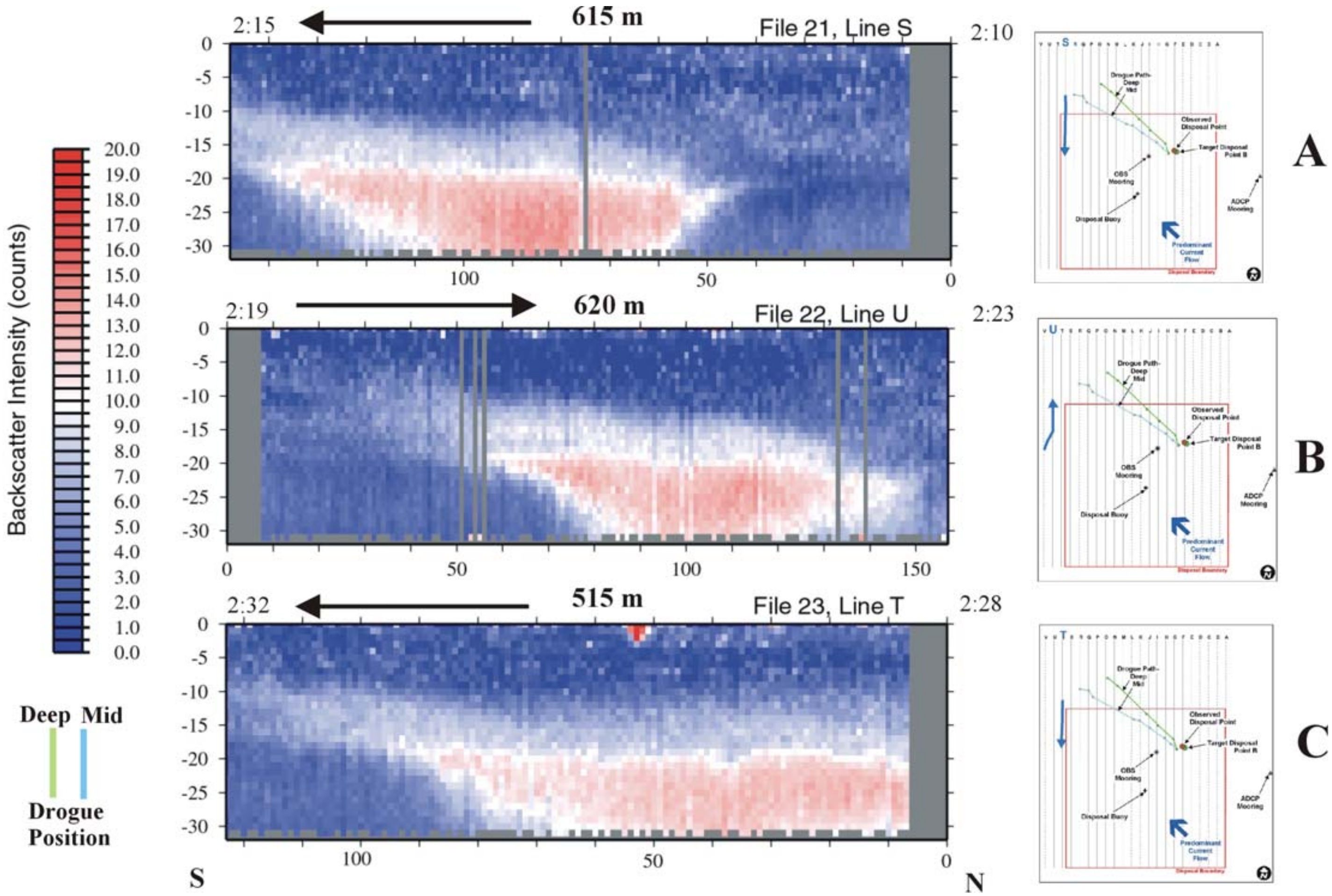


Figure 3-57. Profile plots of data collected from ADCP transects S, U, and T on 10 April 2004 (Plume 3) displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to illustrate plume morphology 130 to 152 minutes after the dredged material disposal event at Point B.

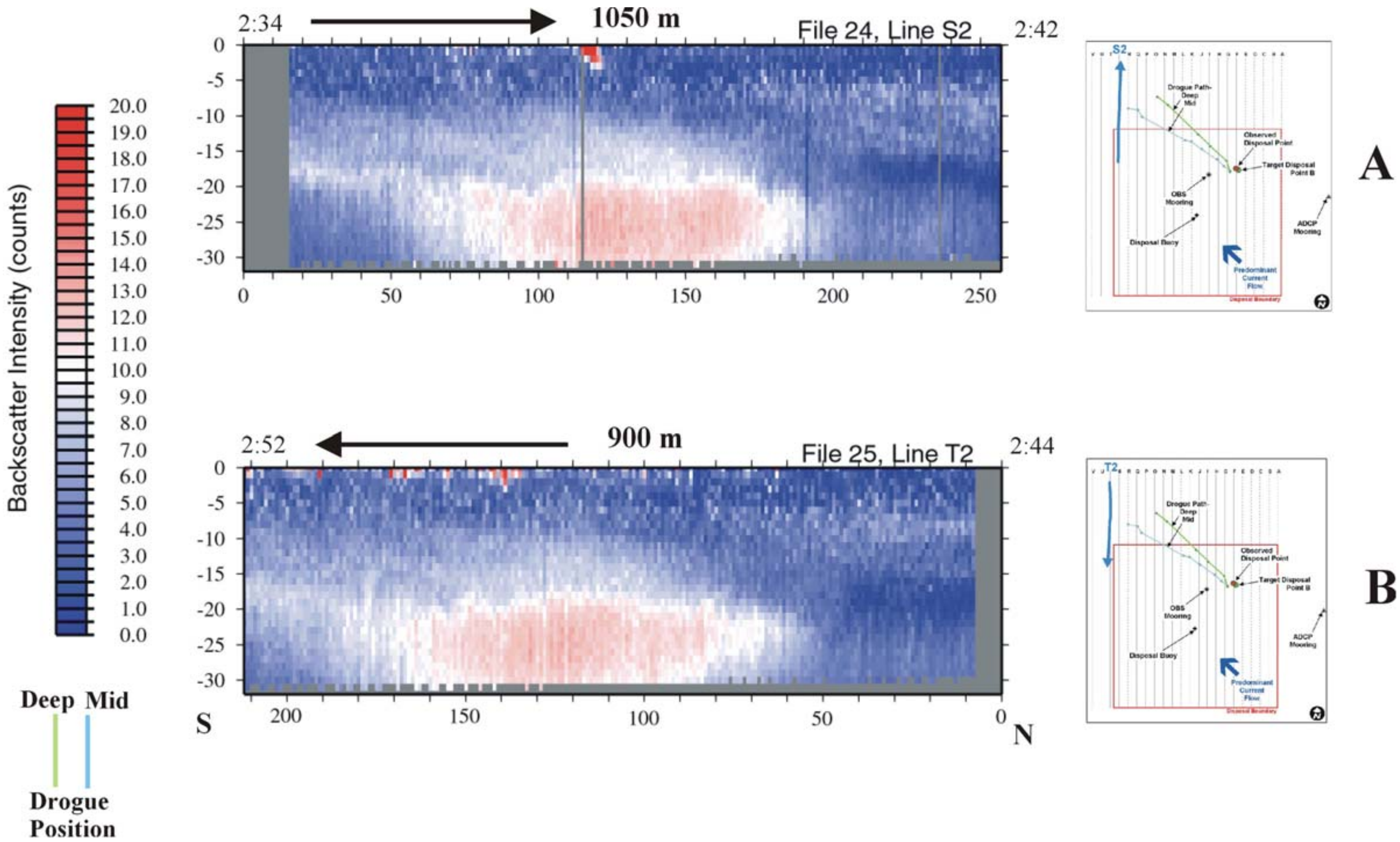


Figure 3-58. Profile plots of data collected from ADCP transects S2 and T2 on 10 April 2004 (Plume 3) displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to illustrate plume morphology 154 to 172 minutes after the dredged material disposal event at Point B.

increase in suspended sediment concentration was first detected in the 13 m and 18 m sensors at 14:50 UTC (31 minutes post-disposal). The plume in the mid-water column was short-lived, persisting for only 26 minutes before turbidity levels returned to background conditions for the remainder of the deployment period (Figure 3-59). The suspended sediment concentrations appeared higher and the duration of the elevated turbidity event appeared slightly longer at the 13 m depth horizon relative to the 18 m horizon. A maximum OBS value of 30 FTUs was observed at the 13 m depth horizon during the first few minutes of plume passage. In addition, OBS readings above 10 FTUs were consistently recorded for a period of nine minutes before turbidity levels gradually returned to background. Although comparable, the maximum OBS reading recorded in the 18 m depth horizon was 25 FTUs, with the levels over 10 FTUs recorded for a period of only four minutes before returning to background conditions.

The near-bottom sensor (32 m depth) also detected elevated turbidity levels, but displayed a slightly different record relative to those in the mid-water column. Although the near-bottom record shows some noise, close examination of the data indicated a slight increase in near-bottom turbidity, with levels above 5 FTUs at approximately 14:55 UTC (36 minutes post-placement; Figure 3-59). This pulse of turbidity passed the near-bottom sensor within three to four minutes, with near background levels detected during a ten-minute period. At 15:08 UTC (49 minutes post-disposal), the near-bottom OBS record displayed a distinct increase in near-bottom turbidity as OBS readings rapidly reached levels of 20 FTUs and a maximum value of 43 FTUs was recorded. OBS readings appeared to fluctuate between 5 and 20 FTUs for a period of 64 minutes before background levels were detected once again.

Given the position of the OBS mooring relative to the initial disposal point and timing of the plume passage, the average rate of transport was determined to be 16.1 $cm \cdot s^{-1}$. According to the data collected by the moored ADCP units, current velocities in the mid-water column ranged between 14 and 19 $cm \cdot s^{-1}$ during the period between the disposal event and the initial detection. The good agreement between the calculated average transport rate and the measured current velocities suggests the turbidity detected in the mid-depth sensors (13 m and 18 m) was attributable to the primary sediment deposit placed at Disposal Point B. The limited duration of the elevated turbidity event in the mid-water column, suggested the most turbid portion of the plume to pass by the OBS mooring was approximately 86 m wide at the 13 m depth horizon, and less than 40 m wide in the 18 m depth horizon. These findings suggested that only a side lobe of the primary sediment plume passed through the OBS mooring position, while the majority of the plume likely migrated to the north of the mooring.

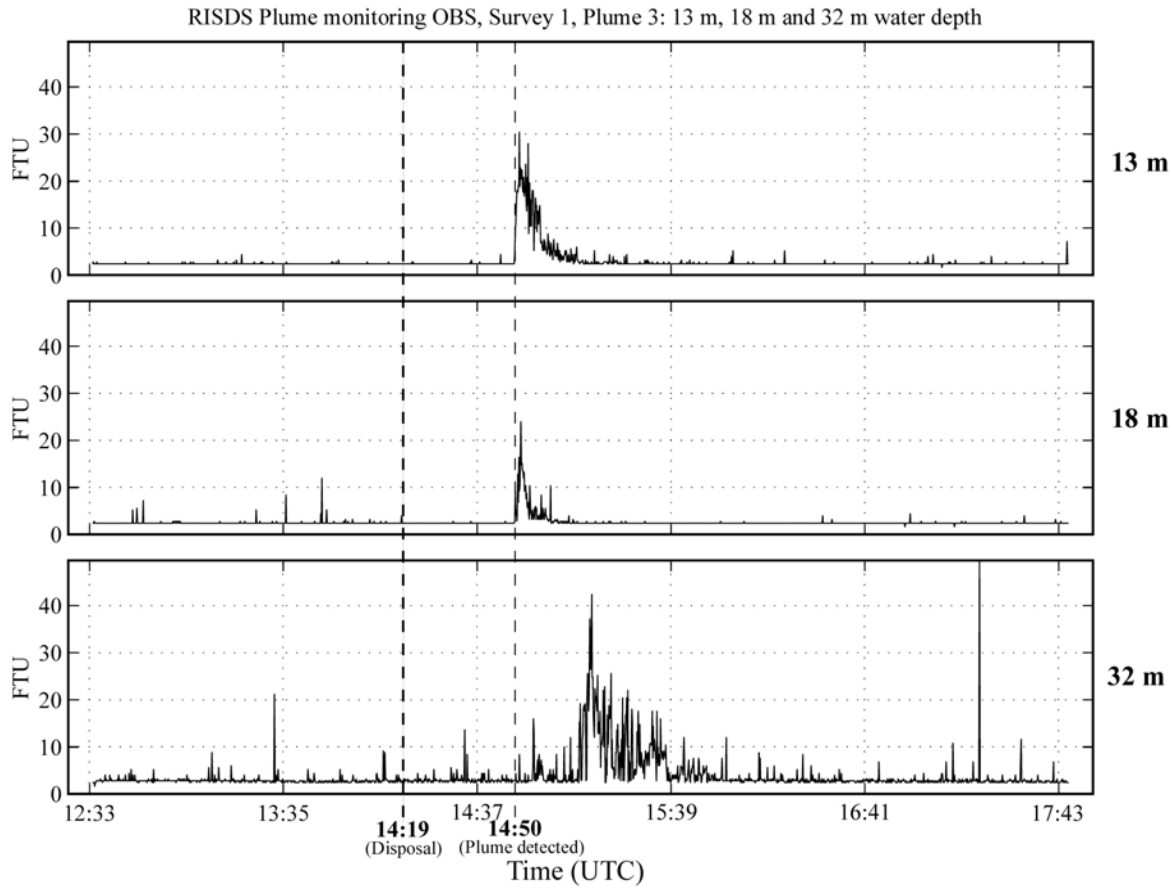


Figure 3-59. Time-series (UTC) plot of OBS data collected on 10 April 2004 (Plume 3) from three levels in the water column (13 m, 18 m, and 32 m), displaying changes in turbidity (FTU) over time resulting from sediment plume passage. Dashed lines represent barge disposal time (14:19) and an increase in suspended sediment (14:50), indicating the possible of the leading edge of the plume.

The results from the near-bottom OBS sensor displayed a small increase in turbidity 36 minutes after disposal, followed by a larger, more coherent pulse 49 minutes following the disposal event. Based on the 300 m distance between the OBS mooring and the primary disposal point, the average rate of transport of the first pulse or leading edge of the plume would be 13.9 $cm \cdot s^{-1}$. This transport rate generally correlated with the near-bottom current velocities measured by the moored ADCP during the time period between the disposal event and initial detection in the OBS record. The more pronounced secondary pulse was likely attributable to the widespread presence of a near-bottom turbidity layer south of the central portion of the plume. The acoustic backscatter imagery captured in Line I2 (Figure 3-54B), which was completed in close proximity to the OBS mooring, best depicted the plume morphology 50 minutes following the disposal event. The duration of the entire turbidity event (64 minutes) suggested the size of the near-bottom portion of the plume as detected by optical backscatter was approximately 530 m, in the east-west dimension (perpendicular to Line I2).

3.2.3.6 Toxicity of Water Samples

No toxicity testing was conducted for the Plume 3 survey, as the study objectives required toxicity testing on only two of the three survey days.

4.0 PLUME MORPHOLOGY AND CHARACTERISTICS

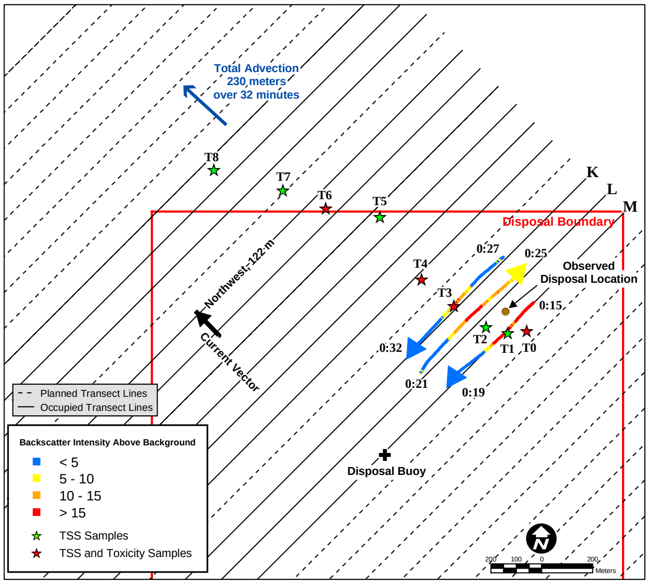
The abundance of data collected as part of the first plume monitoring survey indicated that the morphology and characteristics of each sediment plume are the product of multiple mechanical and environmental factors associated with the subaqueous disposal of dredged material. Geotechnical characteristics of the material, barge configuration and volume, water column current velocities, and water depth dictate the formation, transport, diffusion, and settlement of sediments entrained within the water column during disposal. Section 3 of this report presented detailed results for each survey completed during the April 2004 field effort relative to the individual disciplines used to characterize elements of plume behavior.

The following subsections offer a synthesis of these data to chronicle the observations made during the course of the three April 2004 surveys. To simplify the presentation of findings, particular emphasis was placed on the attributes of each plume at the 32 m depth interval as maximum turbidity was often detected in the acoustic, optical, and water sample data collected along this near-bottom horizon. In addition, this depth interval corresponded to the depth of the deep drogue and near-bottom current record, allowing strong correlation between the individual data sets.

4.1 Plume One (8 April 2004)

Prior to the start of the 8 April 2004 sediment plume survey (Plume 1), 4,600 m^3 of fine-grained maintenance material dredged from Sabin Point Reach was loaded into a 6,000 yd^3 split-hull barge (GL-61) and transported to RISDS for disposal. Following a four hour transit, the disposal barge entered RISDS from the north, deposited Load 754 at Disposal Point B within the northeastern quadrant of the site, then proceeded south eventually making a turn to the west and north for the return transit. Current-following drogues deployed at the time of disposal tracked northwest with ambient currents, with only small-scale differences in speed and direction noted between the surface, mid-water and near-bottom waters. The near-bottom drogue was consistently used as a visual marker by the CTD vessel for the collection of water column profiles and samples for TSS analysis.

The figures referred to in this section display the vessel-mounted ADCP data obtained during the Plume 1 (8 April 2004) survey. In particular, Figures 4-1 through 4-3 indicate 1) the ADCP transect occupied over distinct time intervals following the disposal event, 2) the current vector determined by the ADCP over distinct time intervals (from 15



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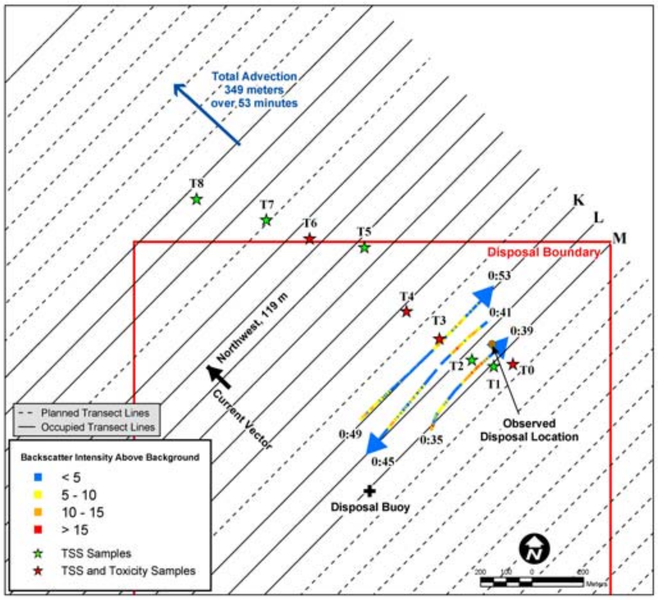


B

Figure 4-1. Residual acoustic backscatter intensity values from the 32 m depth interval representing suspended sediment concentrations along individual survey lines occupied during the Plume 1 monitoring survey, 15 to 32 (A) and 35 to 53 (B) minutes after the disposal event.

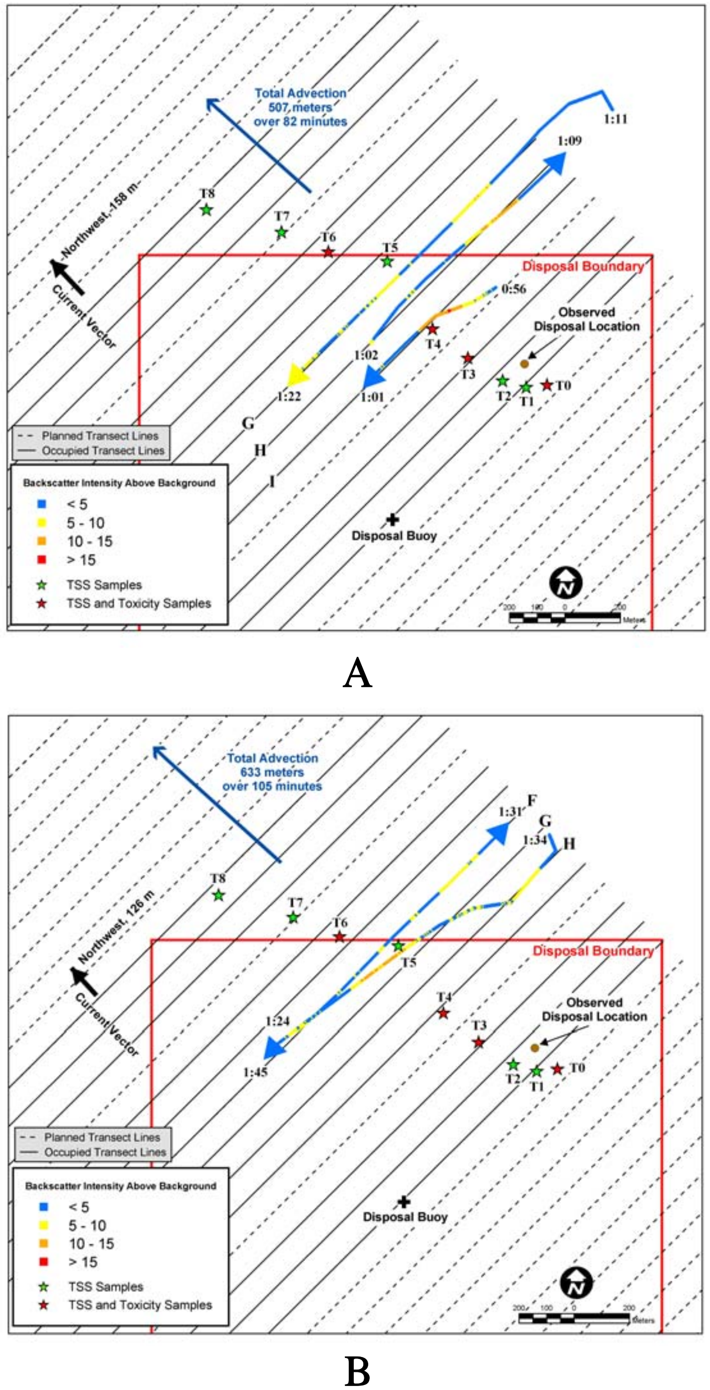
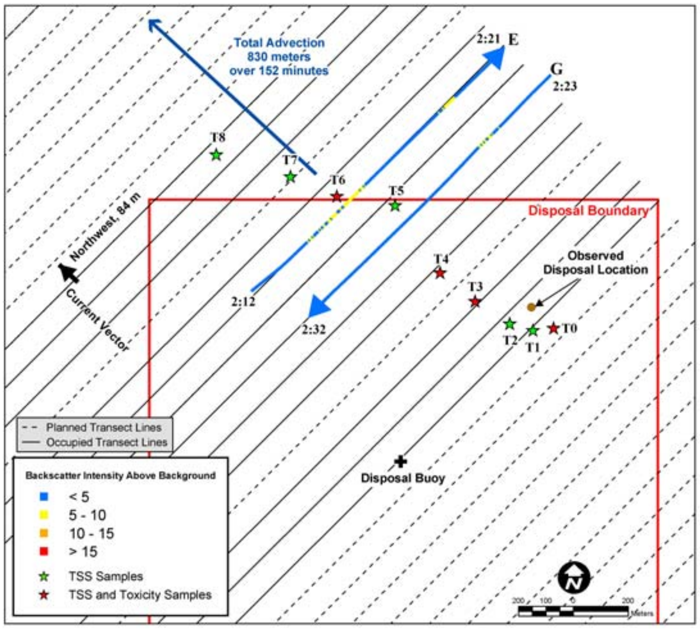


Figure 4-2. Residual acoustic backscatter intensity values from the 32 m depth interval representing suspended sediment concentrations along individual survey lines occupied during the Plume 1 monitoring survey, 56 to 82 (A) and 94 to 105 (B) minutes after the disposal event.



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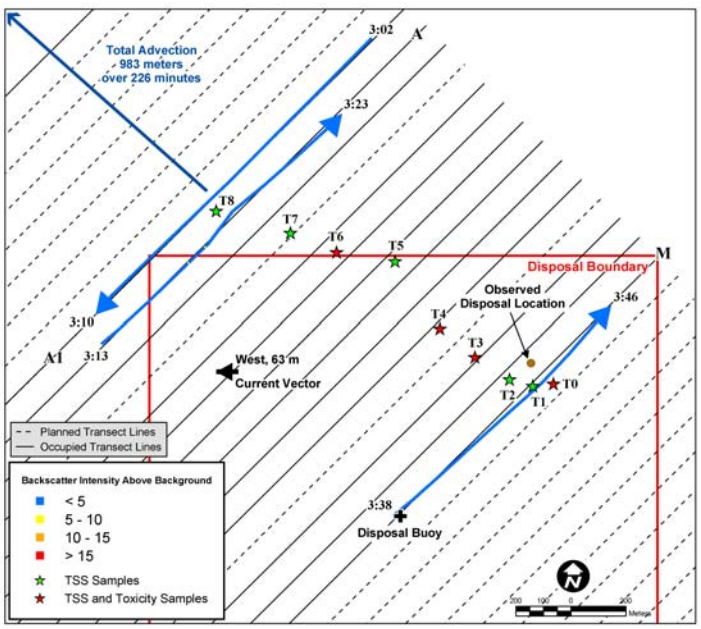


B

Figure 4-3. Residual acoustic backscatter intensity values from the 32 m depth interval representing suspended sediment concentrations along individual survey lines occupied during the Plume 1 monitoring survey, 132 to 152 (A) and 182 to 226 (B) minutes after the disposal event.

to 226 minutes) following the disposal event, 3) the current vector since the initial disposal event, and 4) locations of both TSS and toxicity water samples.

The T1 profile and water samples were collected eight minutes following the placement event, approximately 80 m south of the observed disposal point. The transmissometer profile exhibited background turbidity levels throughout most of the water column, with the exception of discrete intervals at mid-depth (15 and 20 m) and near-bottom (33 to 39 m). The water samples for TSS analysis were collected within the turbid layer at a depth of 16.7 m and provided a replicate-averaged value of 28 $mg \cdot L^{-1}$ (Figure 3-7). The near-bottom portion of the plume appeared somewhat more turbid than the mid-water portion based upon the transmissometer profile, but was not sampled for TSS analysis to confirm the optical data. The morphology of the plume, as depicted by the transmissometer readings, suggested the T1 CTD cast and water samples were acquired from the southern edge of the concentrated plume rather than the central core.

The acoustic data recorded 19 minutes after the disposal event detected the presence of a broad, intense residual backscatter signal on Line M. The sediment plume extended from the surface to the seafloor, with entrained sediments acoustically detectable over a 260 m portion of the initial 430 m long cross-section (Figure 3-13A). The T2 (20-minute) profile and water samples were obtained 50 m down-current (northwest) of Line M and detected a substantial amount of entrained sediment within the upper water column, as well as near-bottom. Maximum turbidity within the water mass was encountered at a depth of 33 m, with TSS analysis indicating a sediment load of 27 $mg \cdot L^{-1}$ (Figure 3-7). These results suggested the T2 CTD cast and TSS replicate samples were closely aligned with the plume centroid.

During the early stages of the Plume 1 survey, the near-bottom currents (32 m depth) flowed northwest at an average velocity of 12 $cm \cdot s^{-1}$, resulting in a net transport of 122 m between the start of Line M and the end of Line K. Total advection from the original disposal location was 230 m within the near-bottom layer during the first 32 minutes of the survey (Figure 4-1A). As the near-bottom portion of the plume was carried by currents, clear water was introduced into the concentrated sediment plume resulting in diffusion and broadening of the plume over time. The acoustic data collected along Line L 25 minutes post-placement provided evidence of the plume becoming larger (greater than 400 m wide) and more diffuse within the 32 m depth interval. Residual acoustic backscatter values along Line L ranged from 5 counts to an excess of 15 counts, but the size of the area displaying the highest turbidity was reduced relative to Line M (Figure 4-1A). The acoustic data from Line K represents the leading edge of the plume, which was located 200 m northwest of the observed disposal point approximately 30 minutes post-placement.

The second occupation of Lines M, L, and K by the ADCP vessel provided a double peaked signal at depth (10 and 15 counts) indicating two distinct pockets of turbidity separated by clear water (Figure 4-1B). In general, the acoustic backscatter signal from each transect was somewhat weaker, indicating a reduction in water column turbidity in comparison to the first pass. The cross-sectional data confirmed that the primary plume element detected in the nearbottom layer exhibited slightly higher backscatter intensities and was co-located with the mid-water portion of the plume (Figure 3-14). The secondary element existed as a pocket of residual more diffuse turbidity only detectable below a depth of 30 m and was generally offset to the south. Of the three lines that were re-occupied, the residual backscatter signal detected along Line M remained the most distinct 40 minutes following the disposal event.

The T3 CTD profile and water samples were collected in proximity to Line K, (200 m west-northwest of the observed disposal point) and aligned with the primary plume feature 35 minutes post-placement (Figure 4-1B). The transmissometer record revealed turbidity levels over background in both the mid-water and near-bottom layers, while the water samples for TSS were obtained from a depth of 37 m and yielded an average turbidity of 13.3 $mg{\cdot}L^{-1}$. Although the optical and analytical data were representative of the disposal plume, the acoustic record suggests that maximum turbidity was located closer to Lines M and L 35 minutes post-placement and the T3 sampling was performed ahead of the plume centroid.

The northwest flow of ambient currents continued to transport the sediment plume away from the original disposal point, towards the northern boundary of RISDS. Just prior to the T4 (60-minute) sampling interval, total advection of the plume core based on near-bottom current flow was approximately 350 m (Figure 4-1B). The T4 profile and water samples were obtained 340 m down-current of the observed disposal point in an area that exhibited a substantial amount of near-bottom turbidity based upon acoustic records (Figure 4-2A). The T4 transmissometer profile displayed discrete layers of turbid water at mid-depth and near-bottom, separated by layers of relatively clear water. The water samples for TSS analysis were collected from the 37 m depth interval, which displayed the lowest light transmittance value and a sediment load of 9.7 $mg{\cdot}L^{-1}$ (Figure 3-8). The acoustic data acquired 60 minutes post-placement indicated the near-bottom plume was relatively concentrated, as residual backscatter values of 10 to 15 counts were detected in proximity to the T4 sampling station. The acoustic data collected along Lines G and H detected minor amounts of suspended particulates directly down-current of the T4 sampling station, indicative of the leading edge of the decaying plume. In addition, the ADCP record showed an area outside the northern boundary of RISDS exhibiting residual backscatter intensities ranging from 5 to 15 counts, suggesting an isolated pocket of turbidity.

Between the time of the T4 and T5 (90-minute) sample intervals, near-bottom currents had transported the core of the sediment plume an additional 158 m northwest, resulting in a total advection distance in excess of 507 m from the original disposal point (Figure 4-2A). Following the T4 sample interval, the ADCP data indicated the rate of plume decay was accelerating as the sediment plume became broader and less distinct in the lower portion of the water column. Similar to the acoustic records collected earlier in the survey, Lines G and H both displayed multiple pockets of turbid water at depth separated by clear water. Residual backscatter values ranging from 5 to 15 counts were detected within these areas of turbidity, with the more coherent and concentrated areas located just outside the northern boundary of the disposal site (Figure 4-2A).

The T5 (90-minute) sampling event was completed in close proximity to the northern disposal site boundary, with water samples collected from a layer of relatively turbid water detected at a depth of 36 m. The transmissometer profile indicated the surface water turbidity was at background levels, but a sharp increase in sediment load was detected at 16 m water depth, which persisted through the remainder of the water column and was indicative of plume sediments. Percent light transmission gradually decreased with depth and a minimum light transmittance (corresponding to maximum turbidity) occurred within a layer of water existing 2 to 3 m above the seafloor (Figure 3-10). A replicate-averaged TSS value of 7.7 $mg \cdot L^{-1}$ was calculated for the T5 sample interval, which was obtained from a pocket of seawater located 610 m northwest of the observed disposal point. The ADCP records obtained near the T5 sampling station 100 minutes post-placement exhibited residual backscatter values approaching 15 counts (Figure 4-2B). The calculated total advection distance from the original disposal point was determined by current vectors which were based on high resolution water flow data captured by the bottom mounted ADCP. Based on these current vectors, the total advection distance from the original disposal point was calculated to be 633 m, suggesting the T5 sample was collected in close proximity to the position of the plume centroid.

The acoustic data collected during the second hour of the Plume 1 survey showed substantial reduction in turbidity levels within the sediment plume. Residual backscatter values were generally less than 5 counts along the majority of survey lines occupied (Lines E and G), indicative of turbidity levels near background conditions at the 32 m depth interval (Figure 4-3A). Isolated segments of each survey line exhibited acoustic backscatter signatures above background, but were constrained in both size and intensity. The most coherent area of elevated turbidity was detected along Line E approximately 135 minutes post-placement, which roughly corresponded to the northern boundary of RISDS and the location of the T6 (120-minute) profile and water sample. The T6 transmissometer profile displayed turbidity over background conditions throughout the majority of the water column, with the highest levels detected near-bottom. A hydrocast was obtained from a depth of 36 m, approximately 3 m above the seafloor. The replicate-averaged TSS value for the T6 samples was 9.4 $mg \cdot L^{-1}$, which represented a slight-increase over the average value for the T5 samples (Figure 3-10). Based on the speed and direction of near-bottom currents, the centroid of the plume would have been advected 830 m northwest 135 minutes post-placement (Figure 4-3A). The T6 samples were obtained 800 m down-current of the observed disposal point approximately 118 minutes post-disposal, suggesting the T6 samples were collected in close proximity to the centroid.

The T7 (150-minute) sampling interval was completed at a station located nearly 1 km northwest of the observed disposal point (Figure 4-3B). The transmissometer record indicated the top 20 m of the water column exhibited turbidity quite similar to background conditions, with suspended particulate concentrations generally increasing with depth. A minimum transmissometer (maximum turbidity) reading of 65% was detected within the water column profile, which corresponded to the 36 m depth interval from which the TSS samples were collected (Figure 3-11). A replicated averaged TSS value of 7 $mg \cdot L^{-1}$ indicated turbidity levels were quite comparable to background as the sediment plume continued to travel northwest with the ambient currents.

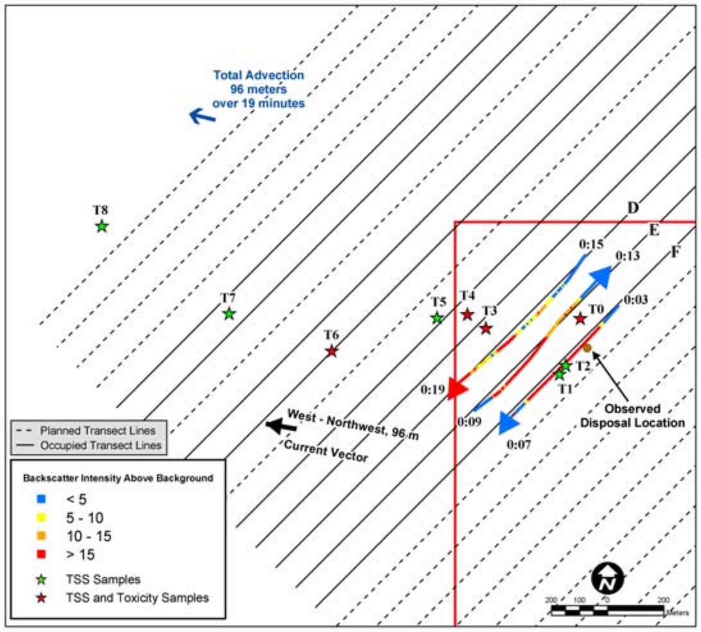
The acoustic data collected during the third hour of the Plume 1 survey detected little difference in the acoustic backscatter intensity along the anticipated track of the plume, compared to that of the surrounding ambient seawater (Figure 4-3B). Residual backscatter readings of less than 5 counts dominated the survey area prior to the collection of the T8 water column profile and TSS samples, suggesting the plume sediments had become mixed with the ambient seawater northwest of RISDS. The T8 profile, which was collected in proximity to the deep drogue approximately 1,200 m down-current from the observed disposal point, was similar in structure to that of the T7 interval (Figure 3-11). At the time of the T8 sample interval, the core of the sediment plume was expected to travel in excess of 900 m, based upon the average velocity of near-bottom currents. High transmissometer values in the surface layers were indicative of low turbidity values. Below a 20 m depth, transmissometer readings decreased to approximately 65% as turbidity levels increased in the lower 18 m of the water column. TSS samples collected from a water depth of 35 m yielded a replicate-averaged value of 5.8 $mg \cdot L^{-1}$, which was roughly equivalent to background levels (2 $mg \cdot L^{-1}$) and indicative of substantial dissipation of the sediment plume within the water column.

4.2 Plume Two (9 April 2004)

Barge GL-63 was loaded with 4,600 m^3 of fine-grained sediment dredged from Sabin Point Reach and transported to the northeastern quadrant RISDS for disposal. The barge entered the disposal site from the north, stopped at Disposal Point A for the placement event, then continued south and eventually turning to the east and north for the return transit. The acoustic backscatter information acquired along the first survey line (Line F) seven minutes after the disposal event indicated high residual backscatter values throughout the water column, with the initial plume existing as a column of turbidity approximately 195 m wide on the surface and nearly 350 m wide at depth (Figure 3-32A). In addition, the near-bottom portion of the plume appeared to be elongated along its south and west axes, which was supported by the intensity of the residual acoustic backscatter documented on subsequent survey lines (Lines E and D; Figures 3-32 and 4-4A).

The figures referred to in this section display the vessel-mounted ADCP data obtained during the Plume 2 (9 April 2004) survey. Particular emphasis was placed on the attributes of the plume at the 32 m depth interval (depth of the deep drogue and near-bottom current record) as maximum turbidity was often detected in the acoustic, optical, and water sample data collected along this near-bottom horizon. In particular, Figures 4-4 through 4-7 indicate 1) the ADCP transect occupied over distinct time intervals following the disposal event, 2) the current vector determined by the ADCP over distinct time intervals (from 3 to 199 minutes) following the disposal event, 3) the current vector since the initial disposal event, and 4) locations of both TSS and toxicity water samples.

The surface and mid-depth drogues served as a visual reference of plume location for the CTD/water sampling vessel and indicated transport was primarily west-northwest for the duration of the Plume 2 survey. Discrete water samples were collected in proximity to either the deep or mid-depth drogue location dependent upon the results of the transmissometer profiles for a given station. The water depth from which the water samples were obtained was consistently below 30 m, as the most turbid water appeared to remain near the seafloor. Figure 4-4A indicates residual acoustic backscatter at the 32 m depth interval was in excess of 15 counts south and west of the observed disposal point for the first 20 minutes of the Plume 2 survey. The T1 (10-minute) transmissometer profile was collected approximately 130 m southwest of the observed disposal point and corresponded to an area displaying high residual backscatter values in the ADCP data. The transmissometer record indicated reduced light transmittance throughout the water column. The minimum transmittance value detected (representing maximum turbidity) was 9% at a water depth of 31 m. The water samples obtained from that depth horizon yielded a replicate-averaged TSS value of 23 $mg \cdot L^{-1}$ (Figure 3-26).



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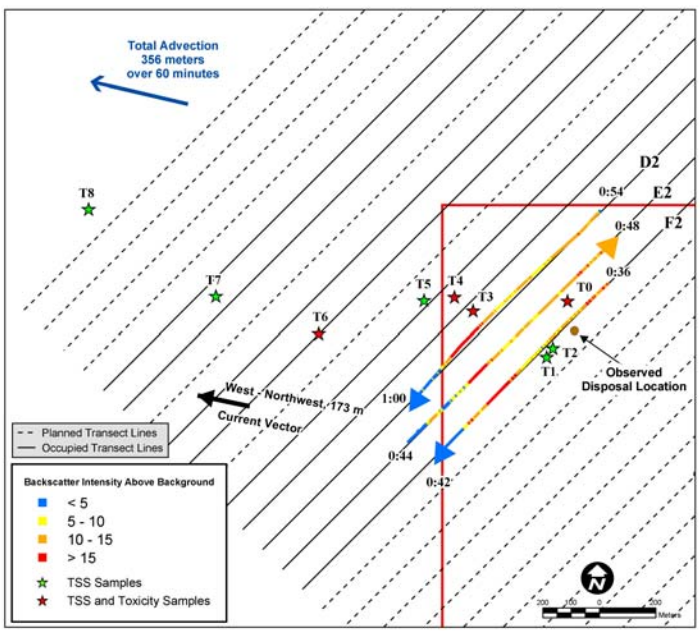

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Figure 4-4. Residual acoustic backscatter intensity values from the 32 m depth interval representing suspended sediment concentrations along individual survey lines occupied during the Plume 2 monitoring survey, 3 to 19 (A) and 36 to 60 (B) minutes after the disposal event.

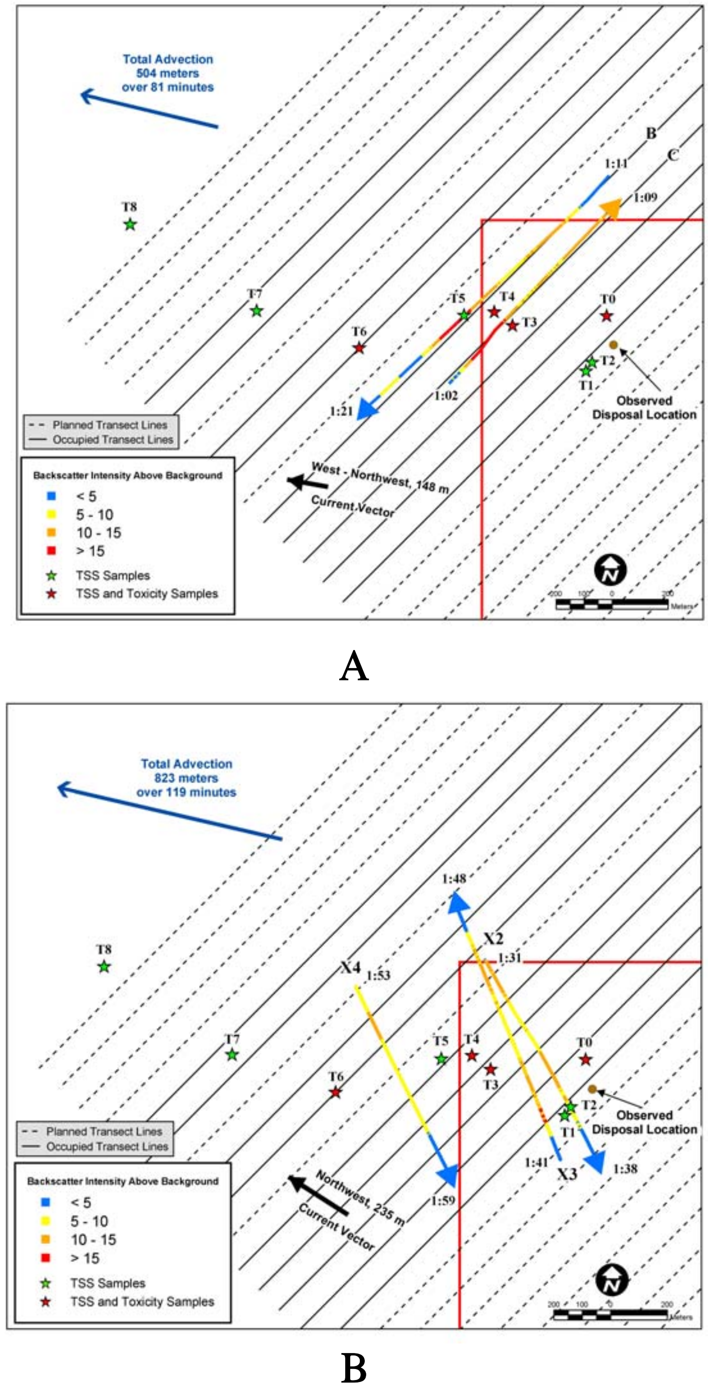
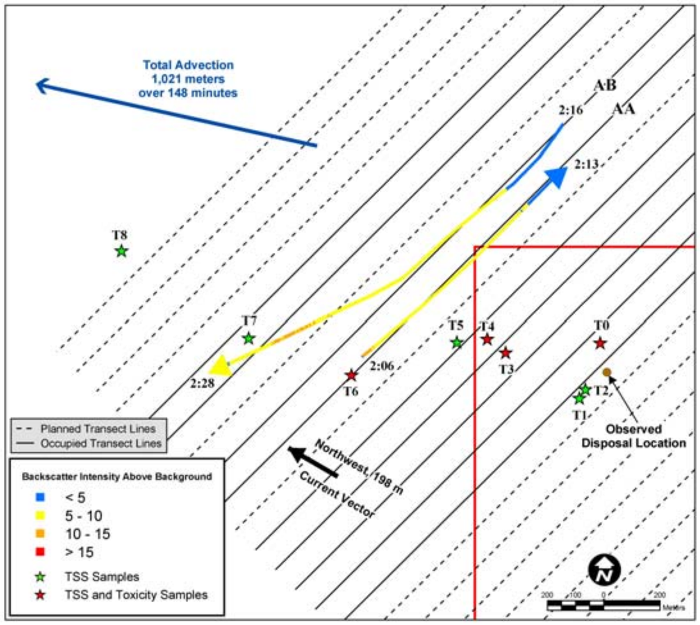


Figure 4-5. Residual acoustic backscatter intensity values from the 32 m depth interval representing suspended sediment concentrations along individual survey lines occupied during the Plume 2 monitoring survey, 62 to 81 (A) and 91 to 119 (B) minutes after the disposal event.



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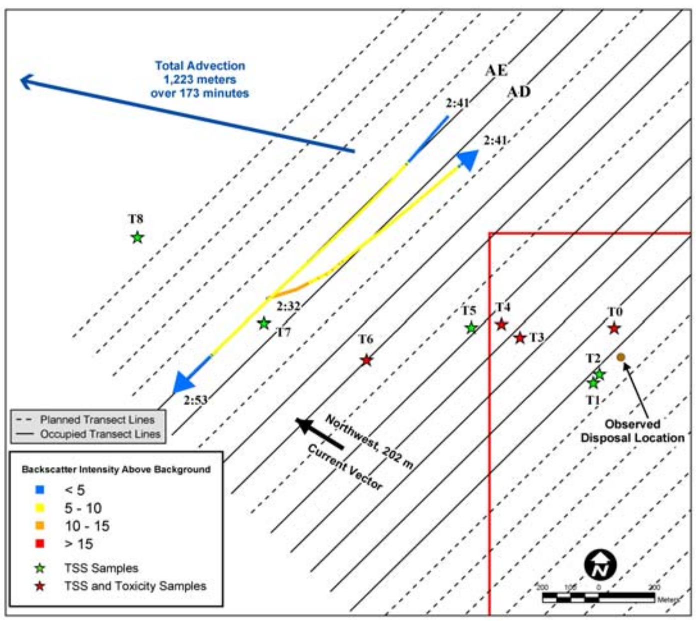


B

Figure 4-6. Residual acoustic backscatter intensity values from the 32 m depth interval representing suspended sediment concentrations along individual survey lines occupied during the Plume 2 monitoring survey, 126 to 148 (A) and 152 to 173 (B) minutes after the disposal event.

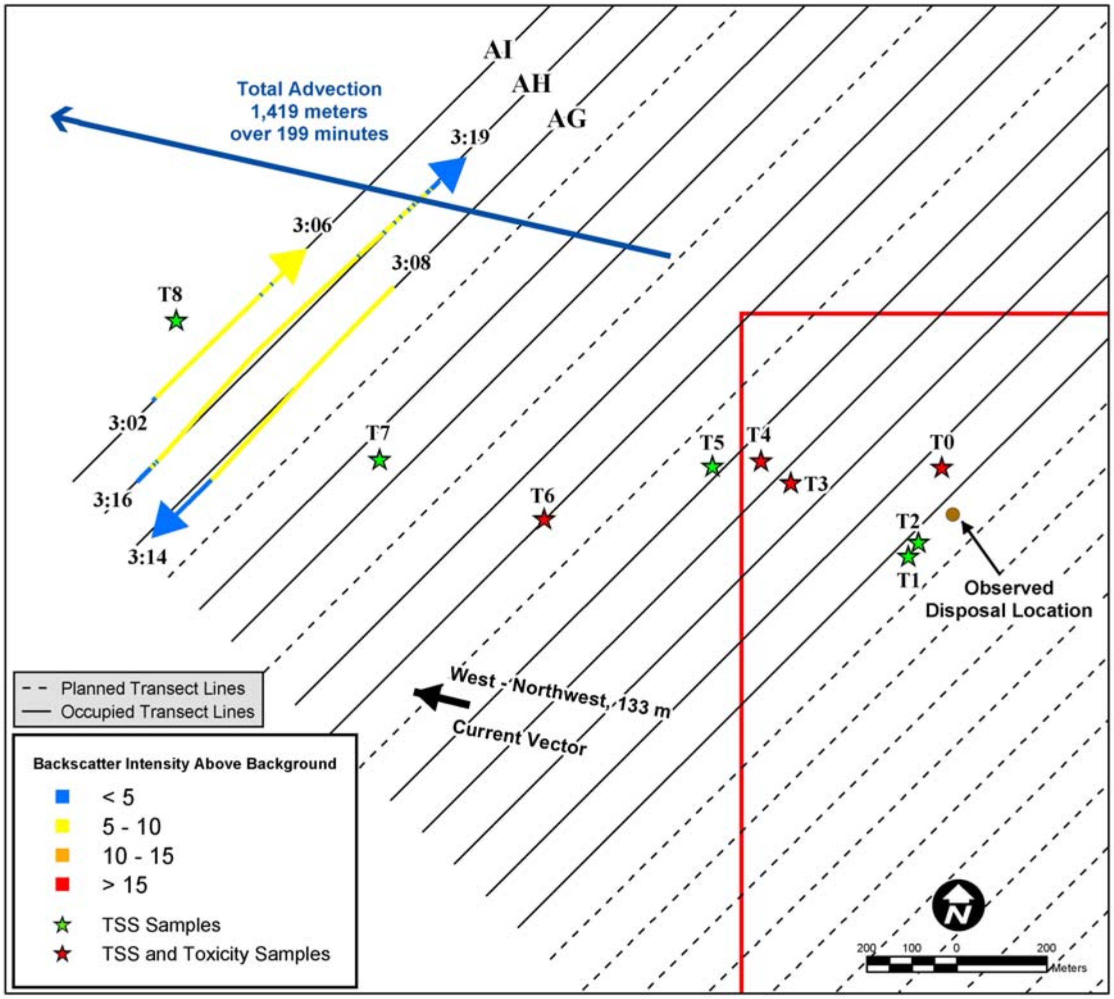


Figure 4-7. Residual acoustic backscatter intensity values from the 32 m depth interval representing suspended sediment concentrations along individual survey lines occupied during the Plume 2 monitoring survey, 182 to 199 minutes after the disposal event.

The water column profile and measured turbidity for the T2 (20-minute) sample interval were similar to those of T1. Maximum turbidity was documented near the seafloor and an average TSS value of nearly 25 $mg \cdot L^{-1}$ was calculated from the hydrocast obtained from a depth of 36 m. The T2 profile and samples were obtained 50 m northeast of the T1 station within the lingering near-bottom turbidity layer, but calculations of total advection suggested the water mass carrying the core of the sediment plume was transported 96 m to the west-northwest between the time of the disposal event and the T2 sampling. As a result, the data obtained at the T2 interval may be more representative of the trailing edge of the sediment plume, rather than its centroid.

The second occupation of Lines D, E, and F with the ADCP suggested the core of the sediment plume continued to move west-northwest in response to the near-bottom currents (Figure 4-4B). In addition, a significant amount of dilution had apparently occurred, as turbid water was observed north and west of the initial disposal point in an area that had previously exhibited background turbidity levels. Residual backscatter intensities ranging from 5 to 15 counts were detected as far as 400 m north of the observed disposal point between the 30 minute and one hour marks of the survey. The T3 (40-minute) profile and water samples were collected approximately 350 m west-northwest of the observed disposal point and displayed a substantial reduction in turbidity levels in comparison to the earlier casts. The transmissometer data provided evidence of plume sediments in both the middle and near-bottom portions of the water column (Figure 3-28). However, based on the acoustic data and low TSS value (5.2 $mg \cdot L^{-1}$), it appeared that the T3 samples were collected 300 m ahead of the plume centroid and was more characteristic of the leading edge.

Between the time of the T3 (40-minute) and T4 (60-minute) water column profiles, the water mass at the 32 m depth interval moved an estimated 173 m to the west-northwest (Figure 4-4B). The T4 samples were collected approximately 85 m northwest of the T3 sample location suggesting the samples obtained 60 minutes post-placement were 88 m closer to the core of the disposal plume, relative to the T3 samples. The concentration of entrained sediments detected in the T4 transmissometer record was similar to that of T3, showing a substantial interval of turbid water at mid-depth, as well as a layer of turbid water near-bottom (Figure 3-28). A comparison of the two profiles showed a small-scale increase in near-bottom turbidity for the T4 sample interval. However, the relatively low TSS value of 6.9 $mg \cdot L^{-1}$ and ADCP records collected in the same general time period indicated the sample was collected approximately 50 m ahead of the actual plume centroid (Figure 4-5A).

Within 80 minutes of the disposal event, the core of the sediment plume was advected a total of 504 m to the west-northwest by ambient currents, with the mid-water and near-surface portion of the sediment plume extending farther to the north and west (Figure 4-5A). The densest portion of the plume existing at the 32 m depth interval continued to display residual backscatter values in excess of 15 counts approximately 10 minutes prior to the collection of the T5 (90-minute) samples. The water column profile for the T5 interval was obtained 540 m west-northwest of the observed disposal point and displayed the attributes of a decaying sediment plume. The profile was obtained within 36 m of the calculated position of the centroid, and displayed a minimum light transmission value of 55% at a water depth of 14 m. This finding was attributable to the continued presence of the mid-depth turbidity layer that was documented earlier in the survey (T2 through T4; Figure 3-29). Similar to the T4 profile, the minimum transmittance recorded within the bottom waters was 68%. The TSS samples for the T5 interval were collected from a water depth of 34 m, but displayed near background levels of turbidity (4.2 $mg \cdot L^{-1}$ average).

Based upon the data collected along Line B, the detectable sediment plume was approximately 950 m wide (at the 32 m depth interval) along its northeast-southwest axis 80 minutes post-placement (Figure 4-5A). Several lines that were run parallel to the plume track between the T5 and T6 samples (Lines X2 through X4) aided in determining the extent of the sediment plume in the direction of transport (west-northwest; Figure 4-5B). The data from Line X2 indicated the acoustically detectable sediment plume was 675 m wide along the northwest-southeast axis, suggesting the sediment plume occupied an area of 0.64 km^2 approximately 90 minutes post-placement. The acoustic data collected from Lines X3 and X4 suggested the leading edge of the sediment plume existing at the 32 m depth horizon was detectable approximately 900 m to the northwest of the observed disposal point approximately two hours after the placement event.

At the time Lines X2, X3, and X4 were occupied, the near-bottom currents were exhibiting a more northwesterly flow. However, the measured distance of the leading edge at 32 m depth obtained from the ADCP record still agreed with the total advection distance of 823 m, calculated for the core of the sediment plume at that depth (Figure 4-5B). Due to the differences in current velocities and direction higher in the water column, the mid-water element of the sediment plume was likely farther down-current (west-northwest) than the near-bottom element, while the near-surface portion of the plume remained somewhat closer to the observed disposal point.

The T6 (120-minute) profile and samples were collected 150 m south of the mid-depth drogue based upon the backscatter intensity information provided by the ADCP data (Line AA), as well as the results of several supplemental CTD profiles. The T6 profile and water samples were obtained in an area exhibiting residual backscatter intensities between 10 and 15 counts at the 32 m depth interval (Figure 4-6A). The transmissometer data indicated a small decrease in turbidity at mid-depth relative to the T5 results, but a small-scale increase in turbidity was noted near-bottom (Figure 3-29). In addition, a slightly higher average TSS value (5.1 $mg \cdot L^{-1}$) was calculated for the T6 samples collected from a depth of 36 m, suggesting more turbid waters were encountered relative to the T5 sample interval.

The acoustic data collected along Line AB just prior to the T7 sample interval detected residual acoustic backscatter over background levels (5 to 10 counts) attributed to a diffuse plume along much of the survey track. An isolated pocket of water with a stronger acoustic backscatter signature (10 to 15 counts) was observed 1,100 m down-current of the observed disposal point, indicative of the plume core (Figure 4-6A). The total advection calculated for the core of the sediment plume at 2.5 hours post-placement was 1,021 m, suggesting the T7 profile and water samples were collected in proximity to the plume centroid. However, the T7 transmissometer profile and water samplesboth indicated only a minor elevation in near-bottom turbidity, with a replicate-averaged TSS value of 3.8 $mg \cdot L^{-1}$, which was comparable to the background turbidity value (2.9 $mg \cdot L^{-1}$) for Plume 2 (Figure 3-30). The results obtained from subsequent ADCP survey lines (Lines AD and AE) following the T7 sample interval indicated the core of the plume was transported 50 m to the north of the station that was sampled (Figure 4-6B).

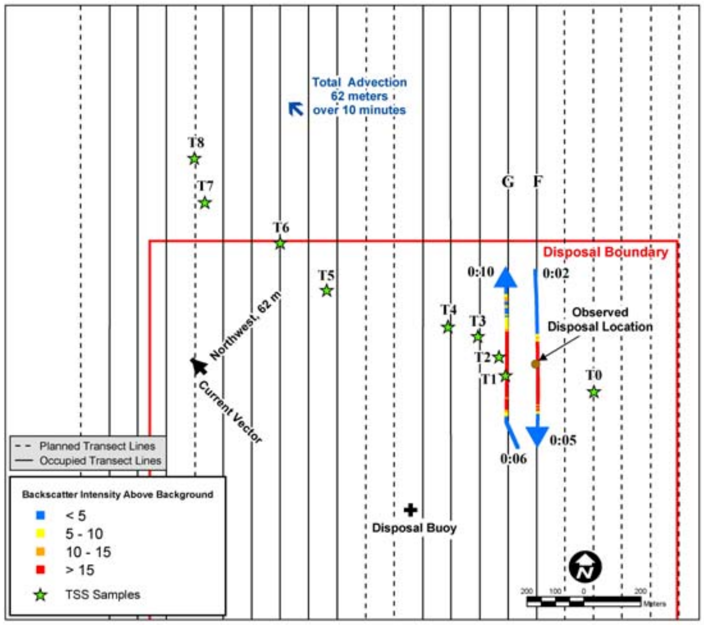
Following the T7 sample interval, the sediment plume remained acoustically detectable in the water column as a large diffuse mass of turbid water, with no discernable core or centroid (Figures 4-6B and 4-7). At three hours post-placement, the plume had decayed substantially at the 32 m depth interval and was documented as an area of water with a slight to moderate acoustic backscatter signature over background (5 to 10 counts) approximately 1600 m west-northwest of the observed disposal point. The lateral extent of the plume (perpendicular to direction of transport) also appeared to be decreasing rapidly as the overall width of the detectable plume decreased and the acoustic backscatter intensity became variable near its periphery. Based on water column current data from the 32 m depth interval, total advection of the disposal plume core was in excess of 1.4 km in 3.25 hours (Figure 4-7). The T8 transmissometer profile, collected 1750 m west-northwest of the observed disposal point 210 minutes post-placement, displayed a persistent turbidity layer within the mid-water (15 m), as well as remnant turbidity near-bottom (Figure 3-30). However, the replicate-averaged TSS value for the samples obtained at a depth 31 m was 2.8 $mg \cdot L^{-1}$ (with a standard deviation of 2 $mg \cdot L^{-1}$), which matched background turbidity values and suggested the plume was in its final stages of existence.

4.3 Plume Three (10 April 2004)

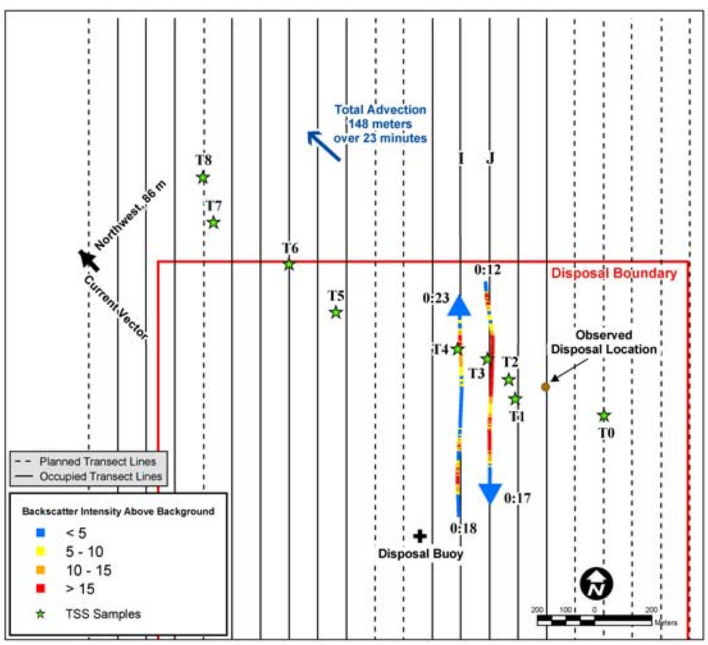
On the approach to Disposal Point B, the loaded 4,000 yd^3 barge was towed into RISDS from the north, deposited 3,200 m^3 of dredged material, then proceeded south while turning to the west to begin its return transit to Narragansett Bay. Based on the acoustic measurements made by the ADCP along North-South axis of the plume (Line F) at five minutes post-placement, the resulting sediment plume was approximately 160 m wide at the surface and nearly 290 m wide near-bottom when initially formed (Figure 3-51A). The subsequent survey line (Line G) was completed 100 m to the west of the observed disposal location, capturing the sediment plume at ten minutes post-placement. The acoustic profile information indicated a significant extension of the near-surface portion of the sediment plume to the south and west, likely as residual sediments were washed from the open barge as it was positioned for return transit, while the near-bottom portion of the sediment plume displayed relatively minor expansion (Figure 3-51B).

The figures referred to in this section display the bottom mounted ADCP data obtained during the Plume 3 (10 April 2004) survey. Particular emphasis was placed on the attributes of the plume at the 32 m depth interval (depth of the deep drogue and near-bottom current record) as maximum turbidity was often detected in the acoustic, optical, and water sample data collected along this near-bottom horizon. In particular, Figures 4-8 through 4-11 indicate 1) the ADCP transect occupied over distinct time intervals following the disposal event, 2) the current vector determined by the ADCP over distinct time intervals (from 2 to 172 minutes) following the disposal event, 3) the current vector since the initial disposal event, and 4) locations of both TSS and toxicity water samples.

Utilizing positional information provided by the ADCP data, the CTD/water sampling vessel remained southwest of the current drogue tracks and identified the plume centroid in the lower water column (Figure 3-41). Water samples for TSS were often collected from the most turbid portion of the plume at levels 3 to 5 m above the seafloor. Figure 4-8A indicates the near-bottom portion of the sediment plume (32 m depth) displayed the highest backscatter intensity over background levels (relative turbidity) immediately surrounding the observed disposal point, as well as 100 m down-current (to the west). The T1 transmissometer profile and water samples were obtained in an area with a significant amount of suspended particulate matter (which was confirmed by the ADCP data), but given the relatively low TSS value near the seafloor (25 $mg \cdot L^{-1}$), the profile and hydrocast were likely collected outside the tightly constrained core of the sediment plume (Figure 3-46). Based on the current meter data, the water mass and initial sediment plume moved approximately 62 m to the northwest during the first ten minutes of the survey.



A



B

Figure 4-8. Residual acoustic backscatter intensity values from the 32 m depth interval representing suspended sediment concentrations along individual survey lines occupied during the Plume 3 monitoring survey, 2 to 10 (A) and 12 to 23 (B) minutes after the disposal event.

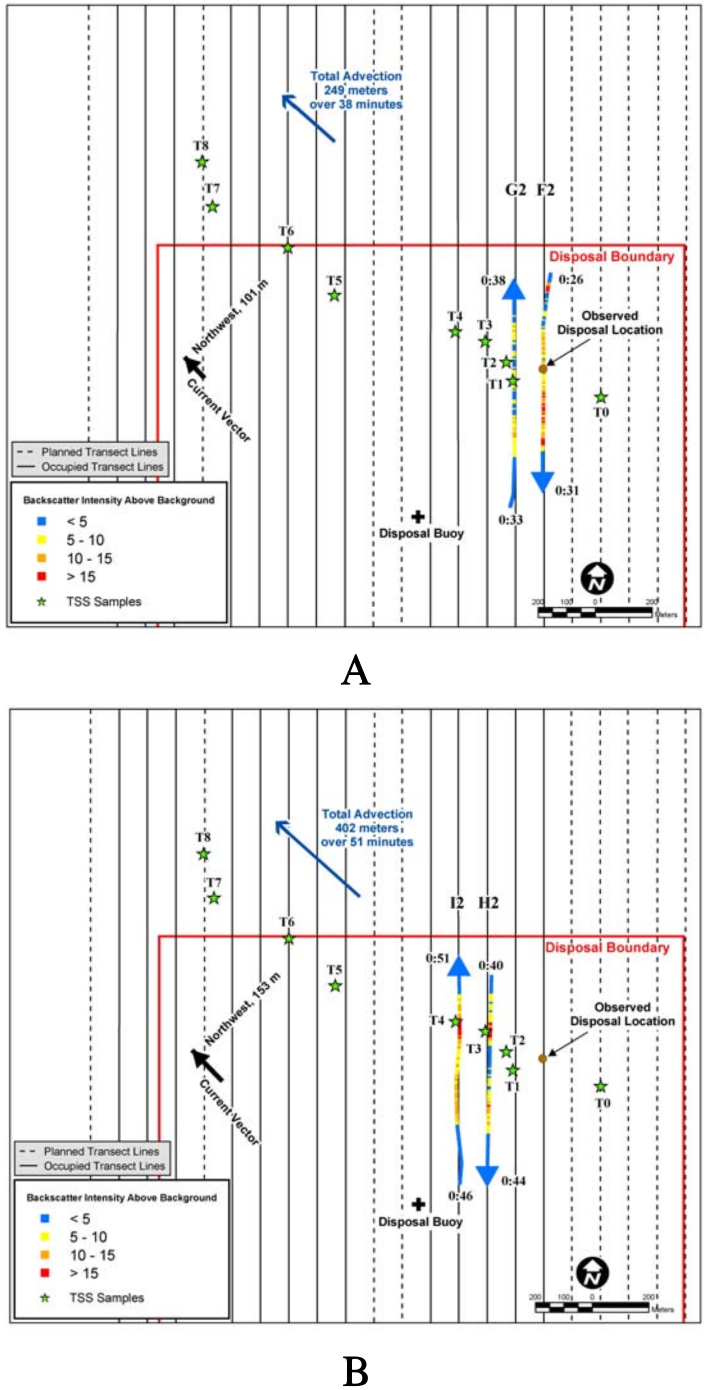
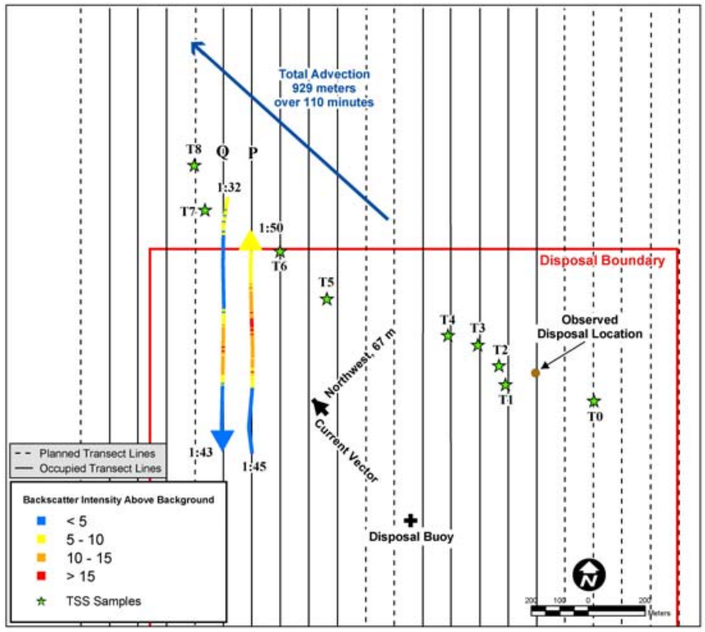
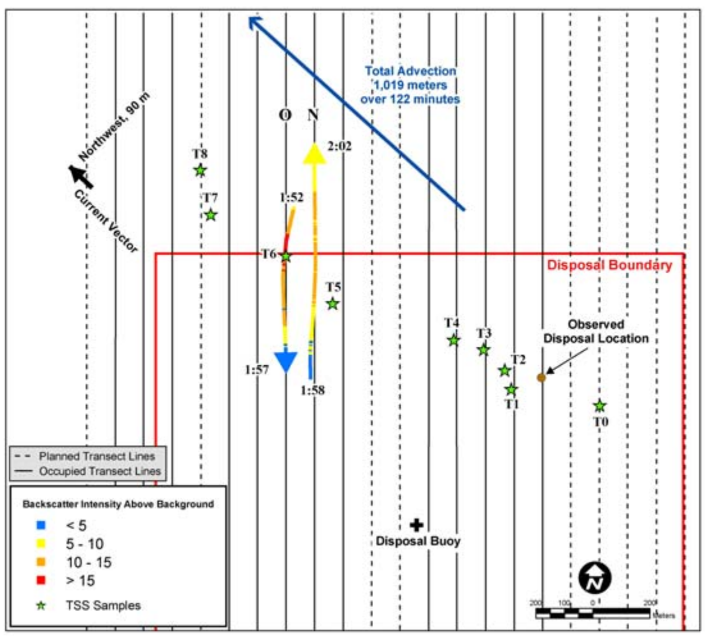


Figure 4-9. Residual acoustic backscatter intensity values from the 32 m depth interval representing suspended sediment concentrations along individual survey lines occupied during the Plume 3 monitoring survey, 26 to 38 (A) and 40 to 51 (B) minutes after the disposal event.



A



B

Figure 4-10. Residual acoustic backscatter intensity values from the 32 m depth interval representing suspended sediment concentrations along individual survey lines occupied during the Plume 3 monitoring survey, 92 to 110 (A) and 112 to 122 (B) minutes after the disposal event.

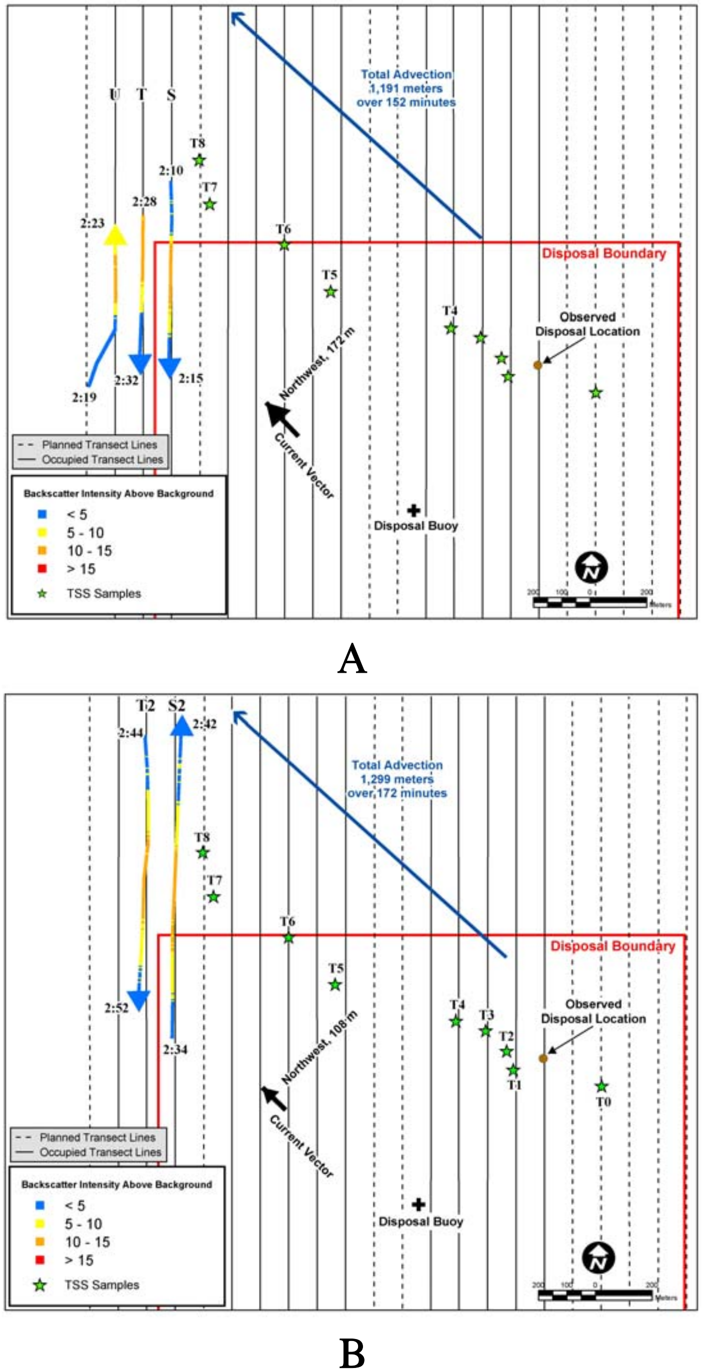


Figure 4-11. Residual acoustic backscatter intensity values from the 32 m depth interval representing suspended sediment concentrations along individual survey lines occupied during the Plume 3 monitoring survey, 130 to 143 (A) and 154 to 172 minutes after the disposal event.

Between 10 and 23 minutes after the disposal event, the water mass at the 32 m depth interval moved an additional 86 m to the northwest, resulting in 148 m total advection (Figure 4-8B). Acoustic backscatter data appeared to be obtained over the leading portion of the plume as it was advected to the northwest by ambient currents.

These data also suggested the presence of two areas of suspended sediments at the 32 m depth interval that were separated by relatively clear water. The formation of two plume features in the water column was attributable to the sediment load within the barge falling to the seafloor as two distinct sediment deposits. The primary plume feature was located west-northwest of the disposal point, while the secondary feature was offset to the southwest (Figures 4-8B and 3-52B). The T2 transmissometer profile and water samples were collected in what appeared to be the central portion of the plume as light transmission was near zero and average TSS was 64 $mg \cdot L^{-1}$ (Figure 3-46).

Traveling at an average rate of 11 $cm \cdot s^{-1}$, the core of the sediment plume was likely transported over 250 m and broadened substantially during the first 40 minutes of the survey. The T3 profile and TSS samples were obtained approximately 225 m northwest of the original disposal point, which indicated maximum turbidity within the plume existed 6 m above the seafloor (suspended sediment concentration of 45 $mg \cdot L^{-1}$; Figure 3-47). The data obtained via the ADCP prior to the T3 survey indicated some residual turbidity existed near the observed disposal point, with isolated pockets displaying residual backscatter values above 15 counts (Figure 4-9A). Approximately 200 m down current, the near-bottom portion of the sediment plume appeared more coherent, but still existed as two distinct features in the water column (Figure 4-9B). The acoustic data collected along these survey lines confirmed the presence of elevated suspended particulates over the T3 sample location, as well as at the T4 sample location that was occupied 20 minutes later.

After 40 minutes of surveying on Day 3, near-bottom current speeds began to increase, impacting the transport and dilution rates as the plume mixed with ambient seawater. The T4 samples were obtained 63 minutes post-placement from a location that displayed a concentrated pocket of turbidity according to the acoustic data (Figure 4-9B). The CTD detected a light transmittance values of 50% and greater, while the average TSS concentration from the 32 m depth horizon was 9 $mg \cdot L^{-1}$. While these data indicate the T4 profile and water samples were collected from within the plume, they may not be representative of its absolute centroid (Figure 3-47).

As water column currents at mid-depth and near-bottom continued to transport corresponding layers of the sediment plume northwest, winds emanating from the west and southwest opposed the northwest current flow at the surface. The wind stress on the surface waters and resulting short-period waves essentially caused differences in velocity and direction in the surface and near-surface elements of the plume from the remainder of the feature, preventing its migration, and concentrating these entrained sediments near the original disposal point. Approximately 90 minutes into the survey, the ADCP vessel investigated the morphology and relative concentration within the near-surface portion of the sediment plume, while the water sampling vessel proceeded with collecting the T5 samples approximately 800 m down current from the disposal point. The T5 transmissometer profile indicated discrete layers of plume sediments at mid-depth and near-bottom, exhibiting values ranging between 50 to 60% (Figure 3-48). The replicate-averaged TSS value calculated for the T5 samples was 12.6 $mg \cdot L^{-1}$ utilizing waters captured from the 32 m depth interval. Comparisons to the turbidity measured earlier in the survey day indicated a small-scale (3 $mg \cdot L^{-1}$) increase in TSS at T5 (90 minutes) relative to the T4 (60 minutes) results. This increase could be the product of increased particle settlement or minor difference in the location of the water sample relative to the centroid of the plume.

At 92 minutes post-placement, the ADCP vessel identified the leading edge of the near-bottom portion of the sediment plume on Line Q, approximately 1,250 m northwest of the original disposal point, while the subsequent survey lines provided insight into turbidity closer to the centroid (Figures 4-10A and B). Ten minutes prior to the T6 sample interval, the near-bottom portion of the plume had been subjected to sufficient advection by ambient currents to transport the turbid water nearly 930 m to the northwest.

The centroid of the plume was re-acquired by the ADCP vessel approximately five minutes prior to the T6 sample interval as an isolated pocket of water displaying acoustic backscatter values greater than 15 counts over background (Figure 4-10B). The CTD/water sampling vessel was directed to this location and completed the T6 (120 minute) profile and sample collection. Both the transmissometer profile and TSS data displayed relatively low turbidity levels at the 32 m depth interval despite the strong acoustic signal detected by the ADCP. Minimum light transmittance values of 65% were detected in the CTD profile and an average TSS value of 6 $mg \cdot L^{-1}$ was calculated from the water samples. Two hours after the disposal event, the core of the plume was identified approximately 1,010 m northwest of the observed disposal point in both the acoustic and optical data, which closely aligned with the calculated total advection distance of 1,019 m based on near-bottom current velocities (Figure 4-10B).

For the remainder of the survey day, the most concentrated portion of the sediment plume was detected in the bottom 10 to 15 m of the water column. Only one coherent plume feature was detectable, as the primary plume and secondary plume likely merged to form a single, broad feature that was advected to the west and northwest by ambient currents (Figures 4-11A and B). Survey lines completed outside the northern and western boundaries of RISDS indicated residual acoustic backscatter intensities between 5 and 15 counts above background nearly three hours post-placement. Estimates of advection based on near-bottom current velocities suggest the core of the sediment plume was transported 1.3 km within 172 minutes (Figure 4-11B). The T7 (150 minute) CTD profile and water samples were obtained from a position approximately 1,300 m down current from the observed disposal point at a location just outside the northern boundary of RISDS. The transmissometer data indicated a slightly lower light transmittance in comparison to background, indicative of a small-scale elevation in suspended particulates. With an average TSS value of 5 $mg \cdot L^{-1}$, the water samples were likely acquired within the diffuse plume, but outside the centroid (Figure 4-11B).

The T8 transmissometer profile and TSS samples were collected 210 minutes after the disposal event from a location that was 175 m north-northwest of the T7 CTD station. Although no acoustic data were obtained during that time period, the ADCP transects completed 40 minutes prior to the T8 sampling event suggested the bulk of the turbid water in the lower half of the water column had moved beyond the disposal site in the form of a broad diffuse sediment plume (Figure 4-11B). The transmissometer profile for T8 was quite similar to that of the T7 sampling event with low levels of particulate matter detected at depths greater than 25 m (Figure 3-49). However, the replicate averaged TSS value for the T8 samples indicated near-bottom turbidity was essentially at background levels (3 $mg \cdot L^{-1}$). Given the rate and direction of transport, total advection for the densest portion of the sediment plume was likely 1.6 km northwest of the original disposal point. The recorded position of the T8 samples was 1.4 km northwest of the disposal point; therefore, the transmissometer profile and TSS results were likely characteristic of the trailing edge of the broad and diffuse sediment plume.

5.0 DISCUSSION

Since its inception in 1977, the monitoring efforts performed as part of DAMOS have shown that when properly managed, the physical, chemical, and biological impacts associated with sediment placement are typically minor and limited to the benthic environment within the disposal site. However, state and federal regulators participating in the Providence River and Harbor Maintenance Dredging Project had placed increased attention and scientific emphasis on the evaluation of environmental impacts resulting from the formation and transport of sediment plumes. As a result, the April 2004 survey activity was conducted to measure the extent and suspended sediment concentrations of the dredged material disposal plumes over their relatively short existence. In addition, the information gathered from this survey activity also allowed the opportunity to evaluate any acute toxicity to marine water column organisms associated with exposure to the sediment plume.

In general, the primary effects of dredged material disposal operations within the water column have been described as limited to short-term changes in water quality, specifically water clarity and contaminant load. Various mass balance studies have estimated that approximately 1 to 5% of the volume of sediment placed at a subaqueous disposal site by a split-hull or pocket-type disposal barge becomes entrained within the water column to form a sediment plume (Tavolaro 1984; Truitt 1986). The cloud of turbidity that comprises a sediment plume generally exists for several hours, tending to broaden and diffuse as the turbid water is advected from the point of disposal by ambient water column currents.

The DAMOS Program studies of dredged material disposal plume impacts date back to 1984 and 1985 with surveys performed at the historic Boston Foul Ground and current Rockland Disposal Sites (SAIC 1984; SAIC 1988b). These studies concluded that dredged material disposal plumes were easily detectable in the water column several minutes after a disposal event, and decayed quickly within a 120 to 150 minute time frame. Suspended sediment concentrations were considered quite high upon the initial formation (750 to 1000 $mg \cdot L^{-1}$) based on acoustic measurements, but decreased rapidly within 40 to 60 minutes to yield concentrations ranging between 10 to 100 $mg \cdot L^{-1}$. The variability in the observations was described as a function of the type and volume of dredged material disposed. Despite the variability in the findings of these early studies, the assessments made as part of these field measurements concluded that sediment plumes were of limited concern to the overall management of any dredged material disposal site and focus shifted to other topics that were more directly associated with ecological impacts.

Since these initial studies, the USACE has developed and refined the STFATE model to estimate the morphology and turbidity of individual sediment plumes formed by a single disposal event based on the volume, as well as the geotechnical and geochemical properties of the sediment disposed. Both optical and acoustic remote sensors were used during the survey in tandem with simultaneous collection of hydrocasts to determine turbidity and acute toxicity within the plume centroid over time. A follow-on study will be conducted in September of 2004 focusing on project material deemed suitable for unconfined open water disposal. However, there will be restrictions on the volume of material disposed during each event (3,000 yd^3 or 2,300 m^3) during this phase.

As would be expected, the general findings of the April 2004 survey indicate the distance, direction and rate of plume transport is highly dependent upon the characteristics of the water column currents over the dredged material disposal site at the time of the disposal event. When initially formed, each plume existed as a concentrated column of turbidity that occupied the water column at the location at which the disposal barge was opened. This column of turbid water was then advected by ambient currents within the various depth levels within the water column. The actual morphology of each sediment plume was primarily a function of current shear, or the differences in the speed and direction of water movement between the various depth levels within the water column. In general, the currents in the depth horizon between 15 and 25 m were the strongest and most significant factor affecting plume morphology.

During the April 2004 survey effort, acoustic sensors detected distinct differences in backscatter intensity in the upper and lower water column in comparison to background conditions during the first 20 minutes of each plume monitoring surveys. Water samples obtained within the plume during this same time period yielded TSS concentrations that ranged from 23 to 64 $mg \cdot L^{-1}$. These values were significantly lower than the values derived from the acoustic measurements collected during the 1984 and 1985 surveys (750 to 1000 $mg \cdot L^{-1}$), indicating a substantial difference in the results from the most recent survey to those of the historic efforts. These disparities in findings may have been attributable to differences in methodology for determining concentration (acoustic versus point sampling), size and volume of the disposal barges employed, or the inability to precisely sample in the highly localized parcel of turbid water representing the absolute centroid of the plume with the carousel water sampler during the very early stages of the survey.

The sediment plumes monitored during the April 2004 effort were transported to the west or northwest following disposal in response to the water column currents. All three plume surveys were conducted during a period of flood tide that varied in duration due to differences in the times of disposal. The bottom-mounted ADCP record indicated that current flow generally increased over time during the flood tide, with maximum flow to the west and northwest within the water column generally coinciding with the time of high tide and slack high water. As water levels at the site decreased in response to the subsequent ebb tide, velocities gradually diminished and the direction of flow slowly rotated counterclockwise to display a more southerly flow. In general, total transport distances within the 3.5 to 4 hour survey windows were somewhat comparable, ranging from 1 to 1.5 km. All three survey periods were relatively equal in duration, so total transport distances were a function of current velocities and consistency in flow within the water column after disposal. In addition, there appeared to be a relationship between the longer plume transport distances and increased exposure to flood tide conditions over RISDS.

The findings of the three plume monitoring efforts performed in April 2004 indicated suspended sediment concentrations within each plume decreased significantly within 60 minutes of the disposal event via a combination of particle settlement and diffusion (plume decay), exhibiting TSS values < 10 $mg \cdot L^{-1}$ near the centroid of each plume (Figure 5-1). Despite the rapid reduction in suspended particulate matter, each sediment plume remained a distinct feature in the water column and remained detectable in both the acoustic backscatter and transmissometer data for the entire survey period. The influx of ambient seawater and particle settlement over the next 2.5 hours resulted in suspended sediment load reduction near the centroid over time. At 3.5 hours post-placement, the turbidity within the centroid was at or approaching background levels once again. Toxicity within the water obtained from the centroid was not an issue at any of the samples collected during the April 2004 monitoring event.

Inter-comparison between the plumes indicates the concentration of entrained sediment observed during the early stages of the Plume 3 survey were noticeably higher than those of the Plume 1 and Plume 2 survey efforts and the initial size of Plume 3 was generally smaller, relative to the preceding plumes. The primary explanation for the differences in plume characteristics in the early stages of Plume 3 could be linked to the differences in the volume of sediment disposed and dimensions of the disposal barge used to transport the material to RISDS. Section 5.4 provides a detailed discussion on the effects disposal barge configurations have on the morphology and turbidity levels of a sediment plume.

When initially sampled at the T1 interval, the average TSS concentrations for Plume 3 were quite comparable to those of Plume 1 and 2. However, subsequent water samples collected at the T2 (20-minute) and T3 (40-minute) intervals indicated much higher TSS concentrations relative to the Plume 1 and Plume 2 results (Figure 5-1). These data

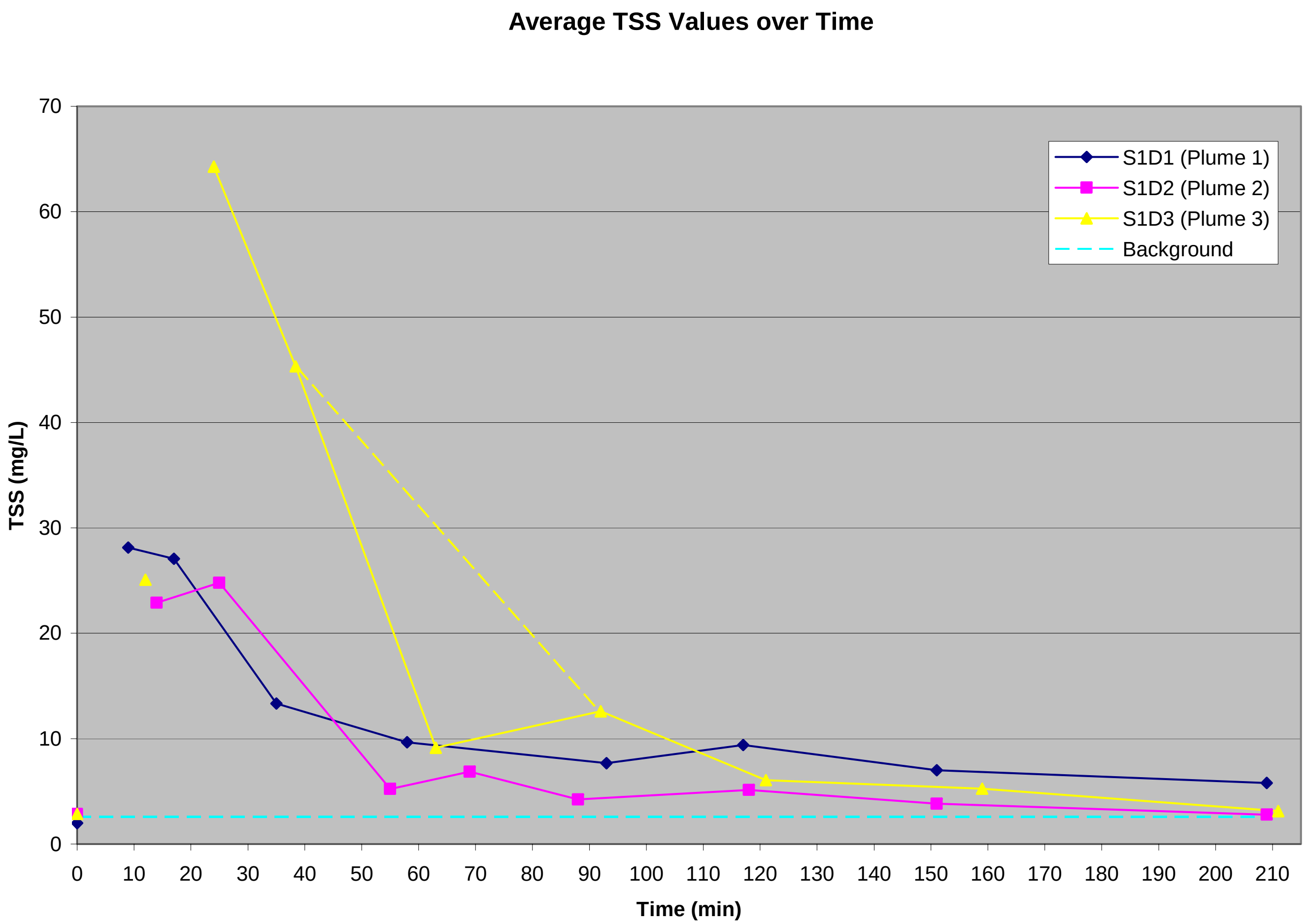


Figure 5-1. Plot of total suspended solids (TSS) concentration versus time since plume event for discrete water samples collected during CTD profiling operations for RISDS plume monitoring.

suggest that Plume 3 was much more concentrated when initially formed, but the T1 water sample was likely not obtained within the highly concentrated and highly localized centroid of the plume and therefore not representative of the core. Following the T3 interval, average TSS values decreased sharply and began approaching background conditions. The T4 sample indicated suspended sediment concentrations fell to 9.1 $mg \cdot L^{-1}$ (near the centroid), 60 minutes post-placement, but increased to 12.6 $mg \cdot L^{-1}$ approximately 30 minutes later in the survey. Given the lack of additional suspended material input, it was theorized that although comparable to the results for Plumes 1 and 2, the T4 sample for Plume 3 was not representative of the centroid. The dashed yellow line on Figure 5-1 represents the inferred change in average TSS concentrations within the centroid between the T3 and the T5 samples and likely concentrations during that 50–minute period of time. Following the T5 sample, the Plume 3 results were analogous to those of Plumes 1 and 2 for the remainder of the survey.

When compared to the STFATE modeling results for sediment plumes formed over RISDS after the deposition of 4,600 m^3, there appears to be a disparity between predicted suspended sediment concentrations and those observed during the 90 to 120 minutes immediately following each disposal event during the April 2004 survey (Figure 5-2). Based on information included within the Final Environmental Impact Statement for the Providence River and Harbor Maintenance project, it was estimated that TSS concentrations within the plume centroid would be approximately 500 $mg \cdot L^{-1}$ 30 minutes post-placement. Suspended sediment concentrations were predicted to rapidly decrease to 130 $mg \cdot L^{-1}$ 60 minutes post-placement, then decrease again to approximately 15 $mg \cdot L^{-1}$ 90 minutes post-placement before returning to near background conditions (3 to 5 $mg \cdot L^{-1}$) 2.5 to 3 hours following each disposal event. The TSS concentrations observed at or near the centroid during the first 90 minutes of each plume monitoring survey were approximately 10% of those predicted by STFATE. The dissimilarity between the model and survey results for the early stages of existence for each sediment plume is likely due to the tendency for STFATE to over-predict the impacts of disposal activity within the water column.

5.1 Accomplishment of Study Objectives

The primary objectives of the April 2004 study were to track the extent and concentration of the disposal plume during three separate disposal events at RISDS during the placement of relatively large volumes (4,600 m^3) of sediment, as well as to assess the toxicity of disposal plumes to marine, water column-dwelling organisms. Three individual sediment plumes generated by the disposal of maintenance material dredged from Sabin Point Reach were investigated. This sediment was characteristic of most maintenance

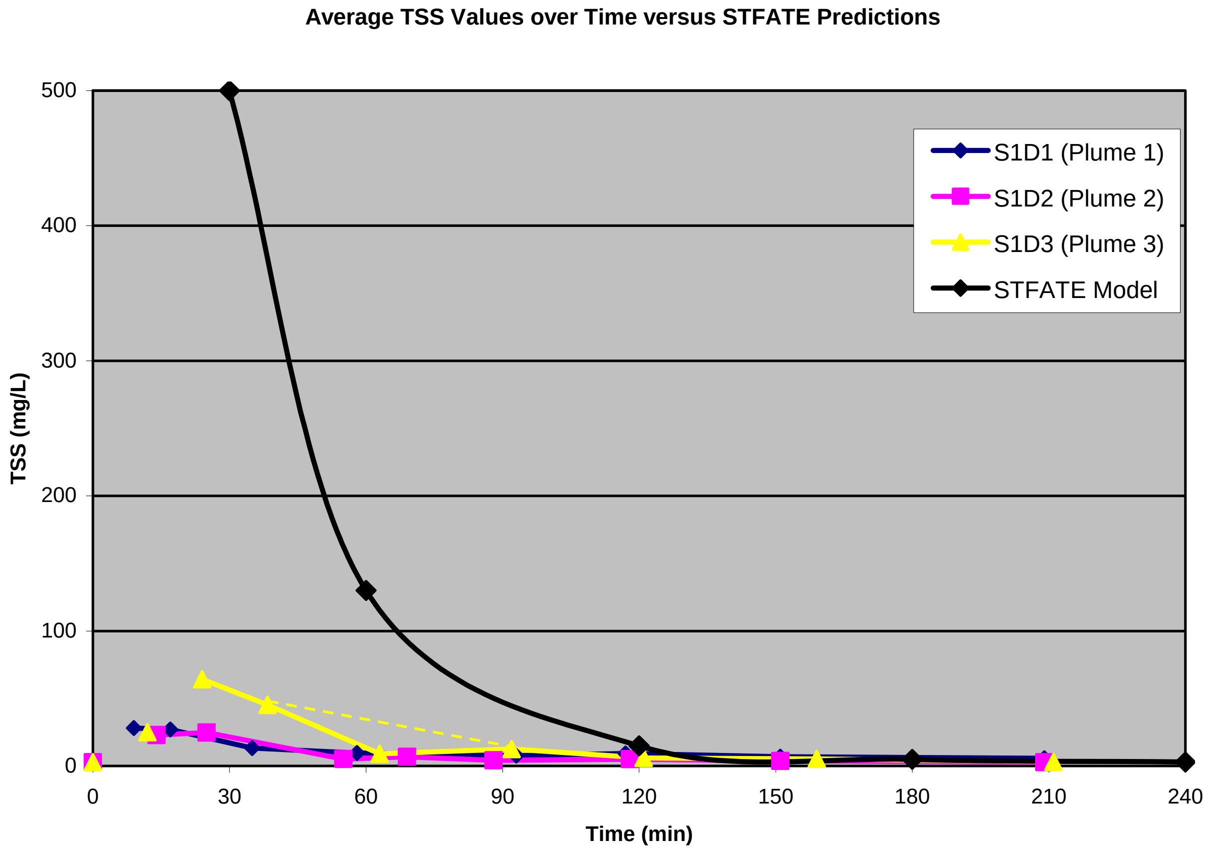


Figure 5-2. Plot of total suspended solids (TSS) concentration versus time for discrete water samples collected during CTD profiling operations for RISDS plume monitoring in comparison to TSS concentrations predicted for the disposal of 4,600 m³ (6,000 yd³) of material dredged from Providence River (USACE 2001).

material, composed primarily of high water content, unconsolidated estuarine silts and clays. This sediment was mechanically dredged with a closed 26 yd^3 (20 m^3) clamshell bucket, transported to RISDS via split-hull disposal barges, and placed on the seafloor as a single deposit.

All study objectives were accomplished within three sequential days of field sampling that yielded accurate and consistent results. Employing a combination of acoustic (ADCPs), optical (transmissometer and optical backscatter), and physical (current drogues and drifters) techniques, all three plumes targeted for monitoring were successfully tracked over a period of three to four hours. Water samples obtained within or near the centroid of each plume at the various time intervals provided sufficient information to follow the decay of each plume over time, as well as to verify a general lack of water column toxicity 40 minutes after the disposal event and any point in time thereafter.

5.2 Assessment of Project Logistics and Field Sampling Techniques

Although the sediment plume monitoring surveys were performed on an ambitious schedule that required tight logistical control, all sampling elements of the field study proved to be operationally feasible. The key to the success of the project was strong logistical planning and coordination between the dredging/sampling operations within Providence River and the survey activity being conducted at RISDS.

The sediment sampling that was conducted on the disposal barges was a relatively straightforward process requiring coordination between the scientific, engineering, and operational elements in advance of sampling. In general, the process of retrieving sediment samples from two locations (bow and stern) within the disposal barge provided a good composite sample from each barge load, with minimal interruption of the continuous dredging process. Due to the four-hour transit time between the dredging area and the disposal site, as well as the unpredictable nature of dredge production efficiency through the course of the evening, multiple barges were often sampled during the evening prior to monitoring operations to provide greater flexibility when attempting to schedule the offshore monitoring operations on the following day. Once it was determined which barge was on a favorable schedule for plume tracking operations, the final homogenizing and sample splits for geotechnical and geochemical analyses were made and sub-samples subsequently shipped to their respective laboratories for analysis.

As described in the methods section of this document, individual sediment samples were collected with a pre-cleaned and decontaminated 0.04 m^2 Van Veen grab sampler, then composited in a pre-cleaned and decontaminated high-density PVC container. The cleaning and decontamination procedures were stringent, requiring detergent scrubs and multiple rinses with deionized water, nitric acid, and methanol to remove surface contaminants prior to sampling. Despite the clean techniques used for sampling the barges, some small-scale contamination of the sediment sample from airborne sources (i.e., diesel power plant exhaust, etc.) cannot be ruled out due to the industrialized setting.

Once a sampled barge was filled at the dredging site, it was transported to RISDS by a tugboat and emptied at a predetermined disposal point. The study parameters were structured such that any delay in monitoring activity would jeopardize the overall success of the survey day. As a result, it was imperative that all measurement systems were adequately prepared prior to the disposal event and functioned properly for the continuous 3.5-hour monitoring period.

5.2.1 Current Measurements

Since the morphology, migration, dilution, and particle settlement rate of the sediment plume were a function of water column currents, accurately determining the direction and magnitude of these currents was a critical element of the monitoring operation. The methodology employed as part of this study offered strong redundancy in current measurements from the three independent measurement systems (current-following drogues, underway ADCP, bottom mounted ADCP).

The current following drogues were relatively simplistic, but provided very useful real-time information on currents for the scientific crews on both survey vessels (ADCP and CTD). Since multi-level, divergent flow was documented within the water column during the April 2004 survey, the sediment plume tended to display differences in transport velocity and direction at mid-depth. When deployed immediately following the disposal event, the drogues and drifters consistently remained with the densest portion of the sediment plume at their respective depth intervals (1 m, 18 m, and 35 m), and served as visual markers for the CTD profiling and acoustic interrogation with the ADCP.

The primary function of the underway ADCP was to assess acoustic backscatter in the water column prior to and following the disposal event to document plume morphology and transport. In addition, the ADCP provided real-time current profile data that were used prior to each disposal event to aid in the positioning of the OBS mooring so that it was in the likely path of the plumes as they were advected away from the disposal point.

The bottom-mounted ADCP provided useful Eulerian (fixed position) time series data on currents throughout the water column for the three to four hour duration of each plume study. The information collected with the bottom-mounted ADCP provided a continuous, high-resolution digital data set that offered insight into the behavior of the plume, as well as confirmed the observations made by the underway ADCP and drogue tracks regarding multi-level, divergent current flow.

5.2.2 Vertical Profiling of Density and Optical Turbidity

The CTD profiling system was quite useful in the plume monitoring program, acquiring accurate and high-resolution data for each vertical profile. The data from the CTD were monitored in real-time, generally allowing profiles to extend to within 1 to 2 m of the seafloor. However, when large swell was encountered (10 April) the depth of profiling was limited to 3 to 4 m above the seafloor (to prevent equipment impact with the bottom and subsequent resuspension).

As documented in the ADCP backscatter results for the background measurement of water column conditions, water column density was a significant factor limiting the ability of the 600 kHz ADCP to resolve the relative concentrations of particulate matter at mid-depth. By comparing the CTD density profile and the transmissometer data with the ADCP data, a correlation was observed between the depth of distinct increase in acoustic backscatter intensity and that of the seawater density gradient. Given that there was no change in ambient water column turbidity detected in the transmissometer record, the increase in acoustic backscatter intensity was therefore attributed to changes in water column density (not an increase in suspended load; Flagg and Smith 1989).

The transmissometer that was also integrated within the CTD package provided significantly more resolution than the Seapoint OBS sensor and was the preferred instrument for sediment plume tracking. The real-time data from the transmissometer provided useful data for making instantaneous judgments on vessel position relative to the depth and location of the plume centroid. The increased resolution of the transmissometer enabled the detection of small-scale changes in water column turbidity that was necessary to distinguish the centroid from the periphery of the sediment plume. The OBS sensor that was also integrated with the CTD yielded sufficient data to identify increases in relative water column turbidity within the profile. However, because the OBS data were not definitive within the denser portions of the sediment plume, these data were not used during the survey nor presented in the report.

5.2.3 Collection of Discrete Water Samples in the Plume Centroid

The Carousel water sampler functioned as expected for the duration of the survey operation, reliably firing Niskin and GO-FLO bottles upon electronic command from the vessel laboratory. All bottles closed properly upon firing, and no samples had to be recollected. The multi-bottle sampler was a critical component to the success of the survey operation given the rapid sampling that was required during the first hour of each survey (sample intervals T1, T2, T3, and T4). By integrating the seawater sampling device with the real-time vertical profile CTD data, there was a high degree of confidence that the hydrocast was acquired within or near the centroid of the plume.

Seawater was captured in either a Niskin or GO-FLO-type bottle based on the required sample volumes and necessary handling procedures for the toxicity samples. Because of concerns that rubber material that functions as a closure mechanism for the Niskin sampling bottles had the potential to affect the toxicity results, the Carousel was outfitted with two 2.5 liter GO-FLO bottles that were used exclusively to collect the volume of seawater required to conduct the multi-species toxicity analyses. The design of the Niskin-type sampler allows the captured seawater to interact with this material, while the GO-FLO bottle design isolates the captured water from this material. The Niskin bottles were used for collecting water for TSS analysis only, since changes to water chemistry would not affect the results.

5.2.4 Vertical Profiling of Acoustic Backscatter along Transects

The primary purpose of the vessel-mounted ADCP was to collect acoustic backscatter information from the water column and provide a cross-sectional view of the sediment plume over RISDS. Similar methodology has been used in plume studies performed within dredging areas and dredged material disposal sites, with varying degrees of success (Land and Bray 2000). In general, use of the 600 kHz ADCP at the open water dredged material disposal site provided useful spatial information on settling and lateral transport of the plumes.

In addition, a 1200 kHz ADCP was used in tandem with the 600 kHz system primarily to provide high-resolution data during the later stages of the plume monitoring surveys when sediment concentrations in the water were expected to dissipate and acoustic backscatter levels diminish. However, due to the density layering within the water column, the higher-frequency, but weaker, outgoing acoustic pulses of the 1200 kHz system were unable to penetrate beyond mid-depth. As a result, these data were only valid for the top 13 to 15 m of the water column, yielding an incomplete profile of the sediment plume.

A series of survey lines aligned perpendicular to the projected direction of plume transport was occupied with the vessel-mounted ADCP to best capture the leading edge, core, and trailing edge of each plume monitored during the April 2004 survey effort. Since the process required collecting data over the acoustically detectable margins of the plume, the length of the survey lines increased with distance from the initial disposal point as the turbid plume broadened with time. As the core of the plume was identified in the real-time ADCP record, its position relative to the current-following drogues was relayed to the water-sampling vessel to aid in directing the CTD profiling operations.

5.2.5 Moored Measurements of Optical Turbidity

The moored OBS array was deployed for each of the three disposal plume tracking events to measure changes to water column turbidity at three levels in the water column during plume passage. The instrument string was deployed following conversations with the approaching tugboat and a determination of the target placement location for the load of interest. The array was placed in the predicted path of the sediment plume based on background current measurements made with the vessel-mounted ADCP. The distance between the OBS mooring location and the target disposal point varied between 200 to 900 m during the three day survey operation, providing information on both near-field and far-field impacts to water clarity.

The OBS mooring collected reliable data during each of the three deployments with the exception of the near-bottom sensor on 8 April (Plume 1). The time-series turbidity data provided by the OBS mooring were useful in evaluating relative turbidity and transport rates in the mid-water column (13 and 18 m depth), as well as near-bottom (32 m depth).

5.3 Characteristics of Dredged Material Disposed and Tracked

All of the sediment plumes tracked during the April 2004 plume monitoring survey consisted of maintenance material removed from Sabin Point Reach. With the exception of minor variations in sand content, the composition of the material was quite similar and consisted primarily of silt and clay, with a high water content in excess of 200% (Table 3-2). However, the plume morphology and concentration of entrained sediment observed during the early stages of the Plume 3 survey were noticeably different than those of the Plume 1 and Plume 2 survey efforts. The initial size of Plume 3 was generally smaller and the concentration of sediment detected at or near the centroid was significantly higher, relative to the sediment plumes tracked on during the Plume 1 and 2 surveys (Figure 5-1).

The Plume 1 and 2 surveys were conducted following the placement of an estimated barge volume of 4,600 m^3 of sediment transported to RISDS by a 6,000 yd^3 split-hull barge. Based on representative cross-sections developed from the underway ADCP data, the sediment plumes formed by these disposal events were approximately 200 m in diameter, near the surface, and over 300 m near-bottom. The Plume 3 survey tracked the sediment plume created following the placement of an estimated barge volume of 3,200 m^3 of dredged material transported and deposited at RISDS by a smaller 4,000 yd^3 barge. As would be expected, the plume formed by the Plume 3 disposal event was somewhat smaller than those formed by the Plume 1 and 2 disposal events, measuring approximately 160 m in width near the surface and 290 m near the bottom. In comparison to Plumes 1 and 2, the center of the Plume 3 appeared much more concentrated during the first 40 minutes of monitoring, despite the 1,400 m^3 (30%) difference in volume disposed. The replicate-averaged TSS values for T2 sample (20 minutes post-placement) collected for Plume 3 was nearly 2.5 times (250%) greater than the corresponding samples collected for Plumes 1 and 2 (Figure 5-1). Furthermore, the T3 sample (40 minutes post-placement) for Plume 3 displayed a replicate-averaged TSS value of 45.3 $mg \cdot L^{-1}$, approximately 3.5 times (350%) greater than those obtained from the two prior days.

Although plume morphology and concentration of entrained sediment could have been influenced by a number of physical factors (i.e., speed of disposal barge upon opening, velocity and diffusional effects of water column currents, sampling location relative to actual centroid, etc.) a likely reason for the differences noted between Plume 3 and those of Plumes 1 and 2 was attributed to the size and configuration of the disposal barge used for transport. Great Lakes Dredge and Dock utilized barges GL-61, GL-63 (6,000 yd^3), and GL-402 (4,000 yd^3) to transport sediment from Sabin Point reach to RISDS. Barge 402 has approximately 33% less capacity and a 35% smaller hopper surface area, or footprint, in comparison to Barges 61 and 63 (Table 5-1; Figure 5-3; USACE 2001). This smaller footprint limited the volume of water directly under the disposal barge, which resulted in less dilution during the placement event and slower diffusion within the first hour following disposal.

Figure 5-3 provides some perspective on the effects of barge scale to plume morphology, while a simplified calculation offers some insight into the likely effects of barge dimensions on suspended load and mixing immediately following disposal. Due to the similarity in sediment composition and high water content, it can be assumed that a consistent 3% of the total barge load dredged from Sabin Point Reach will become entrained in the water column during each disposal event, while the remaining 97% immediately falls to the seafloor to form a sediment deposit. Given the total estimated volume of the load transported by Barge 402 on 10 April (3,200 m^3), a plume comprised of 96 m^3 of sediment would be formed, while the plume formed during the placement of 4,600 m^3 from Barge 61 or 63 would yield a plume comprised of 138 m^3 of sediment. Based on an empty barge draft of 1.2 m and a nominal 34 m water depth (SAIC 2004a), approximately 32.8 m of water exists between the bottom of the disposal barge and the

Table 5-1. Capacity and Dimensions of Split-Hull Disposal Barges Utilized by Great Lakes Dredge and Dock as part of the Providence River and Harbor Maintenance Dredging Project

Barge	Barge Length		Barge Beam		Barge Draft (Loaded)		Barge Draft (Light)	
	(m)	(ft)	(m)	(ft)	(m)	(ft)	(m)	(ft)
GL-402	71	234	16	53	6	20	1	3.5
GL-61	84	277	20	64	7	23	1.2	4
GL-63	84	277	20	64	7	23	1.2	4

Barge	Bin Length		Bin Width		Bin Volume		Bin Surface Area	
	(m)	(ft)	(m)	(ft)	(m^3)	(yd^3)	(m^2)	(ft^2)
GL-402	46	152	12	40	3,050	4,000	552	6,080
GL-61	56	180	15	48	4,600	6,000	840	8,640
GL-63	56	180	15	48	4,600	6,000	840	8,640

* Recreated from information presented in Chapter 7 of the Providence River and Harbor Maintenance Dredging Project Final Environmental Impact Statement, August 2001 (USACE 2001).

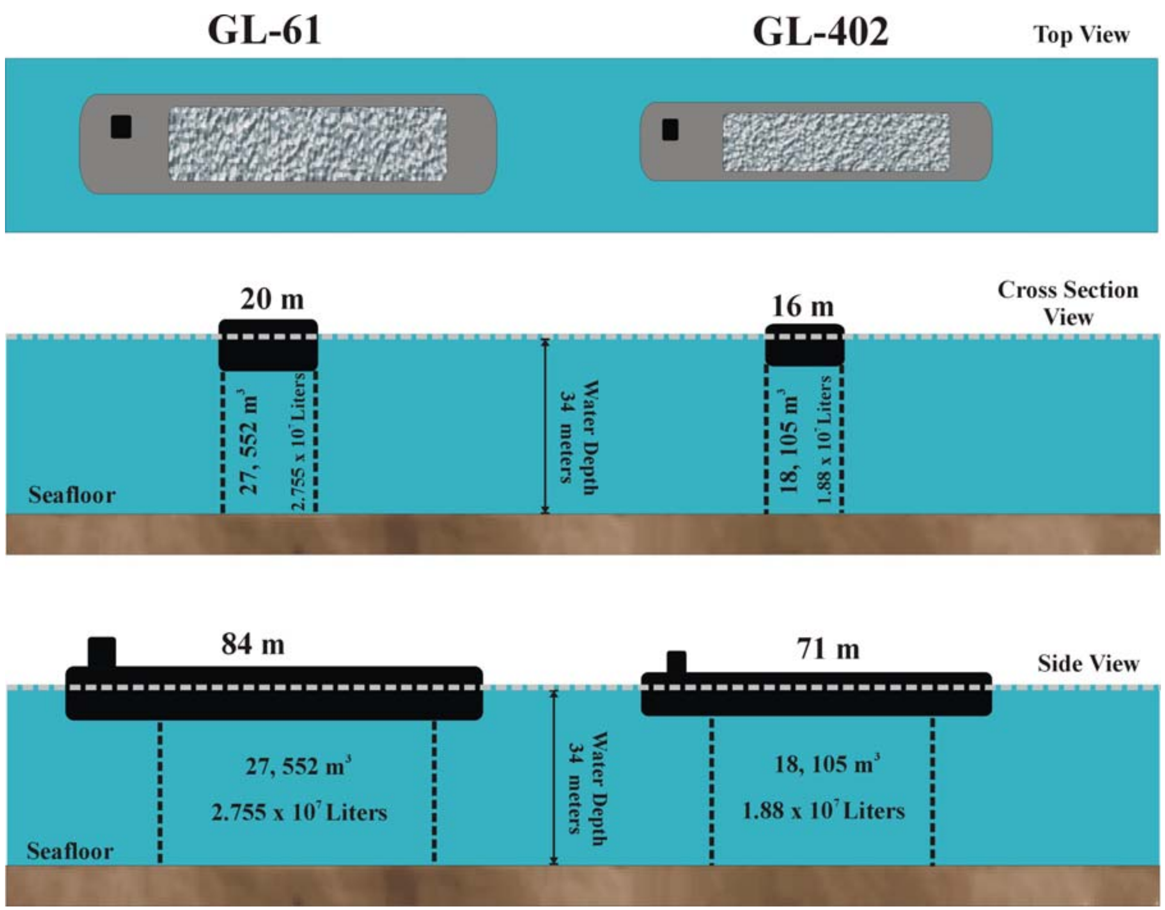


Figure 5-3. Scaled drawing depicting the size of the 6,000 yd³ and 4,000 yd³ barge relative to the depth of water over RISDS and the volume of water within the barge footprint for the initial mixing of sediments entrained within the water column during a typical disposal event.

RISDS seafloor. Utilizing the calculated surface area of the barge to describe its footprint, a simplified estimate suggested a volume of approximately 18,105 m^3 (1.811 X 10^7 liters) of seawater would be available for the initial formation of the sediment plume under Barge 402 versus 27,552 m^3 (2.755 X 10^7 liters) beneath Barges 61 or 63.

A constant wet bulk density of 1.8 $g \cdot cm^{-3}$ (1.8 X 10^6 $g \cdot m^{-3}$) can be assumed to describe the unconsolidated sediments likely to become entrained in the water column during disposal. Releasing 138 m^3 (2.484 X 10^8 g) of sediment within 27,552 m^3 of seawater would theoretically yield a concentration of 9,016 $mg \cdot L^{-1}$ if the sediment comprising the plume was completely and uniformly mixed with the volume of water directly under the disposal barge. Similarly, the mixing of 96 m^3 (1.728 X 10^8 g) of sediment from Barge 402 within 18,105 m^3 of seawater would yield a concentration of 9,541 $mg \cdot L^{-1}$. The theoretical concentration calculated using the values for Barge 402 are 5.5% higher than the theoretical concentration calculated for Barges 61 and 63.

The actual mathematical modeling of a sediment plume involves a much more complex set of computations that incorporates many more parameters relating to sediment composition and physical properties of the water column. The STFATE model developed by the US Army Corps of Engineers, Waterways Experiment Station (WES) incorporates these parameters to forecast the properties of the sediment plume that would be formed by individual disposal events. As part of the assessment of environmental impacts associated with the disposal of the material dredged from Providence River, the STFATE model was used to evaluate the behavior of sediment plumes that would likely be formed over RISDS (see Section 5.0 and Figure 5-2). These analyses yielded estimated TSS concentrations of 500 $mg \cdot L^{-1}$ 30 minutes after a disposal event utilizing a 6,000 yd^3 barge, which was somewhat closer to TSS values observed in the field (USACE 2001). However, the results summary for this modeling exercise also suggested a 33% reduction in TSS concentrations would likely be realized with the 33% reduction in volume disposed when a 4,000 yd^3 barge was employed for disposal at RISDS, while in reality, a 30 to 40 $mg \cdot L^{-1}$ (160 to 200%) increase in TSS was observed.

An STFATE modeling exercise conducted in support of DAMOS to evaluate plume formation and behavior for sediment placed at the Portland Disposal Site (PDS) in 1998 and 1999 provided information that was also useful in evaluating the influence of disposal barge size on the plumes formed at RISDS. Based on the STFATE results from this earlier study to evaluate the morphology of a sediment plume formed by disposal from both a 4,000 yd^3 and a 6,000 yd^3 barge, the smaller disposal barge consistently yielded a more compact and concentrated plume. Throughout the duration of the six-hour model runs, the sediment plume formed by the 4,000 yd^3 barge was depicted as smaller and more concentrated, relative to the plume generated by deposition by a 6,000 yd^3 barge (SAIC

2004b). The most distinct difference in sediment concentrations was noted in the early stages of plume transport (0 to 1.5 hours post placement), with suspended load estimates for the centroid approximately 36% higher within the plume formed by a 4,000 yd^3 barge (though the plume was 29% smaller). The estimated TSS concentrations generated by the model for the 4,000 yd^3 disposal events and 6,000 yd^3 disposal events became better aligned over time (1.5 to 6 hours) as settlement and diffusion affected the predicted plume concentration.

Based on the findings of the recent RISDS plume survey, the theoretical calculations, and the STFATE model results from the prior PDS study, it appears that larger barges promote the formation of a more dilute plume at the time of disposal by discharging the sediment into a larger volume of water. The deposition of sediment from smaller barges should be expected to form a sediment plume that is, initially, relatively constrained in areal size, but more concentrated than those formed by larger volume disposal barges. As a result, it is recommended that disposal barges with a relatively large footprint be utilized for the open water placement of dredged material if suspended load or contaminant concentrations are a regulatory issue or concern with regards to short-term impacts to water quality.

5.4 Characteristics of the Receiving Water at the RISDS

The size, configuration (split-hull versus pocket-type), footprint, and speed of the barge during disposal influence the initial formation of a sediment plume. However, water column currents and the physical properties of the water mass have a direct effect on the overall morphology, transport, and dilution of the sediment plume over time. The water column currents measured over RISDS by the bottom mounted ADCP at the time of three plume surveys displayed a consistent westerly to northwesterly pattern of flow during the three 3.5 hour surveys conducted at RISDS due to the influences of a flood tide. The data from the CTD and water samples suggested clarity was high throughout the water column prior to each disposal event with background light transmittance values above 80% and TSS measurements ranging from 2.0 to 2.9 $mg \cdot L^{-1}$. The low background turbidity confirmed the current profiler data, suggesting that the water mass was moving into the survey area from the continental shelf rather than from nearby coastal estuaries. Furthermore, these findings suggest no residual plume material from the disposal events that had preceded the Plume 1, 2 and 3 surveys remained in the water column.

The background CTD data collected prior to each disposal event also detected the beginning stages of water column stratification and variability in seawater density at depths varying between 5 and 20 m over the course of the three days. The changes in density appeared to be primarily linked to small–scale decreases in temperature ($<0.5°C$) with depth in the water column. Close examination of the corresponding density records showed multiple small increases (0.05 $kg \cdot m^{-3}$) with depth. As noted in Section 3.2.1.4, each of these individual density increases appear to serve as an acoustic reflector in the water column resulting in a band of high background backscatter intensity at mid-depth within the water column. High optical transmittance and low TSS values indicated that there were no anomalous layers of turbid water corresponding to the band of elevated acoustic backscatter.

The background acoustic backscatter data collected by the underway ADCP was influenced by the water column density gradient on all three survey days (Figure 5-4). The Plume 1 data show a distinct band of increased acoustic backscatter intensity between 3 and 18 m water depth (Figure 5-4A). The most significant impact of the density gradient on the ADCP record was experienced during the Plume 2 survey when a series of small-scale changes or variability in seawater density was noted between 5 and 20 m, with a final, relatively distinct change in seawater density documented at 20 m. The band of increased acoustic backscatter intensity, with levels approaching 90 counts (red), corresponded to the same 5 m to 20 m depth interval that displayed the variability in seawater density (Figure 5-4B). Below 20 m, the acoustic backscatter moderated (70 counts) and was relatively consistent with depth to the last valid depth bin of 31 m. The density gradient detected for Plume 3 had only minor impacts to the background acoustic data, as the relatively gradual and smooth increase in seawater density within the water column minimized the appearance of any acoustic artifacts (Figure 5-4C). Background optical transmittance remained high and TSS values were quite low for all three survey days.

Although the density gradient did confound the interpretation of the acoustic backscatter data to some degree, there was no strong, well-established pycnocline detected in the water column that could have a significant effect on plume morphology or rates of particle settlement. However, differences in flow direction and magnitude within the water column currents can have a profound effect on the size, shape, and persistence of the sediment plume over time. The data in the bottom mounted ADCP records did detect differences in current flow throughout the water column at various times during each of the 3.5 hour surveys. The most distinct period of multi-level, divergent flow was documented during the Plume 2 survey as the mid-water column (18 m depth) direction of flow was predominantly to the south and west, while the near-surface and near-bottom currents were moving northwest. However, the effects of the differences in current velocity and direction on the overall morphology of the plume was minor as current speeds remained under 10 $cm \cdot s^{-1}$ for the entire deployment.

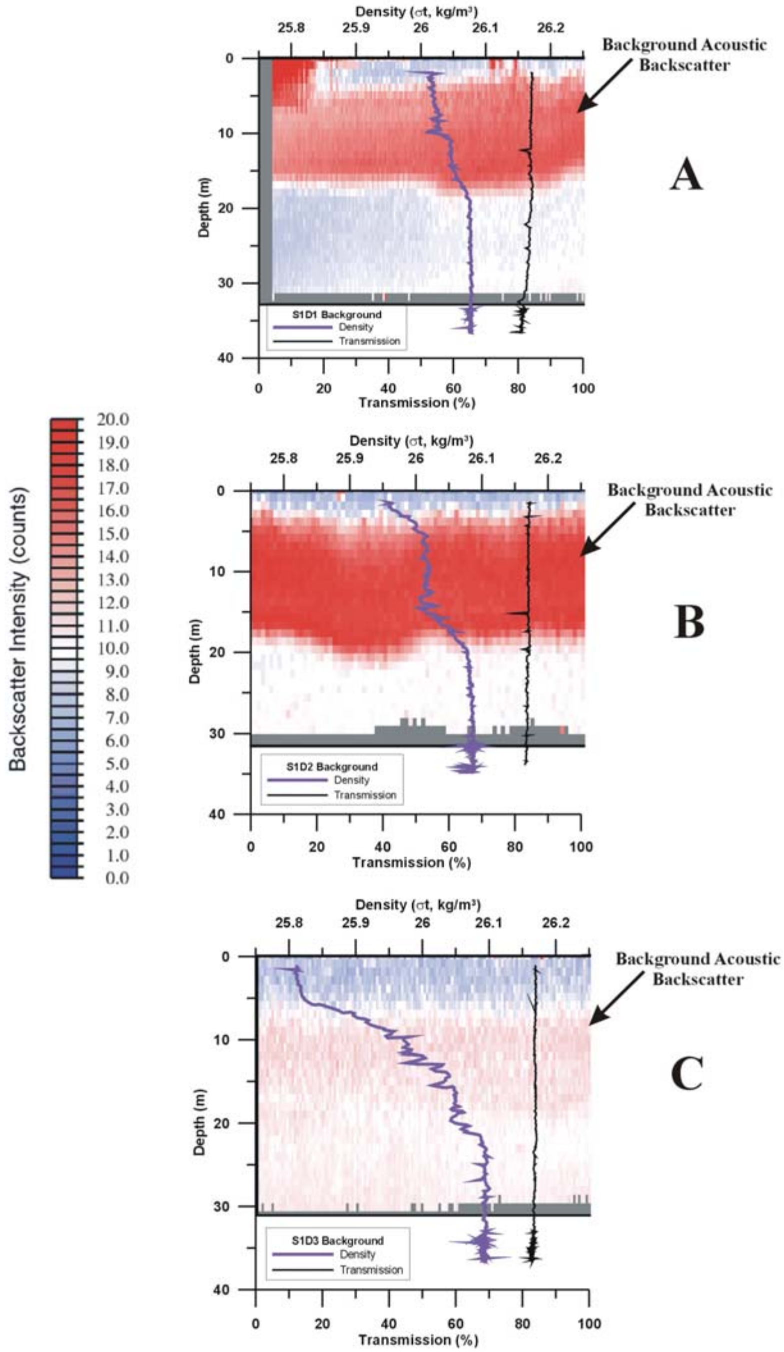


Figure 5-4. Composite graphic demonstrating the relationship between small-scale variability in water column density and background acoustic backscatter intensity measured on 8 April (A), 9 April (B), and 10 April 2004 (C).

The ability to collect cross-sectional data over a sediment plume for several hours after its formation with the underway ADCP provided a substantial amount of insight into its behavior, as well as the processes dictating its morphology. In general, each sediment plume starts as a column of turbid water directly under the disposal barge, with the configuration (split-hull versus pocket-type), footprint, and speed of the barge during disposal influencing the size and concentration within the column (Figure 5-5A). Due to density differences of sediment particles, differential settling of sediment particles results in coarser-grained material within the plume settling rapidly while the finer-grained silts and clays remain entrained in the water column. Typically, mid-water and near-surface currents are of higher magnitude relative to those near-bottom. As the plume interacts with the currents at various intervals of the water column, the sediment cloud is primarily stretched by the differences in flow direction (Figure 5-5B). As a result, the plume becomes extended in the direction of flow becoming more diluted overtime by the influx of ambient seawater and settlement of the material. With regards to the surveys completed at RISDS, turbidity within the disposal plume generally approached background levels one hour after the disposal event. However, elements of the sediment plume remained slightly above background and acoustically detectable in the water column for three to four hours post-placement depending upon the speed and direction of transport within the various depth intervals of the water mass (Figure 5-5C).

5.5 Placement Location for Individual Disposal Events Studied

As described in Section 1.4, a series of target disposal points were selected within the confines of the disposal site to control the changes in bottom topography by selectively distributing the sediment on the RISDS seafloor. The coarser-grained and cohesive materials excavated from Fox Point Reach during the formation of CAD cells were placed along the western boundary of the site to form a containment ridge, while estuarine silts comprising the maintenance material were distributed to the east of this ridge (Figure 1-3; SAIC 2004a). The crew of the tugboat typically was directed to the target disposal point for each load transported to RISDS based upon date, time, and predicted current direction and magnitude at the estimated time of disposal. STFATE modeling work performed by ERDC (formally WES) provided a recommended disposal point for each hour that open water disposal could occur during the 18 to 24 month dredging project. The basis of the recommended disposal pattern was to utilize a target point within the disposal site that would allow the maximum amount of time for the sediment plume to dissipate through particle settlement and dilution prior to leaving the area defined as the "mixing zone" to comply with water quality criteria.

The time of the actual disposal event varied between 13:09 and 14:21 UTC (09:09 and 10:21 EDT) during the three-day survey operation. However, the surveys on each day

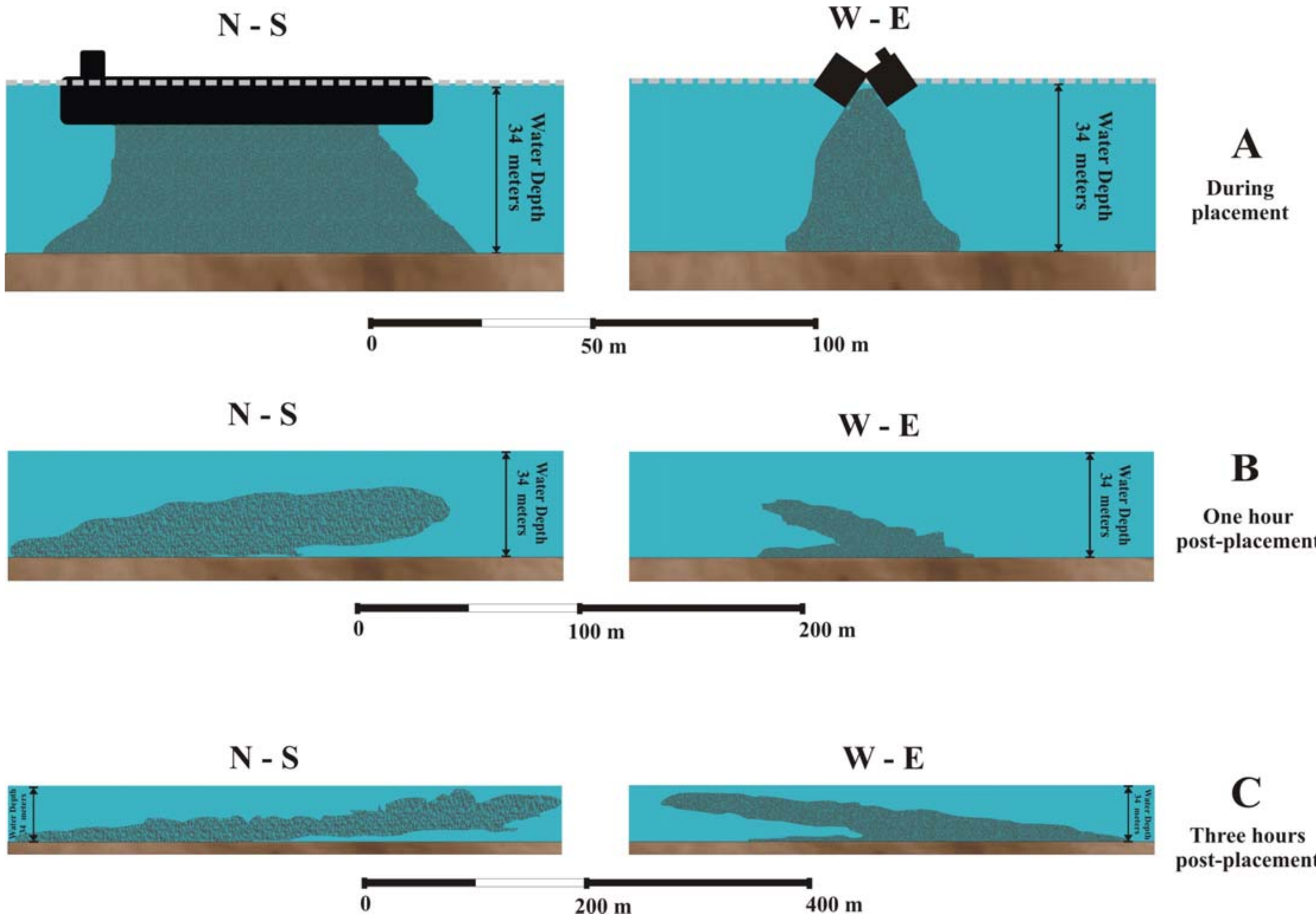


Figure 5-5. Schematic representation of the morphology of a typical sediment plume formed over RISDS immediately following disposal (A), one-hour post placement (B) and three-hours post placement (C).

were completed during different conditions of a flood tide (increasing water levels), slack tide (no change in water level), and ebb tide (decreasing water levels) over RISDS. However, the water column currents observed by the vessel and bottom mounted ADCPs, as well as the current-following drogues displayed a consistent westerly to northwesterly pattern of flow. In response to the westerly and northwesterly bias in the currents at the time of the survey, the sediment plume consistently migrated to the west and northwest with the water mass. The current data collected during the April 2004 plume surveys were collected in three separate 3 to 4 hour deployments.

Point B was the target disposal location on 8 April (Plume 1) and 10 April (Plume 3) and Point A on 9 April (Plume 2) for the barge loads that were tracked during the plume monitoring surveys (Figure 5-6). Given the predominantly northwest and westerly current flow and the likely direction of sediment plume transport, placement at these would, in fact, allow the resulting sediment plumes minimal residence time within the confines of RISDS before being advected over the northern or western site boundaries.

Water samples collected within or near the centroids of the individual plumes showed that suspended particulate concentrations dropped rapidly during the first hour following the formation of each plume. The T4 water samples (60 minutes post-placement) yielded TSS values ranging from 6.9 to 9.7 $mg \cdot L^{-1}$, while background turbidity levels were in the 2.0 to 2.9 $mg \cdot L^{-1}$ range (Figure 5-6). The subsequent water samples collected during each day showed a general trend of decreasing TSS over time as the most turbid portion of each plume was advected by the water mass. Each sediment plume remained detectable with both acoustic and optical sensors for the majority of the 3.5 hour survey periods. The TSS concentrations at or near the centroid of the plumes were comparable to background turbidity values once the plume had been transported outside RISDS.

The plume formed at Disposal Point A on 9 April (Plume 2) was approximately 450 m to the east of the western disposal site boundary, residing within the confines of RISDS for approximately 75 minutes. The TSS data indicated the turbidity levels within this sediment plume could be estimated as 5.0 to 5.5 $mg \cdot L^{-1}$ at the time it crossed the boundary. The difference between the turbidity within the centroid and that of the ambient water are insignificant from a regulatory perspective. Similarly, the selection of Disposal Point B on 8 April (Plume 1) and 10 April (Plume 3) allowed the sediment plumes to leave the disposal site boundary within two hours of each disposal event, but still provided sufficient time for turbidity levels within the centroid to fall to near-background levels (Figure 5-6). Although the data collected as part of this survey suggests the movement of a detectable sediment plume beyond the site boundary is of little environmental significance, it does indicate that refinement of the model calculations used to predict plume behavior at RISDS and the target

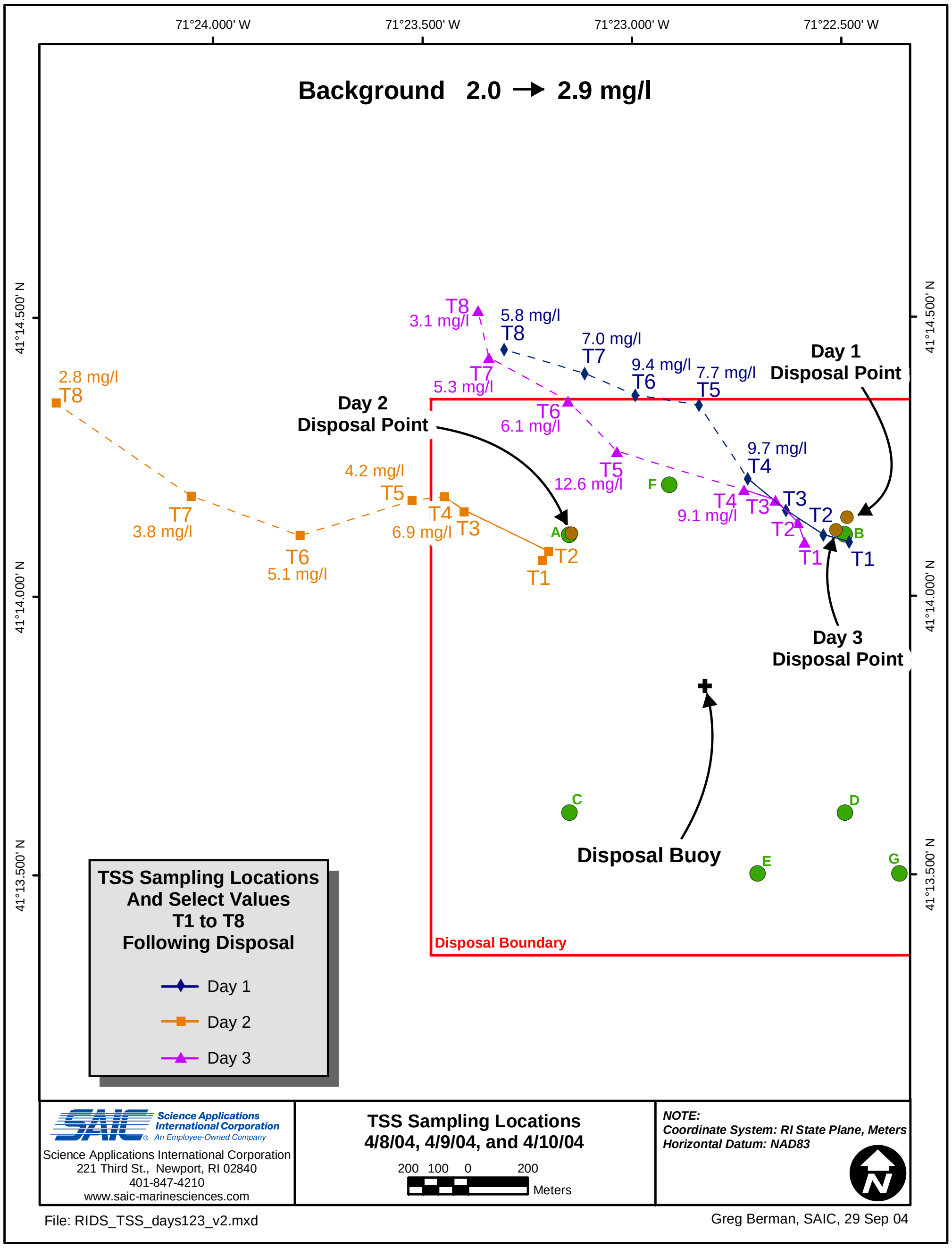


Figure 5-6. Graphic representing the various positions of the centroid of the three sediment plumes tracked during the April 2004 plume monitoring survey relative the RISDS boundaries.

disposal positions could increase plume residence time and allow suspended sediment concentrations to return to background levels prior to leaving the site boundaries.

5.6 Toxicity within the Sediment Plumes Studied

Overall, the results of the toxicity testing performed on the water captured as part of the T0 (background), T3 (40 minutes), T4 (60 minutes), and T6 (120 minutes) samples for Plumes 1 and 2 indicated greater than 90% survival and therefore no lethal effects to the test organisms. This was the anticipated outcome given the source of the sediment (Sabin Point Reach) and the amount of dilution that occurs within the water column during the formation of the sediment plume and its subsequent advection by ambient currents.

The chemistry results for the barge samples were compared to the pre-dredging sediment analyses from the most representative samples for the Sabin Point reach of the river, which was Station I. Bulk sediment chemistry results were available for Station I from 1992 and 1993 for all analytes except cadmium, naphthalene, indeno(1,2,3-cd)pyrene, and dibenzo(a,h)anthracene.

The ranges of trace metals concentrations for the barge samples were very similar to those of the pre-dredge sediment samples (Table 5-2, Figure 5-7). Arsenic concentrations within the barge sample (13 to 15 mg/kg) were slightly higher than the single, pre-dredge arsenic value available (11 mg/kg from 1992 data set). Chromium, copper, and mercury in the barge samples had concentration ranges that were comparable to the pre-dredge range of concentrations, with slightly lower minimum and/or maximum concentrations in the barge samples. For example, copper concentrations in the barge samples ranged from 290 to 350 mg/kg with a mean of 320 mg/kg, while the data from the in-place sediment testing performed in 1992 and 1994 indicated concentrations ranging from 330 to 360 mg/kg (Table 5-2, Figure 5-7). Mercury concentrations were quite low in the barge samples, ranging from 0.5 to 0.8 mg/kg, as well as within the pre-dredge sediment samples (0.7 to 1.0 mg/kg; Table 5-2).

Lead, nickel, and zinc concentration ranges for the barge samples fell within the pre-dredge sample ranges for Station I (Table 5-2). For example, zinc concentrations ranged from 260 to 290 mg/kg, with a mean of 273 mg/kg in the barge samples, in comparison to the 240 to 290 mg/kg range detected in the pre-dredge samples (Table 5-2; Figure 5-7). The barge samples range (34 to 40 mg/kg) and mean concentration for nickel were comparable to the single, pre-dredging nickel concentration available (36 mg/kg) from 1992 data set (1992 to 1994) from Station I within Sabin Point Reach (Figure 5-7). Overall, this indicates that barge sample metal concentrations were very similar to available pre-dredge metal concentration data.

Table 5-2. Comparison of April 2004 Barge Samples to Pre-Dredge Samples

	Barge Sample Results			Pre-Dredge Sample Results	
Metals (mg/kg)	**Min**	**Max**	**Mean**	**Min**	**Max**
Arsenic	13.0	15.0	14.3	11	
Chromium	140	170	157	160	170
Copper	290	350	320	330	360
Lead	120	140	130	110	190
Mercury	0.5	0.8	0.7	0.72	0.97
Nickel	34	40	37	36	
Zinc	260	290	273	240	290
PAHs (µg/kg)					
Naphthalene	51.0	150.0	85.7	140	220
Acenaphthylene	29.0	41.0	33.7	65	110
Acenaphthene	ND	12.0	11.0	51	
Fluorene	20.0	28.0	24.0	70	71
Phenanthrene	110	160	130.0	430	430
Anthracene	41.0	58.0	46.7	140	180
Fluoranthene	230.0	350.0	270.0	810	870
Pyrene	220.0	330.0	260.0	1430	2400
Benz[a]anthracene	92.0	130.0	106.3	450	530
Chrysene	120.0	180.0	143.3	510	530
Benzo[b]fluoranthene	130.0	200.0	156.7	630	630
Benzo[k]fluoranthene	120.0	190.0	143.3	630	650
Benzo[a]pyrene	140.0	200.0	160.0	410	570
Benzo[g,h,i]perylene	120.0	170.0	136.7	830	

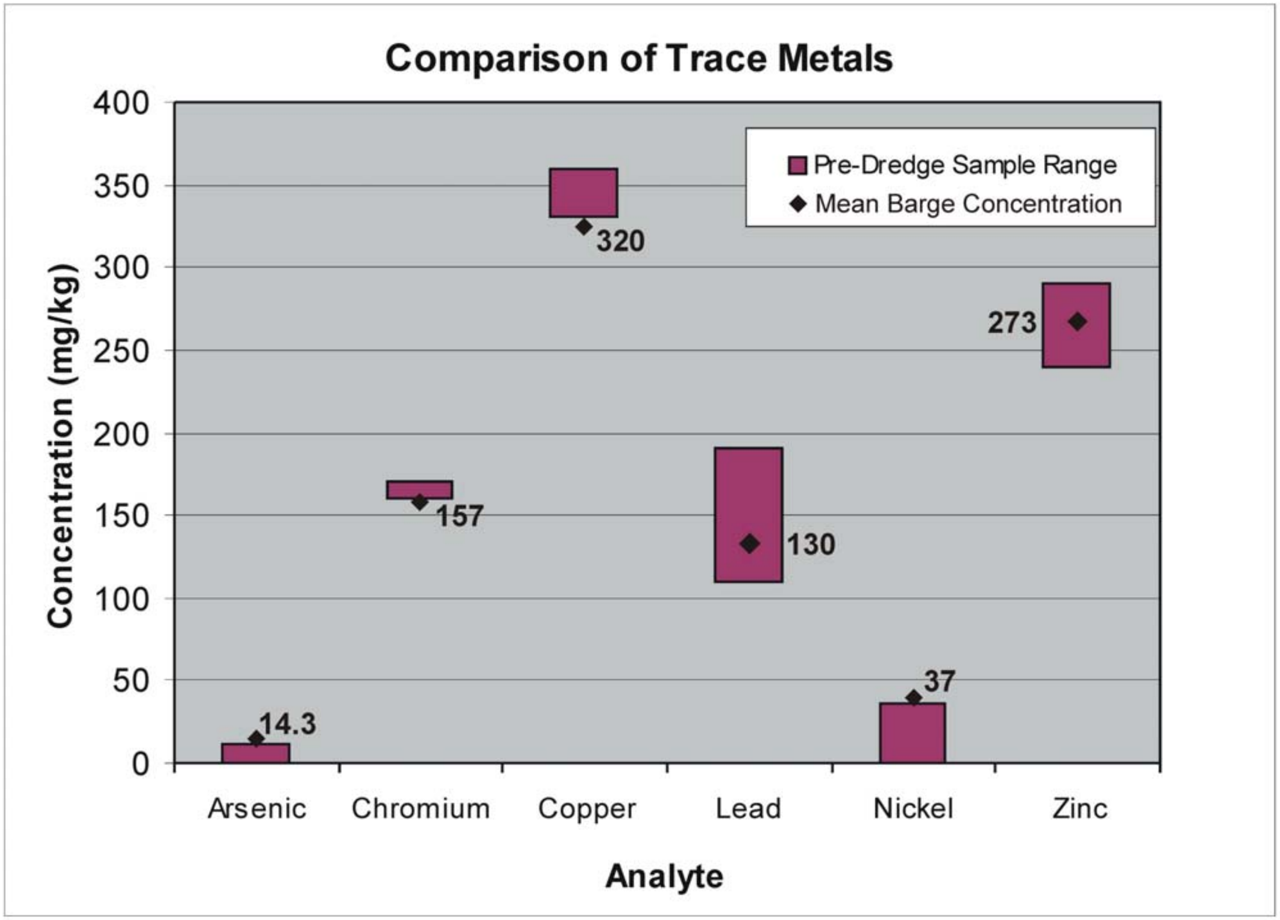


Figure 5-7. Chart showing the relationship between the mean concentration of trace metals in the April 2004 disposal barge samples to the range of concentrations detected in the 1992 and 1994 pre-dredge samples of in-place sediments within Sabin Point Reach.

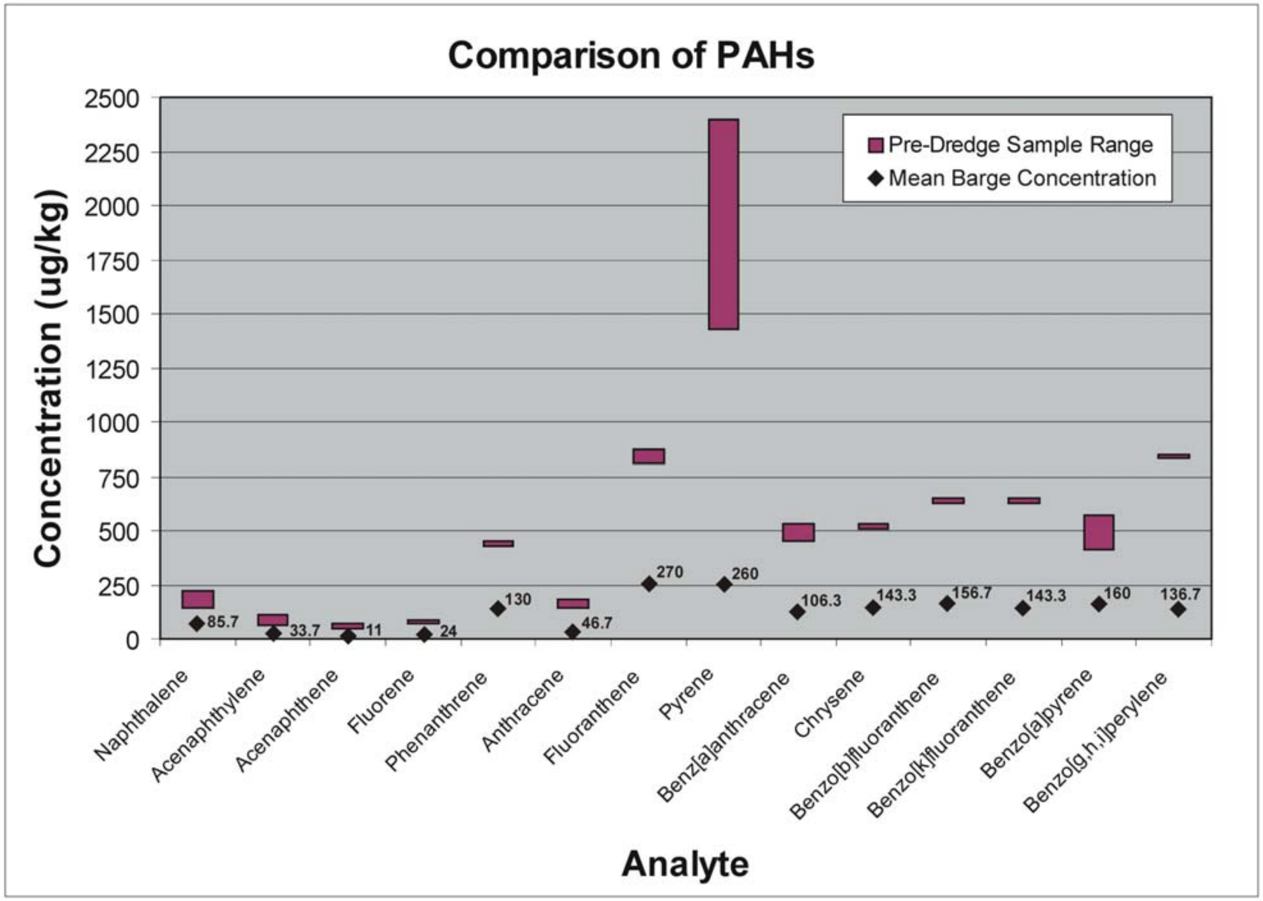


Figure 5-8. Chart showing the relationship between the mean concentrations of PAH compounds in the April 2004 disposal barge samples to the range of concentrations detected in the 1992 and 1994 pre-dredge samples of in-place sediments within Sabin Point Reach.

In contrast to the metals comparison, the data pertaining to PAH compounds exhibited substantially lower concentrations in the barge samples relative to the pre-dredge samples collected from Station I in 1992 and 1993 (Table 5-2; Figure 5-8). PAHs were reported in μg/kg in the barge sample data, and μg/g in the pre-dredge sample data. The pre-dredge data were converted to μg/kg for the comparisons in Table 5-2. Naphthalene was the only PAH compound for which the barge concentration range (51 to 150 μg/kg) overlapped with the pre-dredge concentration range (140 to 220 μg/kg). For all other PAH compounds analyzed in both data sets, the barge sample concentrations were all lower than the pre-dredge sample concentrations. For example, acenaphthylene concentrations in the barge samples ranged from 29 to 41 μg/kg, with a mean of 33.7 μg/kg, while levels within the pre-dredge samples ranged from 65 to 110 μg/kg (Table 5-2; Figure 5-8). Acenaphthene concentrations ranged from not detected to 12 μg/kg in the barge samples, compared to the single, pre-dredge sample concentration of 51 μg/kg (1992 data set). Phenanthrene concentrations ranged from 110 to 160 μg/kg (mean of 130 μg/kg) in the barge sample, compared to 430 μg/kg in the pre-dredge samples (Table 5-2; Figure 5-8). The most distinct difference between the analytical results of the barge samples to that of the in-place sediments was noted for pyrene, as concentrations in the barge samples ranged from 220 to 230 μg/kg (mean of 260 μg/kg), compared to 1,430 to 2,400 μg/kg in the pre-dredge samples (Table 5-2; Figure 5-8). Barge sample maxima ranged from approximately 20% (benzo(g,h,i)perylene) to 60% (acenaphthylene) the pre-dredge minima.

For the pre-dredge samples, many PAH concentrations were qualified "J" indicating that they are estimated values due to detected concentrations lower than the practical quantification limits (i.e., translates into less confidence in the accuracy of the actual reported concentration). This suggests some uncertainty in the results for J-qualified analytes in the pre-dredge data sets. The analytical method used for the 1992 and 1993 data sets was reported as Method 3540/8270; the 2004 barge samples were analyzed using Method 8270-SIM. Improvements in analytical equipment over this time-frame could result in as much as a hundred-fold increase (i.e., two decimal places) in sensitivity for PAH detections using this method (Kirk Young, Severn-Trent Laboratory Burlington, VT, personal communication). Therefore, differences in PAH concentrations between barge samples and pre-dredge samples likely reflect improvements in analytical techniques, as well as the possibility of natural variability in PAH concentrations among samples (Figure 5-8).

In summary, these results suggested metals concentrations in the barge were consistent with pre-dredge sediment characterization data, while PAH concentrations were substantially lower, which was likely attributable to improved analytical techniques. Despite the differences in PAH contaminant load, comparison with ecological screening benchmarks indicated concentrations of contaminants within the barge samples would generally be considered low and therefore of little ecological significance whether in-place or in suspension. Therefore, the lack of toxicity near the centroid of the sediment plumes sampled as part of monitoring effort falls within the expectations of the study.

6.0 CONCLUSIONS

The findings of the April 2004 survey efforts demonstrated that sediment plumes generated by the open water disposal of dredged material remain detectable in the water column for a period of three to four hours following an individual disposal event. Multiple acoustic and optical remote sensors were able to define the general plume morphology and relative turbidity levels above background throughout the water column. Total suspended solids measurements from water samples collected at various time intervals during each survey day showed strong agreement with the data obtained by the remote sensors.

The initial sediment plumes monitored as part of the April 2004 survey typically existed as a concentrated column of turbid water at the dredged material placement location for a short period following the disposal event. Some broadening of the sediment plumes was observed in the surface layers as sediments were washed from the open disposal barge as it was towed away from the primary disposal location. The turbid water comprising the sediment plume was subject to advection by water column currents resulting in broadening and diffusion of the plume throughout the various levels of the water column over time.

During the three to four hour period between the disposal event and dissipation of the resulting sediment plume, portions of the plume existed in the upper, mid, and lower water column. However, the most turbid and most persistent element of each sediment plume was situated in close proximity to the RISDS seafloor. As anticipated, the highest turbidity values were consistently detected within lower 3 m of the water column during the three to four-hour monitoring period following each disposal event. Data from the optical and acoustic remote sensors, as well as the discrete water samples, suggest the centroid of each sediment plume remained relatively concentrated for the first 40 to 60 minutes of each survey, followed by a strong decrease in turbidity. The information obtained over the subsequent two to three hours captured the gradual decay of each sediment plume as advection, diffusion, and particle settlement eventually resulted in the return of near-background turbidity conditions. Relative to the predictions stated in Section 1.6, TSS concentrations within or near the centroid of each plume typically decreased to levels of 10 $mg \cdot L^{-1}$ or less well before the three-hour mark of each survey. In fact, TSS concentrations of approximately 10 $mg \cdot L^{-1}$ were typical within 1 to 1.5 hours of each disposal event.

Water samples were collected specifically for toxicity analysis at 40, 60, and 120 minutes post-placement. After a 96-hour exposure to each water sample collected at or near the centroid of the plume, neither the mysid (*Americamysis bahia*) nor juvenile silversides (*Menidia berylina*) test organisms exhibited a lethal response. Relative to the predictions stated in Section 1.6, the water obtained from the centroid did not exhibit toxicity that was significantly different from background conditions within one hour of disposal. This was the anticipated outcome given the low levels of contamination detected within the sediment dredged from Sabin Point Reach and the amount of dilution that occurs within the water column during the formation of the sediment plume and its subsequent advection by ambient currents.

The overall morphology of the sediment plume was a function of the behavior of the water column currents at a given time. The data collected by a bottom mounted ADCP deployed at RISDS during each plume monitoring event detected differences in current velocity and direction at the various depth horizons, resulting in multi-layer and/or divergent flow. The differences in current flow documented within the vertical axis served to stretch or broaden the sediment plume over time. Clear water was continually introduced into the plume during the advection process, resulting in dilution of the turbid water and diffusion of the suspended sediment particles. Total suspended solids measurements performed on water samples obtained near the most concentrated portion of the plume, or centroid, indicated turbidity values in excess of 20 $mg \cdot L^{-1}$ were common in the early stages of the monitoring operation, returning to near background levels of 2 to 3 $mg \cdot L^{-1}$ within 3.5 to 4 hours of an individual disposal event.

The sediment plumes formed at RISDS during the April 2004 study were the result of dredged material disposal events at pre-determined, target disposal points in the northeast (Point B) and northwest (Point A) quadrants. These points were selected based upon the results of sediment plume behavior modeling prior to the start of the Providence River and Harbor Maintenance Dredging Project in an effort to maximize the amount of time for the sediment plume to dissipate through particle settlement and dilution prior to leaving the area defined as the "mixing zone" to comply with water quality criteria. However, given the predominantly northwest and westerly current flow and the likely direction of sediment plume transport, placement at Points A and B allowed the resulting sediment plumes a residence time of 75 to 120 minutes within the confines of RISDS before being advected over the northern or western site boundaries. Although the TSS data has shown turbidity within this sediment plume was approaching background levels and of little environmental significance at the time it crossed the boundary, refinement of the model calculations used to predict plume behavior at RISDS and the target disposal positions could increase plume residence time and allow suspended sediment concentrations to fully return to background levels prior to leaving the site boundaries.

Comparisons between the suspended sediment concentrations observed during the April 2004 plume monitoring surveys to those predicted by STFATE as part of the Final Environmental Impact Statement, suggested the model output significantly over-predicted the TSS concentrations that would exist within the plume centroid during the 90 to 120 minutes immediately following a disposal event. Actual measurements of turbidity at or near the plume centroid within this time frame were generally 10% of those generated by STFATE. These findings suggest the STFATE model output derived for dredged material disposal operations at RISDS were quite conservative and likely presented a worst-case. STFATE is quite sensitive to several key parameters related to the physical composition of the dredged material to be disposed and the characteristics of the water column. Subsequent model runs to characterize impacts of future disposal at RISDS could benefit from the information presented in this report to derive more realistic values pertaining to suspended sediment concentrations and persistence of the plume within the water column.

Modeling efforts and mass balance studies over the past ten years have examined the relationship between grain size distribution and water content of dredged material to the percentage of a particular barge volume that becomes entrained in the water column. While the mechanics dictating the formation of a sediment plume remain relatively constant within the near coastal environment, the concentration and morphology of each plume monitored as part of the April 2004 survey effort was also heavily dependent upon other variables. The configuration of the disposal barge had a noticeable effect on turbidity levels within the initial plume, as well as its overall size and duration within the water column. In addition, the morphology of the sediment plume over time was directly related to water column currents and the physical properties of the water mass, which impacted transport rate of the suspended sediments and subsequent dilution of the sediment plume over time. From an ecological perspective, variations in these parameters could affect the degree and duration of exposure that pelagic organisms are subjected to environmental contaminants associated with sediments dredged from an industrialized harbor.

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APPENDIX A

Table A-1. Naming Convention for Water Sampling during Plume Monitoring in RIDS

Note: Sample collection times in minutes corresponds to T0 through T8

*T0	Background
T1	10 min
T2	20 min
*T3	40 min
*T4	60 min
T5	90 min
*T6	120 min
T7	150 min
T8	210 min

* Toxicity Samples (collected only 2 of the 3 survey days)

Total Suspended Solids (TSS)
(Survey#)(Day)_(Sample Time)(Sample Letter)
S1D1_T0A
S1D1_T0B
S1D1_T0C

Toxicity Test
(Survey#)(Day)_(Sample Time)(X)
S1D1_T0X (X Signifies Toxicity Test)
S1D1_T3X
S1D1_T4X
S1D1_T6X

Drogues
(Survey#)(Day)_(Flag Color)(Sighting#)
S1D1_Y1 (Y=Yellow=Mid Depth)
S1D1_R1 (R=Red=Deep Depth)
S1D1_SD1 (SD=SurfaceDrogue)

CTD
(Survey#)(Day)_(Cast)
S1D1_A
S1D1_B

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