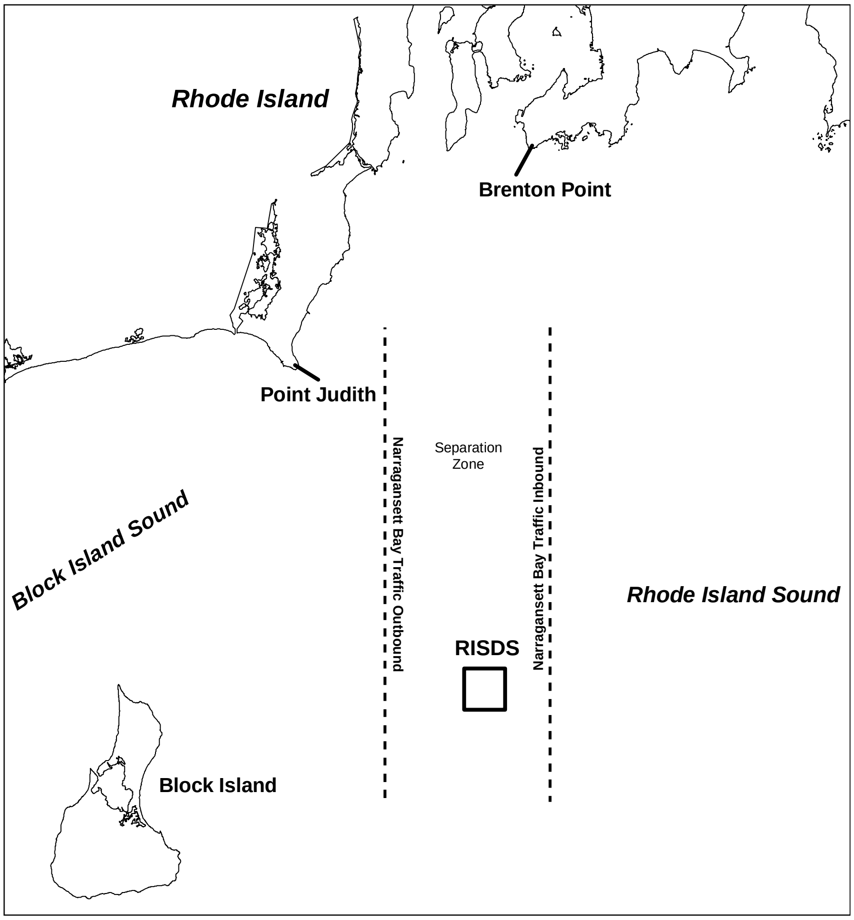
Disposal Plume Tracking and Assessment at the Rhode Island Sound Disposal Site Summer 2004

Disposal Area Monitoring System DAMOS



DAMOS

DISPOSAL AREA MONITORING SYSTEM

Contribution 167
October 2005

US Army Corps
of Engineers®
New England District

REPORT DOCUMENTATION PAGE

form approved
OMB No. 0704-0188

1. AGENCY USE ONLY (LEAVE BLANK)

2. REPORT DATE
October 2005

3. REPORT TYPE AND DATES COVERED
FINAL REPORT

4. TITLE AND SUBTITLE
Disposal Plume Tracking and Assessment at the Rhode Island Sound Disposal Site Summer 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. 678

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

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
Contribution No. 167

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

The second of two planned sediment plume tracking and assessment surveys was completed over the Rhode Island Sound Disposal Site (RISDS) in September 2004. Survey operations entailed tracking individual sediment plumes generated by the disposal of maintenance material dredged from the upper Fuller Rock Reach of the federal navigational channel. Dredged material was placed at Disposal Point D within the southeast quadrant of RISDS on 1 September (Plume 1) and 3 September (Plume 3), and Disposal Point A within the northwest quadrant of the disposal site on 2 September (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. In general, turbidity levels decreased rapidly within one hour of disposal through both diffusion and particle settlement and, 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.

Similar to the results of the April 2004 study, the sediment plumes tracked during the September 2004 survey operation did leave the confines of the disposal site during the survey. Residence time within RISDS varied from 30 to 180 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.

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

15. NUMBER OF TEXT PAGES: 194

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT Unclassified

18. SECURITY CLASSIFICATION OF THIS PAGE

19. SECURITY CLASSIFICATION OF ABSTRACT

20. LIMITATION OF ABSTRACT

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

CONTRIBUTION 167

October 2005

Contract No. DACW33-03-F-0017
SAIC Report No. 678

Submitted to:

New England District
U.S. Army Corps of Engineers
696 Virginia Road
Concord, MA 01742-2751

Submitted by:

Science Applications International Corporation
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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, Summer 2004. DAMOS Contribution No. 167. US Army Corps of Engineers, New England District, Concord, MA, 194 pp.

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EXECUTIVE SUMMARY

In accordance with the environmental monitoring plan associated with the Providence River and Harbor Maintenance Dredging Project, the second of two planned sediment plume tracking and assessment surveys was completed over the Rhode Island Sound Disposal Site (RISDS) in September 2004. The survey effort was conducted under 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 1, 2, and 3 September, tracking individual sediment plumes generated by the disposal of maintenance material dredged from the upper Fuller Rock 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 was used to obtain 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 repeatedly 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 D within the southeast quadrant of RISDS on 1 September (Plume 1) and 3 September (Plume 3), and at Disposal Point A within the northwest quadrant of the disposal site on 2 September (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 20 minutes following disposal displayed low light transmittance values at various depth intervals within the water column and TSS concentrations ranging from 47 to 111 $mg \cdot L^{-1}$, strongly contrasting with the ambient seawater, which exhibited background TSS values of 5.6 to 8.9 $mg \cdot L^{-1}$.

All three plume surveys were conducted during a period of ebb tide that varied in duration due to differences in the times of disposal. Water column currents over RISDS displayed differences in velocity and direction, with the water mass flowing to the west, south, and/or southeast depending upon the stage of the tide at which the disposal event occurred. As a result, the sediment plumes were transported to the west, south or southeast 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 less than 30 $mg \cdot L^{-1}$ 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.

For Plumes 1 and 2, the influx of ambient seawater and particle settlement over the course of the 3.5-hour survey resulted in a reduction of the suspended sediment load near the centroid to levels approaching background conditions. However, the weak and variable water column currents at mid-depth and near-bottom during the Plume 3 survey period allowed the sediment plume to linger within the southeast quadrant of RISDS and limited the influx of ambient seawater into the plume. As a result, Plume 3 became quite broad and diffuse, but exhibited higher turbidity values in comparison to Plumes 1 and 2 at the end of the survey period (27.9 $mg \cdot L^{-1}$; approximately 12 $mg \cdot L^{-1}$ above background). Based upon the information collected during earlier survey efforts, it was anticipated that current velocities were likely to accelerate approximately 30 minutes after the conclusion of the Plume 3 survey. This increase in current flow would likely provide the influx of ambient seawater necessary to rapidly dissipate the sediment plume and allow turbidity levels to return to background conditions.

Similar to the results of the April 2004 study, the sediment plumes tracked during the September 2004 survey operation did leave the confines of the disposal site during the survey. Residence time within RISDS varied from 30 to 180 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 suggest 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 beryllina*) test organisms exhibited a lethal response. This was the anticipated outcome given the source of the sediment (upper Fuller Rock 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 survey performed within the Rhode Island Sound Disposal Site (RISDS) as part of the final phase of a sediment plume tracking and assessment study. The information acquired from this survey is compared to estimates of sediment plume dilution contained within the Environmental Impact Statement developed for the Providence River and Harbor Maintenance Dredging Project, as well as to the results of the first phase of the study. Furthermore, findings from this study will provide further 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 m^3 (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 m^3 of suitable maintenance material (material that meets the ocean disposal testing requirements) to be placed at recently selected RISDS. In conjunction with the federal maintenance project, a small group of private facilities, marine terminals and other facilities may utilize 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 m^3 of sediment was dredged within Fox Point Reach and deposited at RISDS.

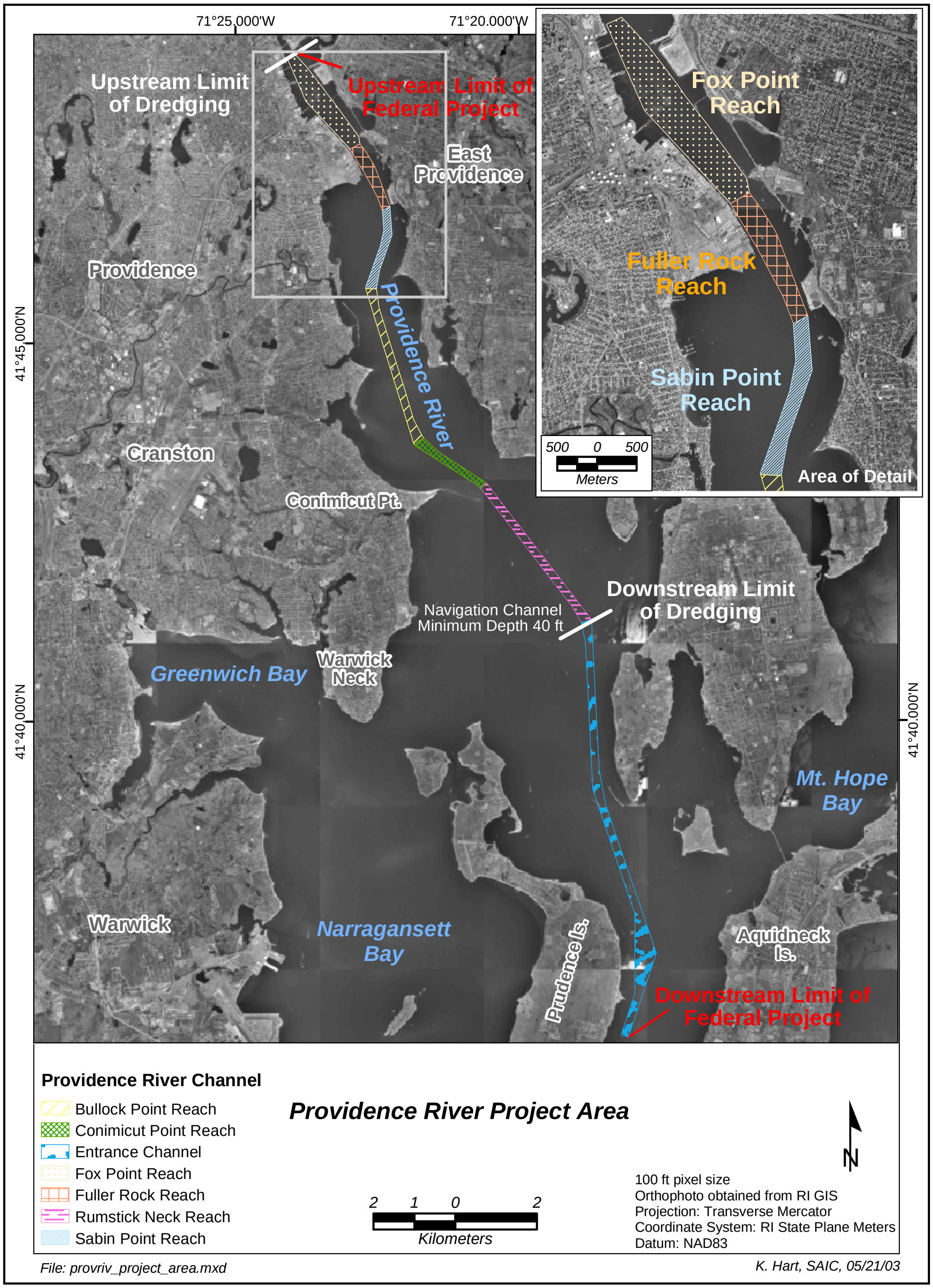


Figure 1-1. Providence River maintenance dredging project area and associated project limits.

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 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 August 2004, a total estimated volume of 2,905,000 m^3 of dredged material was placed within RISDS. The disposal of material generated from both the federal and non-federal maintenance project is anticipated to result in a total estimated volume of 3.6 million m^3 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 RISDS is fine-grained estuarine sediments (silts) derived from dredging operations 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 of 4,600 m^3. The material generated from dredging operations was 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 was 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 open water disposal and require specialized handling techniques for proper 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

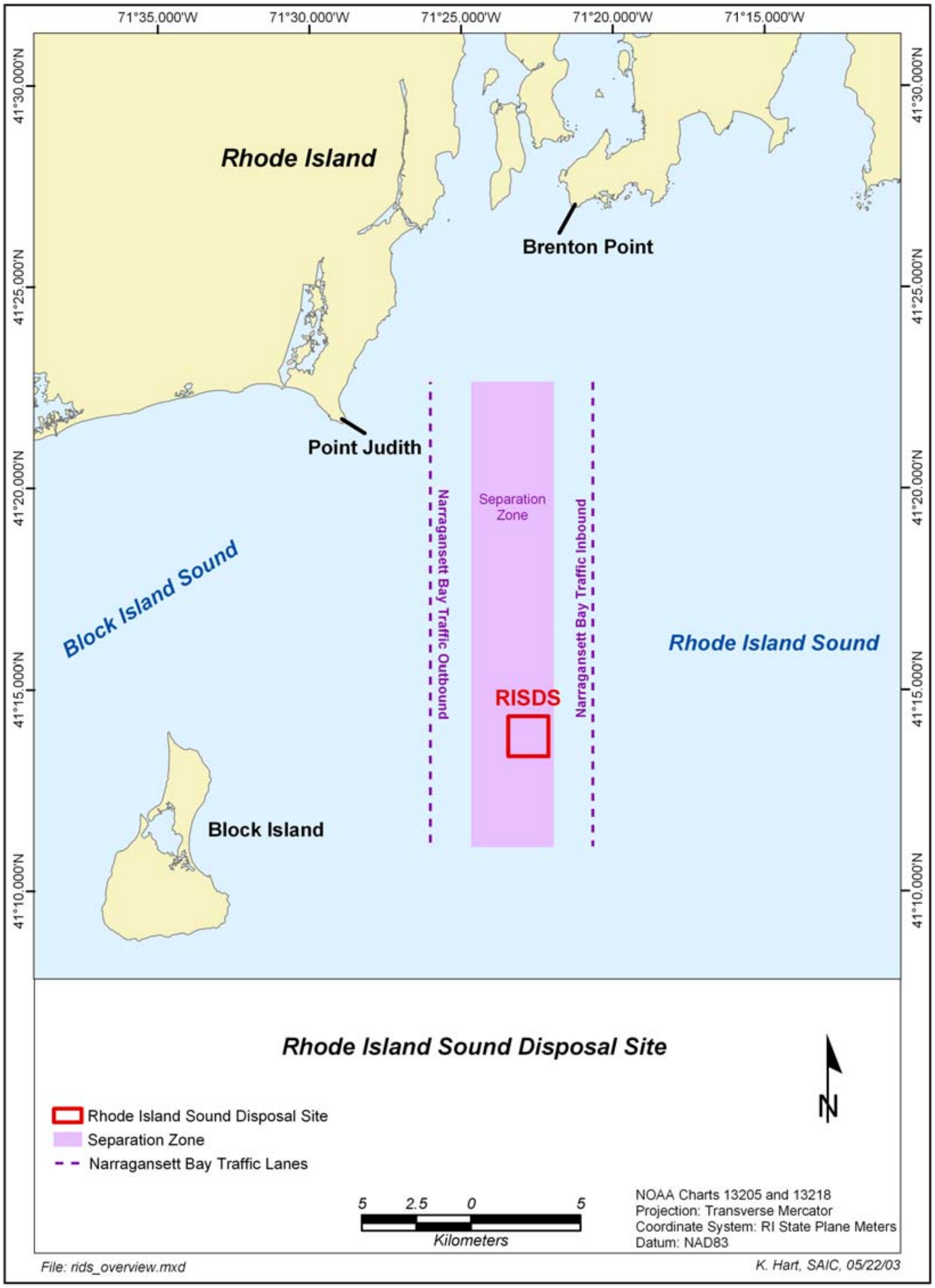


Figure 1-2. Location of the Rhode Island Sound Disposal Site within Rhode Island Sound relative to the coast of southern Rhode Island and adjacent to Block Island, RI.

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.

Between February 2003 and February 2004, several post-disposal bathymetric surveys were conducted over RISDS as part of the disposal site monitoring plan to examine the development of the artificial containment ridge constructed along the western boundary of the disposal site. As of February 2004, a continuous ridge of deposited sediment along the western boundary, in conjunction with a naturally occurring ridge surrounding a depression in the southeast corner of the disposal site, resulted in the formation of an artificial containment cell at RISDS. The continuous ridge was formed to the west of the seafloor depression, essentially increasing the bottom relief of the natural depression to increase its overall capacity from 500,000 m^3 to 2.6 million m^3. The containment structure has been crucial in minimizing the lateral spread of these unconsolidated sediments on the Rhode Island Sound seafloor.

As the Providence River and Harbor Maintenance Dredging Project progressed, a total estimated volume of 1,216,000 m^3 of maintenance dredged material comprised of fine-grained, estuarine sediments was disposed at RISDS within the containment ridge (February 2004 to September 2004). As part of this management strategy, the placement of fine-grained estuarine sediments removed from the various reaches of the Providence River navigation channel was directed to an additional set of pre-defined target disposal locations within RISDS. These target disposal locations (e.g., Targets A-G) were derived based upon the results of disposal modeling efforts conducted by the Engineer Research and Development Center (ERDC; formerly Waterways Experiment Station) prior to the start of the dredging project (Figure 1-3). The premise for employing these target disposal points was to maximize the amount of time that the sediment plume formed by each disposal event would remain within the site boundaries, thus increasing dilution and settlement prior to being advected out of RISDS. The actual selection of these disposal points was dependent upon the stage of the tide and likely direction and rate of sediment plume transport.

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:

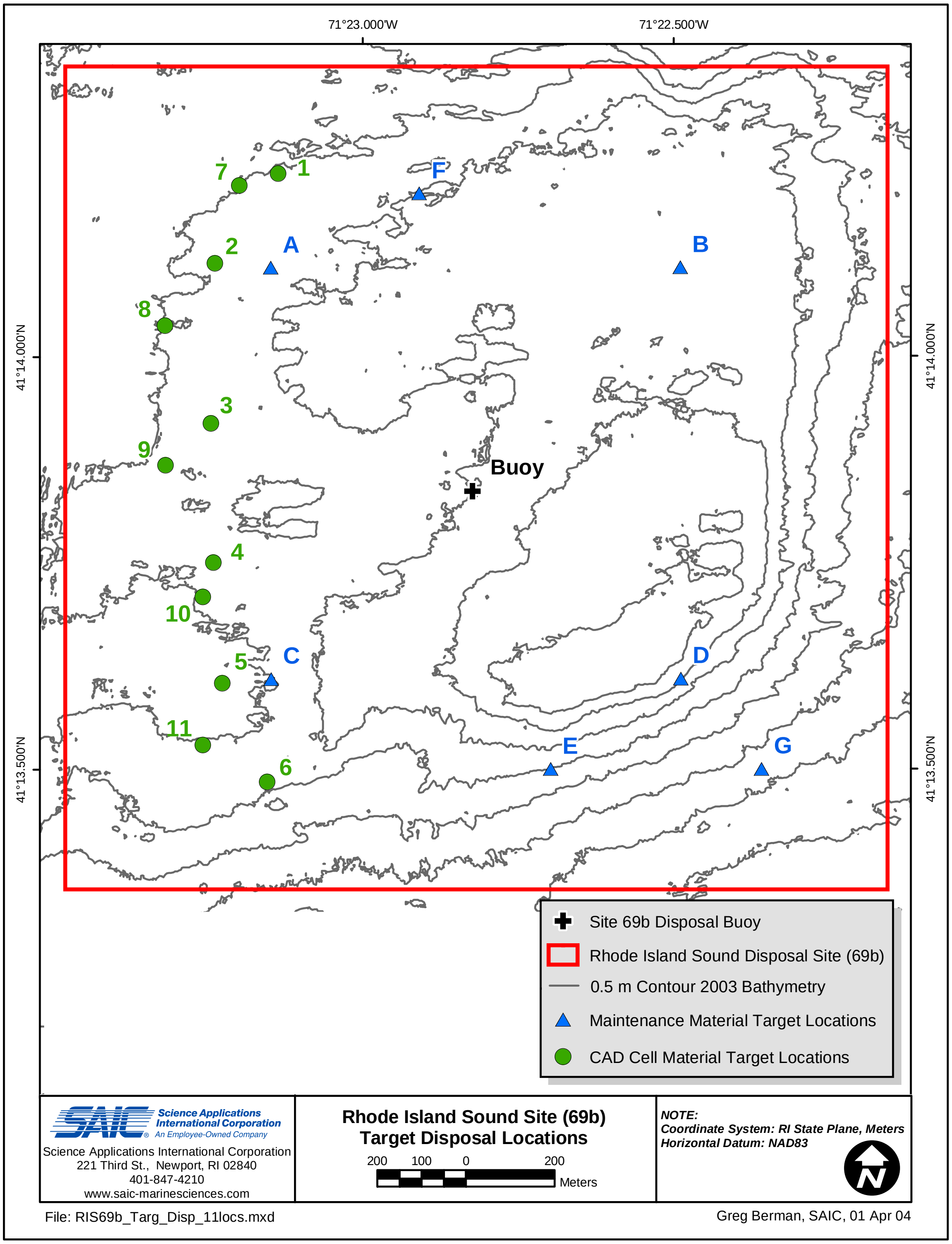


Figure 1-3. Location of the Target disposal locations for maintenance material (blue) and CAD cell material (green) relative to the boundaries of RISDS.

convective descent, dynamic collapse, and passive dispersion (SAIC 1988; Figure 1-4). Although most of the dredged material released from a disposal barge during open water placement operations travels directly to the bottom during the convective descent phase to form a deposit on the seafloor, each disposal event creates a disposal plume comprised of sediments that become 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 at various depth horizons and be advected by the ambient currents (Tavolaro 1984; Truitt 1986).

In the relatively shallow water column that exists over RISDS (36 to 39 m depth), the sediment load within each barge falls to the seafloor within 1 to 2 seconds of release. The small percentage of sediments that become entrained in the water column forms a concentrated column of turbid water directly below the disposal barge (Figure 1-4). 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 contributes 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 clouds of entrained material.

Previous studies suggest the size and configuration of a disposal barge, as well as the geotechnical properties of the dredged material, have a direct effect on the initial morphology of a sediment plume with regards to areal size and concentration of the suspended sediment load (SAIC 2004b). After the initial formation of the plume, behavior and morphology are dependent upon the composition of the entrained sediments (typically fine-grained, unconsolidated silts and clays) and the oceanographic conditions at the open-water disposal site. 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 were directed to appropriate areas of the disposal site to maximize the time that the suspended sediment plumes would remain within RISDS boundaries. On 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 to 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 should occur in the northern or western quadrants of RISDS to ensure that the majority of

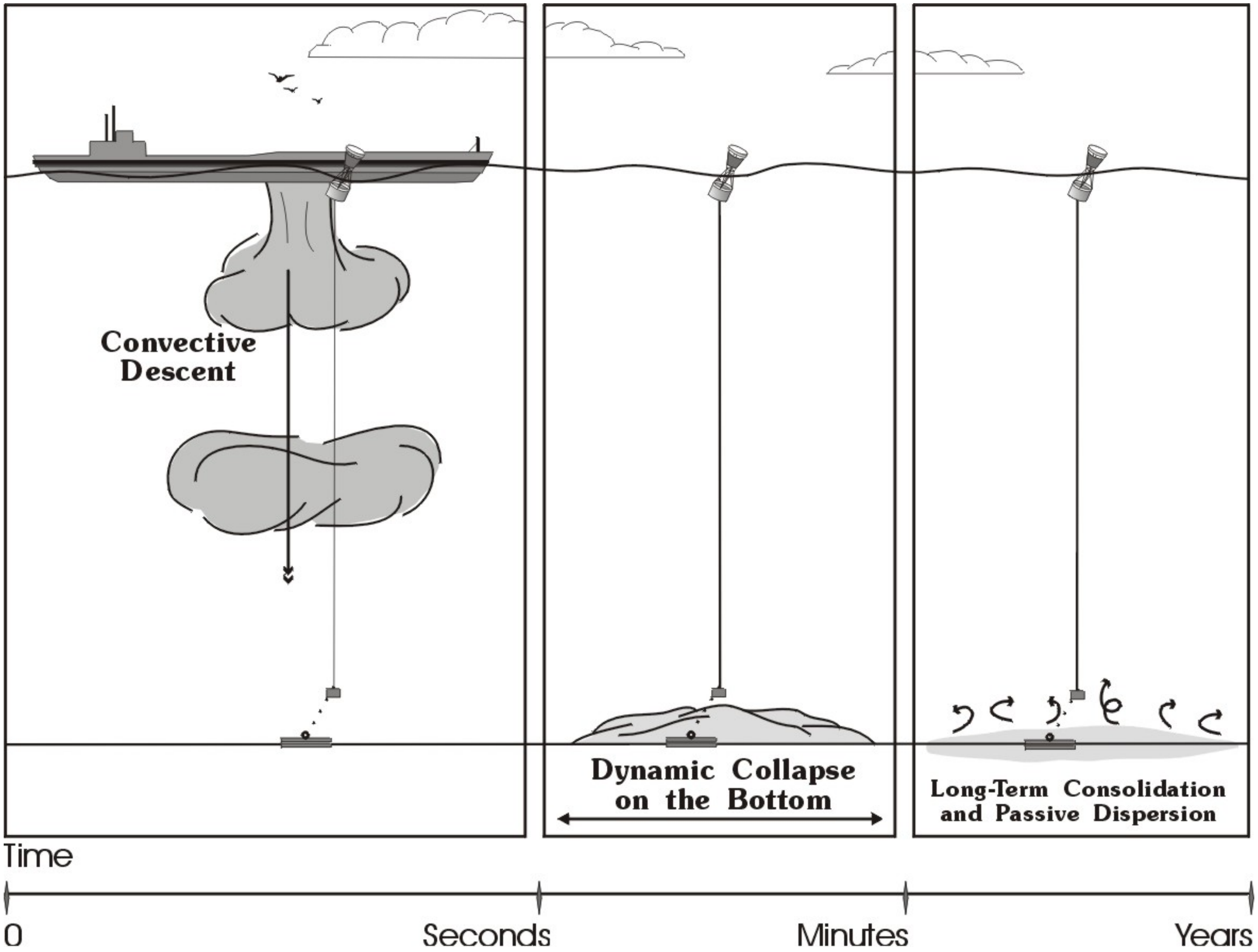


Figure 1-4. Schematic diagram of the three phases of descent encountered during a dredged material disposal event.

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 of maintenance material at RISDS began, 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 ERDC using the Short Term Fate (STFATE) model to predict the concentration and morphology of a typical sediment plume. Sediment plumes following release of Providence River dredged sediment at RISDS were 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 for comparison with estimates made by the STFATE model during the evaluation of the project and included within the Final Environmental Impact Statement (FEIS).

As part of the plume tracking and assessment study, sediment plume tracking was conducted for three disposal events in April 2004 (SAIC, 2005), as well as three disposal events in September 2004. During the April 2004 survey (Survey 1), the sediment plumes formed by the subaqueous disposal of sediment dredged from the Sabin Point Reach were monitored to assess their behavior and morphology. The volume of material transported to the disposal site during the first plume monitoring survey ranged from 3,200 and 4,600 m^3 within two different barge configurations. Comparisons of the three individual disposal events suggested that despite the decrease in the amount of material disposed, the use of smaller capacity barges (4,000 yd^3; 3,050 m^3) yielded a more concentrated and more persistent disposal plume relative to the those generated by disposal activity employing higher capacity disposal barges (4,600 m^3; SAIC 2005).

The final, September 2004 survey (Survey 2) described within this document was performed to observe the transport, morphology, and relative toxicity associated with plumes formed by the open water disposal of sediments dredged from the lower Fox Point and upper Fuller Rock Reaches of the Providence River federal navigation channel. These sediments were of particular interest to regulators, as the results of geochemical and toxicity testing performed on the in-place sediments prior to dredging determined that these sediments were suitable for unconfined open water disposal with a stipulation that individual disposal events be restricted to 2,300 m^3. Disposal barges with capacities of 4,600 m^3 were utilized to transport the smaller volumes (2,300 m^3) of material to the disposal site. The placement of smaller volumes of dredged material by a large capacity disposal barge was expected to result in a relatively dilute sediment plume and minimize any issues associated with acute toxicity in the water column.

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 over RISDS in September 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 water column organisms.

The September 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 solids (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 September 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 second of two distinct monitoring events within RISDS. The September 2004 plume monitoring survey utilized identical sampling techniques to those used during the first monitoring event conducted in April 2004 (SAIC 2005) and was performed during the disposal of material dredged from the Fuller Rock reach of the federal navigation channel.

The second plume-tracking survey was comprised of three consecutive days of sampling to minimize mobilization efforts and the potential changes in water column characteristics (i.e., density stratification) that could affect the behavior of sediment plumes. Survey operations were conducted aboard the M/V Beavertail and the R/V Eastern Surveyor from 1 to 3 September 2004. Field data collection efforts consisted of sediment plume tracking employing a vessel-mounted acoustic Doppler current profiler (ADCP), optical backscatter sensors (OBS), a high-resolution Conductivity-Temperature-Depth (CTD) profiling system and transmissometer, surface and subsurface current drogues, as well as the collection of hydrocasts for total suspended solids (TSS) and toxicity analysis. The sediments dredged from Fuller Rock Reaches were sampled and subjected to geochemical and geotechnical analyses. Individual barge loads 1282, 1286 and 1291 (all with a volume of 2,300 m^3) were targeted for survey operations at RISDS and sampled during the barge filling process at the dredging site to form a single composite. 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 profiling operations within the sediment 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 data, were viewed in real-time to assist with plume location activities and direction of the water sampling operations.

2.2 Barge Sampling

2.1.1 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 a specific reach of the navigation 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 the disposal barge at 30 minute intervals during an approximately three-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.

A rinsate blank was collected as part of each barge sampling effort to verify that the Van-Veen sediment grab sampler was not a source of contamination for the sediment samples extracted from the disposal barge. As described above, the sampling device was cleaned to proper decontamination standards prior to sediment collection. The rinsate blank was then obtained by capturing 8 liters of deionized water that was sprayed over the sediment sampler as a final rinse. The deionized water was collected in a pre-cleaned HDPE five-gallon bucket then transferred to a pre-cleaned 2.5-gallon cube-container and stored on ice for transport off the barge. Upon return to the laboratory, the rinsate water was then transferred to four 1-liter amber glass bottles and one 250-ml polyethylene bottle and preserved with nitric acid (HNO_3). The rinsate samples were then shipped to Woods Hole Group's analytical laboratory at 4° C on the day after collection to ensure the holding times (7 days) were met. The rinsate water within the amber glass bottles was tested for PAHs, while the water stored in the polyethylene bottle was tested for trace metals.

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.

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 were 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.

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

2.2.2.2 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 was 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 September 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 HYPACKMax® 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, HYPACKMax® 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 HYPACKMax®. Depending on the type of field operations being conducted, the real-time navigation information was displayed in a variety of user-defined modes within HYPACKMax®.

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 that were 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 sensor (OBS) 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 in deciding 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 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 that may have resuspended ambient sediment and interfered with measurement of the dredged material plume.

The CTD/transmissometer, in conjunction with the towed ADCP and water-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

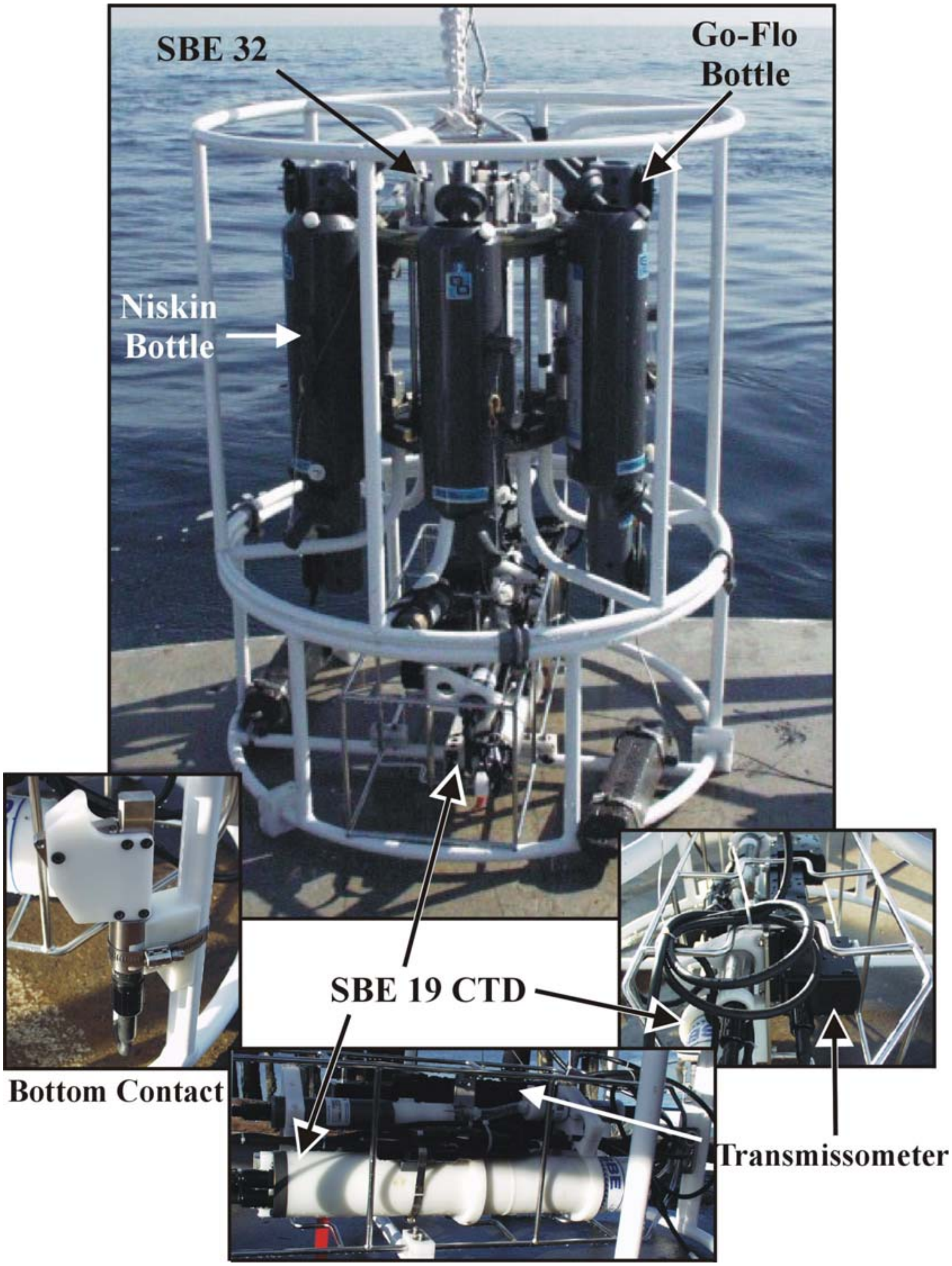


Figure 2-1. Photograph of the Seabird (Model SBE-32) Carousel Water Sampler used for plume tracking and water quality monitoring.

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).

On survey Day 3, a number of supplemental stations were established in Rhode Island Sound to examine background turbidity within the region prior to the dredged material disposal event. A total of seven far field profiles were collected several kilometers outside the boundaries of RISDS, two profiles each to the north, east, and west, as well as one profile to south of the disposal site boundary (Figure 2-2). In addition, three near-field profiles were collected within the disposal site boundary, which included the initial (T0) water sample (Background 8). Background Stations 0 through 4 represented an east-west transect through RISDS, while Stations 2, 5, 6, and 7 comprised a north-south transect. Stations 8 and 9 were established in proximity to the pre-determined disposal point selected by the outbound tug.

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

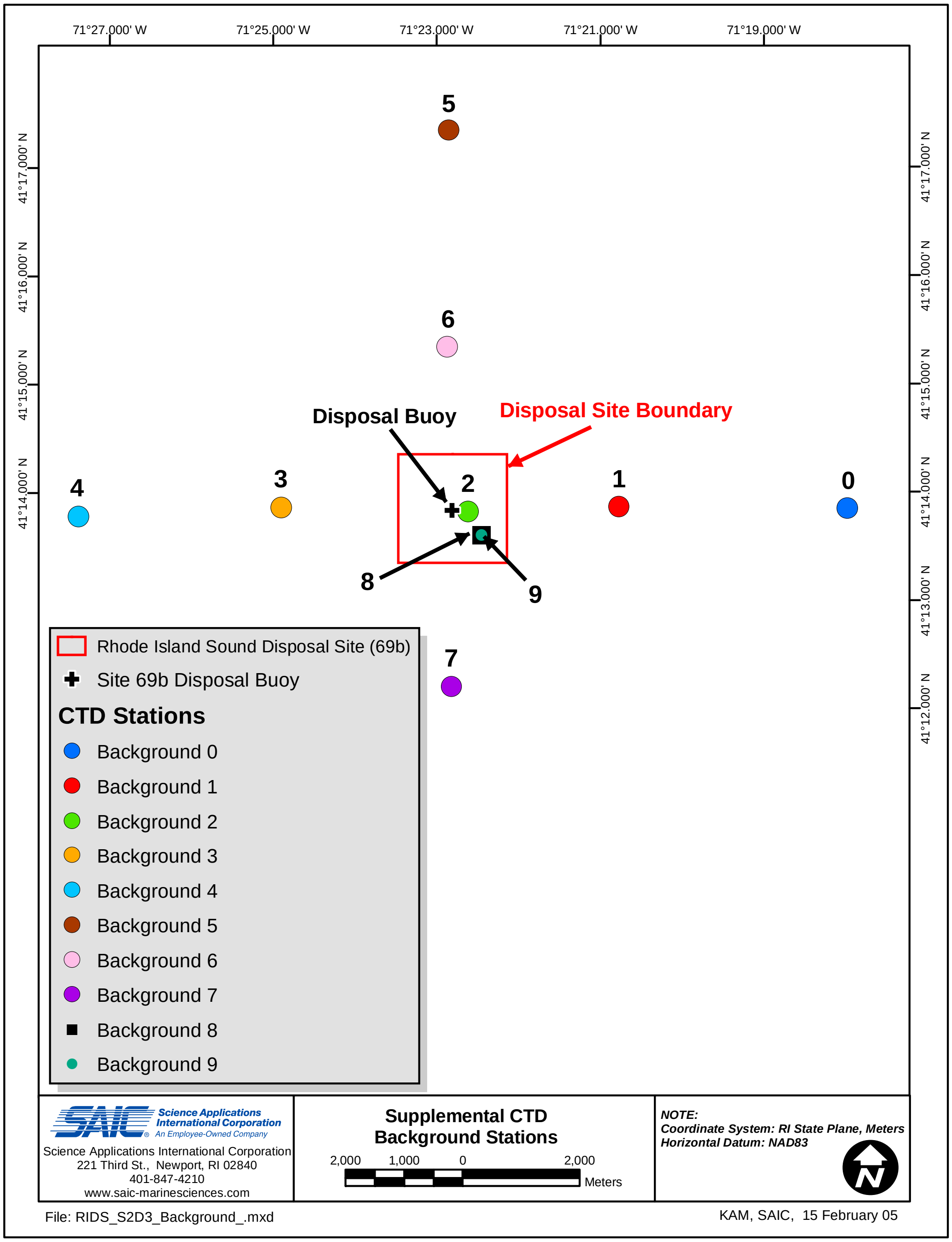


Figure 2-2. Location of supplemental CTD stations occupied in the region to examine background water column turbidity prior to dredged material disposal operations on 3 September 2004, relative to the RISDS boundary (red).

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 1 September and 2 September 2004 only)

triplicate samples 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). Positioning of the CTD survey vessel within the footprint of the plume was based upon the real-time assessment of drogue tracks and the downward-looking ADCP (backscatter profiler) data.

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 three survey days (S2D1, S2D2, and S2D3) were associated with plumes formed by the release of 2,300 m^3 of dredged material from a 4,600 m^3-capacity barge (Loads 1282, 1286, and 1291). The naming convention for RISDS water samples was established prior to survey activities (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 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 345312GG and 345314CM) were used for the total suspended solids analyses. The QC sample (Samples 27997 and 27040) was a Certified ULTRAcheck™ standard obtained from Fisher Scientific (Manufacturer's Lot # 74958). 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 2-3 through 2-5 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 areas, the depth of the lowest OBS sensor 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 was 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.

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 provided 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 intended goal of characterizing the transport and dispersion of the dredged material sediment plumes in the water column.

Underway *in-situ* measurements of acoustic backscatter and horizontal currents were acquired throughout the water column using a vessel-mounted ADCP on a second survey vessel. A single downward-looking, vessel-mounted ADCP (600 kHz) was 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

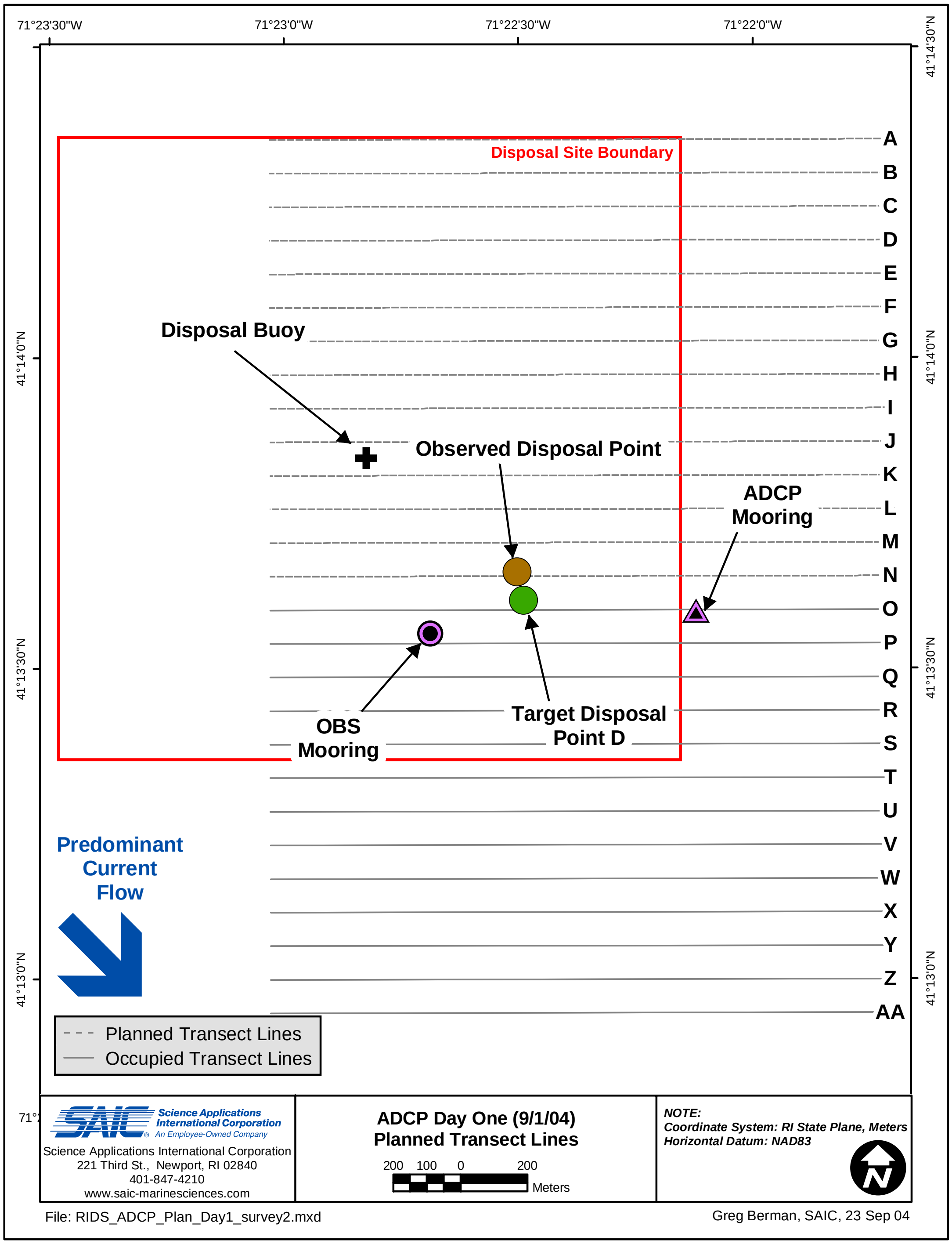


Figure 2-3. Survey tracklines for acoustic monitoring of suspended sediment for Plume 1 during RISDS plume monitoring.

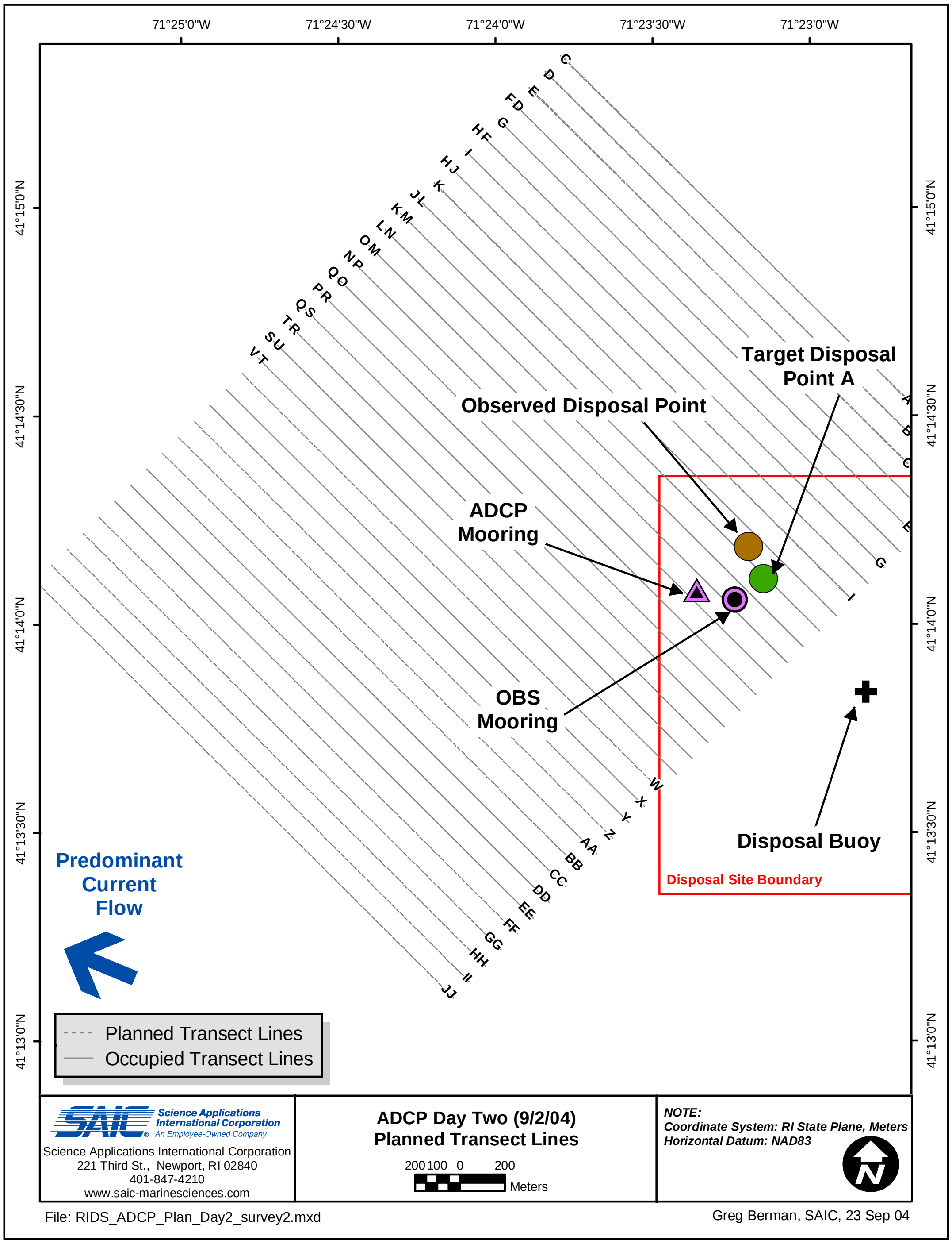


Figure 2-4. Survey tracklines for acoustic monitoring of suspended sediment for Plume 2 during RISDS plume monitoring.

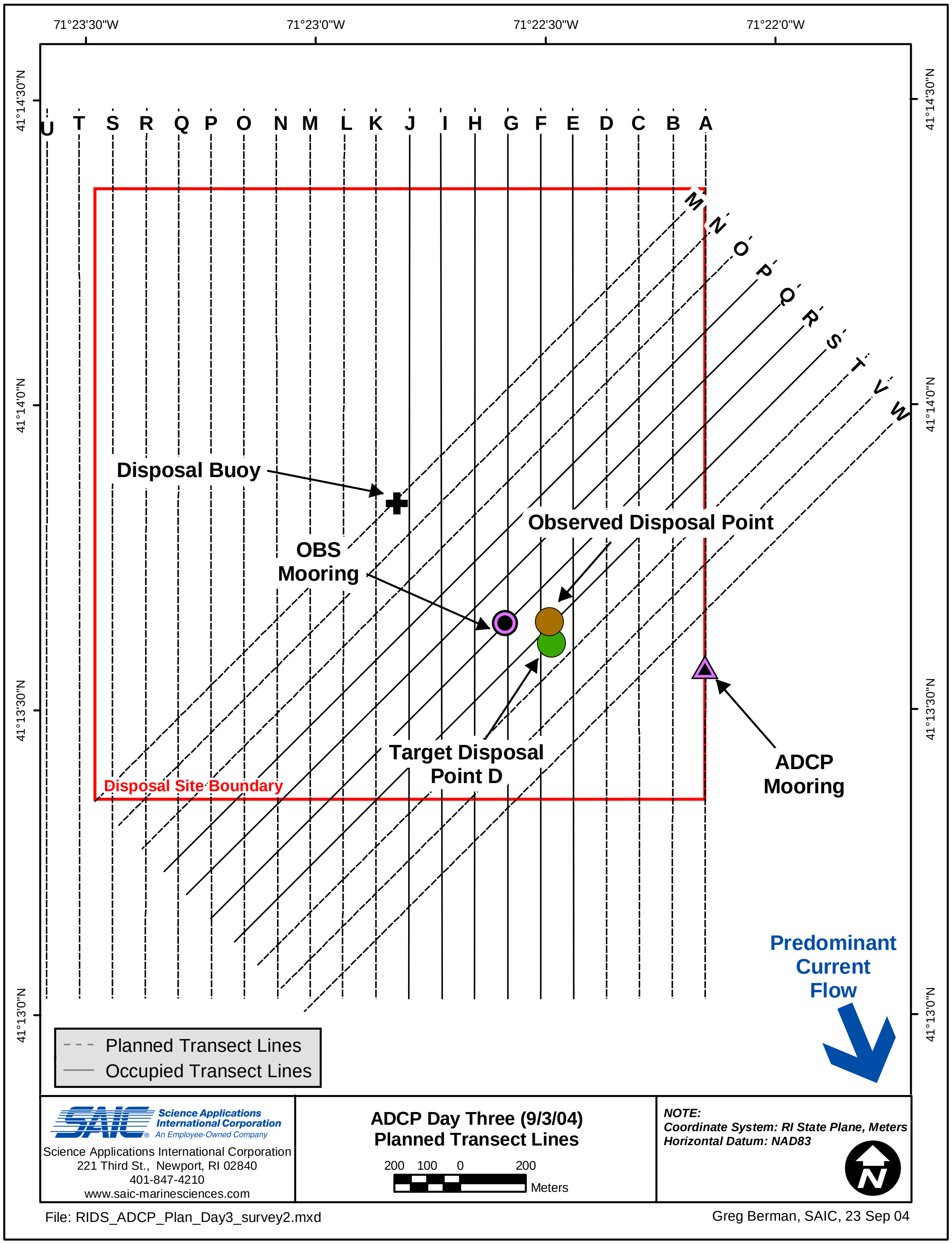


Figure 2-5. Survey tracklines for acoustic monitoring of suspended sediment for Plume 3 during RISDS plume monitoring.

vertical shear in the water column currents and also to monitor the changes in plume morphology in both time and space.

The 600 kHz Broadband ADCP provided a useful blend of resolution and range for identifying the boundaries of the plume and centroid of maximum sediment concentration within the first two hours of each survey operation. The ADCP was also 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 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 collection of cross-sectional data from the moving sediment plume (Figures 2-3 through 2-5). Multiple survey lines oriented along different heading were established over the planned disposal area. Based upon review of the water column current data obtained by the vessel mounted ADCP prior to a disposal event, a survey line orientation that was perpendicular to the anticipated direction of plume transport was selected. East-west oriented survey lines were occupied by the underway ADCP vessel on 1 September, while lines running northwest-southeast were occupied on 2 September. The 3 September field effort utilized lines oriented along a northeast-southwest direction for the first hour of the survey. However, due to a change in water column current flow and the direction of plume transport during the early stages of the survey, pre-established lines running north-south were employed for the remaining 2.5 hours.

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 were 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 a 96-hour water column toxicity test with mysids (*Americamysis bahia*) and juvenile silversides (*Menidia beryllina*). 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 Site 69B 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 ADCP, SAIC deployed two upward-looking ADCPs moored on one bottom mount during the monitoring project. The array supporting both a 1200 kHz and a 300 kHz ADCP 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 1 and 3 September (Days 1 and 3) the ADCP mooring was positioned near the eastern boundary of RISDS within the southeastern quadrant in close proximity to the selected target disposal location (Target D; Figures 2-3 and 2-5). On 2 September (Day 2), this near-field ADCP array was deployed within the western quadrant of RISDS near Disposal Target A in the expected downstream path of the disposal plume (Figure 2-4). Additionally, the high-resolution multibeam bathymetric dataset from the February 2003 baseline survey for Site 69B (SAIC 2004a) was used to assist with selection of mooring placement locations.

The temporal sampling objective required rapid (i.e., 1 Hz) sampling by the ADCPs to acquire high resolution, near-bottom current (and potentially turbidity) data during the relatively brief placement events in order to assess 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 in 1-m intervals 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 one-minute intervals. The ADCP current velocity data were later post-processed to provide the six-minute averaged current magnitude and direction at each useable bin level. In addition, backscatter intensity data 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 were also 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 consisted of a 4.9-m long by 0.6-m diameter nylon cylinder that was attached to a small surface buoy by a small-diameter, nylon line (Figure 2-6). The depth of the mid-water drogue was determined based on the depth of the observed pycnocline within the water column from the real-time CTD profile obtained prior to disposal operations on the first day of monitoring. For each deployment, one mid-depth drogue (15 m) and one near-bottom drogue (32 m, roughly 5 m above the bottom) were deployed as a pair to facilitate real-time tracking of the lateral movement of the plumes at the mid-depth and near-bottom levels. In addition, a single Davis-style surface drifter was deployed at the start of each plume-monitoring event to provide an indication of current flow in the near-surface layer. The surface drifter, mid-depth drogue, and deep-water drogue provided a real-time indication of current shear 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 advected

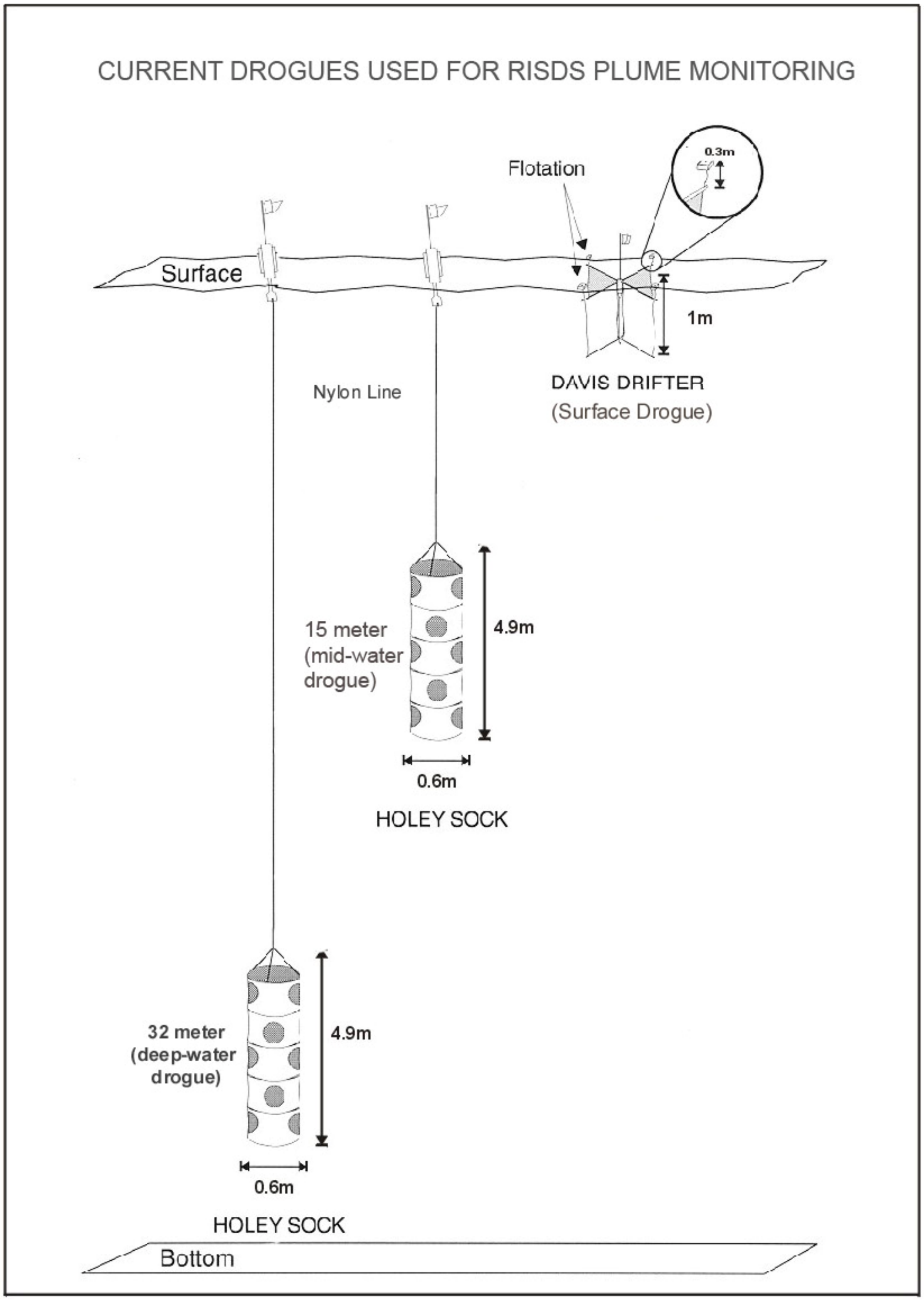


Figure 2-6. Drawing of holey sock drogue and Davis drifter (surface drogue) used for current measurements at mid-water, deep-water, and surface levels.

from the initial placement site by currents. In addition, the majority of the CTD/transmissometer profiles and hydrocasts used to quantify water column turbidity and TSS 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.

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 Fuller Rock Reach the evening prior to each survey effort. In addition, a rinsate blank was also collected as part of each barge sampling effort by capturing a volume of deionized water that was sprayed over the pre-cleaned and decontaminated sediment sampling device. The analytical results for samples deemed S2D1, S2D2, and S2D3 were compared to the results for material collected from Stations G and H during the pre-dredging sediment characterization in 1992, 1993, and 1994.

3.1.1.1 Barge Sample Results

Comparison of the three Fuller Rock Reach dredged material samples collected in September 2004 (S2D1, S2D2, and S2D3) indicated consistent metal concentrations, with metals detected in all samples and standard deviations ranging from 4 to 12% of the means (Table 3-1). The results for the PAH compounds showed greater variability than those for the trace metals; standard deviations for the compounds detected in the three samples ranged between 38 to 58% of the means (Table 3-1). The only analyte that was not detected in each of the three barge samples was acenaphthene, which was present at levels above the detection threshold of 10 μg/kg in two of the three samples analyzed.

The ecological significance of contaminant concentrations were evaluated using comparisons to ecological screening benchmarks (Table 3-1; Buchman 1999). For trace metals, the mean value for each analyte exceeded the most conservative Effects Range-Low (ER-L) benchmark to varying degrees. The mean and maximum concentrations for arsenic and cadmium exceeded the ER-L by roughly a factor of two for arsenic and a factor of three for cadmium, but did not exceed the Probable Effects Level (PEL). Chromium, lead, nickel and zinc concentrations exceeded the corresponding ER-L and PEL benchmarks, but not the Effects Range-Medium (ER-M) benchmarks, with exceedances ranging from 2.3 (nickel and zinc) to 3.6 (lead) times the ER-M. Finally, copper concentrations exceeded the ER-M benchmark for all three samples by a factor of 1.5 to 1.7.

Table 3-1
Sediment Chemistry Results for the Fuller Rock Dredged Material Barge Samples Compared to Ecological Screening Benchmarks.

		Barge Sample Results					NOAA Screening Benchmarks		
Metals	**Units**	**Min**	**Max**	**Mean**	**Stdev**	**Stdev as % of mean**	**ER-L[1]**	**PEL[1]**	**ER-M[1]**
Arsenic	mg/Kg	14.0	16.0	15.0	1.0	6.7	8.2	41.6	70.0
Cadmium	mg/Kg	2.6	2.9	2.8	0.2	5.5	1.2	4.2	9.6
Chromium	mg/Kg	170	200	183	15	8.3	81	160	370
Copper	mg/Kg	400	480	430	44	10.1	34	108	270
Lead	mg/Kg	160	170	163	6	3.5	47	112	218
Mercury	mg/Kg	0.6	0.8	0.7	0.1	12.4	0.15	0.70	0.71
Nickel	mg/Kg	41	48	44	4	7.9	20.9	42.8	51.6
Zinc	mg/Kg	300	350	323	25	7.8	150	271	410
PAHs									
Naphthalene	µg/Kg	36.0	140.0	90.7	52.2	57.6	160	391	2100
Acenaphthylene	µg/Kg	25.0	62.0	48.7	20.6	42.2	44	128	640
Acenaphthene	µg/Kg	ND	33.0	25.5	10.6	41.6	16	89	500
Fluorene	µg/Kg	19.0	58.0	38.3	19.5	50.9	19	144	540
Phenanthrene	µg/Kg	97.0	280.0	192.3	91.7	47.7	240	544	1500
Anthracene	µg/Kg	35.0	90.0	68.0	29.1	42.8	85	245	1100
Fluoranthene	µg/Kg	210.0	500.0	390.0	157.2	40.3	600	1494	5100
Pyrene	µg/Kg	200.0	450.0	363.3	141.5	39.0	665	1398	2600
Benz[a]anthracene	µg/Kg	88.0	200.0	159.3	62.0	38.9	261	693	1600
Chrysene	µg/Kg	120.0	270.0	220.0	86.6	39.4	384	846	2800
Benzo[b]fluoranthene	µg/Kg	130.0	290.0	236.7	92.4	39.0		1800*	
Benzo[k]fluoranthene	µg/Kg	100.0	240.0	193.3	80.8	41.8		1800*	
Benzo[a]pyrene	µg/Kg	130.0	290.0	233.3	89.6	38.4	430	763	1600
Indeno[1,2,3-cd]pyrene	µg/Kg	92.0	210.0	167.3	65.4	39.1		600*	
Dibenz[a,h]anthracene	µg/Kg	28.0	62.0	50.7	19.6	38.7	63	135	260
Benzo[g,h,i]perylene	µg/Kg	100.0	220.0	180.0	69.3	38.5		670*	
Inorganics									
Solids, Percent	%	30.0	32.0	30.7	1.2	3.8			

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.

For PAHs, there were several exceedances of the ER-L benchmark, including acenaphthylene (mean and maximum of 62 and 49 μg/kg compared the ER-L of 44 μg/kg), fluorene (mean and maximum of 58 and 38 μg/kg compared to ER-L of 19 μg/kg), phenanthrene (maximum of 280 μg/kg compared to ER-L of 240 μg/kg), and anthracene (maximum of 90 μg/kg compared to ER-L of 85 μg/kg, [Table 3-1]). These are relatively minor exceedances of the more conservative benchmark, and no concentrations exceeded the PEL. The remaining PAH compounds exhibited maximum concentrations that were below their respective ER-L.

3.1.1.2 Rinsate Blank Results

A rinsate blank was collected along with the barge samples collected during the Fuller Rock Reach dredging in September 2004. Rinsate blanks consisted of the collection of a sample of rinse water following equipment decontamination, providing information on the adequacy of the equipment decontamination procedures. Blank sample S2D2 RISDS-1286-GL63 collected on 1 September 2004, yielded very low detections of all but two metals (mercury and cadmium were not detected) ranging from 1.4 $\mu g \cdot L^{-1}$ (arsenic) to 65 $\mu g \cdot L^{-1}$ (zinc) and all but three PAH compounds with detected concentrations ranging from 5.6 to 78 $ng \cdot L^{-1}$ (part per trillion). The maximum occurred for naphthalene, which was also detected in the laboratory blank, suggesting it was introduced during the laboratory procedures.

The detected metal concentrations in the part per billion (ppb) range were 4 to 5 orders of magnitude lower than the range of concentrations for metals in the sediment samples (15 to 430 mg/kg or part per million, ppm). Similarly for PAH compounds, analytes detected in the rinsate blank, between 5.6 and 78 $ng \cdot L^{-1}$, were 4 to 5 orders of magnitude lower than the concentrations detected in the barge sediment samples (58 - 500 ppb). Therefore, the contributions of the metal and PAH concentrations detected in the rinsate blank to the sediment concentrations would be inconsequential to the sediment results.

3.1.2 Geotechnical Characterization

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

Table 3-2
Barge Sampling Sediment Grain Size Results

Sample	% Cobble	% Gravel	% Sand			% Fines		% Water Content	% Total Solids
			Coarse	Medium	Fine	Silt	Clay		
S2D1	0.00	0.00	0.02	0.13	2.64	54.83	42.39	263	28
S2D2	0.00	0.00	0.05	0.18	1.51	49.29	48.97	234	30
S2D3	0.00	0.00	0.00	0.18	1.19	46.78	51.85	215	32
S2D3 QC replicate	0.00	0.00	0.00	0.18	1.30	45.03	53.50	215	32

Method: ASTM D422

The sediment collected from Load 1282 that would form the plume to be studied on 1 September was predominantly fine-grained (97.22%) with a small fraction of sand (2.79%) (Table 3-2). The fine-grained component was comprised of 42.39% clay and 54.83% silt, while the 2.79% sand fraction contained fine (2.64%), medium (0.13%), and trace amount of coarse (0.02%) sand. Total solids composed 28% of the sample collected from Load 1282. Water content (ratio of water to sediment particles) was 263%; this high value was likely the result of the incorporation of water into the excavated sediment load due to the use of a closed dredging bucket (Table 3-2). 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 1282 above, sediment grab samples were collected from GLLD Barge 63 (Load 1286) and composited during the filling process prior to the 2 September disposal event. A summary of the grain size results associated with the barge sediment sampling data is provided in Table 3-2. Once again, the sediment collected was predominantly fine-grained, with a very minor sand component (1.74%). Silt comprised 49.29% of the sample while clay-sized grains made up 48.97% (Table 3-2). The 1.74% sand fraction was predominantly fine-grained (1.51%), with only 0.18% of the total sample classified as medium-grained sand and 0.05% classified as coarse sand. Total solids composed 30% of the sample collected from Load 1286, while water content was 234% (Table 3-2).

The sediment sample collected from GLLD Barge 65 (Load 1291) prior to the 3 September disposal event was predominantly fine-grained sediment with a very small fraction of sand (1.37%); no coarse sand, cobble or gravel was present in any of the samples (Table 3-2). The fine-grained material was comprised of 51.85% clay and 46.78% silt. Total solids within the sample were 32%, while water content was 215%, suggesting slightly less incorporation of water in the excavated material relative to previous barge loads sampled (Table 3-2).

3.2 Disposal Plume Monitoring

3.2.1 Plume 1

The first day of the plume survey operations occurred on 1 September 2004, in association with the sediment plume generated by the disposal of 2,300 m³ of material dredged from the Fuller Rock Reach and placed at Point D within RISDS. Load 1282 was deposited by a split-hull barge in the southeastern quadrant of the disposal site at 18:12 universal time coordinated (UTC; four hours ahead of local daylight time). Comprehensive plume tracking and water sampling were performed using two 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 began during the final stages of an ebb tide (Figure 3-1). The plume monitoring activity continued through the slack tide and early stages of the subsequent flood tide, concluding around 22:00 UTC. During this time period, the net transport of the sediment plume was to the south/southeast 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 south/southeast direction in response to water column currents (Figure 3-2). The average speed of the surface water was determined to be 21 $cm \cdot s^{-1}$ 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 average speed of 15 $cm \cdot s^{-1}$, based on the information from the positional fixes for drogues at deployment and recovery. The track of the mid-depth drogue suggested the mid-water column currents were moving a rate of 24 $cm \cdot s^{-1}$ (Table 3-3). These data suggested that the direction of flow was somewhat consistent, but the increased currents in the mid-water likely had a significant effect on the overall plume morphology during this survey period.

The bottom-mounted ADCP records for 1 September provided additional information on currents within RISDS during the plume monitoring event. Overall, the ADCP current data agreed well with the information from the drogues and drifter with regards to direction and magnitude of flow. The moored ADCP confirmed a uniform southeastward direction of flow throughout the water column that was observed in the drogue transport, with speeds ranging from near 0 $cm \cdot s^{-1}$ at depth to a maximum value in excess of 50 $cm \cdot s^{-1}$ near surface (Figure 3-3). The high resolution data indicated the currents in the upper water column were stronger than those at depth. Mean speeds ranged from 15 $cm \cdot s^{-1}$ near-bottom to over 30 $cm \cdot s^{-1}$ in the upper water 15 m of the water column, resulting in vertical shear in horizontal currents (Figure 3-3).

The time-series of six-minute averaged ADCP current data showed coherent flow (little rotation with depth) in the water column to the southeast for the entire 4.5 hour deployment period (Figures 3-4 and 3-5). During the first two hours of the deployment, the strongest currents were observed at mid-depth (approximately 18.5 m depth), with average velocities exceeding 30 $cm \cdot s^{-1}$ at times. At approximately 19:30 UTC, near-surface currents became the strongest transport mechanism within the water column as velocities

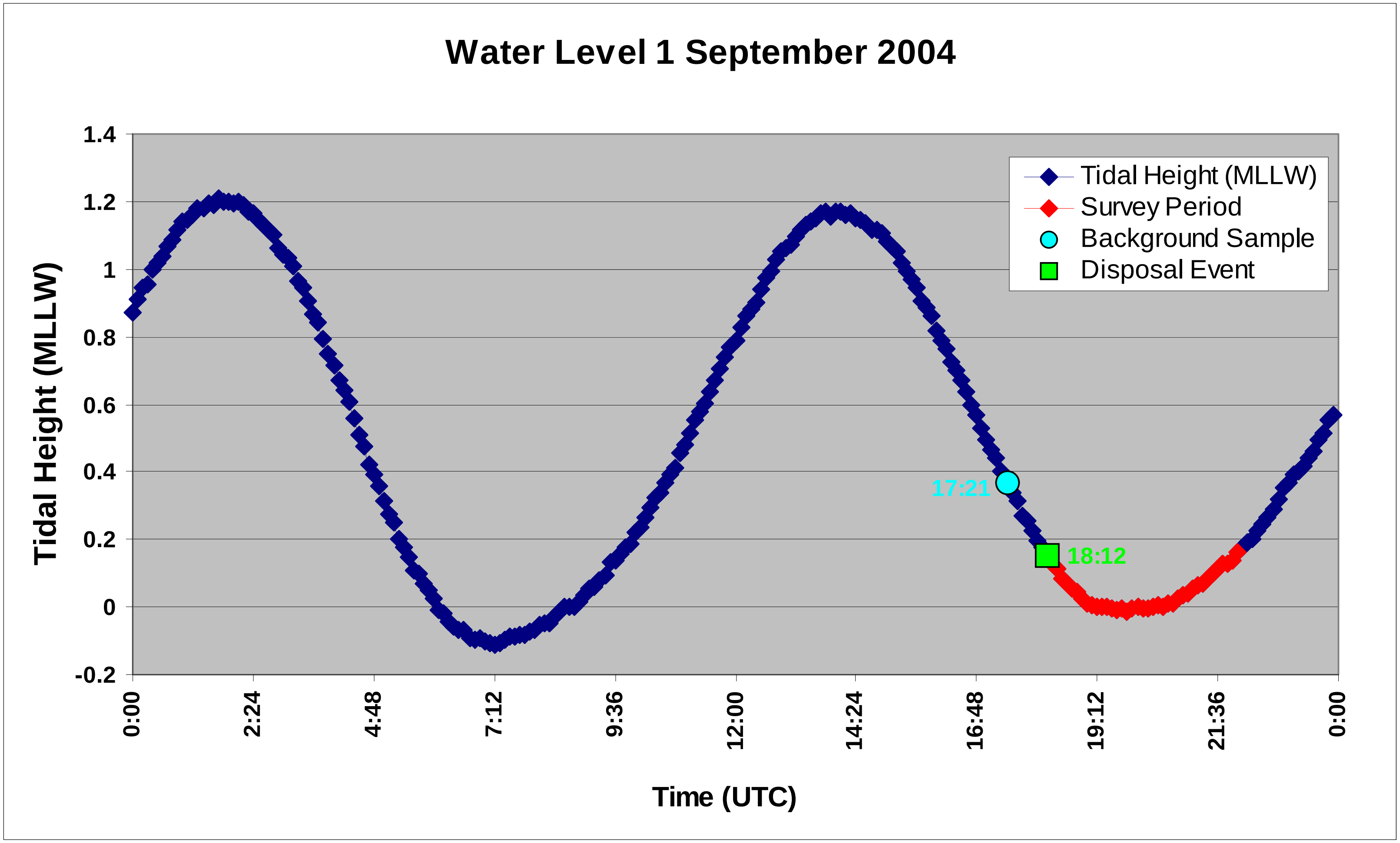


Figure 3-1. Water level data from the NOAA tide station in Newport, RI, corrected to the tide zone encompassing RISDS for 1 September 2004. The Background Sample and Disposal event are shown in comparison to the tidal stage.

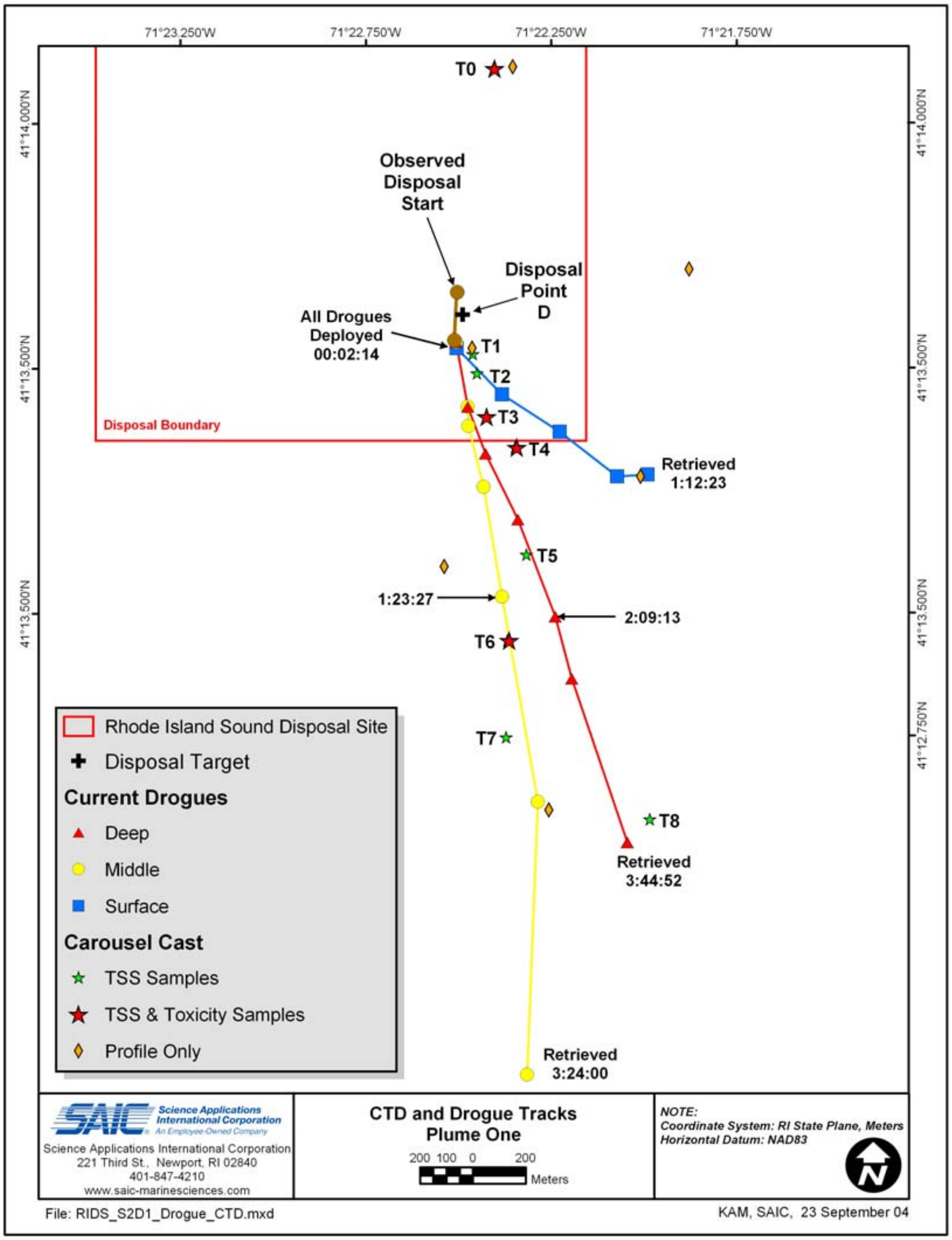


Figure 3-2. Map indicating current drogue trajectories and CTD cast locations during the tracking of Plume 1. Locations of water samples are also shown. Times represent elapsed time since disposal operations.

Table 3-3

Summary of Drift Statistics for Current Drogues Deployed during the RISDS Plume Monitoring Surveys

		Drogue Depth meters	Deployment Time UTC	Retrieval Time UTC	Elapsed Time HH:MM:SS	Distance Traveled meters	Average Speed cm/s	Average Direction
1 September (Day 1)	Surface	1	18:14:59	19:25:08	1:10:09	870	21	SE
	Mid	15*	18:14:59	18:40:45		-	-	-
	Mid	15**	18:45:04	21:36:45	2:51:41	2475	24	S
	Deep	32	18:14:59	18:40:45		-	-	-
	Deep	32**	18:45:04	21:57:37	3:12:33	1725	15	SSE
2 September (Day 2)	Surface	1	13:42:40	16:26:28	2:43:48	1315	13	W
	Mid	15*	13:42:40	16:52:05	3:09:25	2571	23	WSW
	Deep	32	13:42:40	17:06:59	3:24:19	2095	17	W
3 September (Day 3)	Surface	1	17:17:44	19:59:04	2:41:20	1033	11	S
	Mid	15*	17:50:15**	20:09:57	2:19:42	754	9	SSW
	Deep	32	17:17:44	20:22:14	3:04:30	551	5	SE

Note: * Height adjusted relative to Survey 1.
**Drogue Re-Deployed due to entanglement

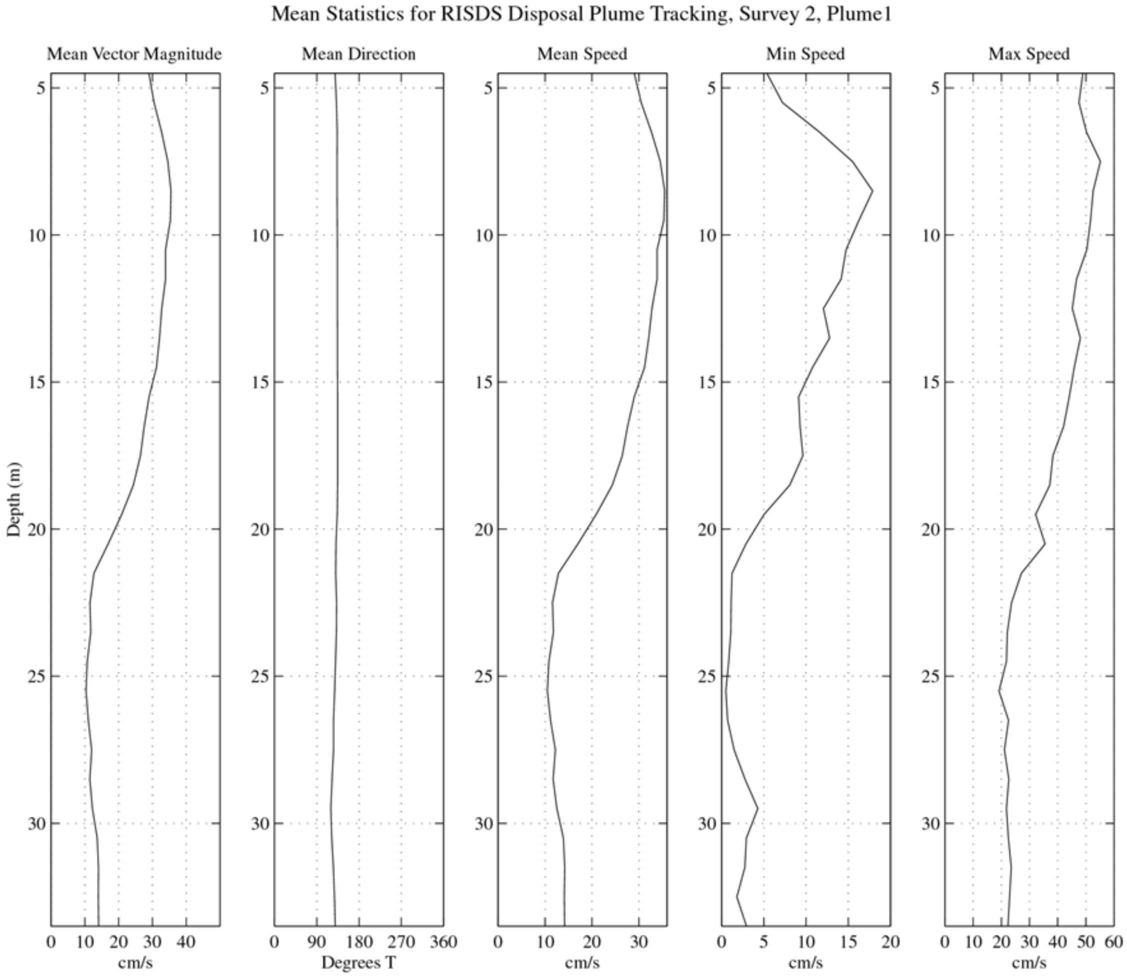


Figure 3-3. Statistics of moored current meter data collected on site during Plume 1 disposal monitoring activities. Parameters plotted include mean vector magnitude, mean vector direction, mean speed (regardless of direction), minimum speed and maximum speed.

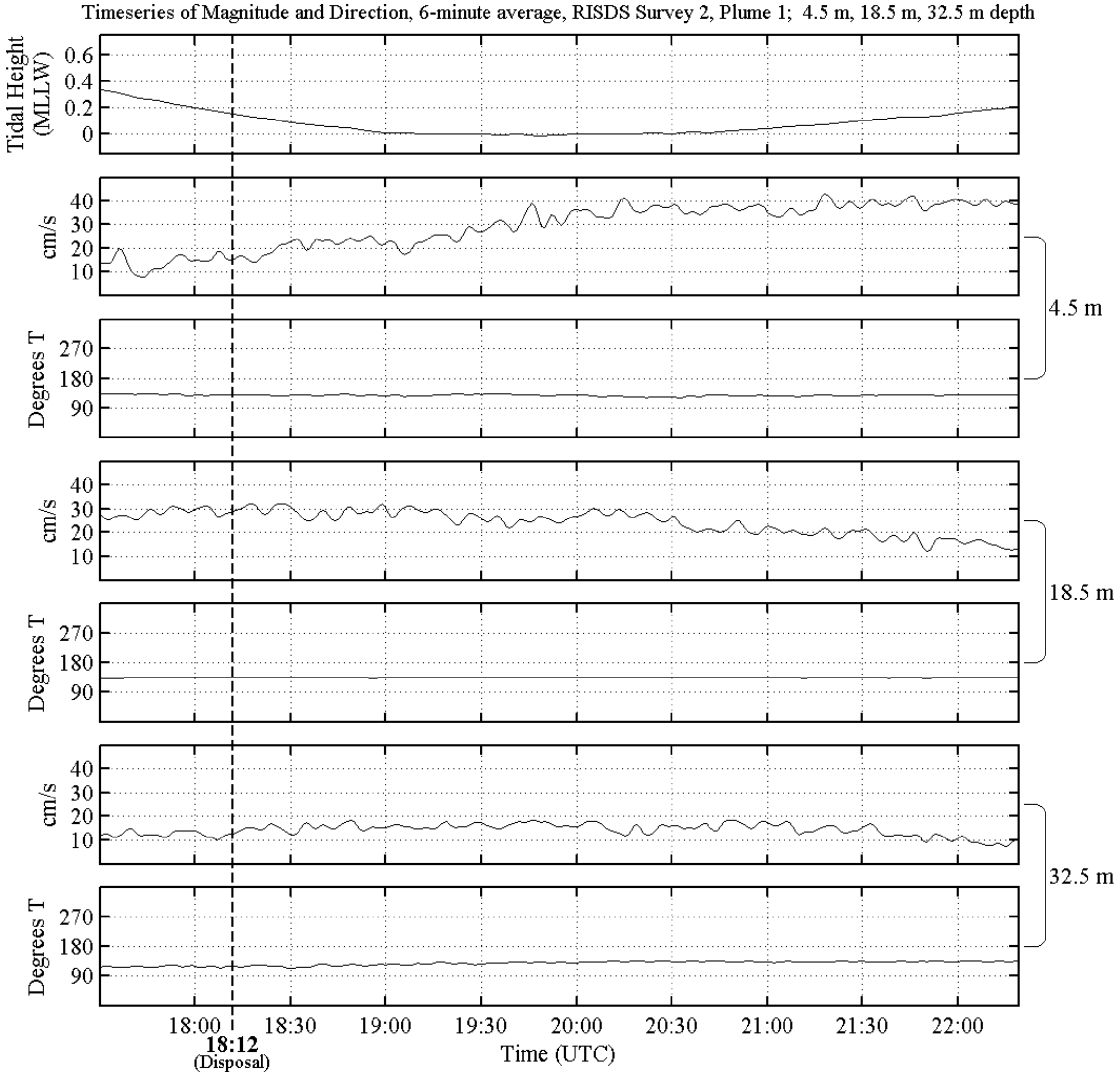


Figure 3-4. Time-series plot of current magnitude and direction during Plume 1 at the near-surface level (~4 m; top two panels) and the two selected drogue depth levels of ~18 m (middle two panels) and ~32 m depth (bottom two panels). Currents were sampled at 1-minute intervals, and filtered with six-minute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

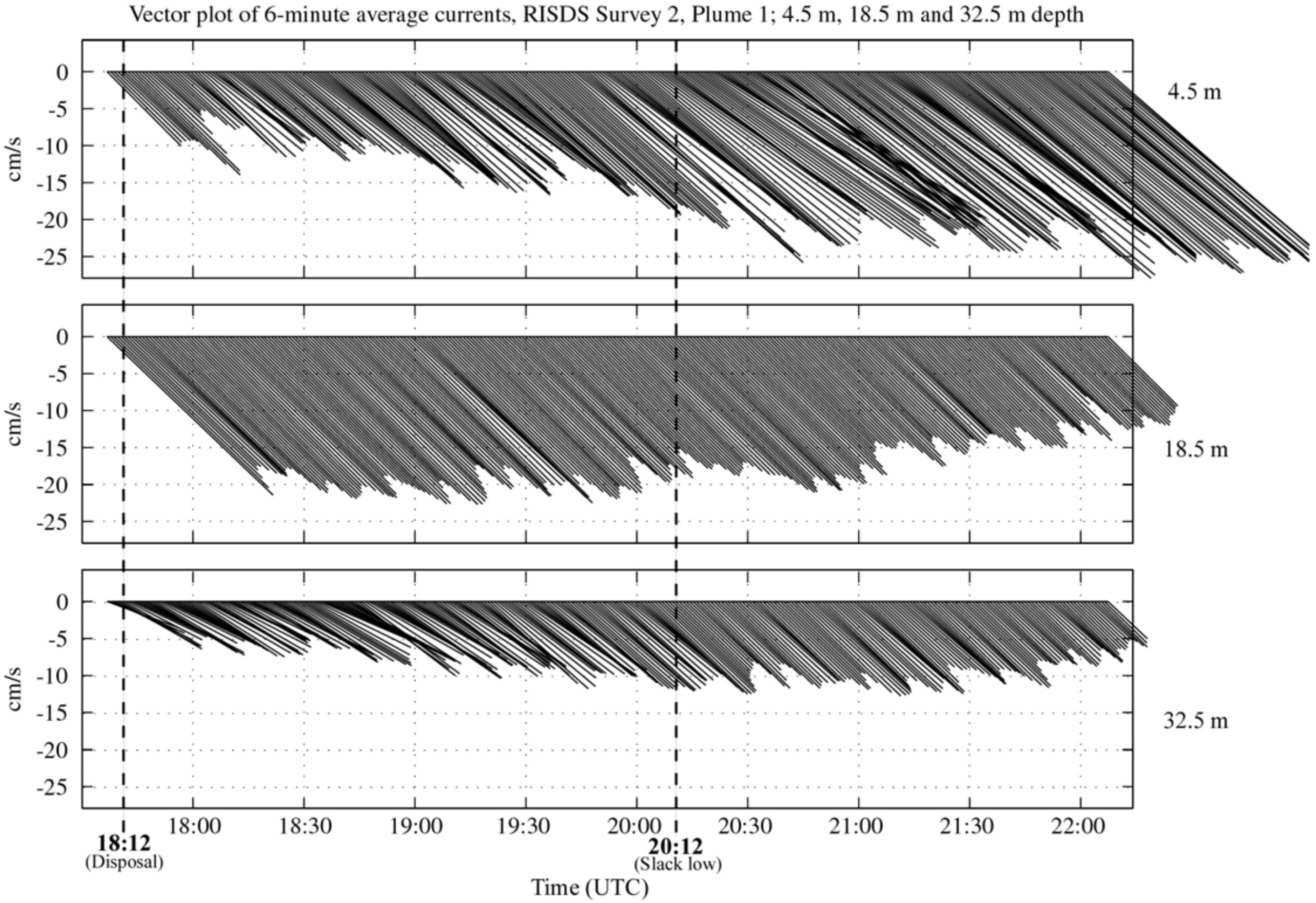


Figure 3-5. Time-series plot of current vectors (six-minute LPF) during Plume 1 at the near-surface level (~4 m; top panel), as well as the two selected drogue depth levels of ~18 m (middle panel) and ~32 m (bottom panel).

approached 40 cm·s^{-1}. Currents at mid-depth gradually decreased in velocity over time, but maintained a consistent southeast direction of flow.

The vessel-mounted ADCP data collected on 1 September agreed with the observations of the bottom-mounted instruments and current-following drogues. The vessel-mounted ADCPs detected southeastward flow over most of the survey period, with average speeds ranging between 0 and 10 cm·s^{-1} in the lower water column and between 10 and 20 cm·s^{-1} in the upper water column. Toward the end of the survey day, current velocities in the upper water column increased somewhat, to an average speed of approximately 25 cm·s^{-1}, however, currents still flowed in a southeastward direction.

3.2.1.2 CTD/Transmissometer Profiles

As part of the plume monitoring operations for Load 1282, a total of 15 CTD profiles were acquired within and adjacent to RISDS during the 3.5-hour monitoring period. A background CTD profile and water samples (T0) were collected prior to disposal operations in the vicinity of the targeted disposal location (Figure 3-2). Due to difficulty in establishing communication with the outbound tugboat and disposal barge, the background sample was collected approximately one hour prior to the disposal event in the northeast corner of the disposal boundary, north of the assumed disposal event (Disposal Target B). Although the disposal barge ultimately placed the material in proximity to Disposal Target D, the background water sample was still considered representative of water column conditions within the disposal site.

The term “background” represented local water column conditions (e.g., temperature, salinity, density, light transmission, etc.) prior to disposal. The corresponding background water column profile displayed relatively consistent salinity values with depth, maintaining a value of 31.9 PSU, while both density and temperature displayed noticeable changes with depth (Figure 3-6). As anticipated during the summer months, water temperatures decreased with depth (21.0 to 12.1°C), with distinct thermoclines detected at approximately 7 and 20 m depths. Seawater density tracked closely with the temperature profile, and displayed a general increase with depth (21.7 to 24.2 sigma-t). Distinct pycnoclines were observed within the density profile and corresponded to the depths of the thermoclines (7 and 20 m).

Data from the transmissometer indicated that percent light transmittance remained between 76 to 81% within the majority of the water column, but displayed a sharp decrease at approximately 30 m depth (Figure 3-6). Below 30 m, values decreased rapidly and eventually reached the minimum light transmittance value of 44% approximately 2 to 3 m above the seafloor. The distinct near-bottom turbidity feature detected in the background profile could have been attributable to a variety of potential sources (i.e., local

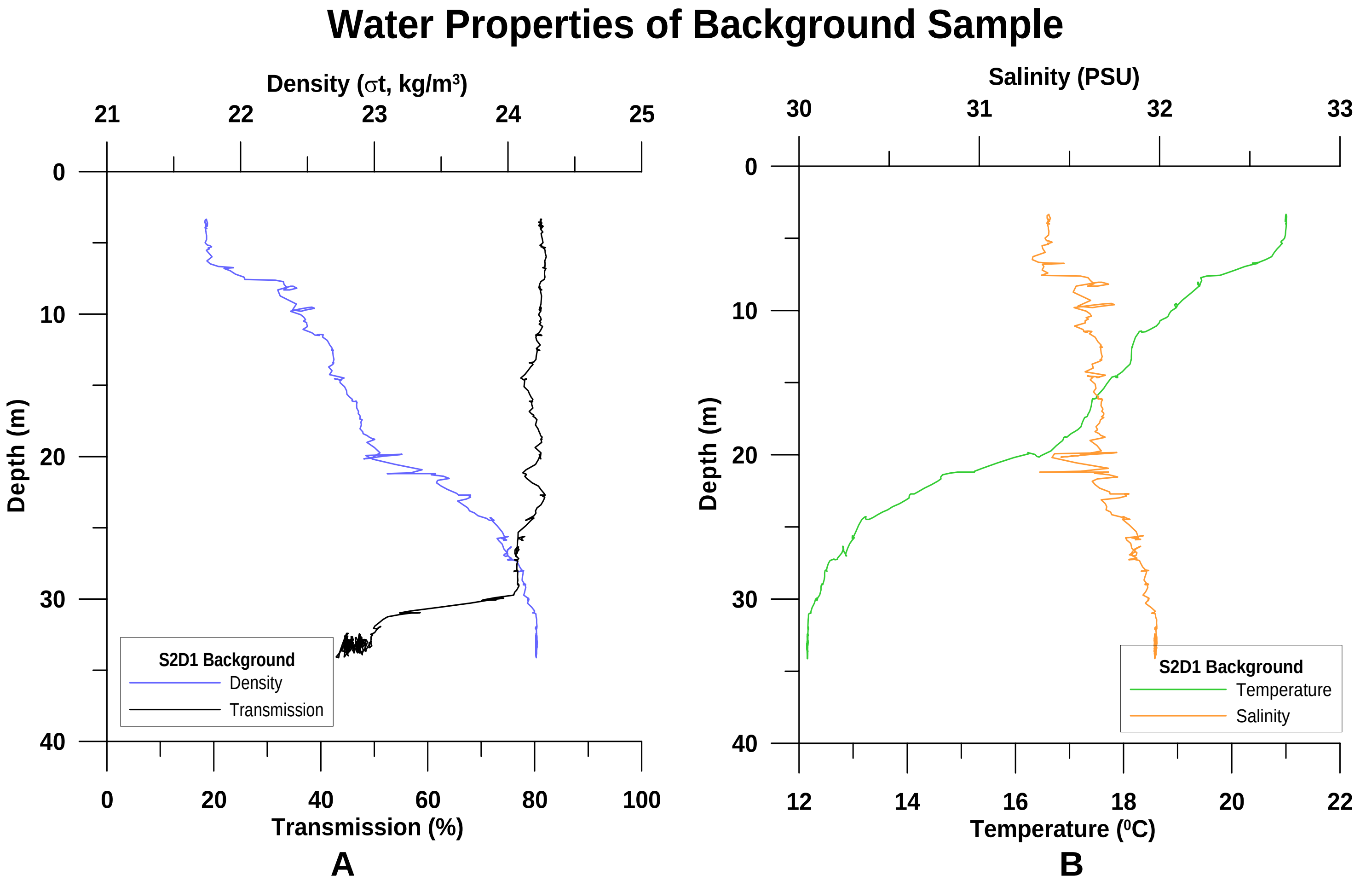


Figure 3-6. Profile plots of percent light transmission and seawater density versus depth (A) and temperature and salinity versus depth (B) acquired during the CTD background sample interval for Plume 1. Data are from the downcast profile only.

resuspension or residual plume sediments from previous disposal events). Although this elevation in near-bottom turbidity appeared isolated to a 2- to 3-m layer, it had the potential of obscuring the suspended sediments associated with the tracked plume by preventing differentiation of the plume material from pre-existing turbidity.

As the disposal barge approached Disposal Target D from the north, the CTD sampling vessel positioned itself immediately astern. The disposal event began at 18:12 UTC and was completed within two minutes. During that period of time, the draft of the split-hull barge decreased by more than 3 m while it drifted approximately 200 m south (Figure 3-2). As sediment was released from the barge, a surface plume was evident in close proximity to its track.

The T1 sampling interval occurred twelve minutes after the start of the disposal event, at a location approximately 100 m south of Disposal Target D and in close proximity to the drogue positions (Figure 3-2). The CTD profile was completed in an area displaying a water depth of 35 m and provided data on the physical characteristics of the water column, as well as suspended sediment load to a depth of 33 m. The transmissometer record indicated the presence of three distinct layers of turbid water existing at the near-surface, mid-depth, and near-bottom, each separated by relatively clear water (Figure 3-7). A high concentration of entrained sediments from the surface to a depth of 10 m resulted in very low light transmittance values (nearly zero). Turbidity levels remained at near-background conditions between 11 and 20 m depth, but a second layer of turbid water was encountered at a depth of 21 m causing transmittance values to drop sharply from 81 to 0%. Another sharp contrast in turbidity was detected at approximately 23 m, with relatively clear water present within the 23 to 27 m depth interval. The near-bottom portion of the sediment plume was detected below 27-m water depth and appeared as a gradual increase in suspended sediments with depth. At a depth of 33 m (2 m above the seafloor), the transmissometer profile displayed a rapid decrease in percent transmittance denoting the most turbid portion of the near-bottom plume. A water sample for TSS analysis was collected approximately 2 m above the seafloor within this portion of the plume (Figure 3-7).

The strong surface plume during the T1 profile may have been the result of the CTD survey vessel being positioned very close to the disposal location and centroid of the concentrated plume. The CTD profile acquired during T1 sampling was most likely representative of a lowering of transmittance along the edge of the plume. The lower transmittance values are similar to the turbid waters that would be found closest to the centroid. However, the morphology of the concentrated sediment plume several minutes following the disposal event, as depicted in Figure 3-7, suggests that although this sample was most likely collected within the plume, it was outside the absolute core or centroid.

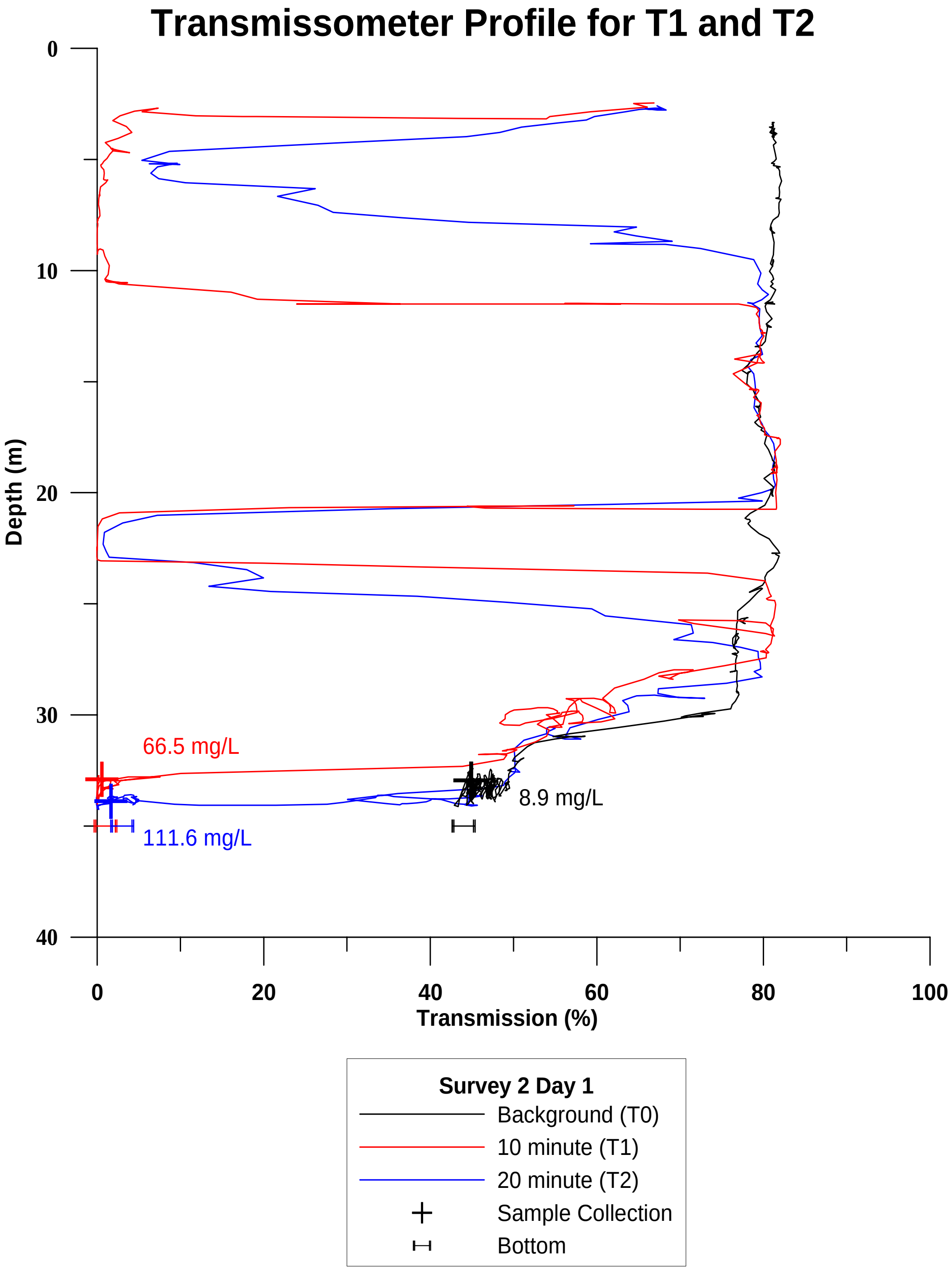


Figure 3-7. Profile plot of percent light transmission and sensor depth acquired during CTD sample intervals T1 and T2 for Plume 1. Locations of water sample collections within the plume are also shown.

At the 20-minute sampling interval (T2), a vertical CTD profile was collected in proximity to the surface drifter (Figure 3-2). Similar to the T1 profile, the transmissometer record for the T2 profile showed three discrete layers of turbid water separated by intervals of clear water. This layering effect was likely a function of the survey vessel being positioned along the edge of the concentrated plume. The near-surface portion of the plume was present from approximately 3 to 10 m depth and displayed light transmittance values ranging between 5 and 25% (Figure 3-7). A layer of clear water was encountered in the middle portion of the water column between 12 and 21 m water depth. A sharp decrease in percent light transmittance (increase in turbidity) was then detected below 21 m depth and persisted to a depth of 25 m. This 4-m interval of turbid water displayed transmissometer values ranging from 5 to 20% before returning to near-background conditions. The near-bottom portion of the sediment plume was first detectable at a depth of 27 m, with light transmittance decreasing gradually with depth until a maximum turbidity was encountered at a depth of 33 m. A water sample was collected at a depth of 33.8 m for the determination of the total suspended solids concentration within the near-bottom portion of the plume.

The CTD profile for the 40-minute sampling interval (T3) was collected at a location that was in close proximity to both the mid- and deep-water drogues (Figure 3-2). In general, light transmission values remained low in the top 10 m of the water column due to elevated turbidity, while less turbid waters were found at mid-depth in the water column (Figure 3-8). Light transmittance values in the surface layer ranged from 8% to 71%, with the highest concentration of suspended particulates detected at approximately 8 m depth. Light transmittance levels similar to background were observed within the mid-water column (depths ranging between 12 m and 27 m), indicating a lack of a mid-water plume element and a significant change in morphology relative to the T1 and T2 profiles. Below 27 m depth, light transmittance values steadily decreased in response to increasing suspended sediment load associated with the near-bottom portion of the sediment plume. The lowest transmission values (ranging from 10 to 20%) were detected between 33 and 34 m depth. Water samples for both TSS and toxicity analyses were collected within the 1-m layer of turbid water during the upcast (Figure 3-8).

The T4 profile was acquired 60 minutes post-disposal at a station located between the position of the deep-water drogue and the surface drifter (Figure 3-2). The CTD profile indicated that turbidity levels near-surface and at mid-depth were similar to background conditions (Figure 3-8). In contrast to the earlier profiles, the majority of the water column exhibited low suspended sediment concentrations, with the first indication of elevated levels of suspended particulates observed at a water depth of 27 m depth. Between 27 m and the seafloor (34 m), light transmittance steadily decreased with depth, declining from 81 to 10% within a 5 to 6 m interval. The lowest transmittance value occurred at a water depth of 33 m (transmittance of 8.4%), representing the highest

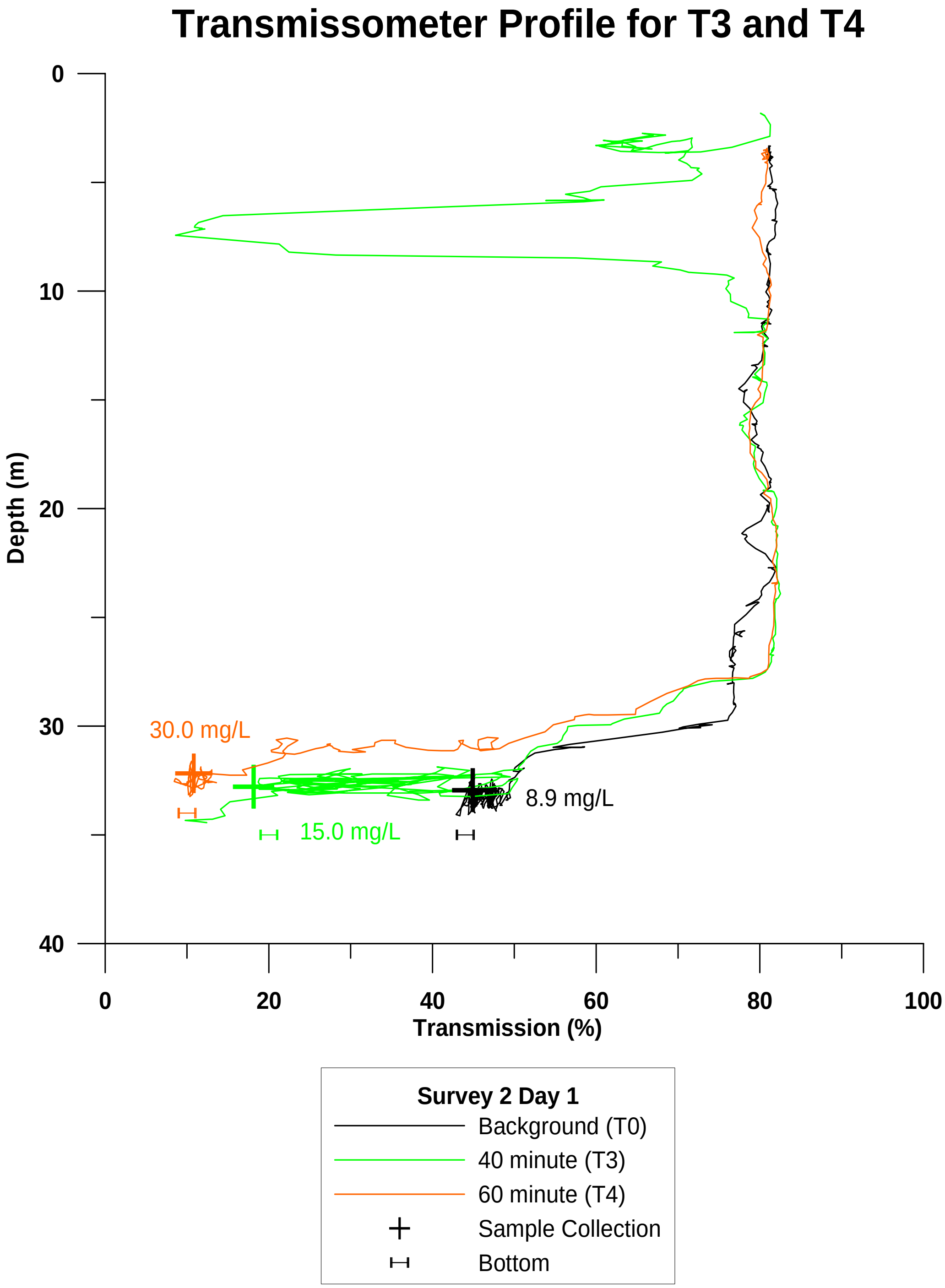


Figure 3-8. Profile plot of percent light transmission and sensor depth acquired during CTD sample intervals T3 and T4 for Plume 1. Locations of water sample collections within the plume are also shown.

turbidity in this portion of the plume (Figure 3-8). Water samples were collected for the 60-minute sampling interval at a depth of 32 m, within the near-bottom portion of the plume but slightly above the most turbid interval.

At the 90-minute sampling interval (T5), the CTD profile was completed approximately 450 m south of RISDS, in proximity to the position of the deep-water drogue (Figure 3-2). The profile indicated that the first substantial increase in turbidity occurred at a depth of 6 to 7 m, suggesting that dilute plume sediments were present just below the surface layer (Figure 3-9). Small decreases in light transmittance values were also observed at water depths of 3 and 13 m, but the corresponding layers of turbid water appeared to be confined to thicknesses of 0.5 to 1 m. Turbidity levels, similar to background conditions, were detected at a water depth of 13 m and extended to a depth of 27 m. Below 27 m, the transmissometer record displayed a general increase in turbidity with depth, indicating the presence of plume sediments in the lower portion of the water column. A minimum transmissometer reading of 37.5% was recorded at a water depth of 32 m (approximately 3 m above the seafloor) and the T5 water sample was collected within this near-bottom portion of the sediment plume as part of the upcast (Figure 3-9).

The CTD profile and water sample for the T6 interval were collected in proximity to the mid-depth drogue 120 minutes after the disposal event (Figure 3-2). The mid-depth drogue was expected to mark the mid-water element of the sediment plume. However, the profile data indicated that water column properties at the surface and within the mid-water were analogous to background conditions with little evidence of plume material. The first indication of entrained sediments in the water column was observed in the T6 profile at an approximate depth of 28 m (Figure 3-9). Below 28 m, light transmittance values decreased with depth, eventually reaching a minimum value of 48% at a water depth of 33 m. The T6 water samples for TSS and toxicity analyses were collected 3 m above the seafloor from a depth of 32.9 m during the upcast.

Comparisons of the CTD profile obtained at the T6 sample interval to that of the background profile showed only minor differences in light transmittance values 1.5 hours post-placement to those recorded prior to the disposal event. These differences were most noticeable in the lower portion of the water column with the T6 profile displaying turbidity 2 to 3 m higher in the water column than what was observed in the background profile. The range of transmittance values recorded within each cast was quite similar, with the background profile actually displaying slightly lower values near-bottom. Given the similarities between the T6 profile and background profile in both light transmittance values and height of the turbid water above the seafloor, differentiation between the background signal and that of the residual plume became problematic.

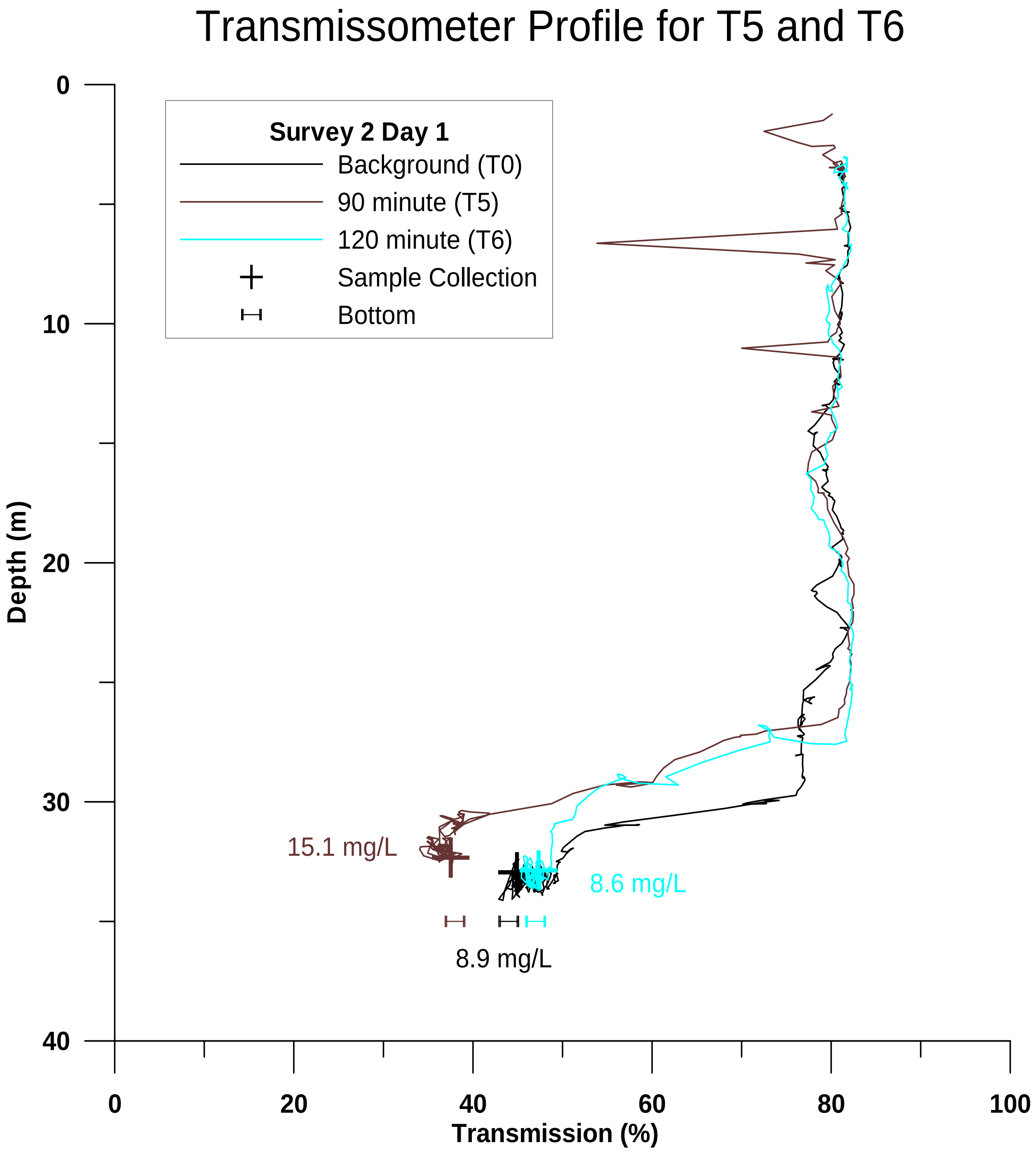


Figure 3-9. Profile plot of percent light transmission and sensor depth acquired during CTD sample intervals T5 and T6 for Plume 1. Locations of water sample collections within the plume are also shown.

In general, the CTD profiles acquired at the T7 (150-minute) and T8 (210-minute) intervals were obtained well south of the RISDS boundary and displayed a transmissometer record similar to that of the T6 sample interval. Both profiles were remarkably similar in light transmittance results, with relatively clear water detected from the surface to an approximate depth of 26 m. Below 26 m depth, turbidity levels increased with depth causing a corresponding decrease in percent light transmittance (Figure 3-10). The T7 profile was obtained 50 m west of the mid-water drogue track, while the profile at (T8) was collected 50 m to the east of the deep-water drogue one hour later, yielding a total distance of 650 m between the two stations (Figure 3-2). Relative to the background transmissometer profile, the increase in turbidity noted in the T7 and T8 profiles occurred 3 to 4 m higher in the water column, suggesting the increase in sediment load was the result of the passage of the disposal plume. The strong similarities in the structure of the profile indicated the plume was likely quite wide and relatively homogeneous as it was transported in the bottom portion of the water column.

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 (S2D1_T0) were obtained approximately 1 hour prior to the disposal event at RISDS and displayed an average TSS value of 8.9 mg·L^{-1}. The background sample was collected approximately 5 m above the seafloor. The majority of the TSS samples obtained within the plume were collected 2 to 4 m above the seafloor, dependent upon the location of the plume centroid. The location of each TSS sample within the water column during the plume monitoring surveys was based on real-time observations of transmissometer data and generally corresponded to the depth level of greatest turbidity.

As stated in Section 3.1.2.2, the background transmissometer profile indicated low turbidity in the upper levels of the water column, with a distinct increase in suspended sediments below a depth of 30 m. The replicate background samples (S2D1_T0) were obtained at a depth of 33 m one-hour prior to the disposal event and displayed an average TSS value of 8.9 mg·L^{-1} (Table 3-4). Although relatively high for a background TSS values in the waters of Rhode Island Sound, the analytically derived results for suspended sediment load appeared to correlate with the remote sensor record.

Approximately ten minutes post-placement, the replicate-averaged TSS concentration near-bottom was determined to be 66.5 mg·L^{-1} (Figure 3-7; Table 3-4). The water samples for TSS were collected at a depth of 32.9 m (2 m above the seafloor), within the near-bottom portion of the sediment plume. This sample (S2D1_T1) had the second

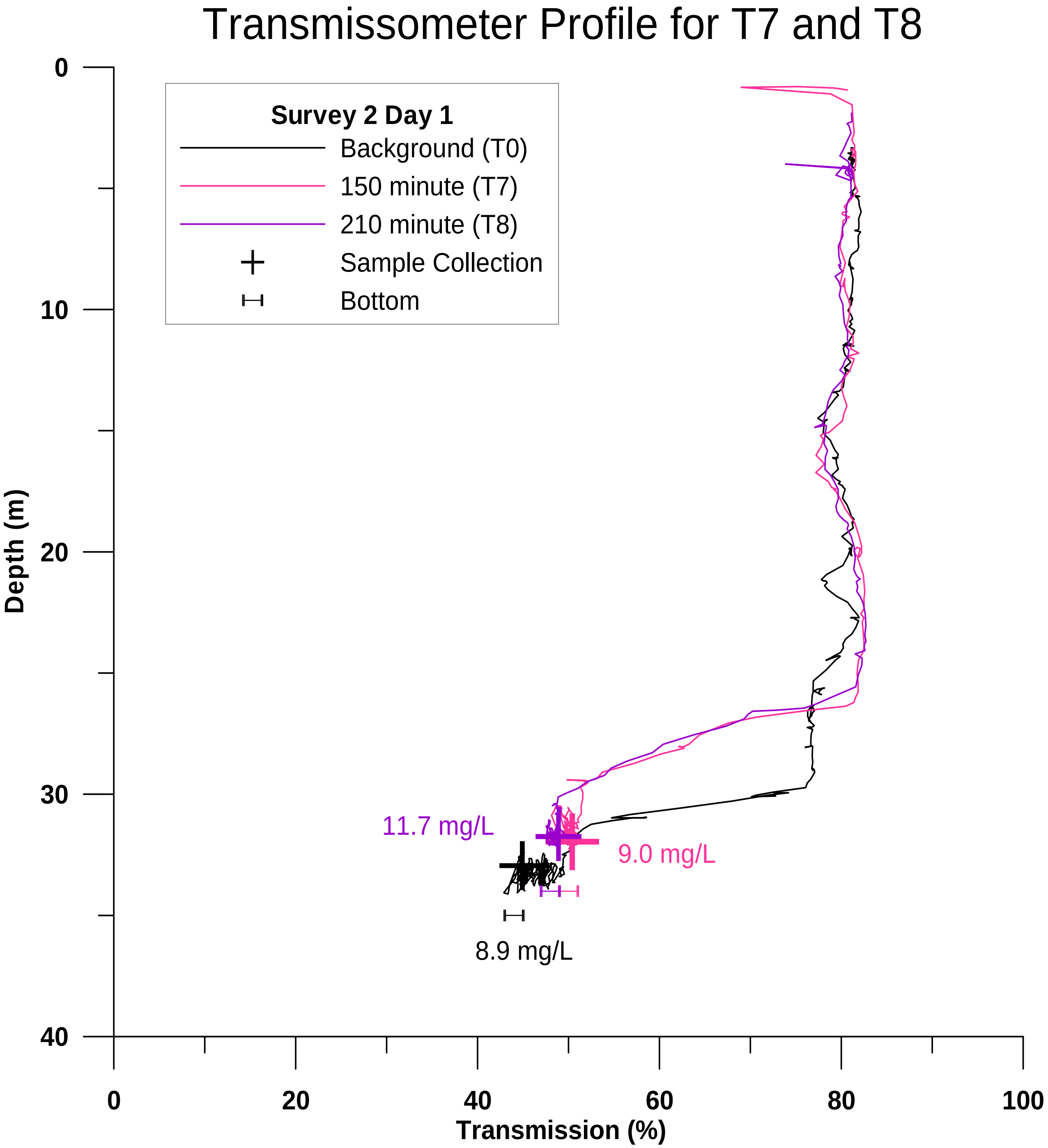


Figure 3-10. Profile plot of percent light transmission and sensor depth acquired during CTD sample intervals T7 and T8 for Plume 1. Locations of water sample collections within the plume are also shown.

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
S2D1_T0	0	0:00	32.9	44.9	15.3	7.6	7.6	11.6	8.9	2.31
S2D1_T1	10	0:12	32.9	0.6	44.0	63.2	63.6	72.8	66.5	5.43
S2D1_T2	20	0:21	33.9	1.7	31.7	110.4	109.2	115.2	111.6	3.17
S2D1_T3	40	0:42	32.8	18.1	20.1	16.0	12.0	17.0	15.0	2.65
S2D1_T4	60	1:00	32.2	10.8	23.8	26.8	24.8	38.4	30.0	7.34
S2D1_T5	90	1:35	32.3	37.5	16.5	17.0	12.2	16.2	15.1	2.57
S2D1_T6	120	2:01	32.9	47.3	14.0	6.4	7.6	11.8	8.6	2.84
S2D1_T7	150	2:32	32.0	50.4	14.0	7.8	10.6	8.6	9.0	1.44
S2D1_T8	210	3:38	31.7	48.9	14.0	6.6	9.0	19.5	11.7	6.86

Plume tracked from the disposal of material from a 4,600 m^3-capacity split-hull disposal barge, loaded only to 2,300 m^3.

highest reported average TSS concentration observed during the 1 September plume monitoring event, suggesting that the sample was obtained in close proximity to the plume centroid (Table 3-4). Vertical transmissometer profiles obtained during the T1 sampling interval also yielded very low percent transmission of light values (0.6%), supporting the conclusion that this sample was representative of the sediment plume's core.

The TSS sample collected at the T2 interval was obtained approximately 4 m above the seafloor, with turbidity remaining elevated 20 minutes following the disposal event. A replicate-averaged TSS value of 111.6 $mg \cdot L^{-1}$ was obtained from the water samples, the highest average value reported for the three plume survey events completed in September 2004 (Table 3-4; Figure 3-7). This high TSS concentration value corresponded to a low light transmittance of 1.6% in the corresponding CTD profile and indicated the sample was obtained within the absolute centroid of the sediment plume.

TSS values decreased substantially for the subsequent sampling intervals during the 3.5-hour survey completed on 1 September (Table 3-4). Although the turbidity levels generally decreased with time as the sediment plume decayed, a noticeable increase in the average TSS concentration was observed between the T3 (40-minute) sample (15 $mg \cdot L^{-1}$) and the T4 (60-minute) sample (30.0 $mg \cdot L^{-1}$). The results of the CTD profile supported the analytical findings, showing lower light transmittance values and suspended particulates higher in the water column. Both samples were collected within 2 to 3 m of the seafloor, but the apparent increase in suspended sediment load was likely related to differences in the position of the sample relative to the plume centroid, rather than input of additional sediment.

Following the T4 sample, TSS values generally decreased between the remaining sample intervals. A value of 15 $mg \cdot L^{-1}$ was derived for the sample obtained during the T5 sample interval (90 minutes post-placement), while the TSS values for samples T6 (8.6 $mg \cdot L^{-1}$) and T7 (9.0 $mg \cdot L^{-1}$) collected 120 and 150 minutes post-placement, respectively were approaching background values. Although still considered close to background, the TSS results for sample T8 were slightly higher, displaying a replicate-averaged value of 11.7 $mg \cdot L^{-1}$, primarily driven upward by one of the triplicate samples.

3.2.1.4 ADCP Backscatter from Underway Profiling

The acoustic backscatter data acquired by the vessel-mounted ADCP were utilized to characterize the morphology of the disposal plume both in spatial extent and relative concentration over time. As naturally occurring particulates in the water column contribute to the acoustic backscatter intensity, data on the background backscatter intensity were collected at the site each day prior to the disposal event. Data were acquired for several minutes, and an average backscatter intensity profile was generated then subtracted from the subsequent plume monitoring data. Consistent and reliable background acoustic backscatter data were obtained for the water column to a depth of 30 m. In general, acoustic backscatter intensity ranged from 62 to 68 acoustic counts from the 4 to 20 m depth interval, and increased to 75 counts within the depth interval between 20 and 25 m before decreasing again in the lower portion of the water column (Figure 3-11). This profile of average acoustic backscatter intensity was then subtracted from the individual, raw vessel transects to generate cross-sectional plots that differentiated backscatter directly related to the concentration of suspended sediments comprising the plume (residual backscatter) from that of ambient seawater.

While data on background acoustic backscatter were being acquired, the water column current speed and direction were also recorded by the vessel-mounted ADCP to determine the optimal direction of vessel transects for plume monitoring. Initially, currents appeared to be flowing toward the east-southeast, as was noted by the surface drifter (Figure 3-2). Thus, a north-south lane orientation was chosen to monitor the disposal plume in an effort to complete survey lines nearly perpendicular to the direction of sediment plume transport. However, after the first few lines were completed, it became apparent from the mid-depth and deep drogues that the sediment plume transport was toward the south-southeast, and thus the lane orientation was changed to an east-west orientation (Figure 2-3).

The 1 September disposal event occurred at 18:12 UTC and Line F was the first transect occupied as part of the survey day. Data were collected along a 1500-m segment of Line F to capture acoustic backscatter intensities in clear water prior to the disposal event, as well as determine the morphology of the sediment plume within a few minutes of formation (Figure 3-12A). The backscatter data obtained along Line F showed a very distinct plume approximately 240 m wide, existing as a column of turbid water extending from the surface to the seafloor. At this early stage, the sediment plume was at its most compact and concentrated form, displaying acoustic backscatter intensities in excess of 30 counts above background.

The direction of approach and barge movement (drift) during the disposal event was documented as north to south, which was parallel to the orientation of Survey Line F. As a result, the data collected along this line was representative of the long axis of the initial sediment plume. Although no acoustic data were collected as confirmation, the size of the sediment plume along the east-west axis was likely much smaller and mimicked the beam (width) of the 4,600 m^3 disposal barge (20 m or 64 ft). At 8 to 10 minutes post-placement, the northern edge of the sediment plume appeared relative vertical, while the leading (southern) edge of the plume appeared somewhat sinuous due to the faster transport of the entrained sediments by the higher velocity currents in the upper levels of the water column. This indicated that the ADCP data appeared to have sufficient resolution to

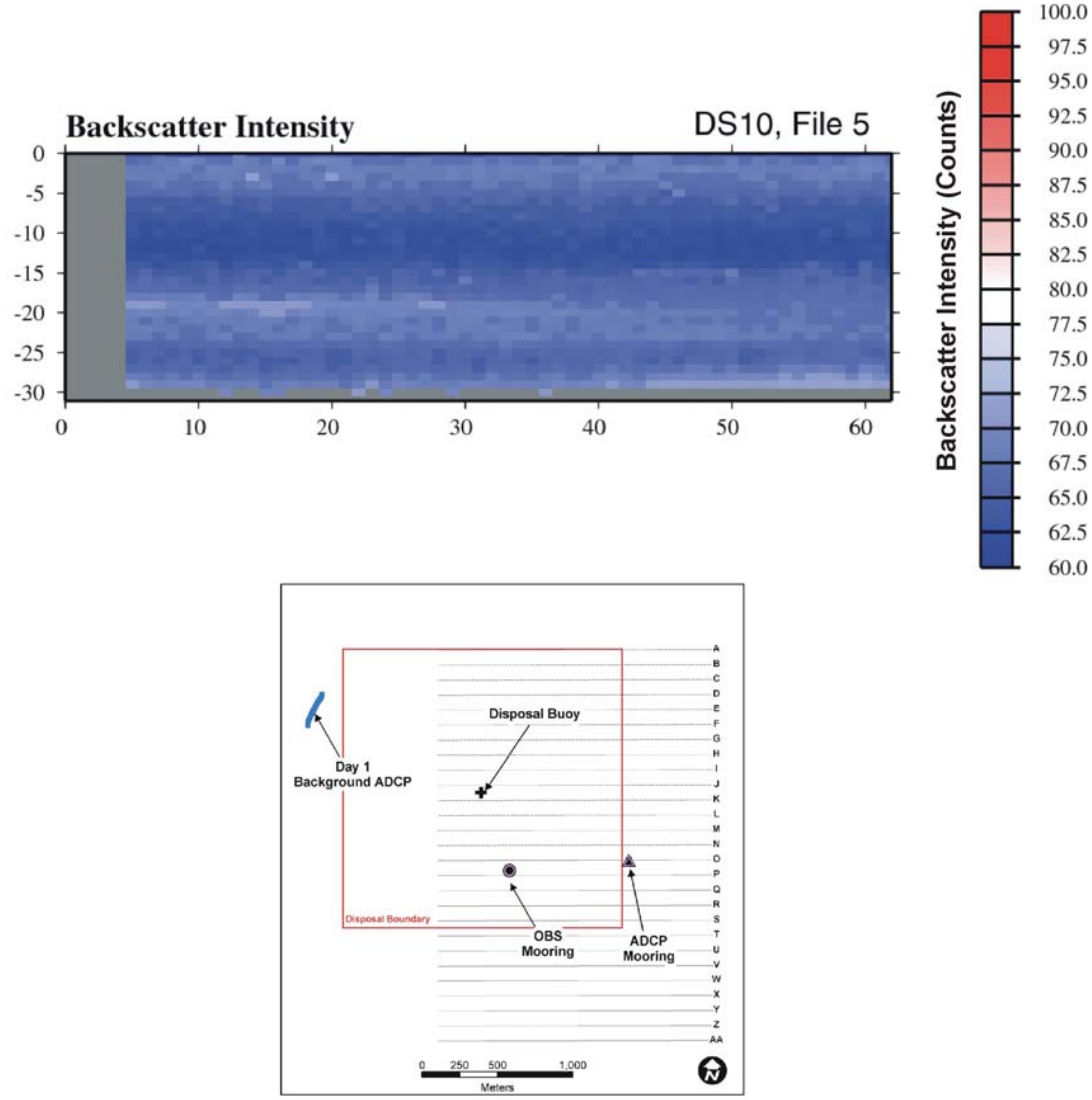


Figure 3-11. Profile plot of raw ADCP backscatter data collected on 1 September 2004 to characterize background conditions at RISDS.

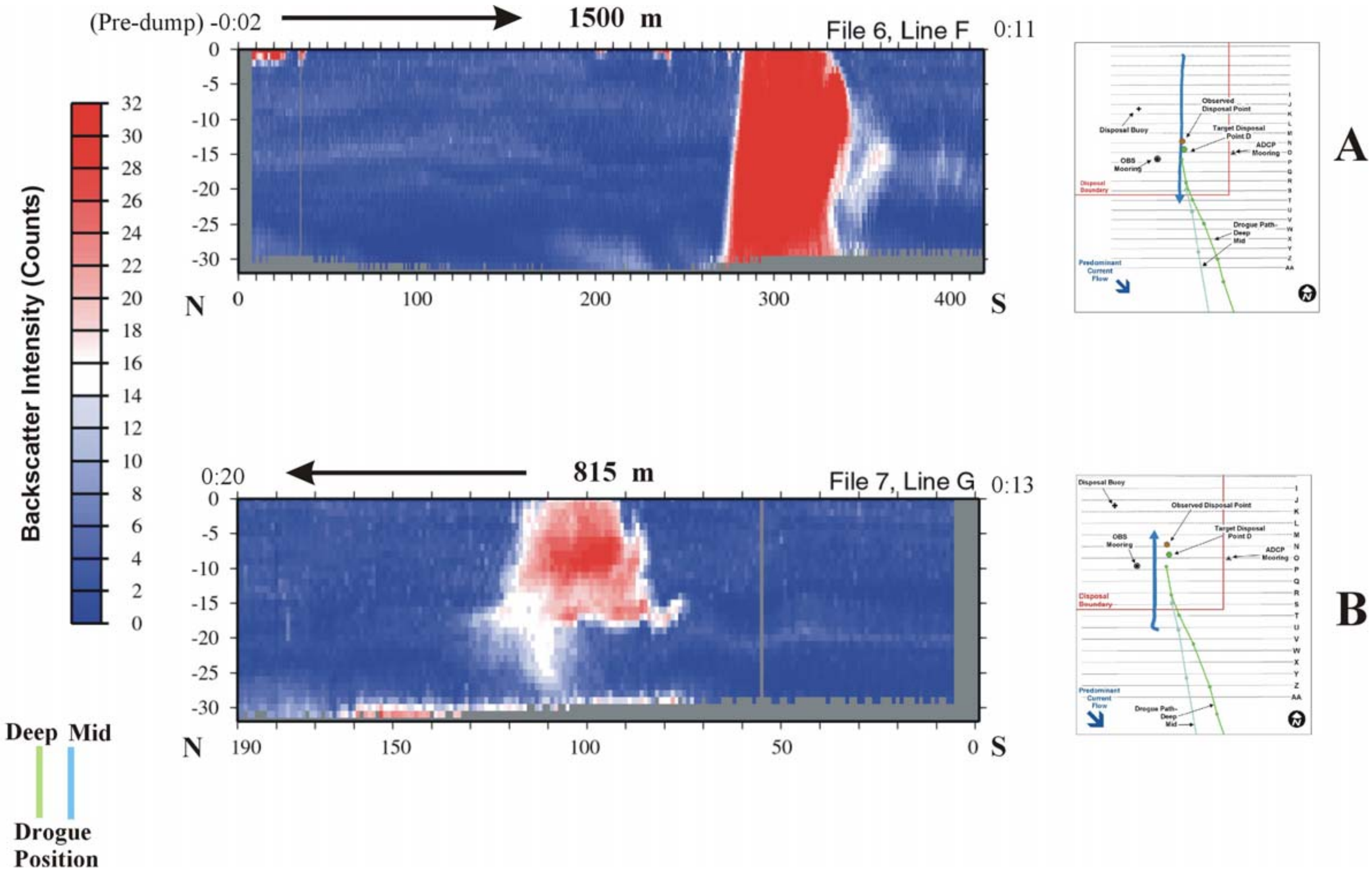


Figure 3-12. Profile plots of data collected from ADCP transects F and G on 1 September 2004 displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to illustrate plume morphology prior to disposal and 20 minutes after the dredged material disposal event at Point B.

capture the effects of water column currents on plume morphology at the earliest stages of the survey.

Line G (to the west of Line F and oriented south to north) was the next transect line to be occupied during the early stages of the 1 September survey. The residual acoustic backscatter data detected a 165 m wide portion of the sediment plume existing in the upper water column extending to a depth of 25 m (Figure 3-12B). This portion of the plume was offset to the south and west of the primary plume feature, and was likely formed as sediments were washed from the open barge as it was towed to the south and west from Disposal Point D in preparation for the return transit to Providence River.

The first east-west survey line occupied on 1 September was Line P, bisecting the approximate point the disposal event concluded (200 m south of the initial placement location; Figure 3-13A). Completed 31 minutes post-placement, the residual backscatter intensity data suggested the majority of the turbid water observed in the upper and middle water column earlier in the survey (north-south Line F) had been advected away. A small acoustic signature detected at a water depth of 30 m suggested some residual turbidity existed in close proximity to the seafloor, but remained below the maximum depth of valid ADCP data (30 m). As a result, these data suggested the bulk of the sediment plume had moved beyond Line P within 30 minutes of the disposal event.

The processed ADCP data acquired along Line Q, which lay 100 m south of Line P, depicted a 300 m wide parcel of turbid water present at depths below 18 m (Figure 3-13B). The sediment plume was centered east of the near-bottom drogue position and displayed maximum residual backscatter intensities above 30 counts. The size of the plume and intensity of the acoustic returns indicated that this feature was representative of the sediment plume core, if not the absolute centroid. There were no acoustically detectable elements of the sediment plume in the upper 17 m of water, suggesting the upper portion of the sediment plume had been quickly advected to the south and east by ambient currents and/or subjected to rapid diffusion that effectively masked the presence of the entrained sediments.

In an effort to characterize the leading edge of the sediment plume, Line R was bypassed and Line S, located 200 m south of Line Q, was occupied. Data were collected along a 615 m segment of Line S, and collection concluded on the eastern boundary of RISDS 45 minutes post-placement. The residual backscatter information depicted a substantial plume feature in the lower half of the water column, as well as parcels of entrained sediment near the surface and along the seafloor (Figure 3-14A). The most substantial element of the sediment plume was a 195 m-wide parcel of turbid water located west of the mid-water drogue position. This feature was the most distinct element of the plume and displayed residual backscatter intensity values in excess of 30 counts. The

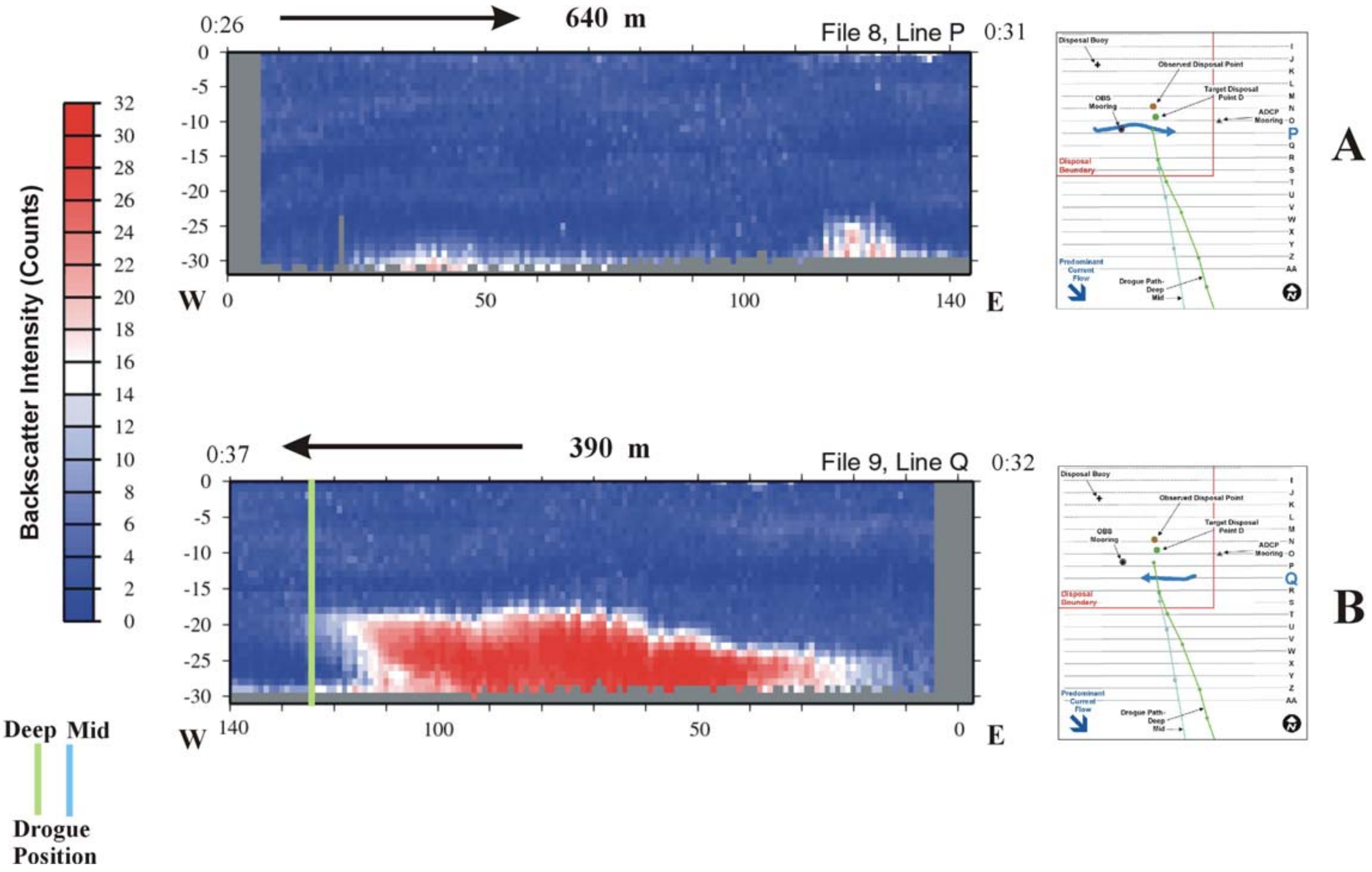


Figure 3-13. Profile plots of data collected from ADCP transects P and Q on 1 September 2004 displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to illustrate plume morphology 37 minutes after the dredged material disposal event at Point B.

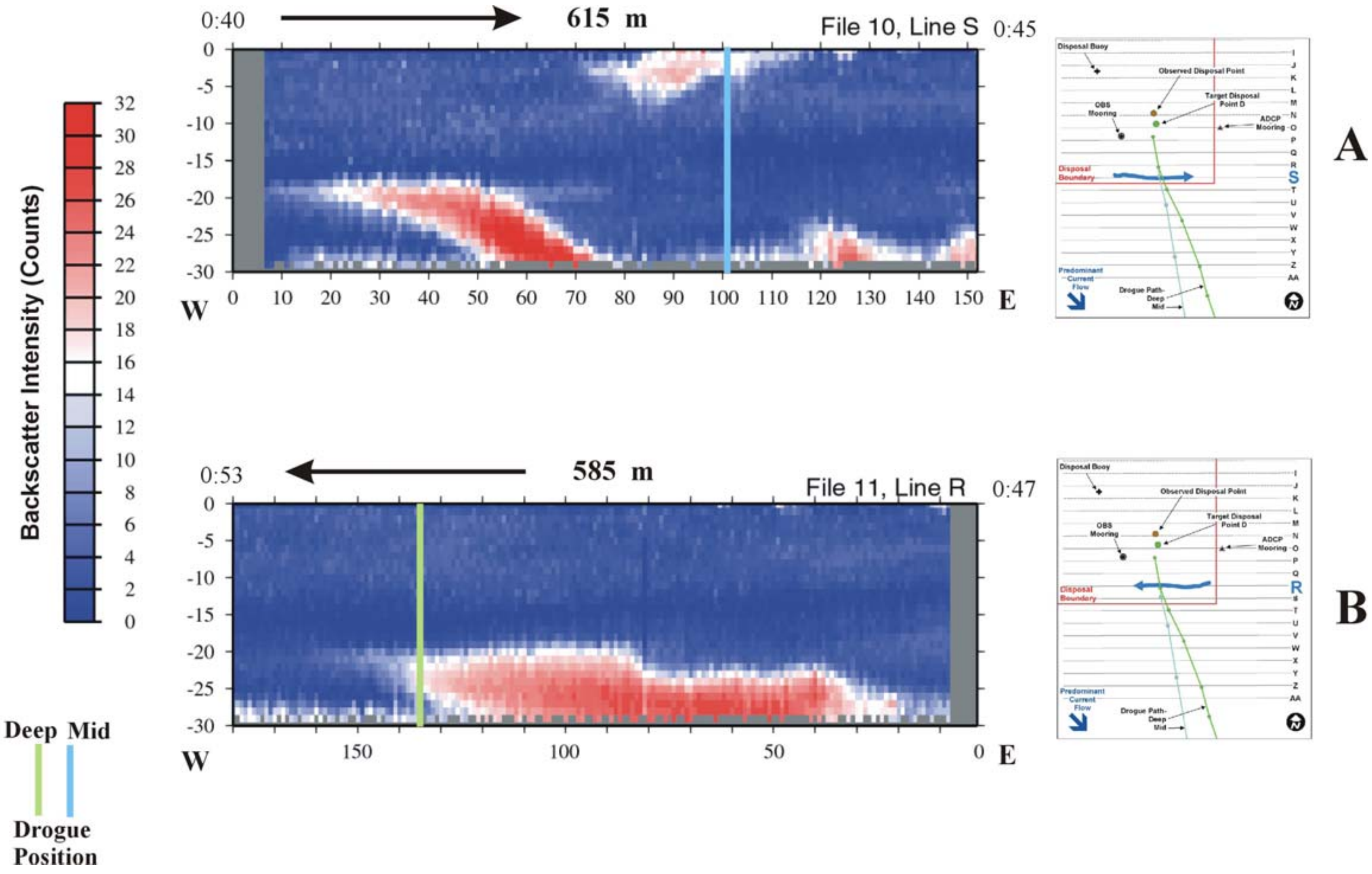


Figure 3-14. Profile plots of data collected from ADCP transects S and R on 1 September 2004 displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to illustrate plume morphology 53 minutes after the dredged material disposal event at Point B.

evidence of turbidity within the near-surface (0 to 5 m depth) and near-bottom (25 m depth to the seafloor) layers was primarily to the east of this mid-water feature, with both displaying backscatter values of 20 to 24 counts.

Upon completion of Line S, the vessel turned and occupied Line R, located 100 m to the north. The acoustic data were collected 53 minutes post-placement and displayed the sediment plume in the lower half of the water column with a very similar morphology to the plume feature detected along Line Q approximately 15 minutes earlier in the survey (Figure 3-14B). The sediment plume was 450 m in width and displayed maximum backscatter intensity values of 26 counts, which was somewhat wider and more diffuse than the plume feature detected along Line Q. The bulk of the sediment plume feature was found east of the deep-water drogue track.

One hour post-placement, Line S was occupied for a second time to evaluate the distribution of suspended sediment in the water column and locate the centroid of the disposal plume. The data collected over Line S displayed a broader plume (675 m in width) with acoustic backscatter values that were less than those detected in previous transects, suggesting the process of diffusion was the principal element affecting plume morphology (Figure 3-15A). The plume was essentially centered on the track of the deep-water drogue with the portion lying west of the track displaying a noticeable mid-water plume element, while the eastern portion was constrained to depths below 22 m.

Line T, lying outside the RISDS boundary, was occupied several minutes after the completion of Line S. The acoustic backscatter intensity data collected along Line T provided evidence of a substantial sediment plume signature 50 m south of RISDS approximately 75 minutes post-placement (Figure 3-15B). In general, the residual backscatter intensity values were lower than those obtained during the second pass over Line S (2), but were of sufficient magnitude to illustrate that this feature represented the main body of the plume rather than the leading edge. These findings suggested that a large parcel of turbidity had likely moved beyond the disposal site boundary within one hour of the disposal event at Disposal Target D.

Upon completion of Line T, Line V was occupied in an effort to reacquire the leading edge of the sediment plume. Line V was established 250 m south of RISDS and the data collected along this line displayed a large and relatively concentrated plume feature extending from mid-depth (19 m) to near-bottom (30 m; Figure 3-16A). Elevated residual backscatter was detectable along much of the 400-m segment of Line V that was occupied during the 1 September survey. The main body of the plume was 290 m wide and displayed acoustic backscatter values ranging from 10 to 20 counts above background. The majority of the plume feature was located west of the mid-depth drogue position. The data collected along Line U (100 m up-current of Line V), 90 minutes post-placement,

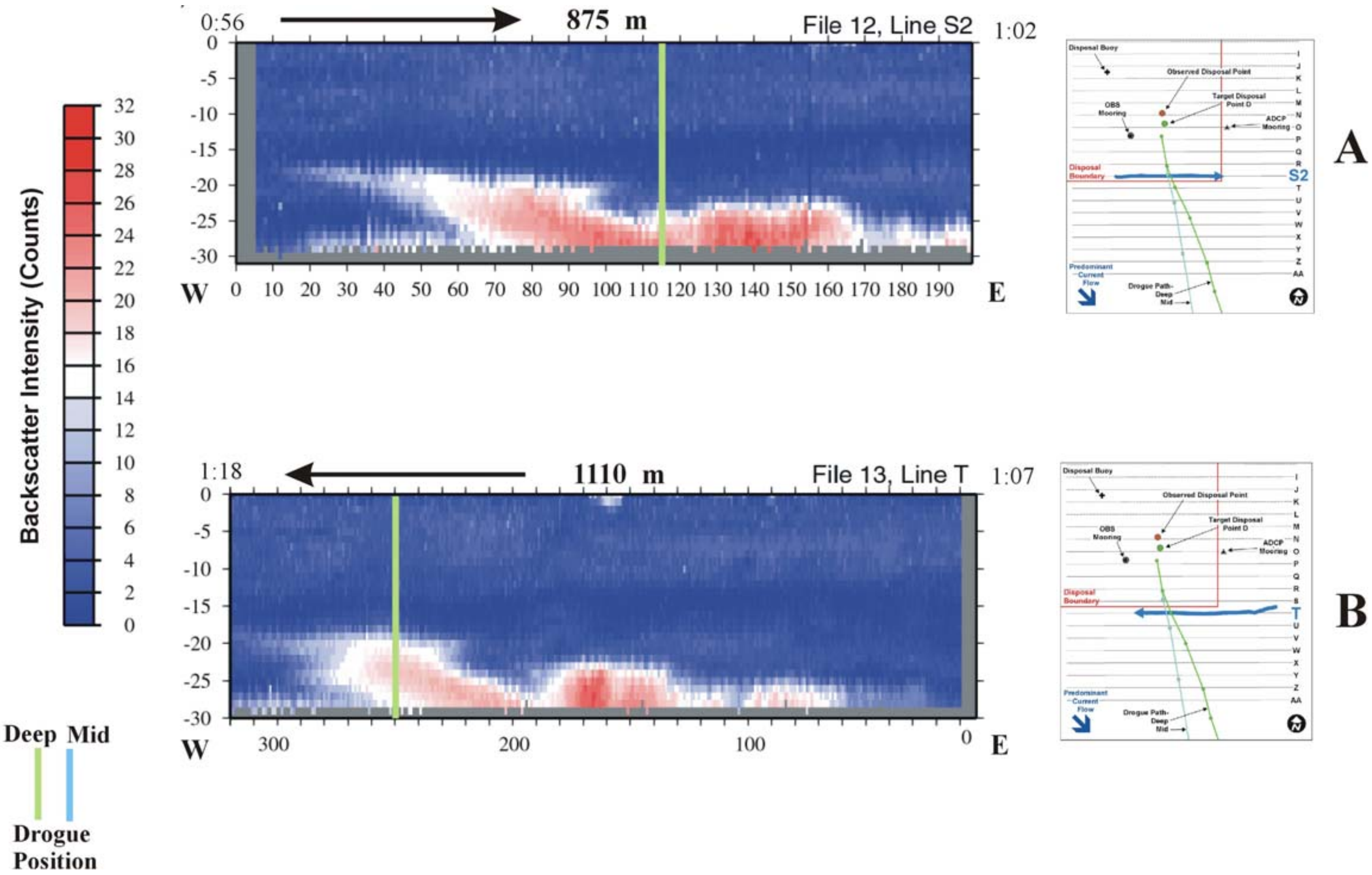


Figure 3-15. Profile plots of data collected from ADCP transects S2 and T on 1 September 2004 displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to illustrate plume morphology one hour and 18 minutes after the dredged material disposal event at Point B.

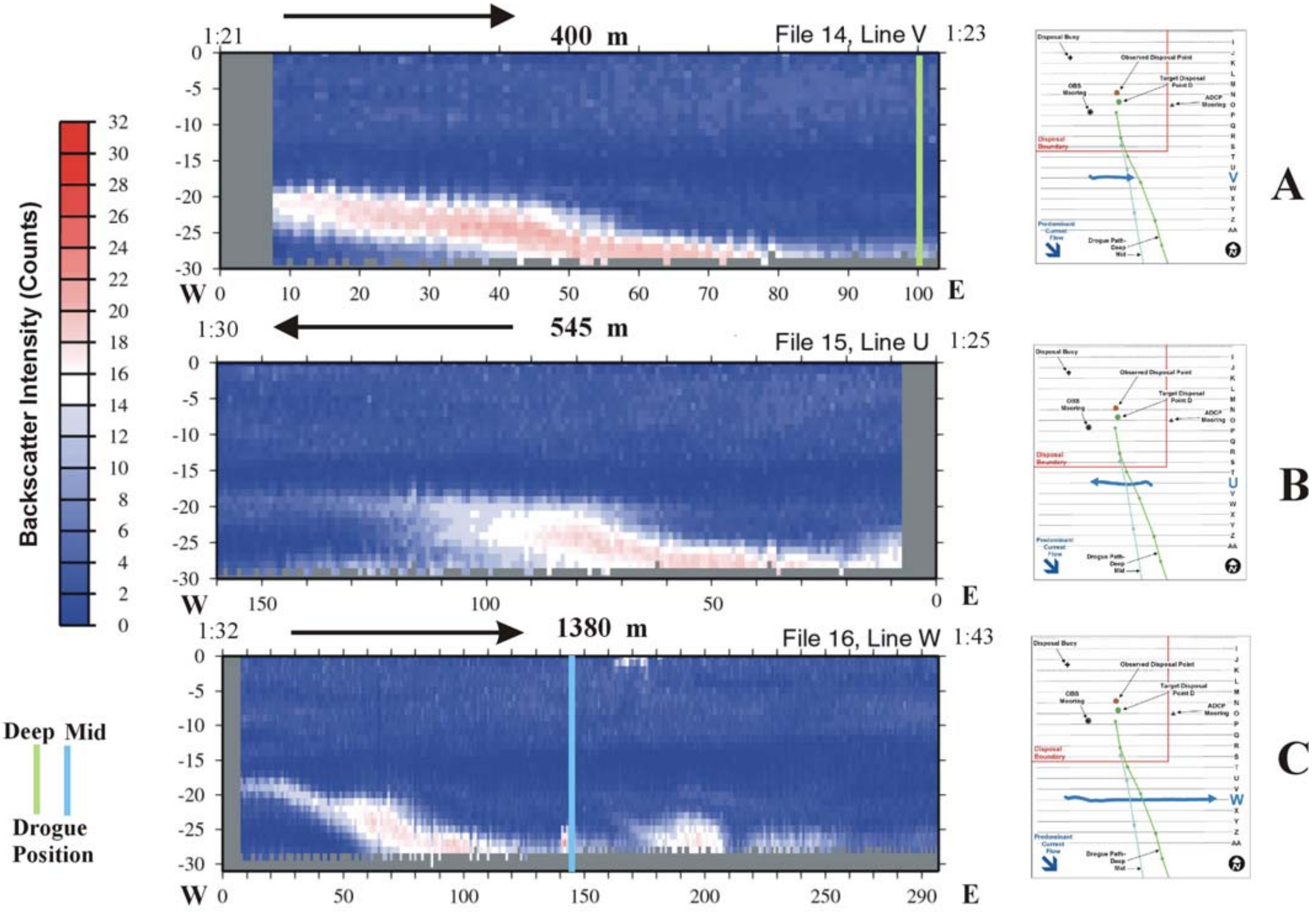


Figure 3-16. Profile plots of data collected from ADCP transects V, U, and W on 1 September 2004 displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to illustrate plume morphology one hour and 43 minutes after the dredged material disposal event at Point B.

displayed a 405 m-wide plume feature with a similar shape and residual backscatter intensity values relative to the parcel of turbid water detected along Line V (Figure 3-16B).

The data collected along a 1380 m segment of Line W displayed evidence of entrained sediments within the water column at mid-depth and near-bottom, 103 minutes post-placement (Figure 3-16C). A prominent plume feature displaying morphology similar to those features documented in Lines U and V was detected on the western side of Line W, while a smaller element of the sediment plume was detected east of the mid-depth drogue. The larger parcel of turbidity to the west was approximately 540 m wide and displayed residual backscatter values ranging from 12 to 18 counts. This relatively concentrated sediment plume extended from mid-depth (18 m) to the limit of the valid acoustic data (30 m).

The remainder of the data presented for the 1 September survey pertains to the location, morphology, and residual backscatter intensity of the sediment plume along the leading edge (Figures 3-17 and 3-18). The long acoustic survey lines that were run well south of the RISDS boundary (450 to 750 m) each detected parcels of elevated backscatter readings in the mid-water column and near bottom. As anticipated, the sediment plume continued to expand in width, while turbidity concentrations declined over time due to the influx of ambient seawater and diffusion of the plume. During the third hour of the survey, maximum residual backscatter values within the core of the sediment plume features were approximately 12 counts, and substantially reduced relative to earlier phases of the 1 September survey.

3.2.1.5 Water Column Optical Backscatter

As part of the 1 September survey, the OBS sensor mooring was placed approximately 300 m to the southwest of the anticipated disposal point where the water depth was 38 m (Figure 2-3). The data collected at 10-second intervals showed generally low levels of background turbidity in the upper and middle water column (13 and 18 m), with values averaging 2 FTU and small variations throughout the record (Figure 3-19). However, the near-bottom sensor showed noticeably higher turbidity values (22 to 25 FTU) throughout the deployment. The strong trend in the OBS data from the bottom sensor was indicative of true elevated background near-bottom turbidity and likely not a product of noise within the data set. This finding was supported by the transmissometer record obtained during the background CTD profile, which showed a significant decrease in percent light transmission at 30 m water depth (Figure 3-6). Furthermore, these data did display short duration (10 to 20 seconds) turbidity increases at all depth levels, which

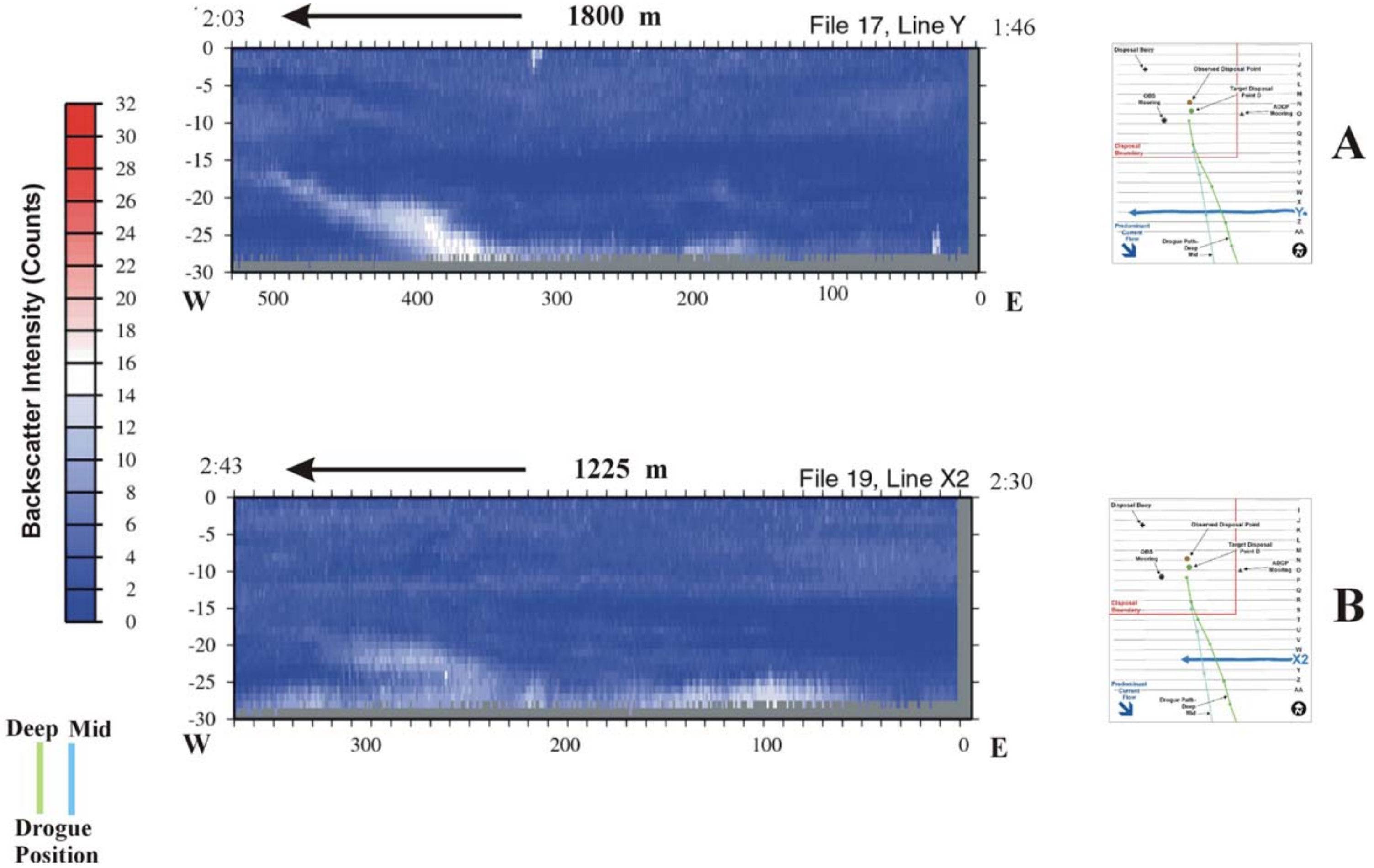


Figure 3-17. Profile plots of data collected from ADCP transects Y and X2 on 1 September 2004 displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to illustrate plume morphology two hours and 43 minutes after the dredged material disposal event at Point B.

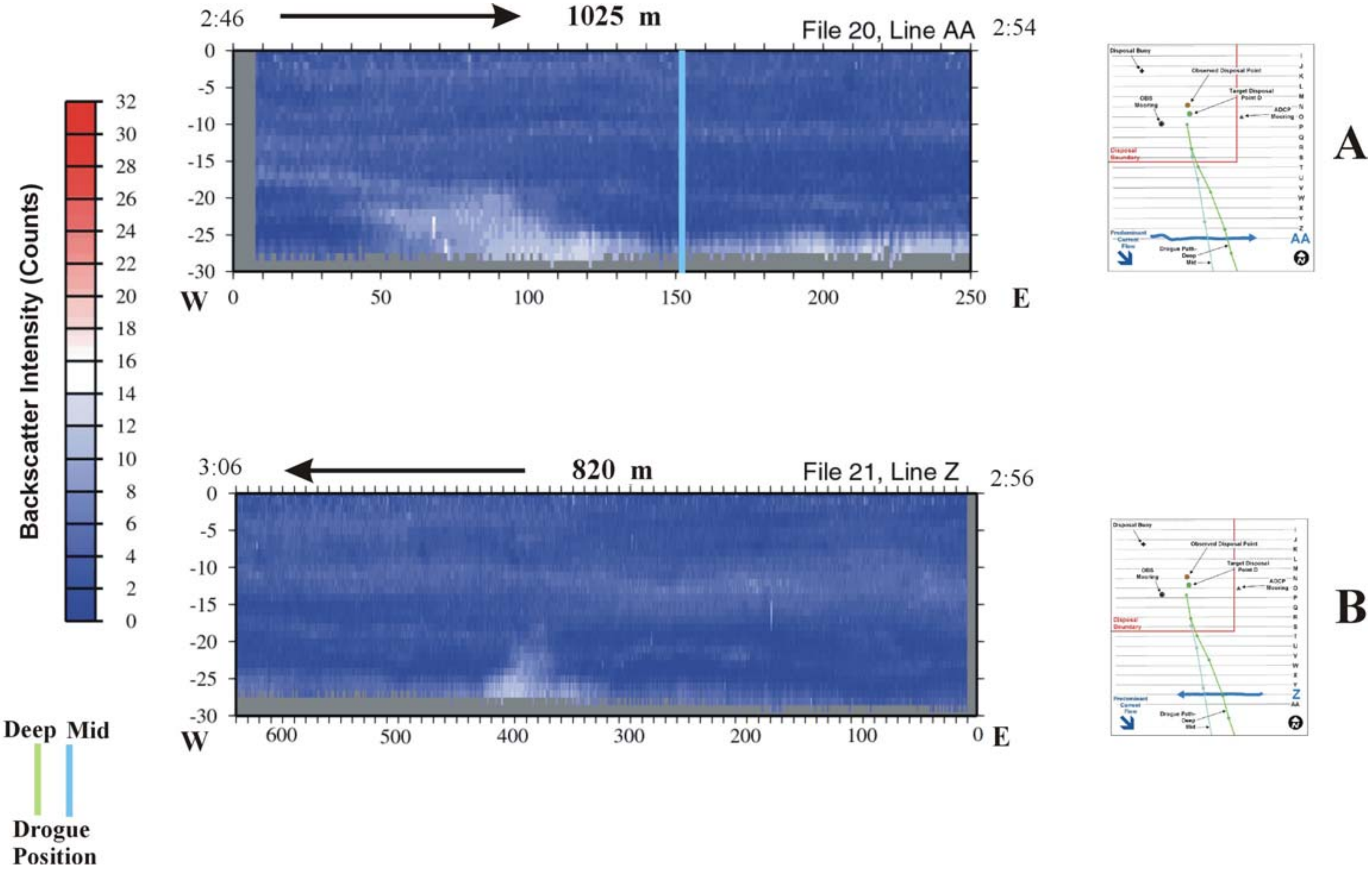


Figure 3-18. Profile plots of data collected from ADCP transects AA and Z on 1 September 2004 displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to illustrate plume morphology three hours and six minutes after the dredged material disposal event at Point B.

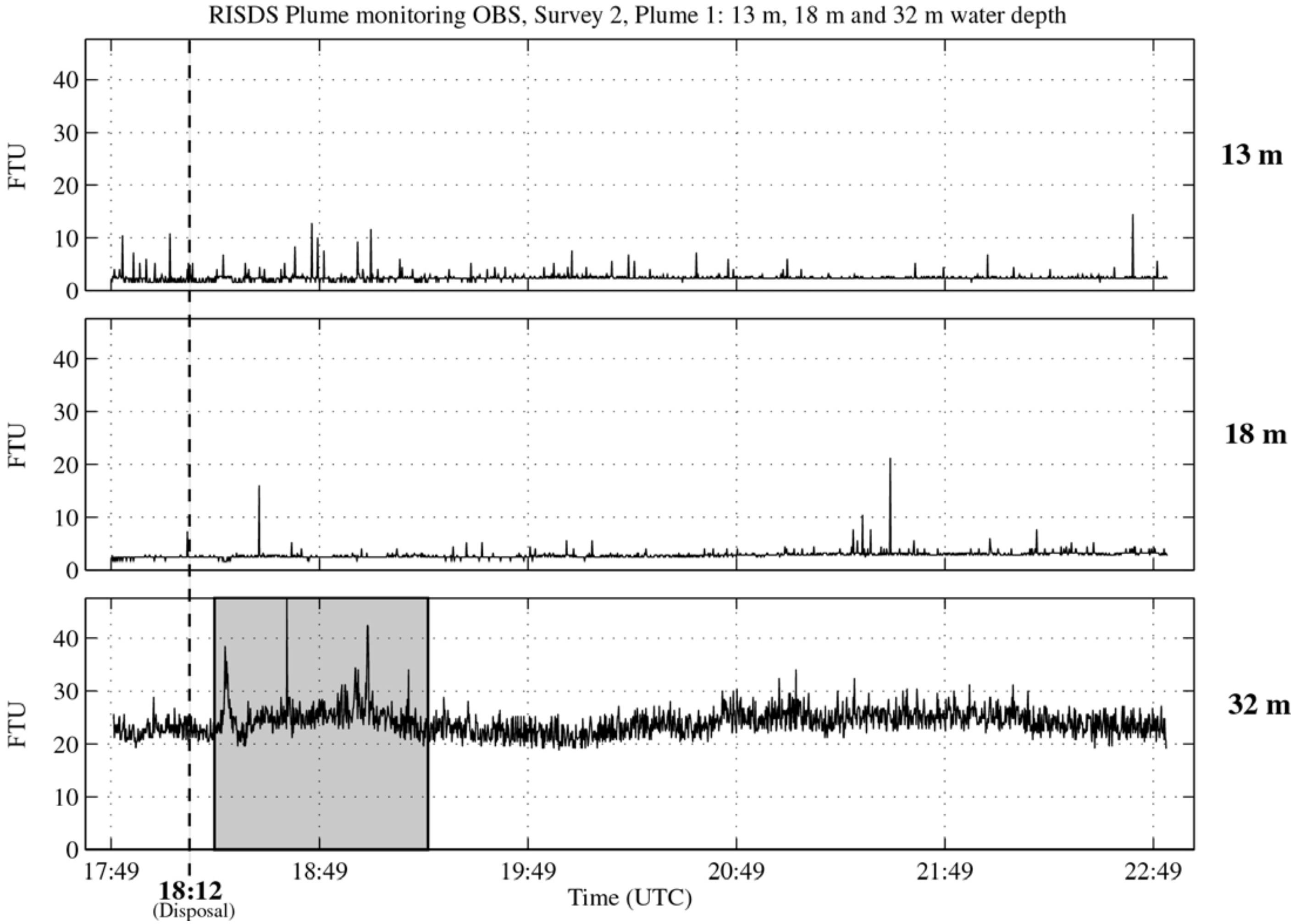


Figure 3-19. Time-series plot of OBS data collected on 1 September 2004 from three levels in the water column (13 m, 18 m, and 32 m), displaying changes in turbidity over time resulting from sediment plume passage.

are most likely the result of suspended particulate matter in the water column that may have been the product of the disposal event or naturally occurring.

The lack of any distinct increase in turbidity over background in the data record suggested that the OBS mooring was not within the direct path of the disposal plume and could not document its transport through the deployment location. However, the data obtained by the sensor positioned at the 32 m depth level did show several points of interest during the 1 September survey. The first item was related to a short-lived, 20 FTU increase in optical backscatter above the relatively high background levels (20 to 22 FTU) ten minutes after the disposal event (Figure 3-19). This small, but detectable change in near-bottom turbidity was most likely related to the passage of horizontal energy and suspended sediment associated with the dynamic collapse of sediment deposit. In addition, the near-bottom sensor data displayed an increase in the average background turbidity after this event, with the average turbidity values holding at 25 FTU for approximately one hour. There also were a number of short-term increases (apart from the noise caused by suspended particulates) that likely represented variability in the sediment concentrations as the already turbid water that existed near the seafloor passed the mooring location.

3.2.1.6 Toxicity

A summary of the toxicity results associated with the water sampling data for the Plume 1 is provided in Table 3-5. 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 2 September 2004, and followed the sediment plume generated by the disposal of 2,300 m^3 of material dredged from the Fuller Rock Reach that was placed at Disposal Point A. Load 1286 was deposited by a split-hull barge at Disposal Point A in the northwestern quadrant of RISDS at 13:40 UTC. Comprehensive plume tracking and water sampling were performed using two vessels for 3.5 hours immediately following the disposal event. Based on the water level data from the NOAA tide station in Newport, RI (Station 8452660), corrected to the tidal zone encompassing RISDS, this disposal event began during the final stages of a flood tide (Figure 3-20). The plume monitoring survey activity continued through a short period of slack tide (no change in water level from 14:24 to 15:24 UTC) and into the subsequent ebb, concluding at approximately 17:20 UTC. Within this time period, the net transport of the sediment plume was to the west-northwest as described in further detail below.

Table 3-5

Toxicity Results from Discrete Water Samples collected during CTD Profiling Operations during RISDS Plume Monitoring.

Day 1

Sample	Time Interval	Mysid % Survival	Menidia % Survival
Control		96	98
S2D1-TOX	Background	96	100
S2D1-T3X	40 min	100	100
S2D1-T4X	60 min	96	100
S2D1-T6X	120 min	100	100

Day 2

Sample	Time Interval	Mysid % Survival	Menidia % Survival
Control		96*	98
S2D2-TOX	Background	100	100
S2D2-T3X	40 min	100	98
S2D2-T4X	60 min	100	100
S2D2-T6X	120 min	100	100

* Control value from Group A

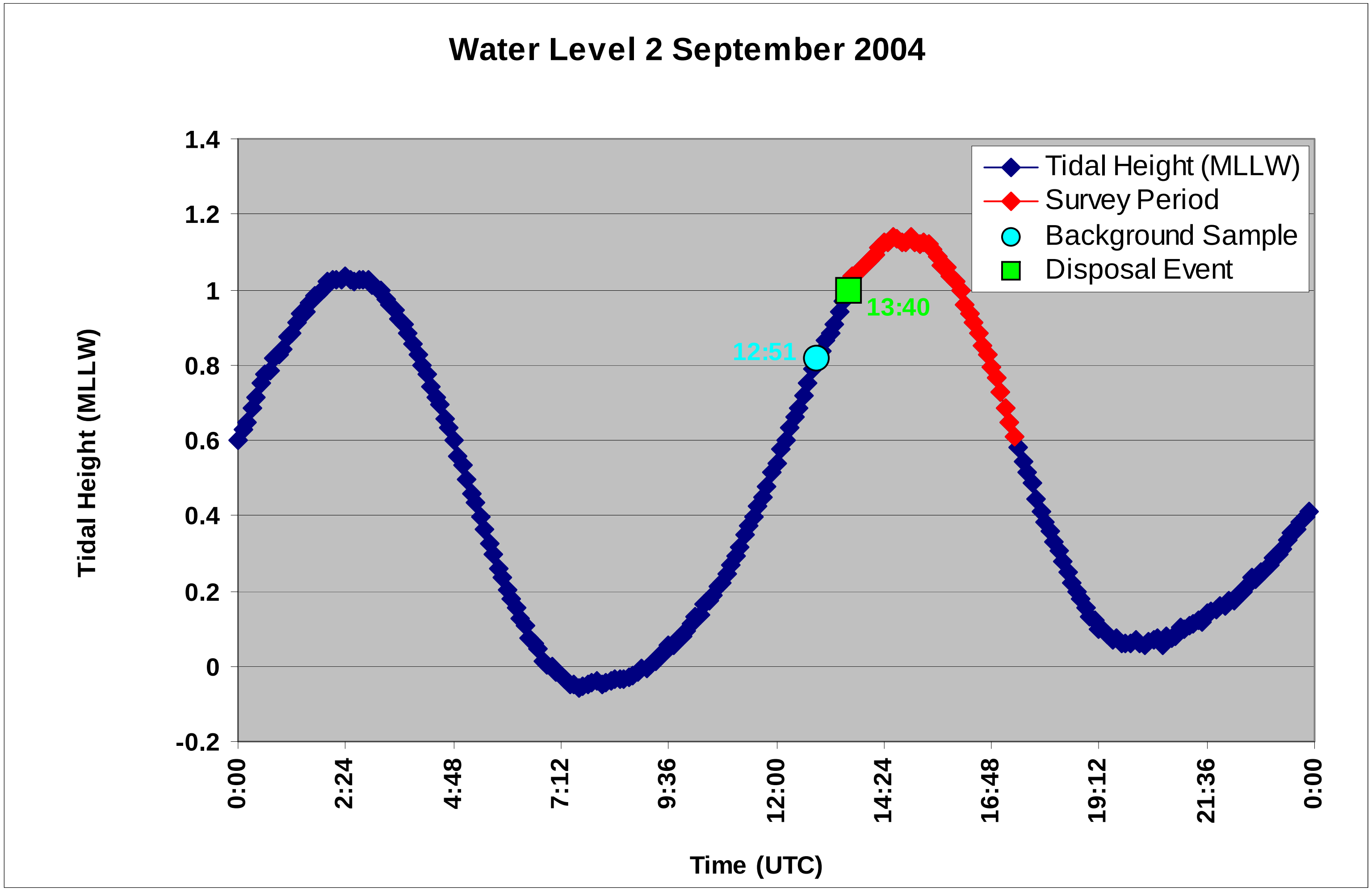


Figure 3-20. Water level data from the NOAA tide station in Newport, RI, corrected to the tide zone encompassing RISDS for 2 September 2004. The Background Sample and Disposal event are shown in comparison to the tidal stage.

3.2.2.1 Water Column Currents

Similar to the 1 September survey, the surface drifter, mid-water and deep-water current drogues were deployed immediately following the disposal event and allowed to drift with ambient currents for the duration of the survey day. The surface drifter displayed a slower speed relative to the mid and deep-water drogues, drifting west-southwest at an average velocity of 13 $cm \cdot s^{-1}$ (Table 3-3; Figure 3-21). The deep-water drogue displayed a similar direction of transport, but slightly stronger current velocities of 17 $cm \cdot s^{-1}$ during the 2 September monitoring survey. The currents dictating the transport of the mid-water drogue were somewhat stronger than both the surface and deeper water column layers. An average speed of 23 $cm \cdot s^{-1}$ was calculated for the mid-water column currents based upon the time and position of drogue deployment and recovery (Table 3-3). For the initial part of the survey, both the surface and deep-water drogues tracked relatively close to each other, heading in a westerly direction. However, the mid-water drogue tracked much faster in the southwest direction (Figure 3-21).

In agreement with the information provided by the current-following drogues, the bottom-mounted ADCP record for 2 September displayed multi-layer flow within the water column. Overall, the mean current direction calculated for the Day 2 deployment period was generally in a westerly direction, with mean speeds between 12 and 22 $cm \cdot s^{-1}$ (Figure 3-22). Water column currents appeared to be both the strongest and most consistent within the depth interval between 10 and 15 m (mean speed approaching 22 $cm \cdot s^{-1}$ and maximum speeds in excess of 30 $cm \cdot s^{-1}$), while the velocities at other depth intervals were somewhat weaker and variable in intensity (Figure 3-22).

A relatively consistent west to northwest flow was exhibited in both the near-surface and near-bottom currents during the first few hours of the survey period (Figure 3-23). As the survey day continued, the westerly surface currents decreased in velocity, assumed a more southerly flow (likely in response to the ebb tidal effects), then accelerated. Near-bottom currents appeared to follow that same pattern, but lagged behind the surface currents by approximately 90 minutes (Figure 3-23). Although the mid-water column currents displayed minor fluctuations in velocity, the direction of flow was relatively consistent throughout the survey period. Based upon the ADCP data, mid-water current flow was to the southwest or west-southwest at speeds that varied between 8 and 22 $cm \cdot s^{-1}$, with the slowest current speeds recorded in the later stages of the deployment (Figure 3-23).

At the time of the disposal event (13:40 UTC), near-surface, mid-depth, and near-bottom currents were similar in magnitude with documented at speeds of 15 to 18 $cm \cdot s^{-1}$,

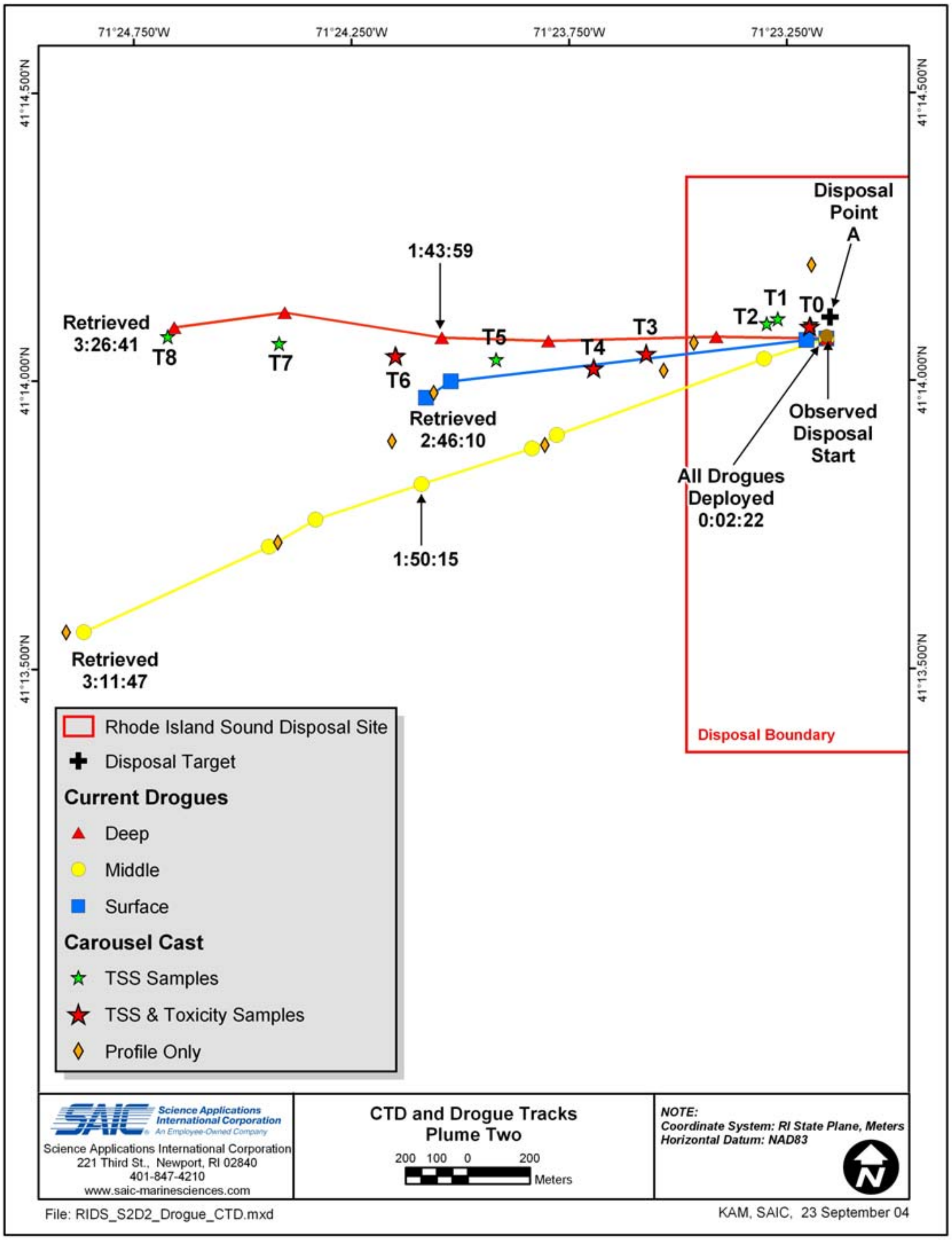


Figure 3-21. Map indicating current drogue trajectories and CTD cast locations during the tracking of Plume 2. Locations of water samples are also shown. Times represent elapsed time since disposal operations.

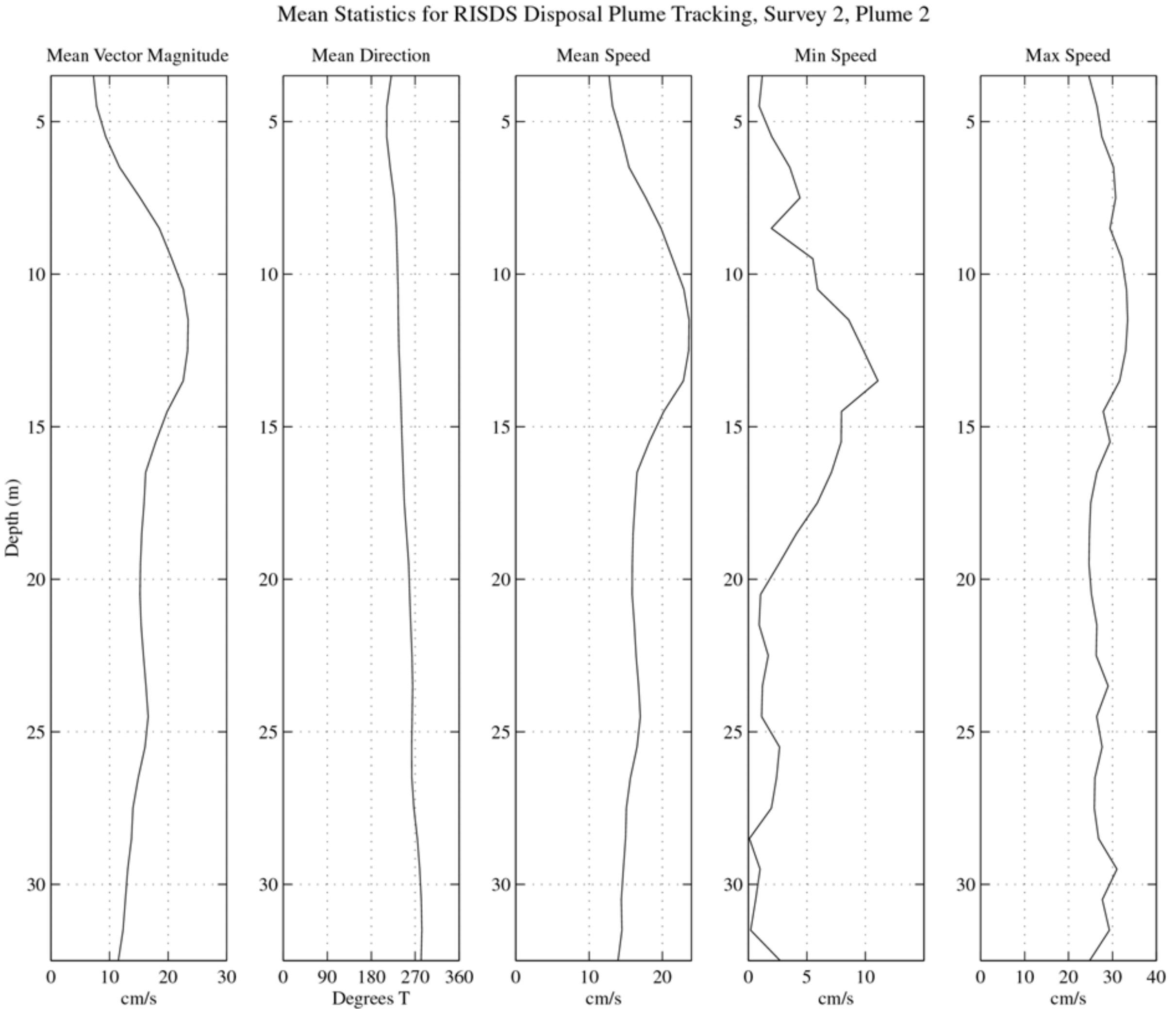


Figure 3-22. Statistics of moored current meter data collected on site during Plume 2 disposal monitoring activities. Parameters plotted include mean vector magnitude, mean vector direction, mean speed (regardless of direction), minimum speed and maximum speed.

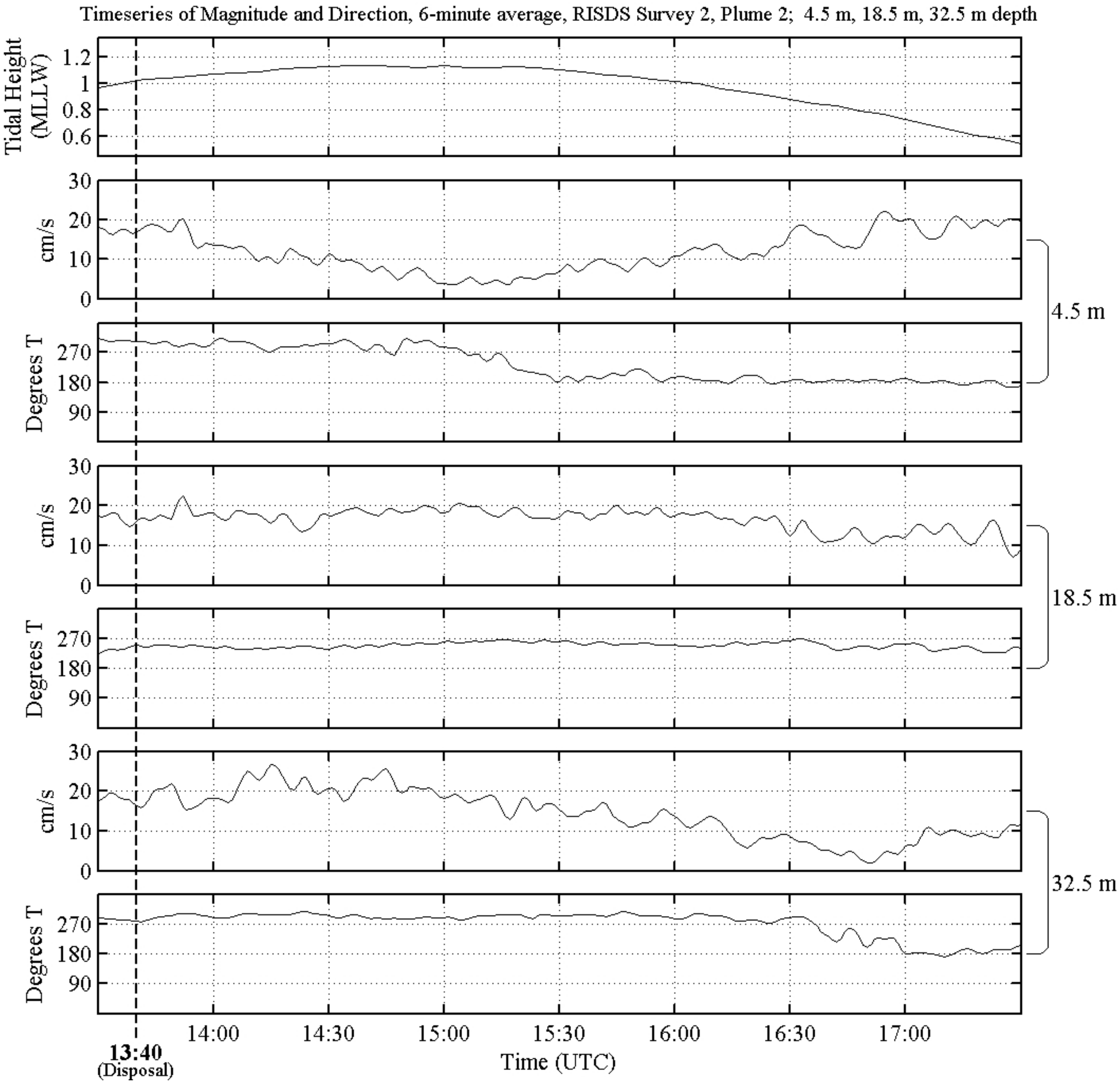


Figure 3-23. Time-series plot of current magnitude and direction during Plume 2 at the near-surface level (~4.5 m; top two panels) and the two selected drogue depth levels of ~18 (middle two panels) and ~32 m depth (bottom two panels). Currents were sampled at 1 minute intervals, and filtered with six-minute Low Pass Filter (LPF) to reduce high-frequency noise.

but did exhibit differences in flow direction (Figure 3-24). The near-surface interval (4.5 m depth) was flowing to the northwest for approximately 1.5 hours before currents speeds diminished and the water mass began moving to the southwest and south. The water mass at mid-depth flowed to the southwest for approximately one hour following the disposal event, then displayed a clockwise rotation to the west and west-southwest for a 30 to 45-minute period of time before returning to a southwest flow. The near-bottom currents were quite strong (displaying speeds in excess of 25 $cm \cdot s^{-1}$ at times) and flowed in a northwesterly direction at the time of the disposal event and for the first three hours of the plume monitoring operation. At approximately 16:30 UTC, current velocities fell below 10 $cm \cdot s^{-1}$ and the flow rotated counter-clockwise to the southwest and south. Following the change in direction of flow, the velocities increased to levels above 10 $cm \cdot s^{-1}$ for a period of 30 minutes prior to the end of the record. In general, the strong, yet divergent flow within the water column was likely the most significant factor affecting the migration and overall morphology of the sediment plume.

The vessel-mounted ADCP data collected on 2 September displayed similar results when compared to the bottom-mounted instruments, suggesting more variability in flow structures relative to the 1 September survey. Flow magnitudes recorded in the vessel-mounted ADCP record were generally 10 to 15 $cm \cdot s^{-1}$ throughout most of the survey. Currents appeared to have some divergence from surface to bottom, with the upper 10 m of the water column flowing west-northwestward, mid-water column currents (from 11 to 30 m) flowing southwestward, and near-bottom currents flowing to the west.

3.2.2.2 CTD/Transmissometer Profiles

A total of 13 CTD profiles were acquired within and adjacent to RISDS during the 2 September plume monitoring survey associated with Load 1286 (Figure 3-21). Background water samples (T0) were collected prior to the disposal event approximately 5 m above the seafloor surface at a depth of 32 m in close proximity to the target disposal location (Location A). Figure 3-25 represents physical properties of the water column to a depth of 33 m prior to the disposal event. In general, both salinity and percent light transmittance, within the background CTD profile, showed some measure of variability throughout the water column, while seawater density appeared to be primarily a function of temperature, as both changed moderately with depth.

Light transmission was 82% in the upper water column and remained relatively constant between the surface and 15 m depth. A gradual decrease in percent transmittance was noted between 15 and 22 m depth, suggesting a trend of increasing turbidity with depth (Figure 3-25). Transmissometer readings were somewhat variable below a water depth of 22 m, ranging from 75 to 80% in the lower portion of the water column. A distinct increase in turbidity was noted approximately 1 to 2 m above the seafloor, as

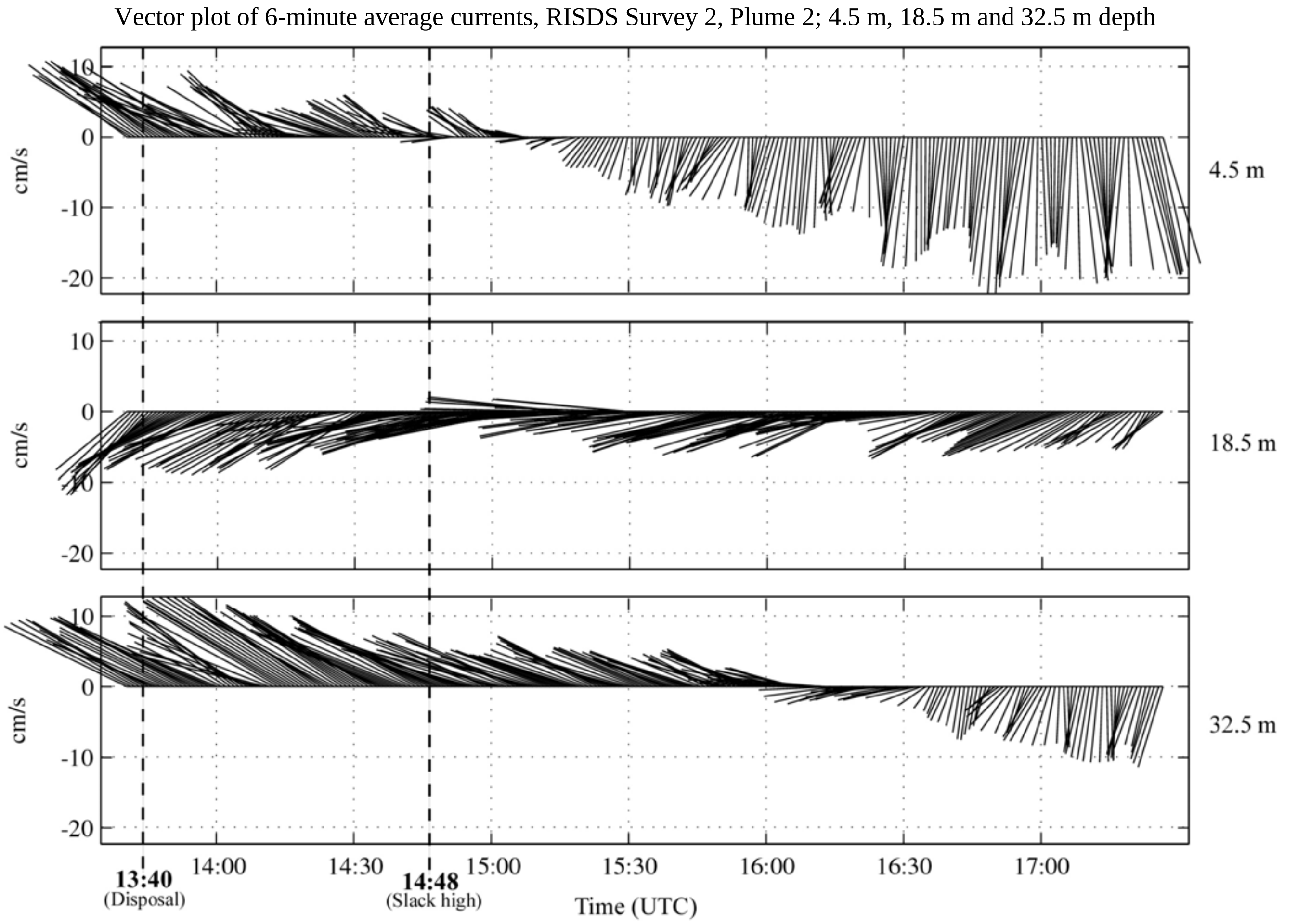


Figure 3-24. Time-series plot of current vectors (six minute LPF) during Plume 2 at the near-surface level (~4.5 m top panel) and the two selected drogue depth levels of ~18 m (middle panel) and ~32 m depth (bottom panel).

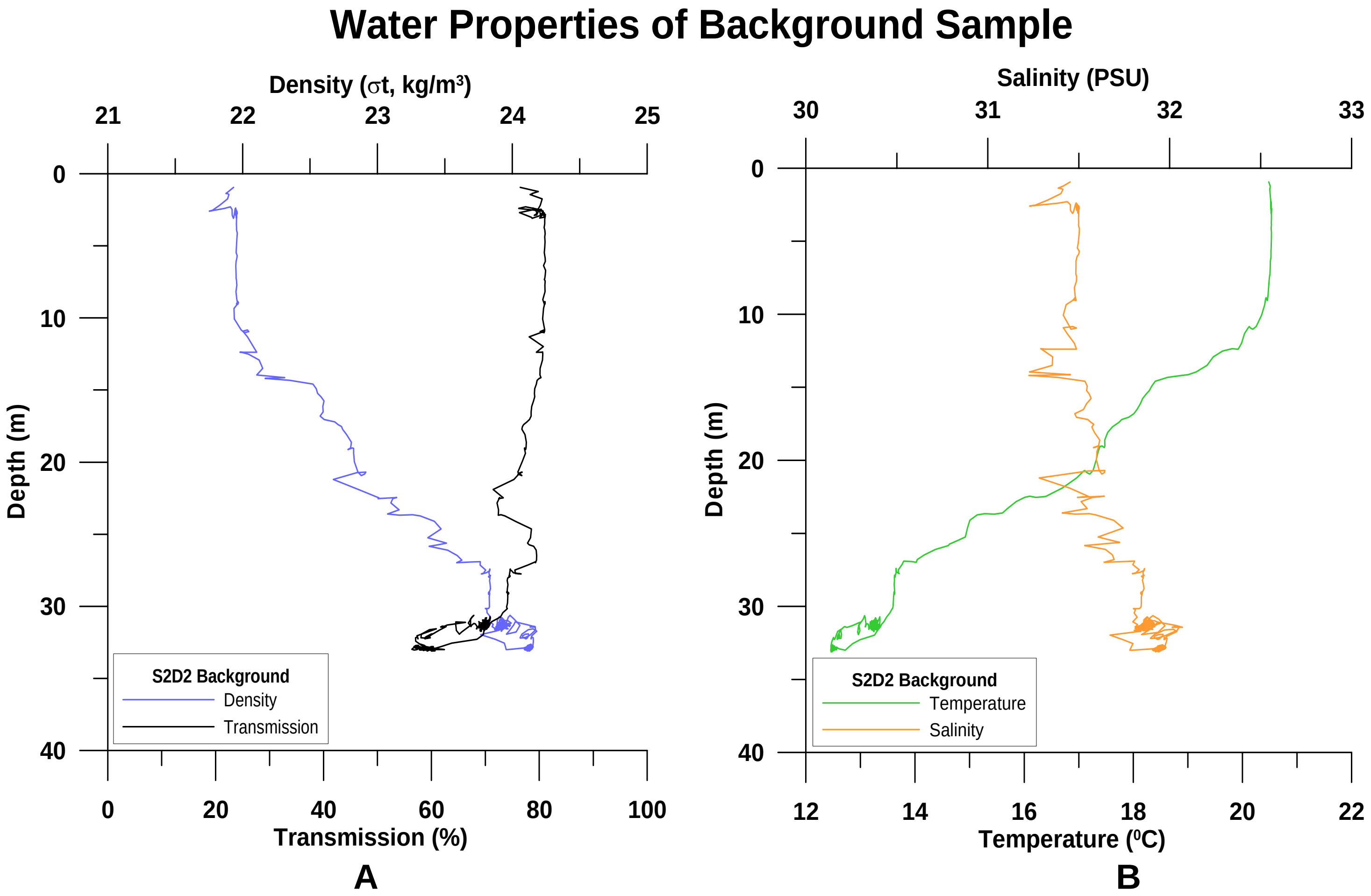

Water Properties of Background Sample

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.

percent light transmission decreased sharply to 55% during the last moments of the downcast.

Salinity showed some variability within the water column, but remained within the narrow range of 31.25 to 32.1 PSU. As anticipated, the more saline water was detected at depth, but several fairly distinct haloclines were detected within the high resolution CTD data at water depths of 15 and 27 m (Figure 3-25). Seawater temperature values within 10 m of the surface were relatively uniform at 20.5°C then gradually decreased with depth to 12.5°C near the seafloor. Similar to the salinity profile, multiple thermoclines of small vertical scales were noted in the profile as relatively rapid decreases in water temperature were detected at depths of 15, 24 and 27 m.

Displaying an inverse relationship to temperature, seawater density showed a general increasing trend from the surface to the seafloor, increasing from 22 sigma-t in the upper 10 m of the water column to 24.1 sigma-t near the bottom. The density profile was relatively uniform in the surface 10 m then displayed a trend of increasing density with depth, which strongly correlated with the decreases documented in seawater temperature (Figure 3-25). Distinct pycnoclines were detected at water depths of 15, 24, and 27 m, indicative of a stratified water column that was primarily a function of seawater temperature. As a result, these conditions had the potential to affect horizontal current shear, settling of particulate matter, and dispersion of the sediment plume during the 3.5-hour period following the formation of the second sediment plume.

After the background conditions of the water column were recorded, the disposal barge approached Disposal Point A from the north, slowed and released its load at 13:40 UTC. Once again, the CTD sampling vessel positioned itself immediately astern of the disposal barge during the disposal event. The barge was emptied within 30 seconds of opening, with the majority of the sediment falling through the water column to form a deposit in the seafloor. Visual observations revealed that a surface plume remained 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 west-northwest of the observed disposal location 10 minutes post-placement (Figure 3-21). The CTD profile displayed reduced light transmittance levels, relative to background conditions, in the top 15 m of the water column, as well as several meters above the seafloor (Figure 3-26). Percent light transmittance values were at 50% within 5 m below the surface before a sharp increase in suspended sediment concentrations resulting from the disposal event caused light transmittance values to decrease to levels below 10% at 10 m depth. Near-background turbidity conditions were detected in the mid-water column (13 to 27 m), with the near-bottom plume element detectable below the depth of 27 m. The

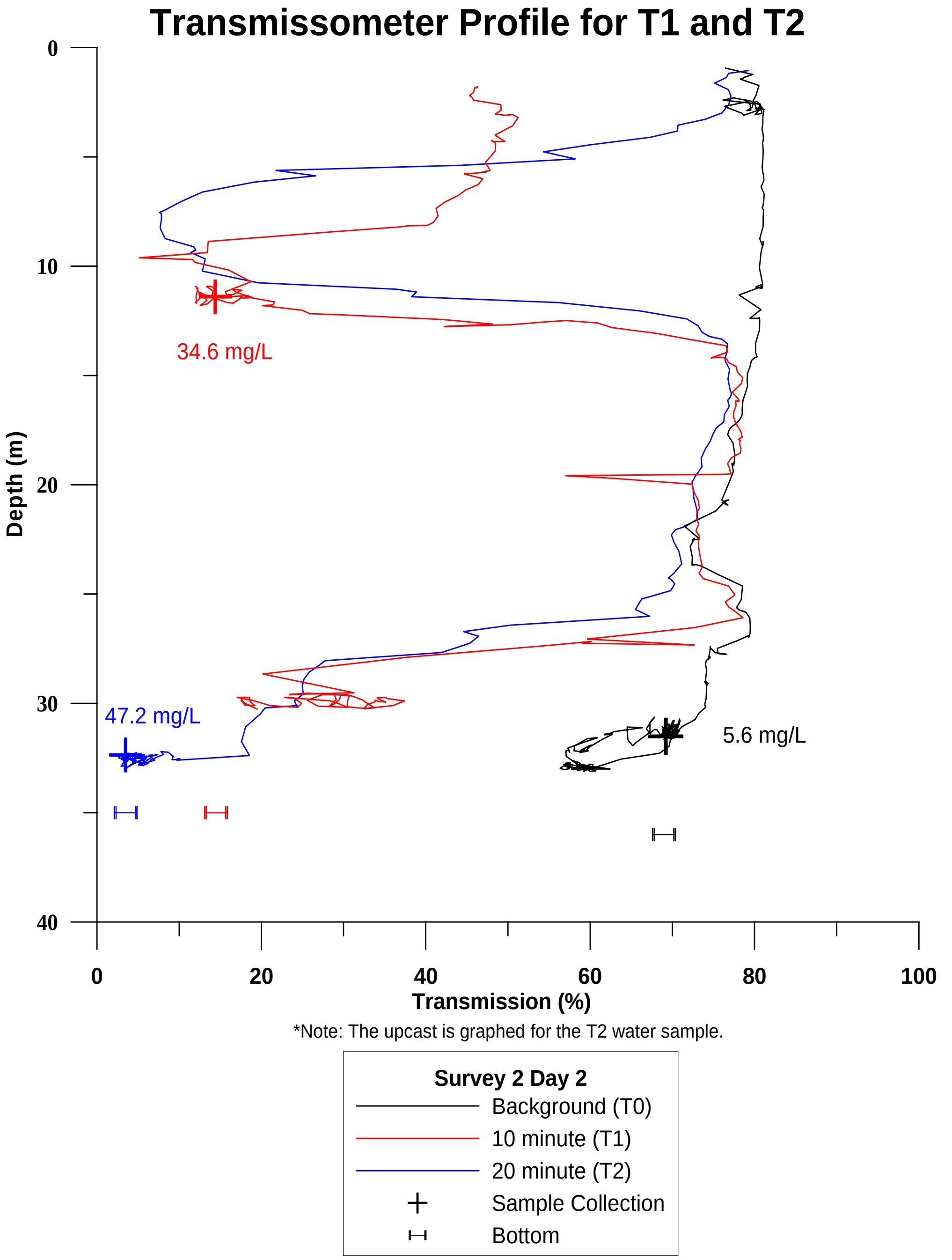


Figure 3-26. Profile plot of percent light transmission and sensor depth acquired during CTD sample intervals T1 and T2 during Plume 2. Locations of water sample collections within the plume are also shown.

suspended sediment concentrations detected near-bottom were lower than those measured in the top 10 m of the water column. As a result, the water samples for TSS analysis were collected at a depth of 10.6 m in the upper portion of the sediment plume during the upcast.

The 20-minute (T2) CTD profile was collected in the vicinity of the deep-water drogue and produced a transmittance profile similar to that of the T1 sample interval. The near-surface portion of the plume was visible from a depth of 3 m, extending down to 13 m before near-background turbidity levels were detected once again (Figure 3-26). The minimum light transmittance value, corresponding to maximum turbidity, was 5% and occurred at a water depth of 8 m. Below the near-surface turbidity layer, light transmittance values were analogous to background values to a depth of 25 m. A distinct trend of increasing suspended sediment concentrations with depth was noted below 25 m in depth, as light transmittance decreased steadily and eventually reached a minimum value of 3%. This discrete near-bottom plume element likely extended to the seafloor, however the CTD profile only encompassed water depths up to 32.5 m, which corresponded to the depth of maximum turbidity for the entire water column. Water samples were collected for TSS within this near-bottom plume element from a depth of 32.5 m prior to the upcast (Figure 3-26).

Based on information provided by the underway ADCP, the CTD profile corresponding to the 40-minute sample interval (T3) was obtained at a location between the deep-water drogue and the surface drifter, in an effort to capture conditions in the apparent plume centroid (Figure 3-21). Due to issues related to positioning the survey vessel over the appropriate location, the T3 (40-minute) sample was obtained approximately seven minutes after the desired sample time (actual time, 47 minutes post-placement). The transmissometer data from the CTD profile displayed turbidity levels similar to background in the upper 20 m of the water column. Turbidity levels were somewhat higher below a depth of 20 m, but appeared quite variable as light transmittance values ranged from 30 to 70% between water depths of 22 to 31 m (Figure 3-27). The water depth for the T3 sampling location was approximately 37 m, however the CTD profile ended at 32 m within a parcel of turbidity, displaying light transmittance values of 10 to 15%. The T3 water samples were collected at a depth of 32 m, within what appeared to be the centroid of the plume.

The T4 (60-minute) profile was obtained near the deep-water drogue approximately 75 m to the northwest of the T3 sample, 55 minutes post-placement (Figure 3-21). Comparisons between the T3 and T4 data sets displayed similarities within the structure of the transmissometer profiles, specifically similar sediment concentrations and plume morphology in the upper and mid-water column (Figure 3-27). However, the near-bottom element of the sediment plume detected in the T4 profile appears to be more diffuse than

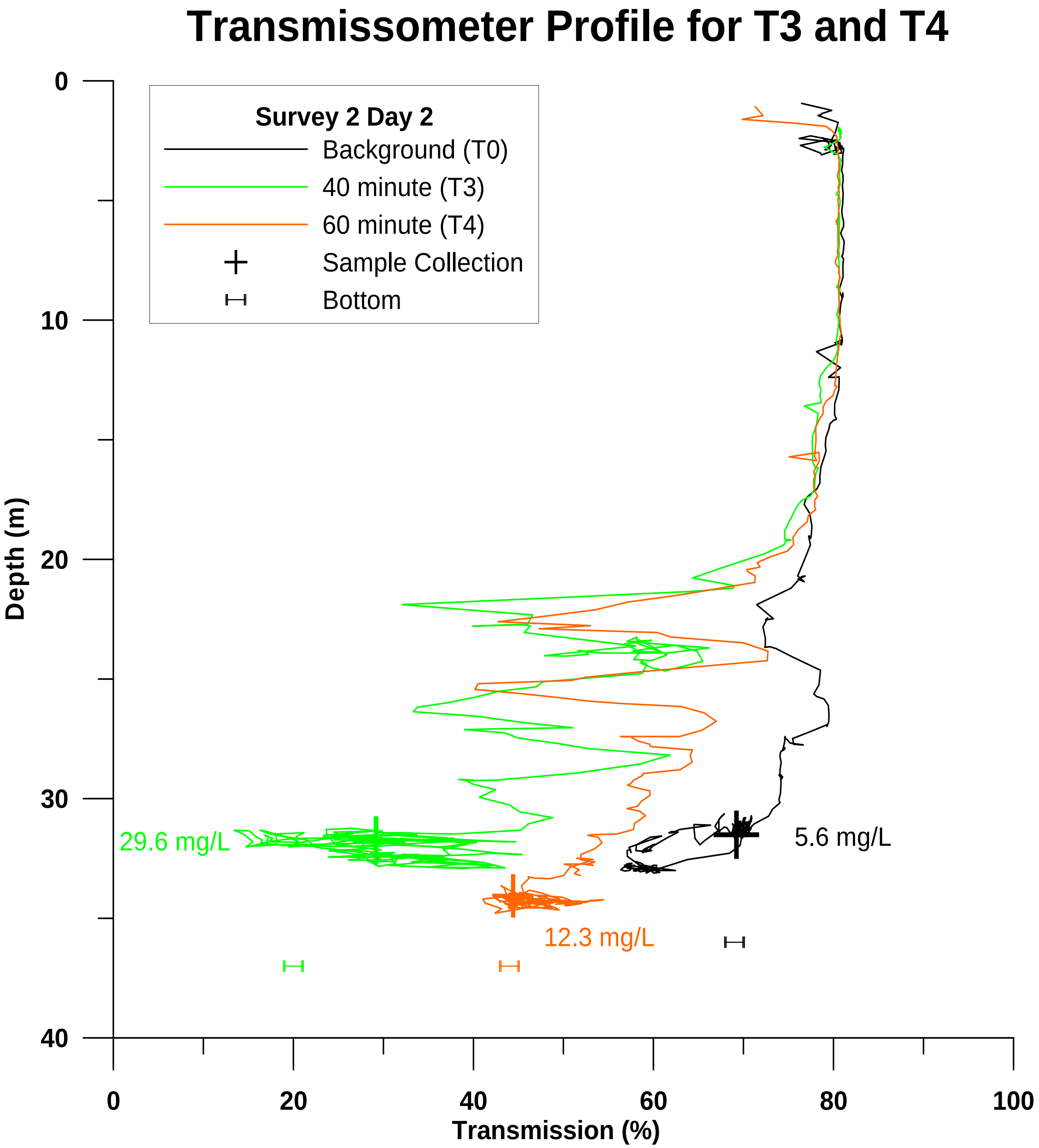


Figure 3-27. Profile plot of percent light transmission and sensor depth acquired during CTD sample intervals T3 and T4 for Plume 2. Locations of water sample collections within the plume are also shown.

observed within T3, with lower concentrations of suspended sediment yielding noticeably higher light transmittance values near the seafloor. A minimum transmittance value of 42% was detected 2 m above the seafloor (34 m depth), prompting the collection of water samples for TSS and toxicity analyses.

Transmissometer profiles for the 90- and 120-minute sampling intervals, T5 and T6 respectively, were quite similar, with both profiles displaying substantially higher light transmittance values relative to the profiles completed earlier in the survey (Figure 3-28). The T5 profile was obtained 1,050 m west of the disposal location, while the T6 profile was obtained 300 m farther west (1,350 m total distance) 30 minutes later (Figure 3-21). Both profiles displayed turbidity levels in the upper water column that were near background conditions, with minimum light transmittance values of 50 to 55% detected near-bottom. The most significant difference between the two profiles related to the structure of the sediment plume was observed within the lower half of the water column. The T5 (90-minute) profile displayed an increase in turbidity at 25 m in depth as light transmittance gradually decreased with depth from a value of 76% at mid-depth to approximately 50% in proximity to the seafloor. The T6 (120-minute) profile also displayed an increase in turbidity levels at 25 m depth, but the transition between clear waters in the upper water column to those affected by the sediment plume was much more distinct in comparison to T5 (Figure 3-28). Between 25 and 26 m depth, the light transmission values decreased sharply from 76 to 55%, then rebounded to approximately 70%, possibly a function of the physical properties of the water column (i.e., density). Below 26 m, suspended sediment concentrations appeared to increase gradually with depth in a manner similar to the T5 profile and eventually yielded transmittance values that were comparable to the T5 data. Water samples for laboratory analyses were collected in the densest portion of the near-bottom plume element at a water depth of 32 m (2 to 3 m above the seafloor) for both sample intervals.

Overall, the structure of the T7 and T8 water column profiles was quite similar to those of the T5 and T6 profiles. However, light transmittance values were somewhat higher in the T7 and T8 profiles, relative to the earlier profiles, as suspended sediment concentrations decreased within the near-bottom portion of the plume, as well as in the upper half of the water column. Collected along the same line as the earlier profiles, both the T7 and T8 profiles indicated the first noticeable decrease in light transmittance at a depth of 27 m (Figure 3-29). Below 27 m, percent light transmittance values gradually decreased with depth, eventually reaching minimum values between 55 and 60%, several meters above the seafloor. Water samples for TSS analysis were collected a depth of 33.5 m during the T7 profile, while the T8 water samples were obtained at a depth of 32 m.

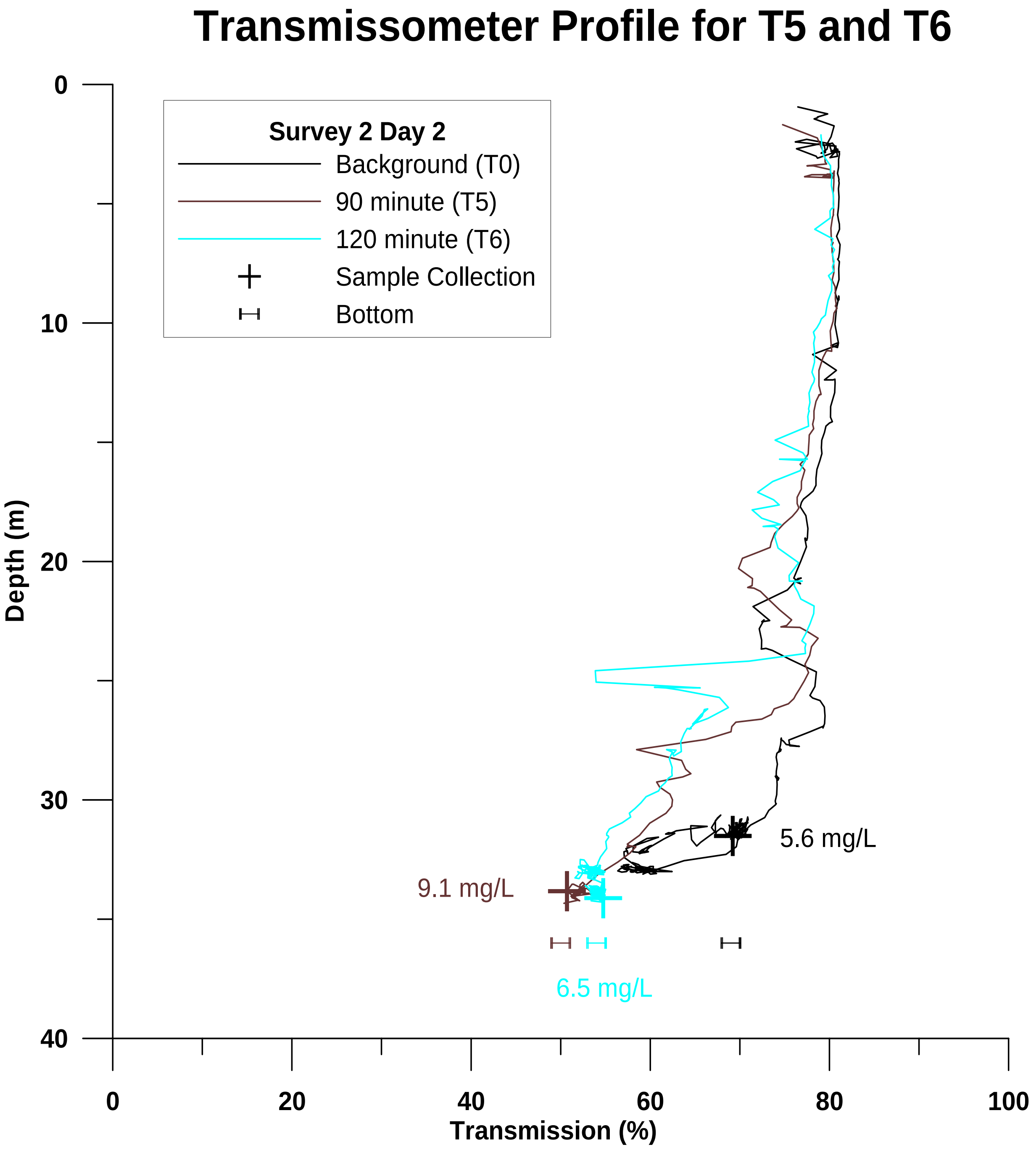


Figure 3-28. Profile plot of percent light transmission and sensor depth acquired during CTD sample intervals T5 and T6 for Plume 2. Locations of water sample collections within the plume are also shown.

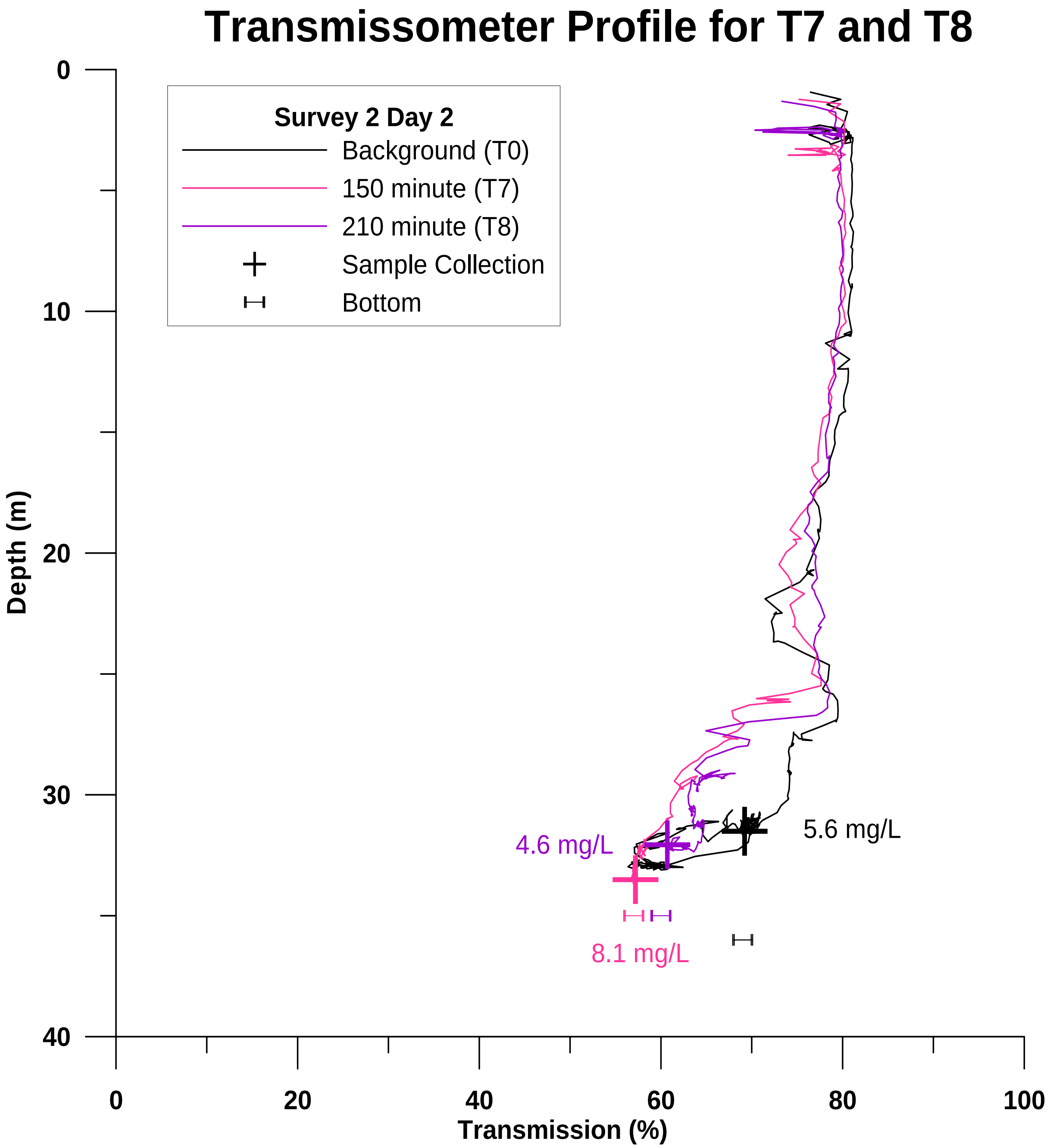


Figure 3-29. Profile plot of percent light transmission and sensor depth acquired during CTD sample intervals T7 and T8 for Plume 2. Locations of water sample collections within the plume are also shown.

3.2.2.3 Total Suspended Solids (TSS)

A summary of the TSS results, including background water samples for Plume 2, is provided in Table 3-6. Upon review of the laboratory data compiled for TSS, the values corresponding to the third replicate sample (replicate C) for a number of sample intervals were consistently higher than those of the A and B replicates and yielded high standard deviation values (STDev). Although the reason for this trend was explored with the analytical laboratory, this bias could not be explained by reviewing the field sampling technique or the laboratory procedures. In order to prevent these biased data from degrading the replicate-averaged results, the information related to each C replicate was omitted in the calculation of average TSS for each Plume 2 sample interval.

The background samples for the Plume 2 tracking event (S2D2_T0) were obtained in the northwest corner of the disposal site (in the vicinity of Disposal Point A) prior to dredged material placement. Background (T0) samples, collected approximately 5 m above the seafloor, revealed a relatively low average TSS value of 5.6 mg·L^{-1}. During the plume monitoring survey, TSS samples were collected based upon real-time transmissometer data, 2 to 3 m above the seafloor, within parcels of water displaying elevated turbidity levels.

The initial CTD profile conducted ten minutes post-placement indicated the presence of a distinct sediment plume in the upper portion of the water column, however, the vessel drifted out of the plume centroid and was repositioned prior to the collection of the water samples. As a result, the T1 water samples were collected 17 minutes after the dredged material disposal event at a depth of 11 m. The replicate-averaged TSS concentration of 34.6 mg·L^{-1}, representing a substantial increase in suspended sediment load relative to background levels, indicated high turbidity levels at this point in the survey (Table 3-6). However, based on the relatively low value of this T1 sample in comparison to the Plume 1 results for T1 (Table 3-4), it was unlikely the sample was obtained from the most turbid portion of the sediment plume.

A water sample collected as part of the T2 (20-minute) sample interval displayed an average TSS value of 47.2 mg·L^{-1}; somewhat higher than the T1 results (Table 3-6). This sample was collected from a depth of 32 m (approximately 3 m off the bottom) within the near-bottom portion of the sediment plume. The percent light transmittance recorded by the transmissometer just prior to the acquisition of the T2 sample (3.5%) was the lowest value obtained during the Plume 2 survey, correlating well with the elevated TSS concentrations detected in the T2 water sample.

Table 3-6
Results of Total Suspended Solids (TSS) Analysis from Discrete Water Samples collected during CTD Profiling Operations during 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*
S2D2_T0	0	0:00	31.5	69.2	11.6	5.4	5.8	17.0	5.6	0.28
S2D2_T1	10	0:17	11.4	14.4	22.6	38.4	30.8	49.2	34.6	5.37
S2D2_T2	20	0:19	32.4	3.5	35.4	46.8	47.6	56.8	47.2	0.57
S2D2_T3	40	0:47	31.7	29.2	23.8	34.4	24.8	42.8	29.6	6.79
S2D2_T4	60	0:55	34.1	44.4	15.3	12.6	12.0	19.0	12.3	0.42
S2D2_T5	90	1:37	33.8	50.7	14.0	10.6	7.6	14.4	9.1	2.12
S2D2_T6	120	1:59	34.1	54.8	13.4	6.0	7.0	15.0	6.5	0.71
S2D2_T7	150	2:32	33.5	57.2	12.8	10.4	5.8	11.6	8.1	3.25
S2D2_T8	210	3:32	32.1	60.7	12.2	3.6	5.6	19.8	4.6	1.41

***** Values calculated based on replicates A and B only.

Plume tracked from the disposal of material from a 4,600 m^3-capacity split-hull disposal barge, loaded only to 2,300 m$^{3.}$

At 40 minutes post-placement, average TSS within the near-bottom portion of the sediment plume was 29.6 mg·L^{-1}, indicating a substantial decrease in turbidity due to diffusion of the suspended sediment cloud and settlement of entrained material (Table 3-6). TSS values continued to fall throughout the remainder of the survey, as average TSS values of 12.3 and 9.1 mg·L^{-1} were detected in the samples collected during the T4 and T5 intervals, respectively. The water samples collected during the final 1.5 hours of the Plume 2 survey (T6, T7, and T8) yielded TSS values quite close to background levels.

3.2.2.1 ADCP Backscatter

Upon arrival at RISDS, background acoustic backscatter intensity and water column velocity data were collected to assess conditions prior to the planned disposal event. Data from the initial transect showed higher backscatter values (75 to 80 counts) at mid-depth (15 to 20 m) in comparison to the remainder of the water column (Figure 3-30). The presence of elevated acoustic backscatter at mid-depth was similar to the findings of the first plume tracking survey performed in Spring 2004, which was attributed to micro-layering within the water column establishing many acoustic reflectors (SAIC 2005). However, the raw values documented during the summer survey were not as high as they were in April, nor were they as disparate from the remainder of the water column.

Due to the predominant flow to the west-southwest, a northwest-southeast survey transect orientation was chosen prior to survey operations. The first ADCP transect completed was Line M. Data collection over Line M began one minute prior to the disposal event at Point A, and continued for approximately 10 minutes, as the ADCP crossed directly over the disposal point. At eight minutes post-placement, a distinct plume, measuring approximately 160 m wide on the surface and in excess of 300 m along the seafloor, was identified immediately following the disposal event (Figure 3-31A). The entrained sediment and gas bubbles comprising the plume occupied the entire water column, with residual acoustic backscatter intensities in excess of 32 counts.

The data collected along Line N, located 100 m to the southwest, displayed a broader sediment plume at the surface and bottom (240 m wide), 10 to 15 minutes post-placement. Residual acoustic backscatter values at the edges of the plume provided a wider gradient between ambient seawater and the sediment plume, indicative of dilution along its margins and dispersal of sediment within the water column (Figure 3-31B). Line O, located 200 m downstream of the observed disposal point, was occupied approximately 20 minutes post-placement. The residual acoustic backscatter data obtained over Line O showed an overall reduction in the concentration of suspended material within the water column in comparison to Line N (Figure 3-31C). In general, the plume features detected along Lines N and O were of similar shape, however the reduction in acoustic return

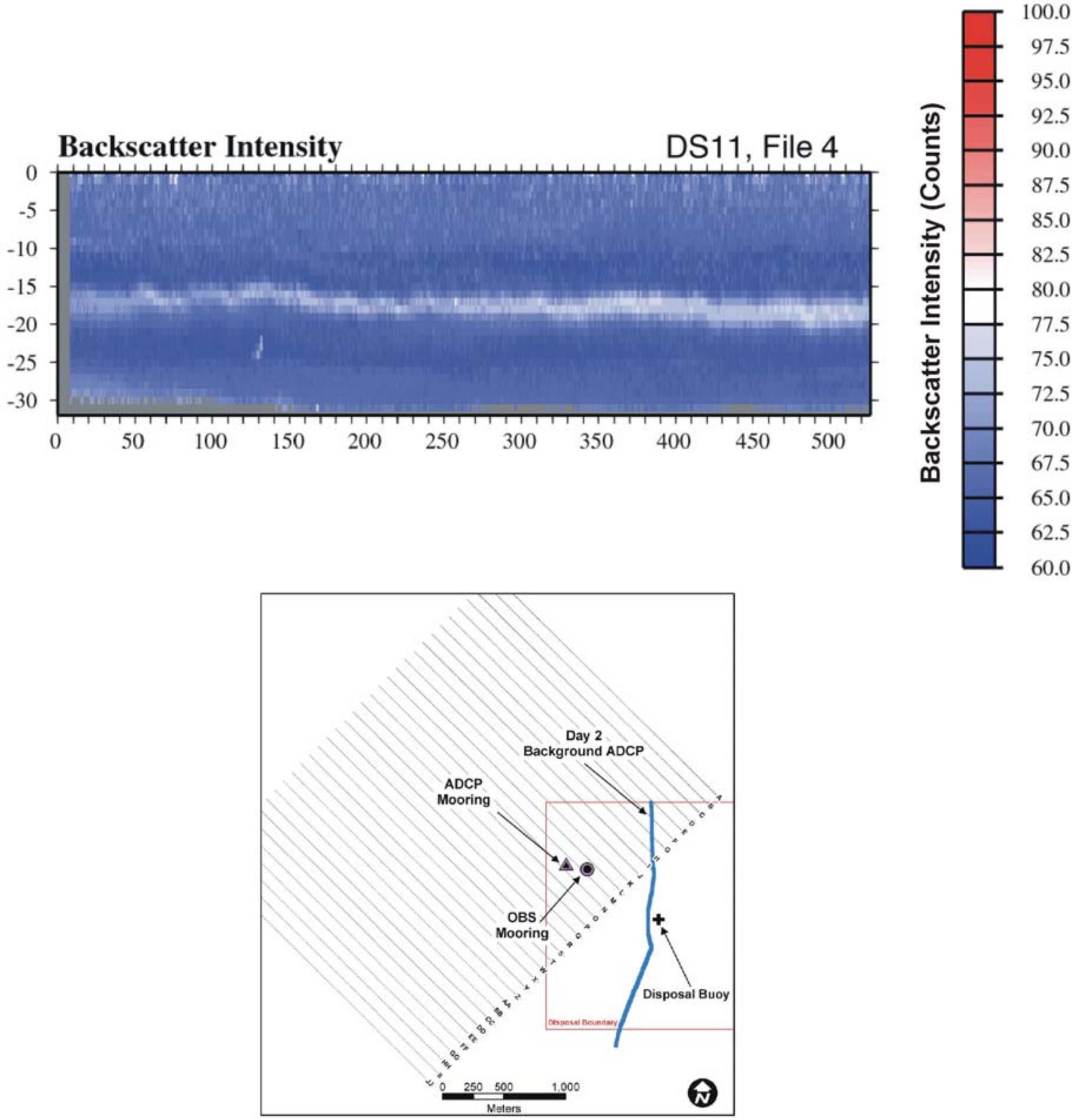


Figure 3-30. Profile plot of raw ADCP backscatter data collected on 2 September 2004 to characterize background conditions at RISDS.

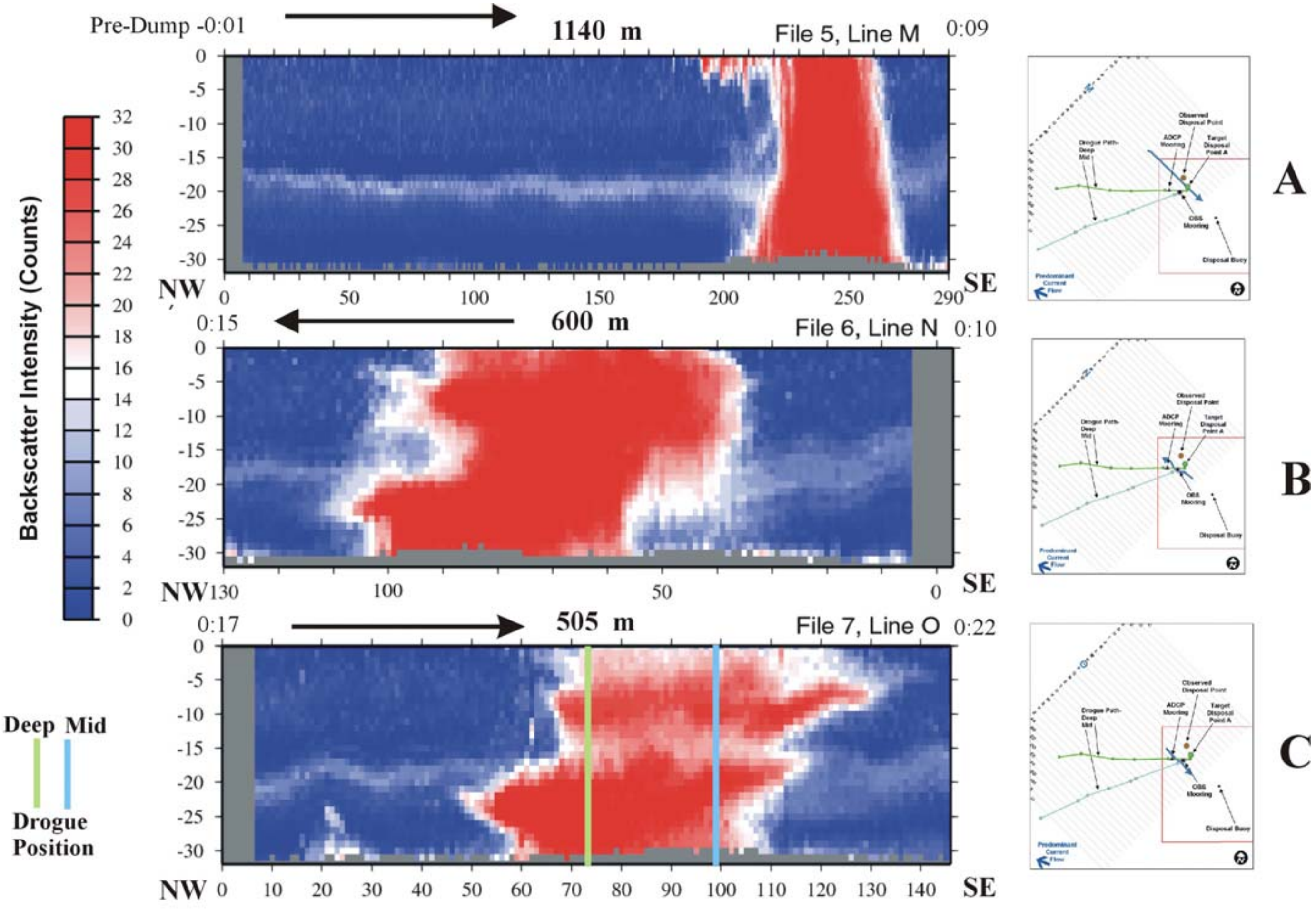


Figure 3-31. Profile plots of data collected from ADCP transects M, N, and O on 2 September 2004 displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to illustrate plume morphology prior to disposal and 22 minutes after the dredged material disposal event at Point A.

within the upper water column suggested the divergent current flow was resulting in a separation of near-surface and near-bottom elements of the plume.

Upon completing Line O, the survey vessel returned to Line M to examine the trailing edge of the sediment plume approximately 27 minutes post-placement. Only a small plume feature measuring approximately 140 m in width remained detectable below a depth of 22 m (Figure 3-32A). This plume feature remained relatively compact, with the ADCP data indicating a high residual backscatter signal (30 counts maximum value). As a result, this near-bottom element of the sediment plume appeared to remain in close proximity to the original disposal location and quite turbid nearly 30 minutes after its formation.

Following the second occupation of Line M, data were collected along Line O, once again to examine the sediment plume at approximately 35 minutes post-placement (Figure 3-32B). At this point in the survey, the residual backscatter data indicated the presence of two separate, yet relatively broad and diffuse plumes within the near-surface and near-bottom layers. Maximum backscatter values in the near-surface plume had decreased to 24 counts, while the near-bottom element of the plume yielded backscatter values of approximately 26 counts. In addition, the near-bottom plume appeared to remain to the northwest of the near-surface plume, indicating some divergence in direction of transport. Although the acoustic record displayed little turbidity at mid-depth, suspended sediments were likely present at concentrations comparable to the remainder of the water column. The acoustic signature of these particles was probably obscured in the residual backscatter data due to the effects of the relatively high background levels.

As the sediment plume was transported to the west and southwest, the survey continued along the grid on Line P (300 m southwest of the disposal point), approximately 40 minutes post-placement (Figure 3-33A). Similar to the results from the second occupation of Line O, the residual acoustic backscatter record suggested the presence of two plume features (upper and lower water column), each restricted to particular levels in the water column. However, a substantial amount of suspended particulate matter likely existed at mid-depth, but was obscured during the processing of the ADCP data due to the elevated raw acoustic backscatter in the ambient water column that was subtracted from the profile data. The processed data for the subsequent survey line (Line Q) confirmed that assumption, as residual backscatter values between 12 and 14 counts were detected between the stronger acoustic signals near-surface and near-bottom (Figure 3-33B). Completed roughly 50 minutes post-placement, the highest residual backscatter observed along Line Q was at a depth of 30 m with levels above 26 counts and was likely representative of the centroid (most turbid portion) of the disposal plume.

In an effort to reacquire and examine the core of the sediment plume, Line S (lying

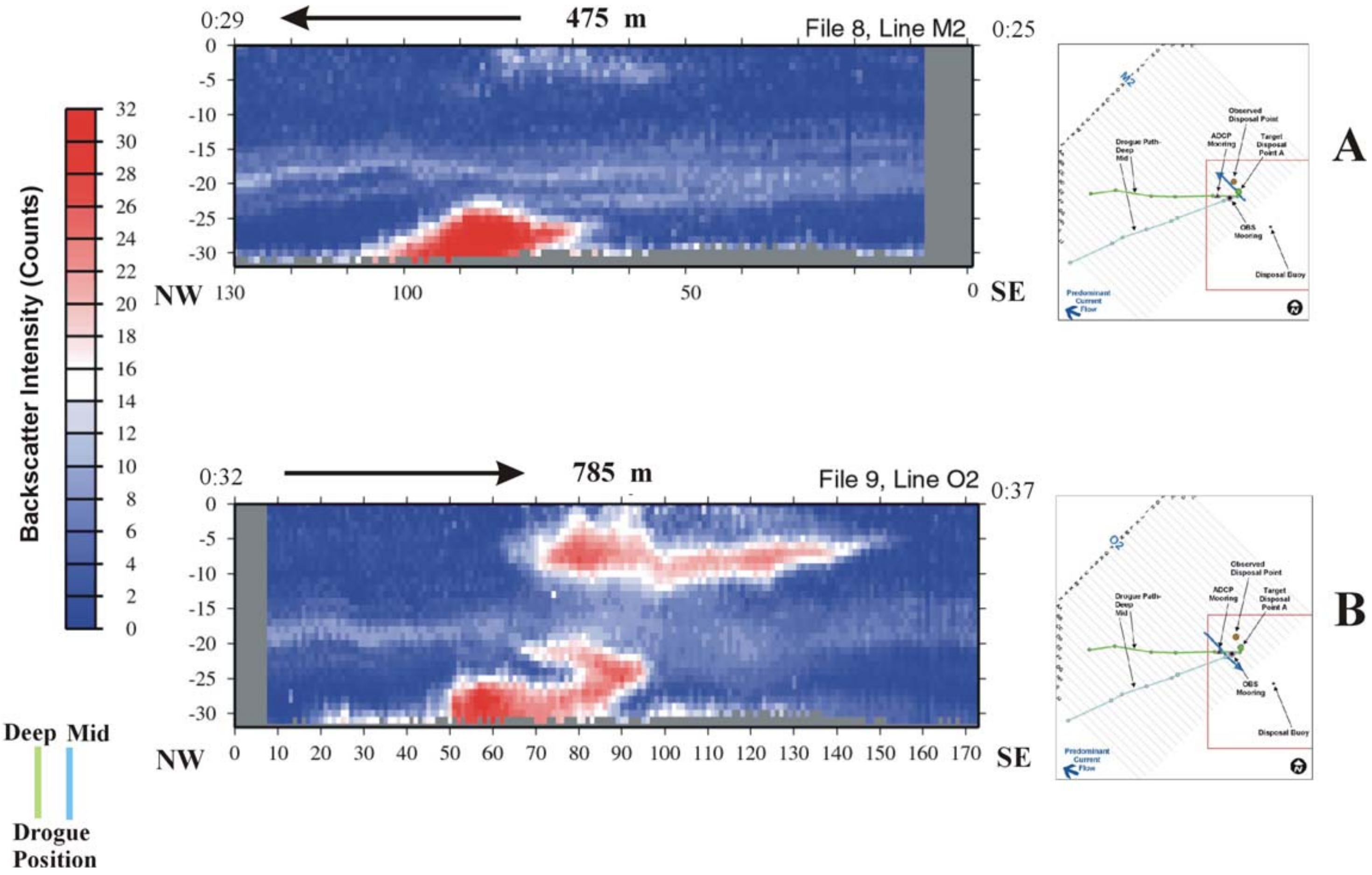


Figure 3-32. Profile plots of data collected from ADCP transects M2 and O2 on 2 September 2004 displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to illustrate plume morphology 37 minutes after the dredged material disposal event at Point A.

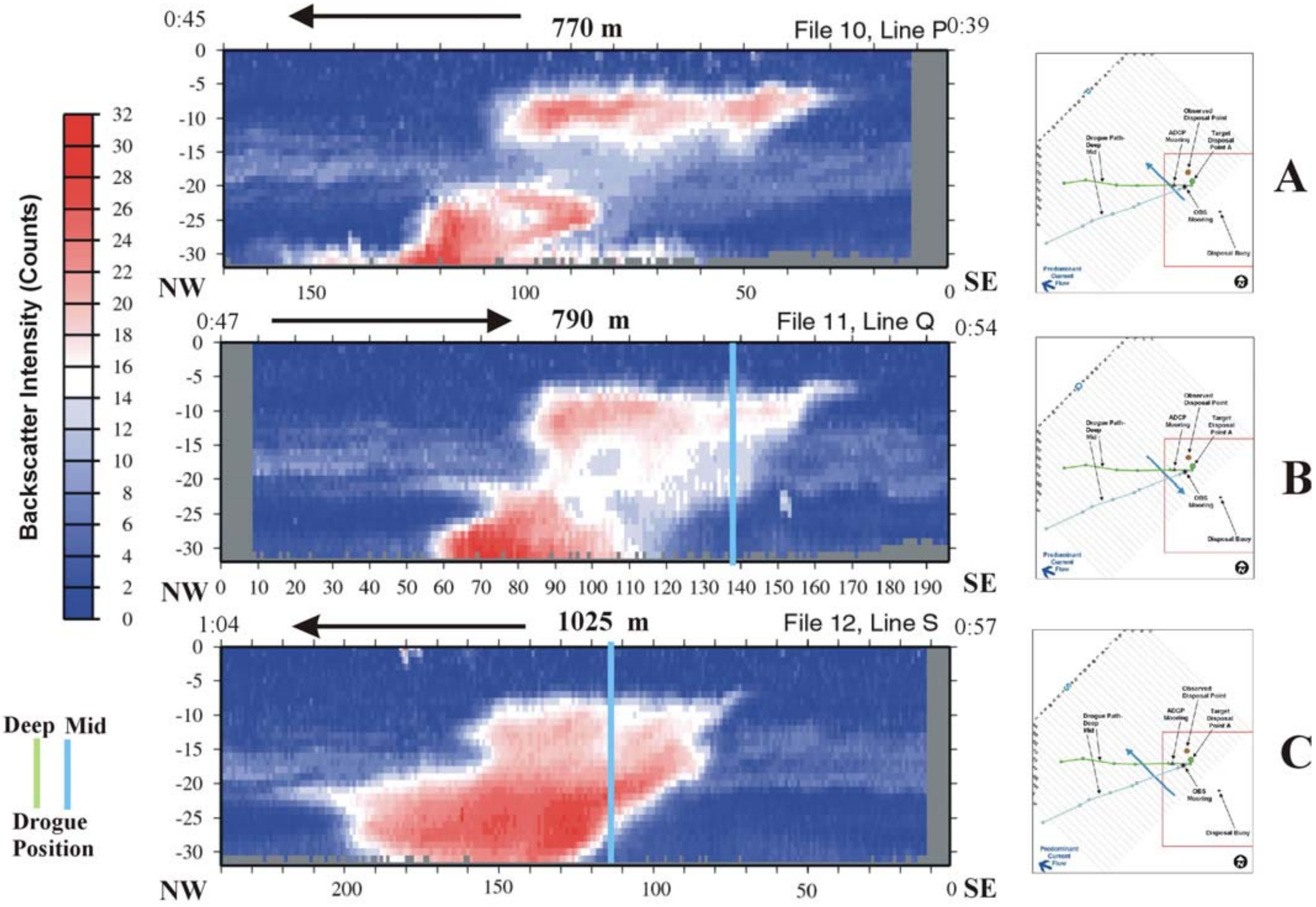


Figure 3-33. Profile plots of data collected from ADCP transects P, Q, and S on 2 September 2004 displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to illustrate plume morphology one hour and 4 minutes after the dredged material disposal event at Point A.

600 m southwest of the observed disposal point) was occupied at approximately 60 minutes post-placement. Overall, the sediment plume detected in the residual acoustic backscatter data was larger than in previous lines, with a maximum width of 565 m detected at a water depth of 22 m (Figure 3-33C). The relative strength of the acoustic backscatter signal remained high in the lower half of the water column, as values of 26 counts were detected at the depth interval between 20 to 30 m. This core of higher backscatter was approximately 90 m wide and appeared concentrated near the mid-depth drogue position.

Subsequent survey lines (Lines U and V) provided insight into the shape and relative turbidity within the leading edge of the sediment plume. Line U was occupied approximately 70 minutes post-placement and showed a substantial plume element at mid-depth, with relatively clear water in the upper 5 m of the water column and at depths below 30 m (Figure 3-34A). The highest concentration of suspended sediments was observed within the 17 to 27 m depth interval, just northwest of the mid-water drogue position. The plume displayed a maximum width of approximately 300 m at the 12-m depth interval, with a lower backscatter intensity (14 to 22 counts) than within the more concentrated element identified within the 17 to 27 m depth interval. A similar pattern of suspended sediment distribution and concentration was observed within the water column along Line V, ten minutes later in the survey (Figure 3-34B). The overall size of the sediment plume was slightly larger (maximum width of 350 m at 12 m depth), but residual backscatter values were within the range that was noted in the data from Line U.

Following the completion of Line V, Line U was reoccupied to observe changes in the plume relative to the previous pass (approximately 20 minutes prior; Figure 3-35A). In general, the shape of the sediment plume, based upon the cross-sectional data collected over Line U, was quite comparable to the results obtained from Line S (located 200 m up-current), 30 minutes prior. Similar to Line S, the majority of the sediment plume was located in the lower half of the water column (below 20 m depth), with a maximum width of 520 m at a depth of 27 m. These findings indicate that the sediment plume maintained much of its size and integrity as it was transported 200 m to the west-southwest by near-bottom currents. However, the relative strength of the acoustic returns was somewhat weaker and more ubiquitous relative to those detected along Line S, suggesting a substantial amount of settlement had occurred over that 30-minute period.

Lines T and R, up-current of the sediment plume core, were occupied 100 to 120 minutes post-placement and displayed the relatively weak acoustic backscatter (12 to 14 counts) associated with the trailing edge of the sediment plume. The data from Line T revealed a parcel of weakly turbid water extending from 5 to 30 m in depth (Figure 3-35B). The effects of water column current direction and magnitude on the sediment plume were obvious in the Line T data. The suspended material entrained within the upper water column was offset toward the southeast end of the survey line and was

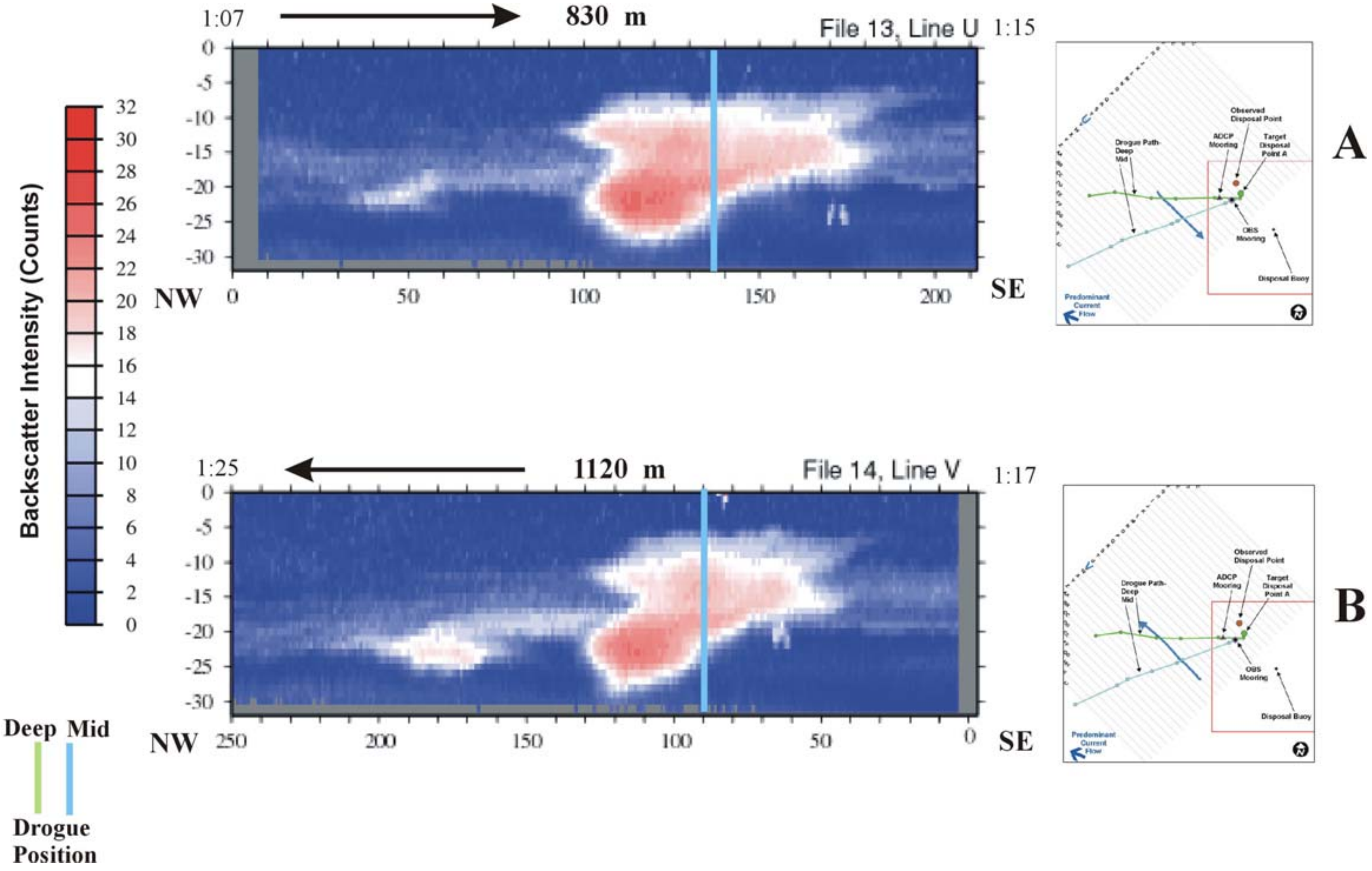


Figure 3-34. Profile plots of data collected from ADCP transects U and V on 2 September 2004 displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to illustrate plume morphology one hour and 25 minutes after the dredged material disposal event at Point A.

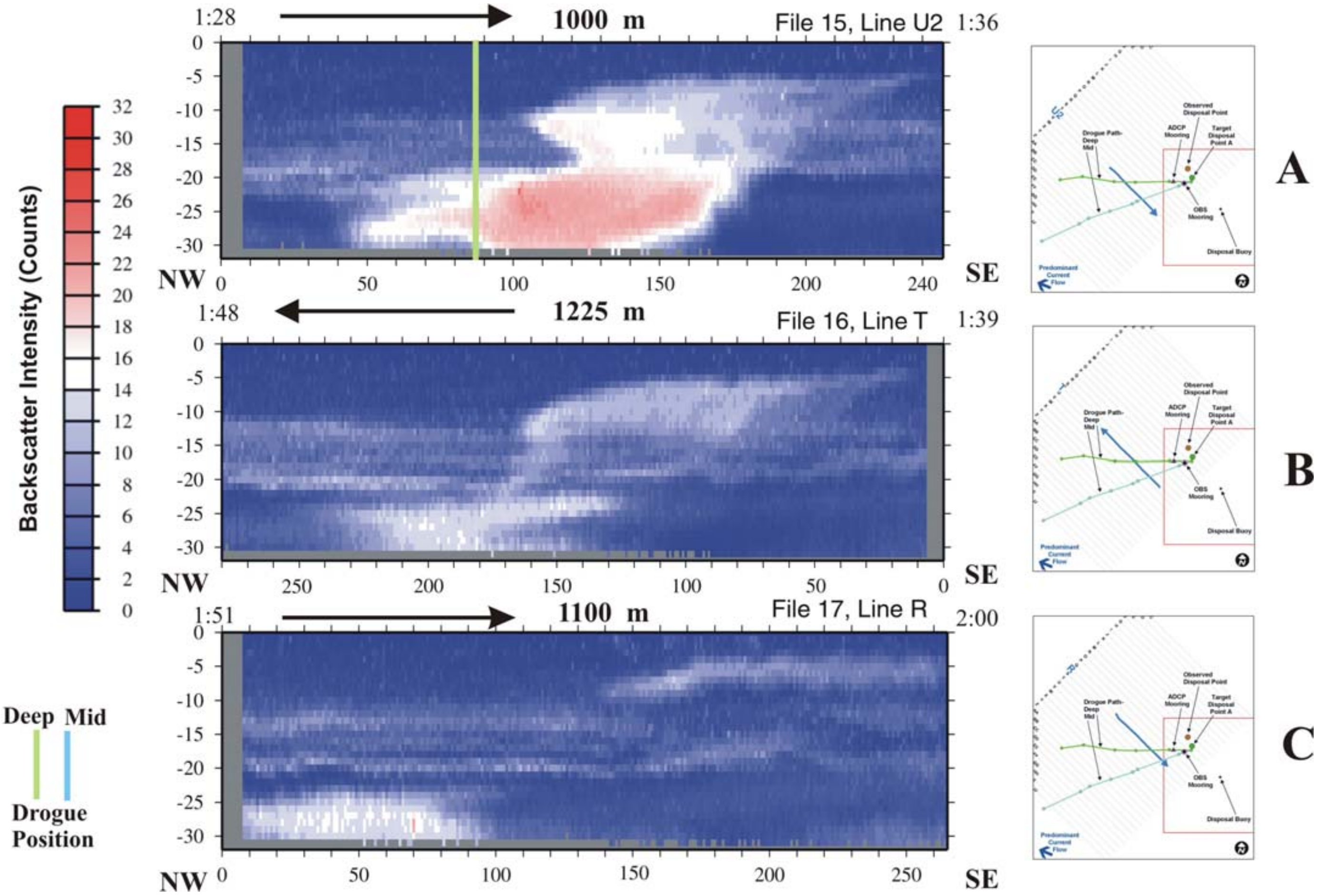


Figure 3-35. Profile plots of data collected from ADCP transects U2, T, and R on 2 September 2004 displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to illustrate plume morphology two hours after the dredged material disposal event at Point A.

slightly more diffuse in comparison to the near-bottom portion of the plume. These two plume elements were connected through the mid-water column by a parcel of turbid water. However, the acoustic artifact associated with the physical properties of the water column, as measured in the background ADCP data, obscured the residual backscatter information at mid-depth. The residual backscatter data from Line R, lying 200 m up-current, generally supported the findings from Line T. A distinct near-bottom plume element was present at the northwest end of a survey line nearly two hours post-placement, with maximum backscatter intensity values of 16 to 18 counts (Figure 3-35C). A weak residual backscatter signal was also noted at a depth of 5 m, and likely associated with the trailing edge of the near-surface plume element.

Line Y, 1.2 km southwest of the observed disposal point, was occupied approximately 130 minutes after the disposal event. The backscatter information collected along Line Y displayed the core of the sediment plume existing in the lower half of the water column, southeast of the deep-water drogue position (Figure 3-36A). The highest concentration of suspended sediment was detected between the 20 and 30 m water depth interval, yielding residual backscatter values of 18 to 20 counts. At 25 m depth, the detectable sediment plume was approximately 870 m wide.

Lines AA through JJ were added to the survey grid to continue monitoring transport and decay of the sediment plume during the final 60 minutes of the field operation. Long segments of Lines CC through EE were occupied during the Plume 2 survey, documenting the morphology of the sediment plume approximately 2 km down-current of the observed disposal location. The data obtained over Line DD displayed a fairly distinct plume feature in proximity to the mid-depth drogue position, with a shape analogous to that detected along Lines U and V approximately 90 minutes earlier in the survey (Figure 3-36B). A noticeable reduction in acoustic backscatter intensity indicated a substantial amount of dilution and settlement had occurred. The data collected along Lines EE and CC displayed the acoustically detectable remnants of the waning sediment plume within the water column 180 to 200 minutes post-placement (Figures 3-37A and B). In general, these transects displayed a broad, disperse plume with residual backscatter values of 12 to 14 counts and widths ranging from 350 to 900 m. The acoustic signature detected over Line EE was similar to that documented over Line DD several minutes prior, while the acoustic returns collected along Line CC, 200 m up-current, were characteristic of the trailing edge of the sediment plume.

Just prior to concluding survey operations for Plume 2, a final survey line was run independently of the survey grid that intersected the 1.9 km length of Rhode Island Sound, oriented toward the south-southwest, and passing the final position of the deep drogue (Figure 3-38). The plume was acoustically detectable in the water column between the mid- and deep drogue positions within the depth interval of 10 to 30 m. Residual acoustic

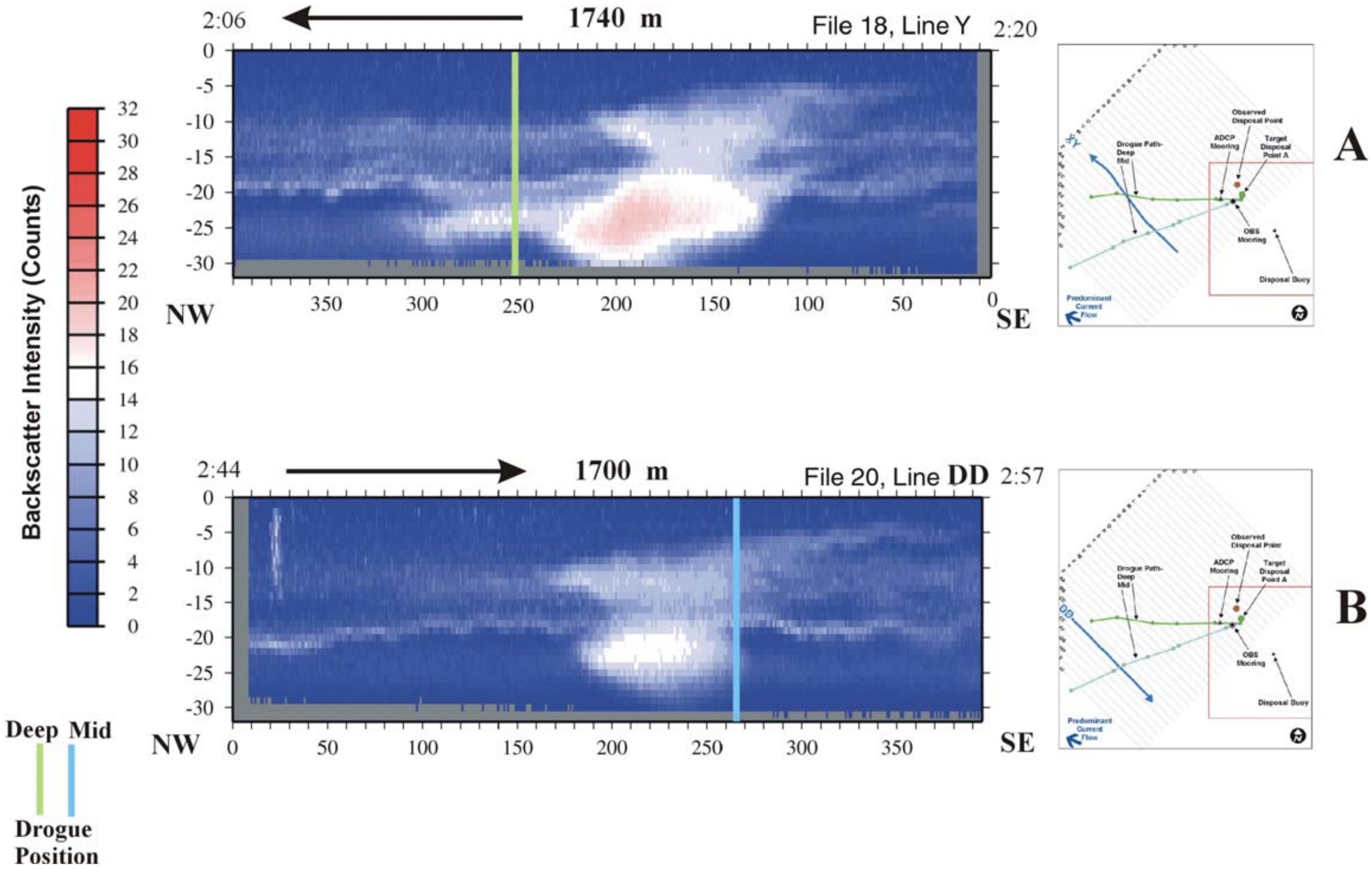


Figure 3-36. Profile plots of data collected from ADCP transects Y and DD on 2 September 2004 displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to illustrate plume morphology two hours and 57minutes after the dredged material disposal event at Point A.

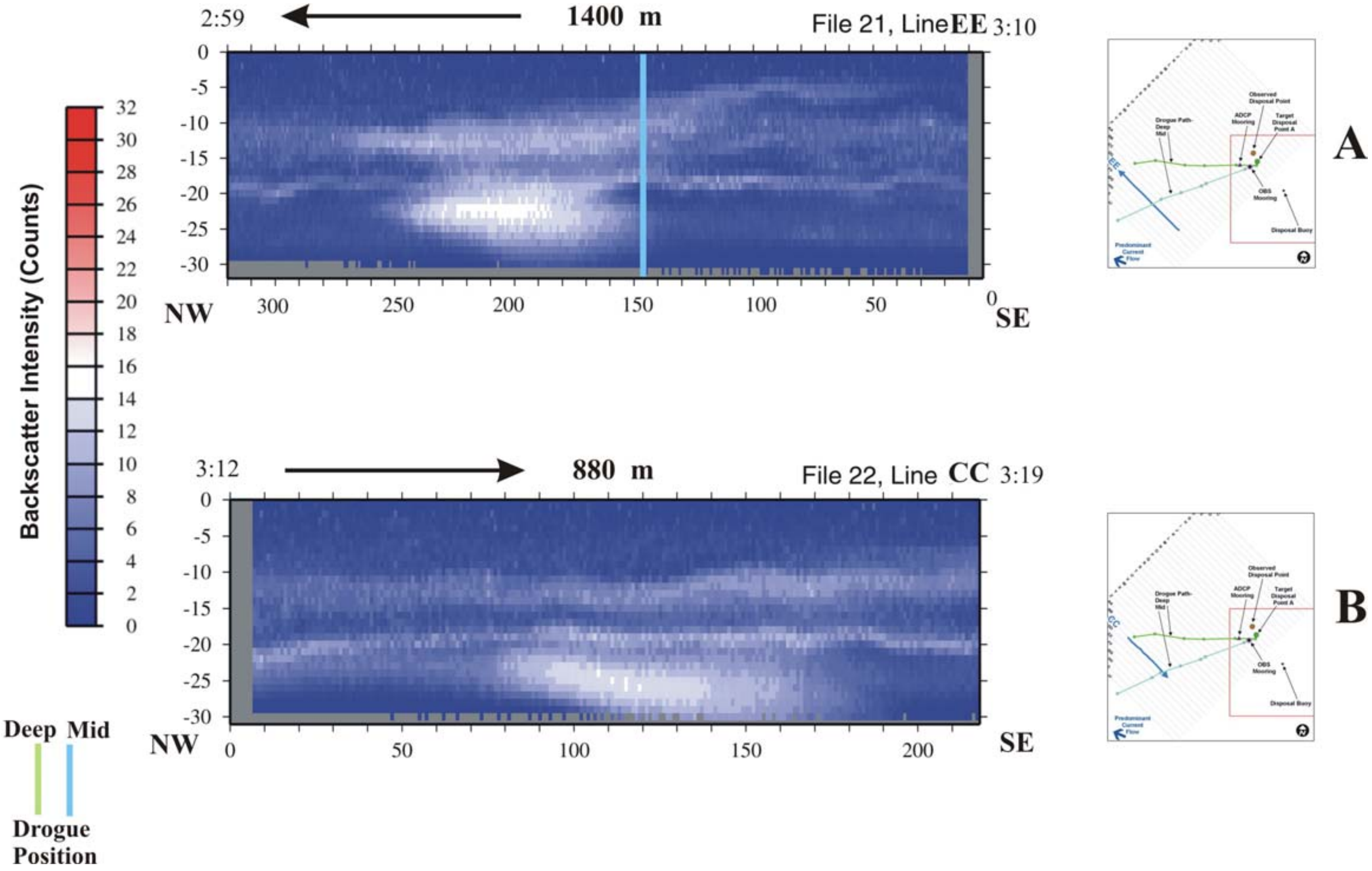


Figure 3-37. Profile plots of data collected from ADCP transects EE and CC on 2 September 2004 displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to illustrate plume morphology three hours and 19 minutes after the dredged material disposal event at Point A.

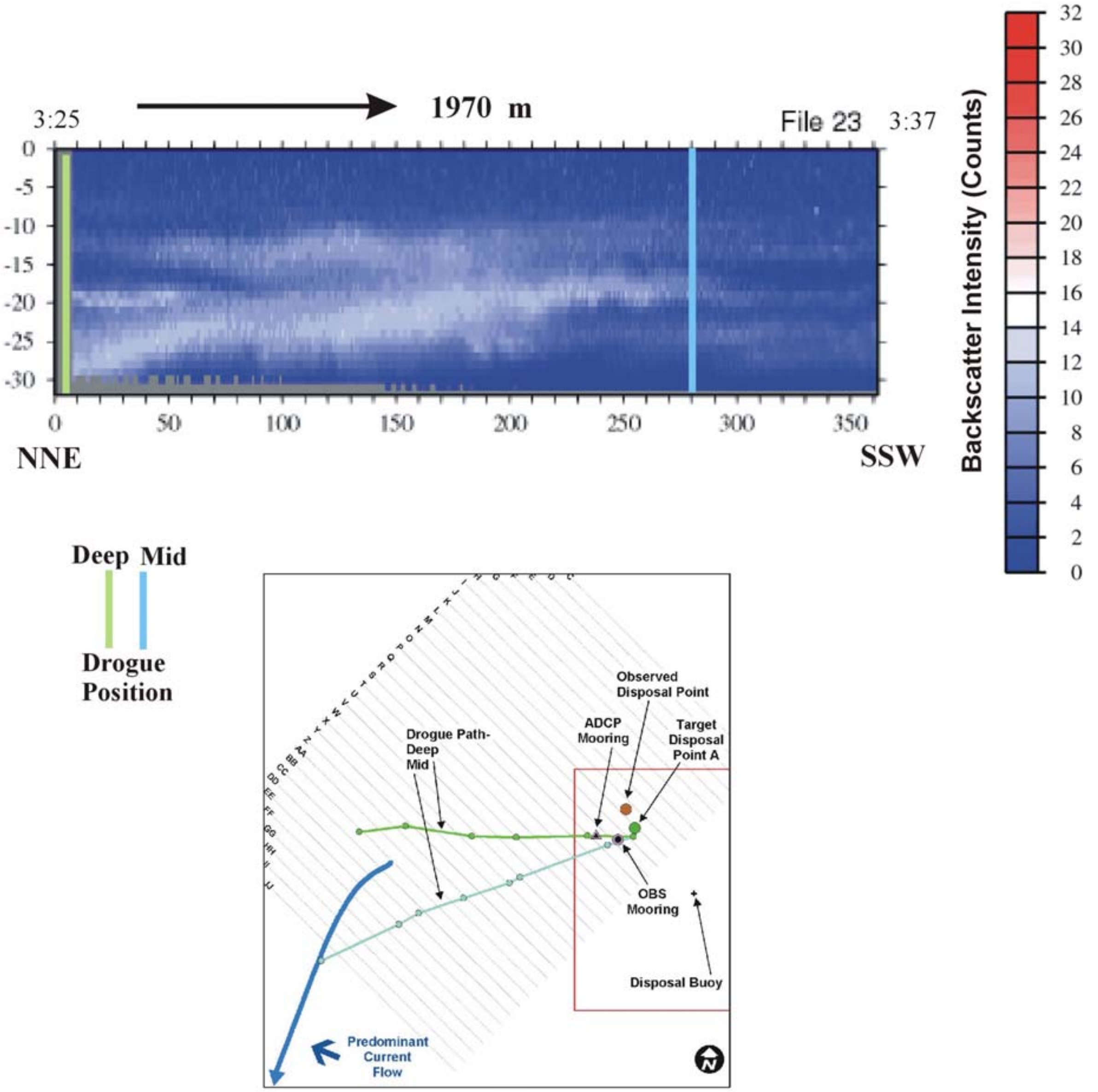


Figure 3-38. Profile plots of data collected from ADCP transect on 2 September 2004 displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to emulate plume morphology three hours and 37 minutes after the dredged material disposal event at Point A.

backscatter values ranging from 12 to 16 counts were detected along a 1,430 m segment of this survey line 210 minutes after the disposal event. These data essentially characterized the leading edge of the entire sediment plume and depicted the elongated morphology of the plume caused by divergent flow within the water column more effectively than examining individual cross-sections along pre-determined survey lines.

3.2.2.5 Water Column Optical Backscatter

As part of the Plume 2 survey, the OBS mooring was placed in the presumed path of the disposal plume at a location approximately 150 m southwest of the target disposal point (Figure 2-4) where the water depth was 36.5 m. The mooring was deployed 38 minutes prior to the disposal event, allowing an ample amount of background data to be collected during this period. Background turbidity data from the three individual depth levels were similar to the previous day, with low background turbidity (less than 5 FTU) recorded by the upper two sensors (at 13 and 18 m depth), and a higher background of 10 to 12 FTU at the lower sensor at 32 m depth (Figure 3-39). Disposal occurred at 13:40 UTC and a very sharp, but short-lived increase in turbidity was noted in the lower OBS sensor at 13:42 UTC, reaching a value of 592 FTU. These high turbidity levels persisted for approximately one minute, after which turbidity levels returned to the previous background values. This initial pulse of turbidity was not detected by the sensors placed higher in the water column, indicating it was isolated to depths below 18 m. Comparison of these results to other studies suggested the dramatic increase in turbidity was attributable to the translation of energy in the vertical axis associated with convective descent to the dynamic collapse phase, which occurs along the horizontal plane (SAIC 2002). This process causes highly turbid water to radiate in all directions from the disposal point in the form of a finite cloud or annulus of turbidity; this initial product of the disposal event is then followed by the full sediment plume.

Two minutes after the passage of the initial annulus of turbid water, the near-bottom sensor recorded an increase in turbidity levels associated with the near-bottom element of the sediment plume. This was followed by increases noted by the mid-depth (18 m) and near-surface (13 m) sensors several minutes later, confirming that the concentrated plume had reached the OBS mooring. Near-bottom turbidity caused by the sediment plume displayed a maximum value of 225 FTU, but displayed consistent measurements of approximately 120 FTU for three minutes, then a gradual decline to background conditions over a 10- to 15-minute period. The deepest sensor also recorded a second period of increased turbidity approximately 30 minutes after the passage of the leading edge. Optical backscatter values fluctuated between 30 and 40 FTU, for a period of 25 minutes before dropping to 12 FTU. Near-bottom turbidity at this level was lowest at 16:40 UTC (approximately 8 FTU), but another period of increased turbidity (18 to 24 FTU) was

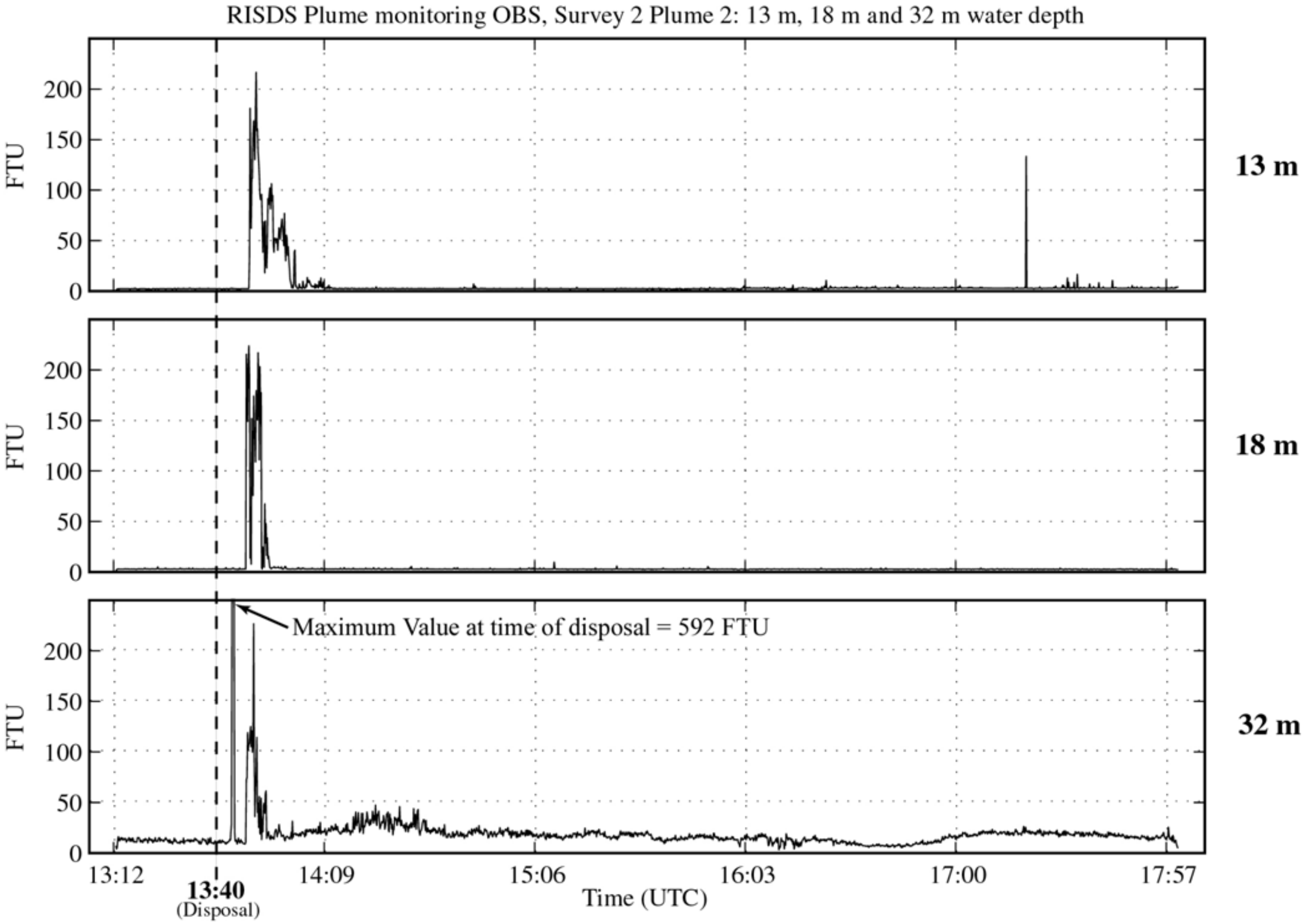


Figure 3-39. Time-series plot of OBS data collected on 2 September 2004 from three levels in the water column (13 m, 18 m, and 32 m), displaying changes in turbidity over time resulting from sediment plume passage.

noted. This increase corresponded in time to a reversal in current direction in the near-bottom layers from westward flow to more southward flow.

The maximum turbidity value detected by the mid-depth sensor was similar to the value recorded by the near-bottom sensor, but the sustained turbidity values were somewhat higher in the mid-water column. Turbidity values above 150 FTU were consistently recorded by the sensor located at 18 m depth, as the sediment plume likely passed through the mooring position (Figure 3-39). Overall, elevated turbidity was recorded at mid-depth for approximately six minutes before suspended particulate concentrations returned to background levels for the remainder of the 4.5-hour deployment period.

The sensor at 13 m depth also recorded an increase in turbidity several minutes following the disposal event, with the leading edge of the plume detected approximately six minutes post-placement. Reporting an initial value of 180 FTU, turbidity levels near-surface (13 m) climbed to 220 FTU, followed by a gradual reduction over a period of 10 to 15 minutes (Figure 3-39). Elevated turbidity levels persisted for the longest period at the near-surface (13 m) sensor, remaining well above background levels for 12 minutes. Very low turbidity conditions were detected near-surface for the remainder of the deployment period, with the exception of occasional noise within the record.

3.2.2.4 Toxicity

A summary of the toxicity results associated with the water sampling data for the Plume 2 survey is provided in Table 3-5 (Samples S2D2-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. No post-disposal samples exhibited toxicity, and all QA/QC requirements for successful conduct of the tests were met.

3.2.3 Plume 3

The Plume 3 survey occurred on 3 September 2004 with the disposal, at Point D within RISDS, of 2,300 m³ of material dredged from the upper Fuller Rock Reach. Load 1291 was deposited by a split-hull barge in the southeastern quadrant of RISDS at 17:16 UTC, with comprehensive tracking and sampling performed for 3.5 hours immediately following the event. Based on the water level data corrected to the local tide zone, this disposal event occurred during the early stages of an ebb tide (Figure 3-40). The plume monitoring activity continued through the remainder of the ebb, concluding at approximately 21:00 UTC. Within this time period, the net transport of the sediment plume was to the south-southeast by the water column currents as explained below.

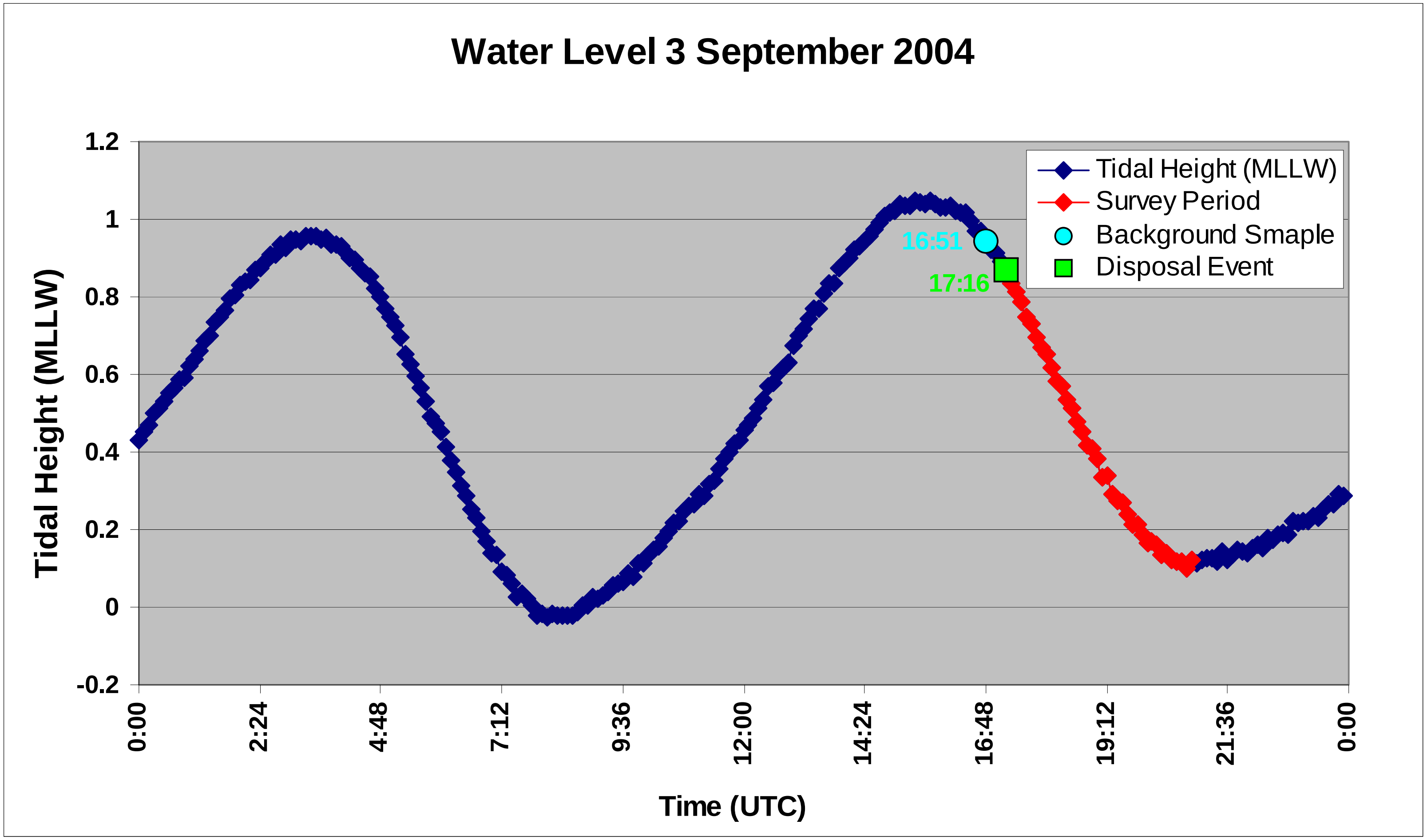


Figure 3-40. Water level data from the NOAA tide station in Newport, RI, corrected to the tide zone encompassing RISDS for 3 September 2004. The Background Sample and Disposal event are shown in comparison to the tidal stage.

3.2.3.1 Water Column Currents

All three drogues (mid-water, deep-water, and surface) were deployed within minutes of the dredged material disposal event. However, due to entanglement, the mid-depth drogue required retrieval and redeployment approximately 50 minutes into the Plume 3 survey. Overall, the distance and track of current drogue movement indicated the water mass had moved rather slowly, and in multiple directions, during the survey period (Figure 3-41). Upon deployment, the deep-water drogue tracked toward the west for the first 80 minutes of the survey, then drifted south for approximately 30 minutes before heading to the southeast, with a calculated average speed from initial deployment to final recovery of 5 $cm \cdot s^{-1}$ (Table 3-3). After redeployment, the mid-water (15 m) drogue followed a southwestward path for the first hour, and then displayed a more southerly track for the remainder of the monitoring survey, with an average speed of 9 $cm \cdot s^{-1}$ (Figure 3-41). The Davis drifter indicated flow within the surface waters was the most consistent, displaying flow to the southwest during the first 60 minutes, followed by a gradual shift to the south-southeast (average speed of 11 $cm \cdot s^{-1}$; Table 3-3).

Currents recorded by the moored ADCP during the Plume 3 survey generally agreed with the information provided by the drogues. As on the two prior survey days, current shear throughout the water column was observed at the 12 m depth interval, with mean velocities between 10 and 18 $cm \cdot s^{-1}$ above this level and under 10 $cm \cdot s^{-1}$ below 12 m (Figure 3-42). Also, there was evidence of divergent flow between surface and bottom layers, with average currents in the 5 to 15 m depth interval predominantly flowing to the south-southwest, whereas currents in the 20 to 33 m depth interval displayed eastward flow and the very near-bottom currents displayed westward flow (Figure 3-42). Maximum speeds were not as high as in previous days, with a water column maximum of 35 $cm \cdot s^{-1}$ at 5 m depth. However, minimum speeds were higher in the upper water column as noted previously, which can be attributed to this depth horizon displaying the most consistent flow through the course of the day.

At the time of disposal (17:16 UTC), the strongest and most consistent flow occurred in the near-surface layers, flowing southwestward at approximately 25 $cm \cdot s^{-1}$, whereas mid-depth and near-bottom currents were weaker in comparison (5 to 10 $cm \cdot s^{-1}$), flowing northwest and west, respectively (Figure 3-43). Within one hour, near-bottom and mid-depth currents rotated counterclockwise to flow in a more southerly direction, in better alignment with the surface currents, but currents remained relatively weak (<10 $cm \cdot s^{-1}$) at the deeper level (Figure 3-44).

The direction of current flow in the near-surface levels was predominantly southwest and remained relatively consistent for the duration of ADCP record. However, the magnitude of the currents in the top 5 m of the water column did decrease over the

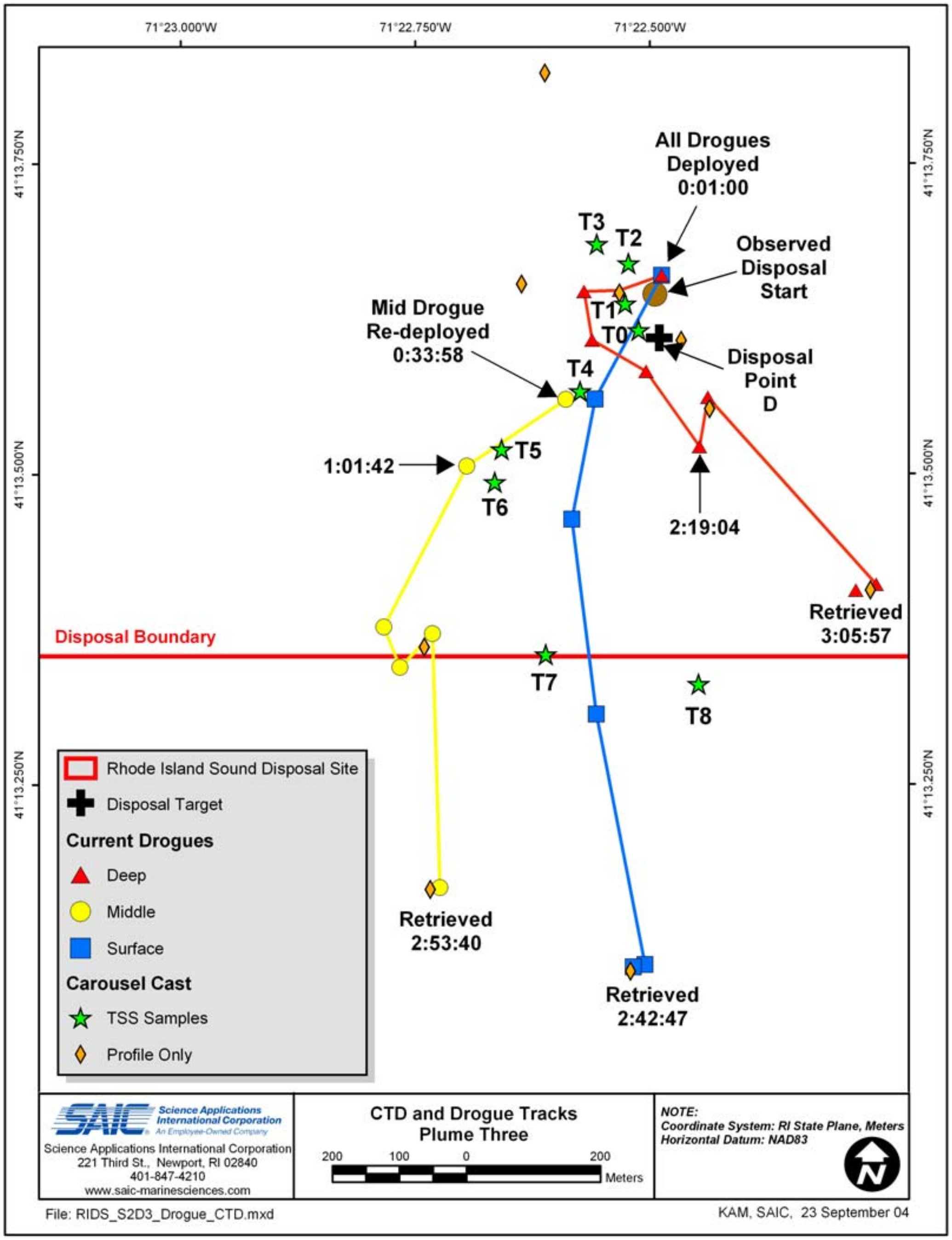


Figure 3-41. Map indicating current drogue trajectories and CTD cast locations during the tracking of Plume 3. Locations of water samples are also shown. Times represent elapsed time since disposal operations.

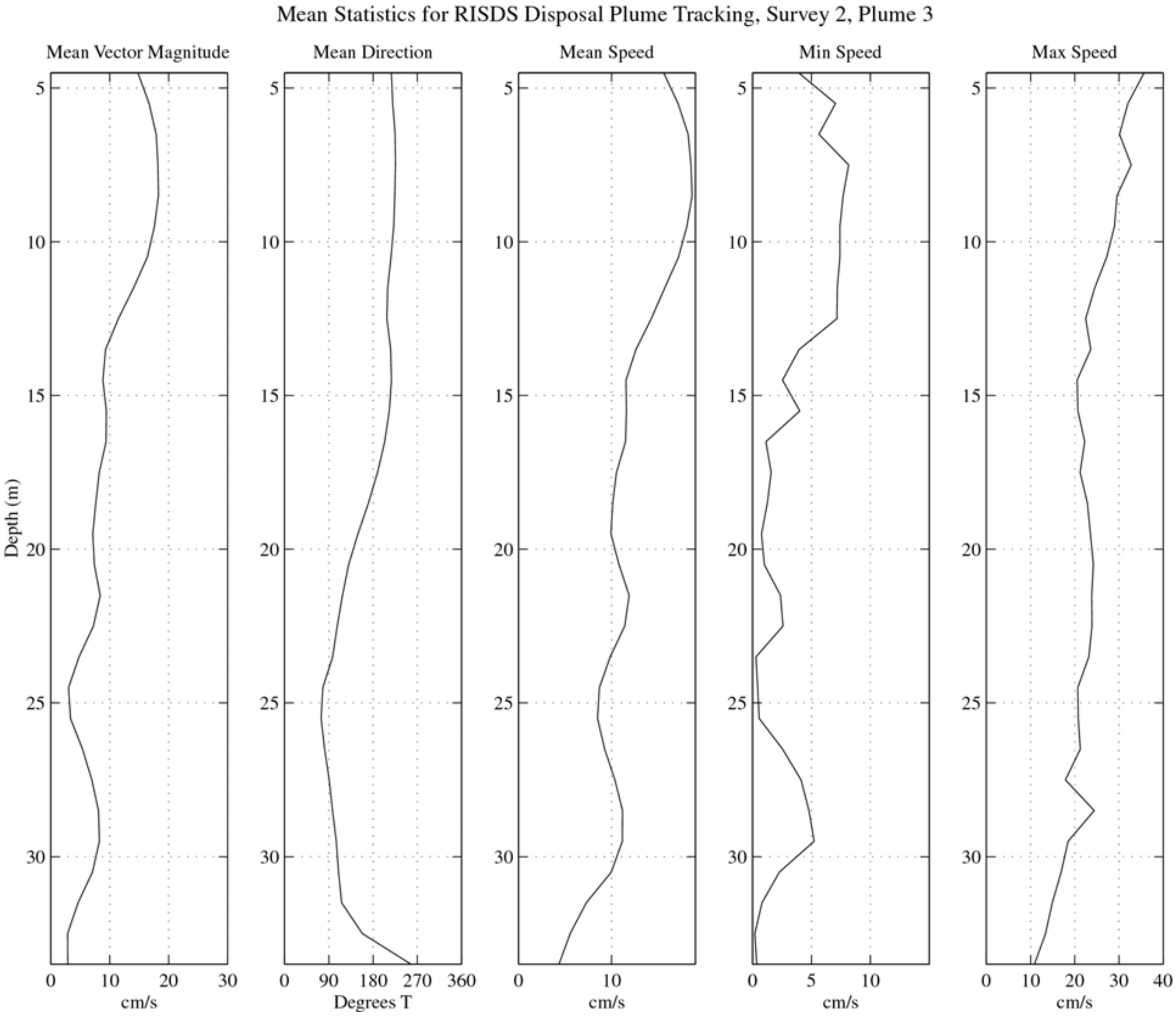


Figure 3-42. Statistics of moored current meter data collected on site during Plume 3 disposal monitoring activities. Parameters plotted include mean vector magnitude, mean vector direction, mean speed (regardless of direction), minimum speed and maximum speed.

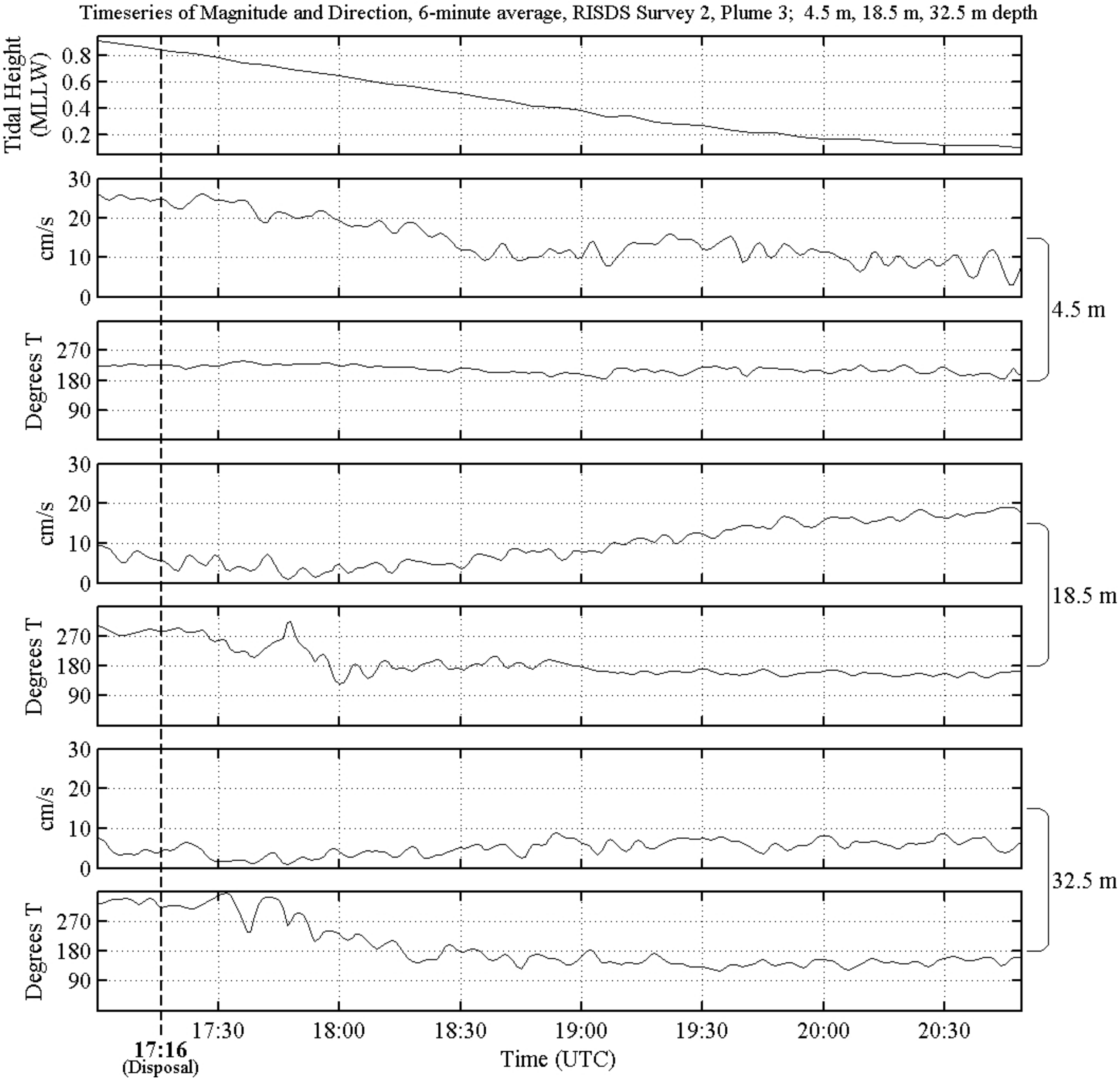


Figure 3-43. Time-series plot of current magnitude and direction during Plume 3 at the near-surface level (~ 4.5 m top two panels) and the two selected drogue depth levels of ~18 m (middle two panels) and ~32 m depth (bottom two panels). Currents were sampled at 1 minute intervals, and filtered with six-minute Low Pass Filter (LPF) to reduce high-frequency noise.

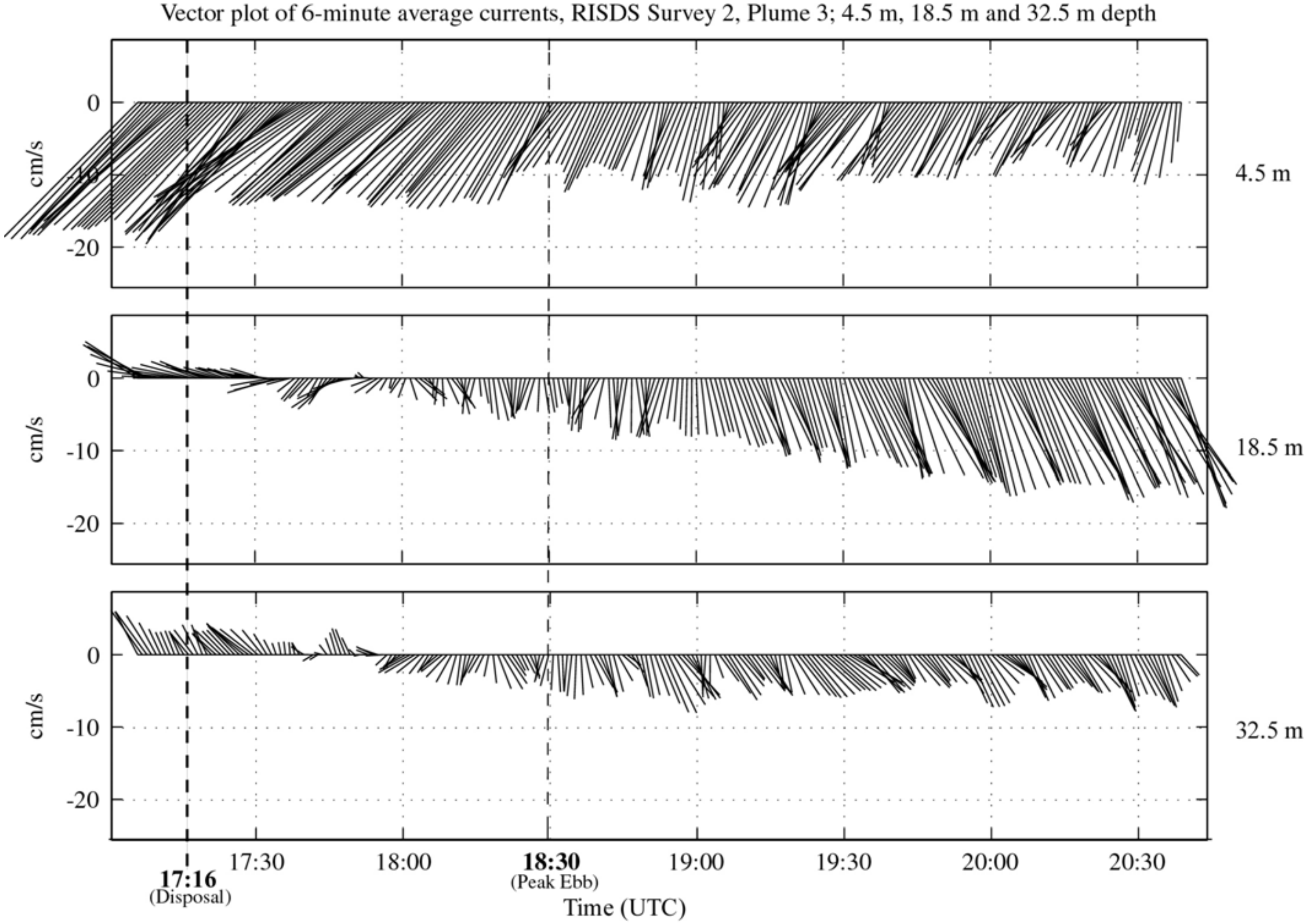


Figure 3-44. Time-series plot of current vectors (six minute LPF) during Plume 3 at the near-surface level (~4.5 m top panel) and the two selected drogue depth levels of ~18 m (middle panel) and ~32 m depth (bottom panel).

course of the day from approximately 25 $cm \cdot s^{-1}$, at the time of disposal to 10 $cm \cdot s^{-1}$ at the end of the deployment period. Currents at mid-depth were weak (< 5 $cm \cdot s^{-1}$) and variable for the first 60 minutes of the survey, becoming consistent in direction (southerly) and magnitude over the subsequent two hours, with velocities of nearly 20 $cm \cdot s^{-1}$ measured at the end of the record (Figure 3-44). The near-bottom currents were considerably weaker in comparison to those of the mid-depth and surface levels, and displayed a more northerly component at the time of disposal. The ADCP record displayed a rotation to the south in the near-bottom flow during the survey period similar to that observed at mid-depth, but lagged behind the mid-water column current by approximately 30 minutes.

The vessel-mounted ADCP data corresponded to the information extracted from the bottom-mounted units, as well as the surface drifter and current drogues. The shipboard instrument, at the start of the survey, showed current shear between surface and bottom currents, while the middle and end of the day displayed a more uniform current direction.

3.2.3.2 CTD/Transmissometer Profiles

On the third day of plume tracking and assessment, a total of 26 CTD profiles were obtained within and adjacent to the disposal site. Nine profiles were obtained in proximity to RISDS solely for background data related to ambient suspended sediment loads within the water column, while a single profile collected within the disposal site served as the baseline for use in data comparisons.

Figure 3-45A presents profiles of light transmittance within the water column at Background Stations 0 through 4 (Figure 2-2), collected prior to the disposal event tracked as part of the Plume 3 survey. With the exception of the CTD cast completed at Background Station 3, the profiles of light transmittance along the east-west transect were quite similar, displaying relatively clear water (transmittance values of approximately 80%) in the 15 m below the surface and small-scale increases of turbidity at depth causing light transmittance values to decrease to 60% near-bottom. The profile for Background 3, conducted 2 km west of RISDS, displayed an increase in turbidity more distinct than the remainder of the profiles in the east-west transect, as transmittance values rapidly declined from 80 to 40% within the depth interval between 28 and 30 m.

Similar to the east-west transect, the majority of the profiles obtained along the north-south transect (Background Stations 2, 5, 6, and 7) generally displayed high levels of light transmittance (values near 80%) in the upper two-thirds of the water column indicating low levels of ambient turbidity (Figure 3-45B). At Stations 2, 5, and 6, small increases in turbidity (transmittance values between 65 and 80%) were detected within the 15 to 20 m and the near-bottom depth intervals. In contrast, the profile for the southernmost station (Background Station 7) displayed a relatively strong turbidity signal in

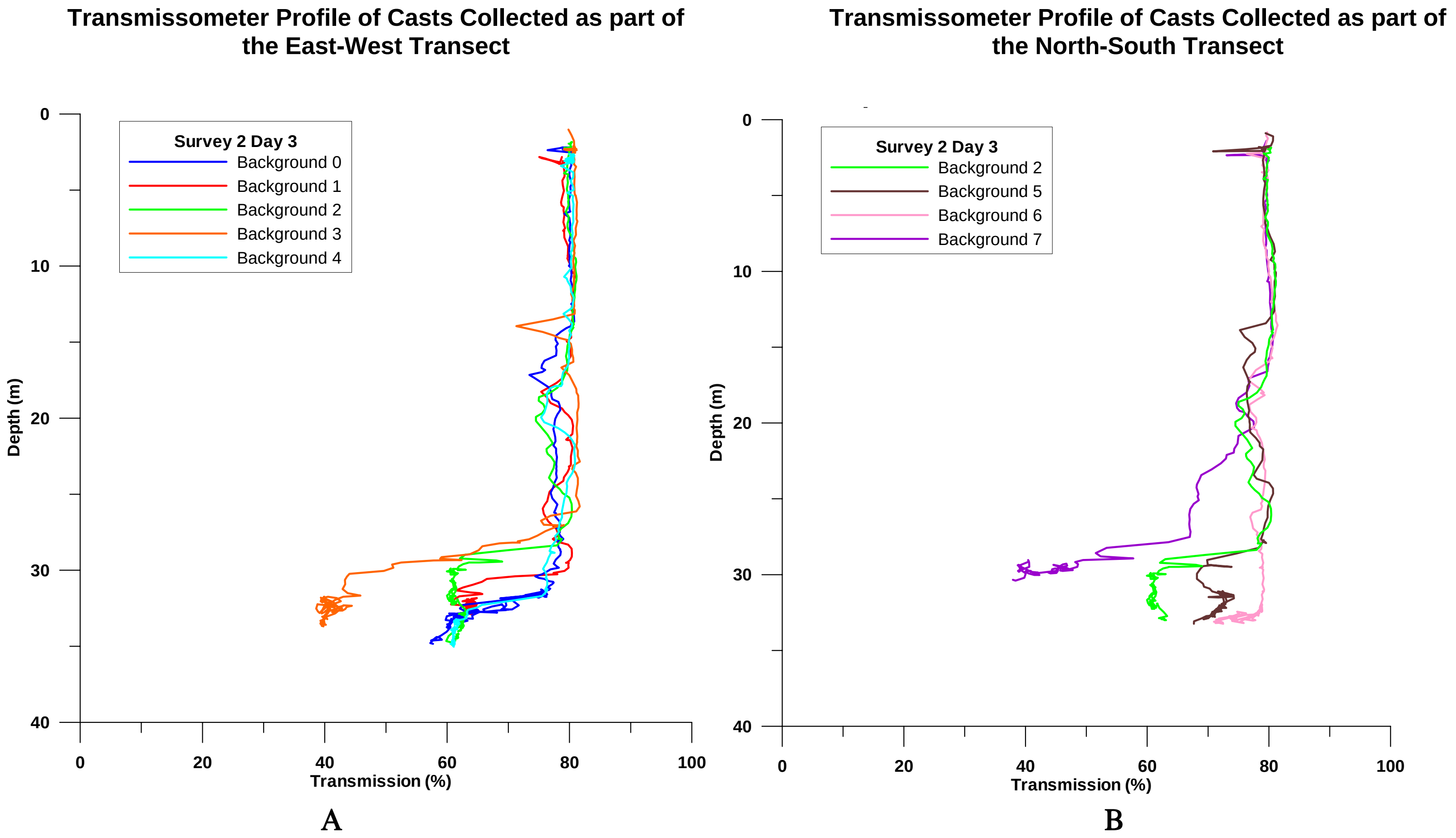


Figure 3-45. Profile plot of percent light transmission and sensor depths acquired during CTD casts collected as background samples prior to the dredge material disposal event at RISDS. Casts 0 through 4 represent an East-West transect (A) across the disposal site, while Casts 2, 5, 6 and 7 represent a North-South Transect (B) that bisects RISDS.

the lower half of the water column that was first encountered at 15 m and increased with depth. Similar to the profile from Background Station 3, transmittance values documented within Background Station 7 rapidly declined to 40% within the 28 and 30 m depth interval. Coupled with the results form Background Station 3, this finding suggested the presence of a consistent, near-bottom turbidity layer extending 2 km south and west of RISDS.

The near-field profiles (Background Stations 2, 8, and 9) were quite comparable, each displaying small increases in suspended sediment load in the lower half of the water column, as well as small to moderate increases in turbidity near-bottom (Figure 3-46). The profile from Background 2 indicated increased turbidity 3 to 5 m higher in the water column, relative to the profiles for Background 8 and 9, but at levels roughly equivalent to those detected in the other near-field profiles. The cast for Background 2 was obtained earlier and several hundred meters away from the positions for Background 8 and 9, which may have contributed to the difference in turbidity.

When the background transmissometer profiles were examined relative to location, a noticeable increase in near-bottom turbidity existed within the disposal site, as well as to the south and west. Stations 3 and 7, located approximately 1 km to the west and south of RISDS, respectively, displayed the lowest transmissometer values of the entire background data set. Given the direction and magnitude of the currents observed early in the survey period (to the southwest), this increase in near-bottom turbidity was likely attributable to residual plume sediments being advected along the seafloor from the disposal event that occurred several hours prior to the on-site arrival of the survey vessel.

The data from the Background 8 profile also served as the T0 sample for the Plume 3 survey, representing the physical properties within the water column prior to the dredged material disposal event. The T0 profile was collected in proximity to Disposal Target D, where water samples for TSS analysis were collected 5 m above the seafloor (32 m depth). The CTD cast displayed distinct changes in the temperature, salinity, and density profiles, suggesting that three layers existed within the water column (Figure 3-47). Surface waters displayed a salinity of 31.7 PSU and a temperature of 20°C, and remained relatively constant to a depth of 8 m. Between 8 and 12 m in depth, the CTD data indicated the presence of a less saline (31 PSU), but colder layer of water, with temperatures decreasing from 20 to 17°C. Below that layer, salinity values increased with depth. Temperature values decreased moderately with increasing depth, but salinity and percent transmittance showed minimal vertical stratification in the lower half of the water column.

The lower salinity, lower temperature water within the 8 to 12 m depth interval in the profile from Background 8 caused the formation of a weak pycnocline as it interfaced

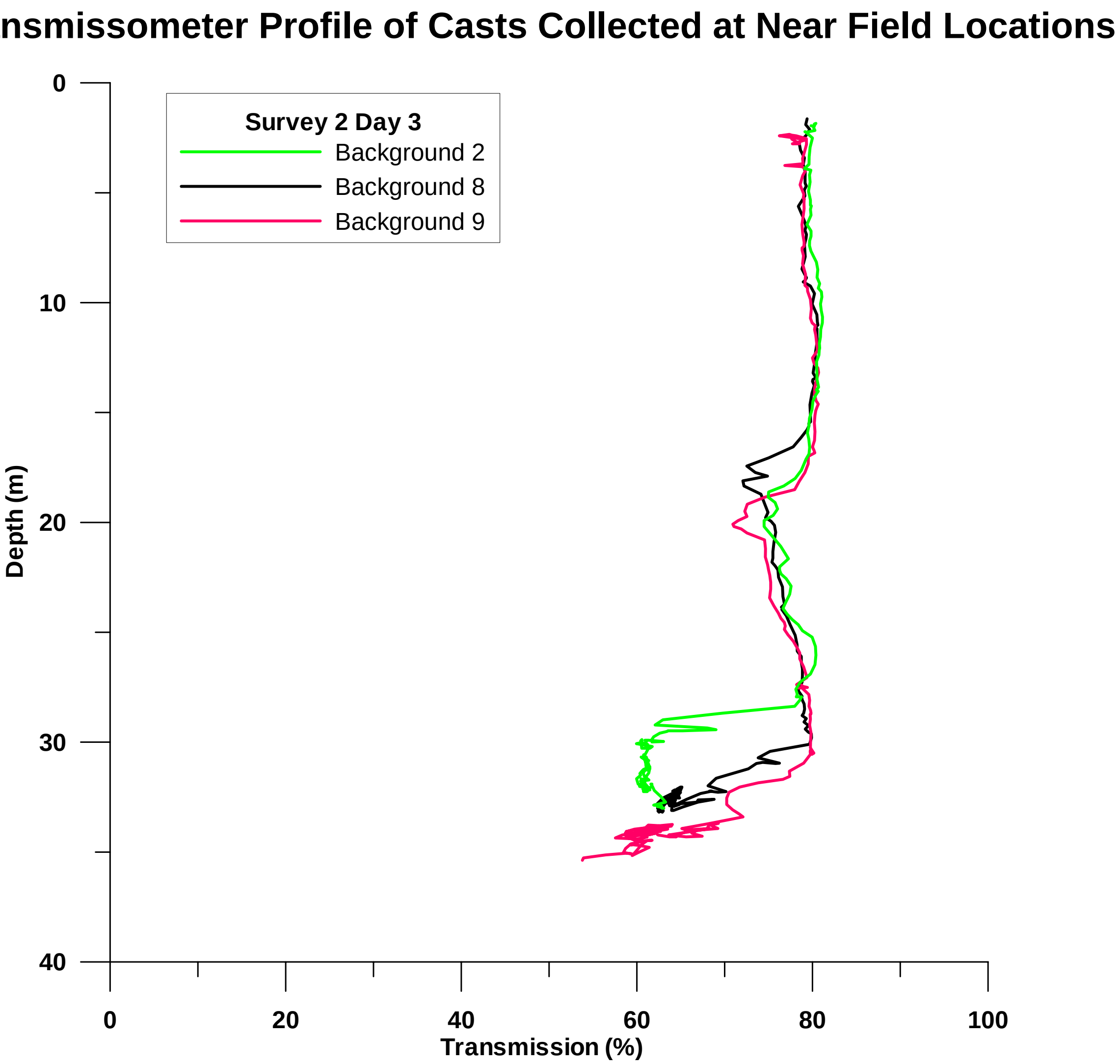


Figure 3-46. Profile plot of percent light transmission and sensor depth acquired during CTD casts collected as background samples prior to the dredge material disposal event at RISDS. Casts 2, 8, and 9 represent the near field stations occupied within the boundaries of RISDS.

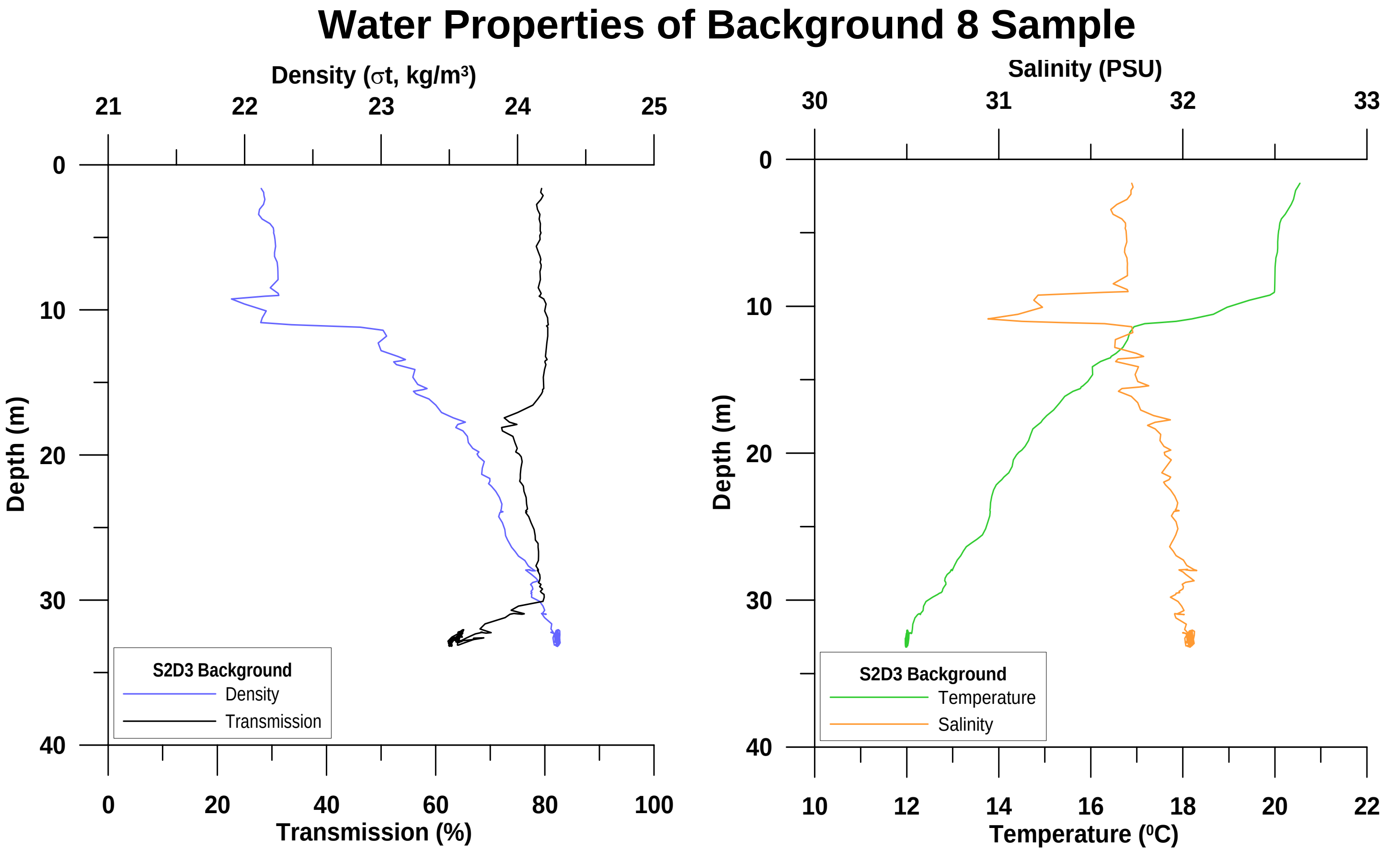


Figure 3-47. Profile plots of percent light transmission and seawater density versus depth (A) and temperature and salinity versus depth (B) acquired during the CTD Profile at Station Background 8 for Plume 3. Data are from the downcast profile only.

with the warmer, more saline surface water. A more distinct pycnocline was detected below 12 m, which represented the interface with cooler, more saline water at depth. Given the distinct nature of the seawater residing within this layer and the effects of this layer on the results for Background 8, the measurements for density, salinity, and temperature for the Background 9 CTD cast were also plotted to verify these findings. The profile for Background 9 displayed a similar, but slightly larger feature in the water column within the depth interval between 9 and 15 m (Figure 3-48). The lower salinity, lower temperature water within this interval caused the formation of a distinct pycnocline as it interfaced with the warmer, more saline surface water and a weaker pycnocline at the interface with the cooler more saline water at depth. (It should be noted that the density inversions shown at depths near 10 m in Figures 3-47 and 3-48 are suspected to be artifacts of incorrect time-lag corrections between the time constants of the temperature and salinity sensors of the CTD profiler. It is likely that more detailed analysis of the sensor time responses and iterative reprocessing of the raw CTD data would yield density profiles that increase monotonically with depth, as is expected in the water column at this location. Such data processing techniques were, however, beyond the scope of this study.)

Light transmittance within both Background 8 and 9 profiles remained relatively constant at approximately 80% in the upper half of the water column despite the changes in temperature, salinity, and density with depth. Both profiles indicated a slight decrease in transmittance values between 15 and 20 m, as a relatively thin layer of water exhibiting transmittance values approaching 70% existed at mid-depth at the time of the background data collection effort. Below 20 m, transmittance values gradually increased to values near 80% until reaching a depth of 30 m. Below 30 m, turbidity increased substantially until a minimum transmittance value of 55% was detected in close proximity to the seafloor at Background 8 (Figure 3-48).

The disposal barge approached Disposal Point D from the south, slowed and released its load at 17:16 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 was emptied 10 to 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 in close proximity to the disposal location.

Ten minutes after the disposal operation, plume monitoring began with a CTD cast located between the surface drifter and deep-water drogue locations to acquire the T1 profile and water sample. The transmissometer profile displayed a substantial amount of turbidity above background conditions in the upper water column, with percent transmittance values near zero detected at the plume centroid (Figure 3-49). The most

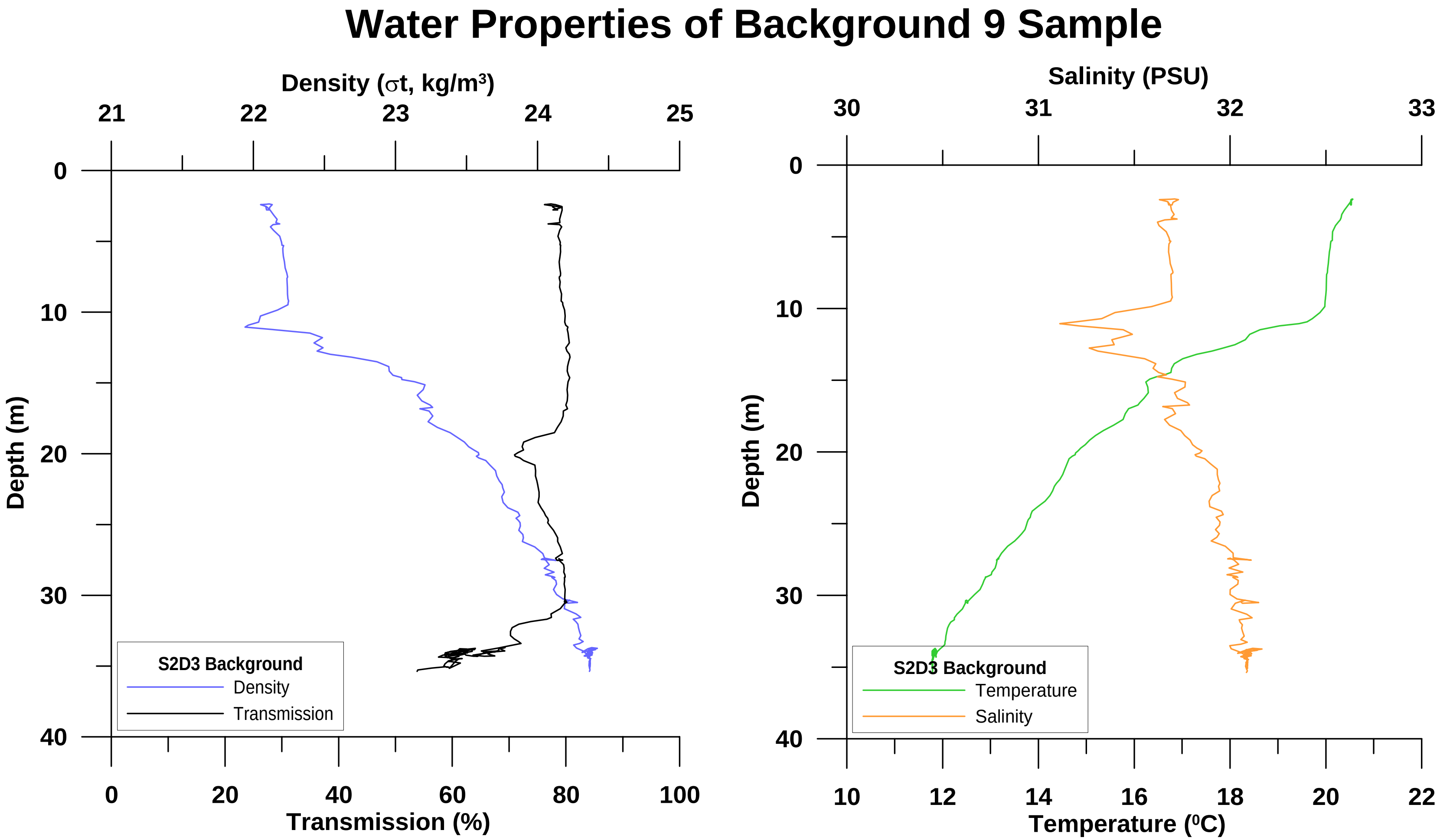


Figure 3-48. Profile plots of percent light transmission and seawater density versus depth (A) and temperature and salinity versus depth (B) acquired during the CTD Profile at Station Background 9 for Plume 3. Data are from the downcast profile only.

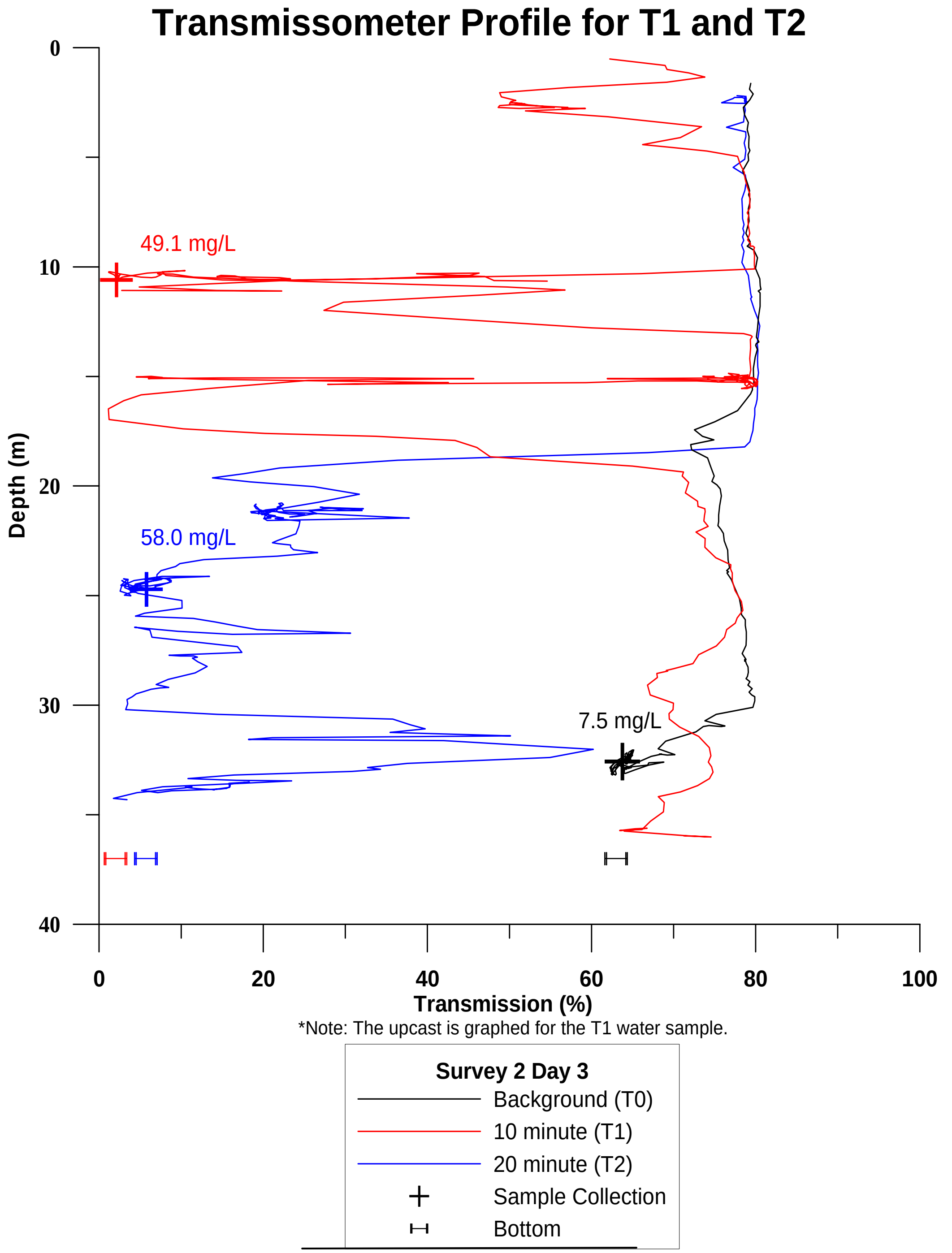


Figure 3-49. Profile plot of percent light transmission and sensor depth acquired during CTD sample intervals T1 and T2 during Plume 3. Locations of water sample collections within the plume are also shown.

significant elements of the plume existed within the depth interval between 10 and 20 m, exhibiting strong variation in suspended sediment concentrations. Below 20 m depth, the concentration of plume sediments decreased significantly, displaying conditions comparable to background. A minimum light transmittance value in the lower water column of 63% was documented near the seafloor, while a maximum value of 75% was recorded at 25 m in depth. The water sample for TSS analysis was collected at a depth of 10.6 m.

The 20-minute sampling interval (T2) profile was collected in proximity to the deep-water drogue. The transmissometer profile detected a relatively clear water column in the top 20 m, followed by a strong increase in turbidity beneath. Transmittance values of 80% in the upper water column rapidly decreased to 10% at 20 m depth, then oscillated between 5% and 60% through the remainder of the lower water column (Figure 3-49). A layer of relatively clear water was encountered approximately 5 m above the seafloor but was only 2 to 3 m in thickness, as turbidity values near-bottom decreased to levels near zero. The water samples were collected for TSS at a depth of 24.7 m as transmittance values remained low (between 5 and 8%) suggesting the sample was collected within the most concentrated portion of the plume.

Information provided by the roving ADCP vessel approximately 30 minutes into the monitoring survey suggested the most turbid portion of the plume was located to the north and west of the original disposal point and a CTD cast was obtained at this location to confirm this finding. Based on the results of the CTD data, the T3 (40-minute) water samples were collected approximately 100 m northwest of the observed disposal point (Figure 3-41). The transmittance profile showed light transmittance at background levels to a depth of 18 m, after which transmittance decreased in response to increasing turbidity. Between 20 and 35 m depth, transmittance values ranged from 40 to 65%, eventually reaching the minimum value of 14%, approximately 1 m above the seafloor (35 m depth; Figure 3-50). The T3 water samples were collected at a depth of 35 m during the upcast, with a transmittance value of 13.9% recorded at the time of the sample collection.

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 20 m where transmittance decreased slightly, but eventually returned to background levels at a depth of 25 m (Figure 3-50). Within the 32 to 34 m depth range, transmittance levels decreased rapidly, reaching the lowest levels of 7.9%, approximately 3 m above the seafloor. The overall structure of this transmittance profile was similar to those of Background 8 and 9, with the exception of the very low transmittance values in proximity to the seafloor. This finding suggested the bulk of the recently formed plume existed elsewhere in the region and was not co-located with the mid-depth drogue. A water sample was collected at a depth of 33.5 m within the most turbid portion of the plume detected in the T4 profile.

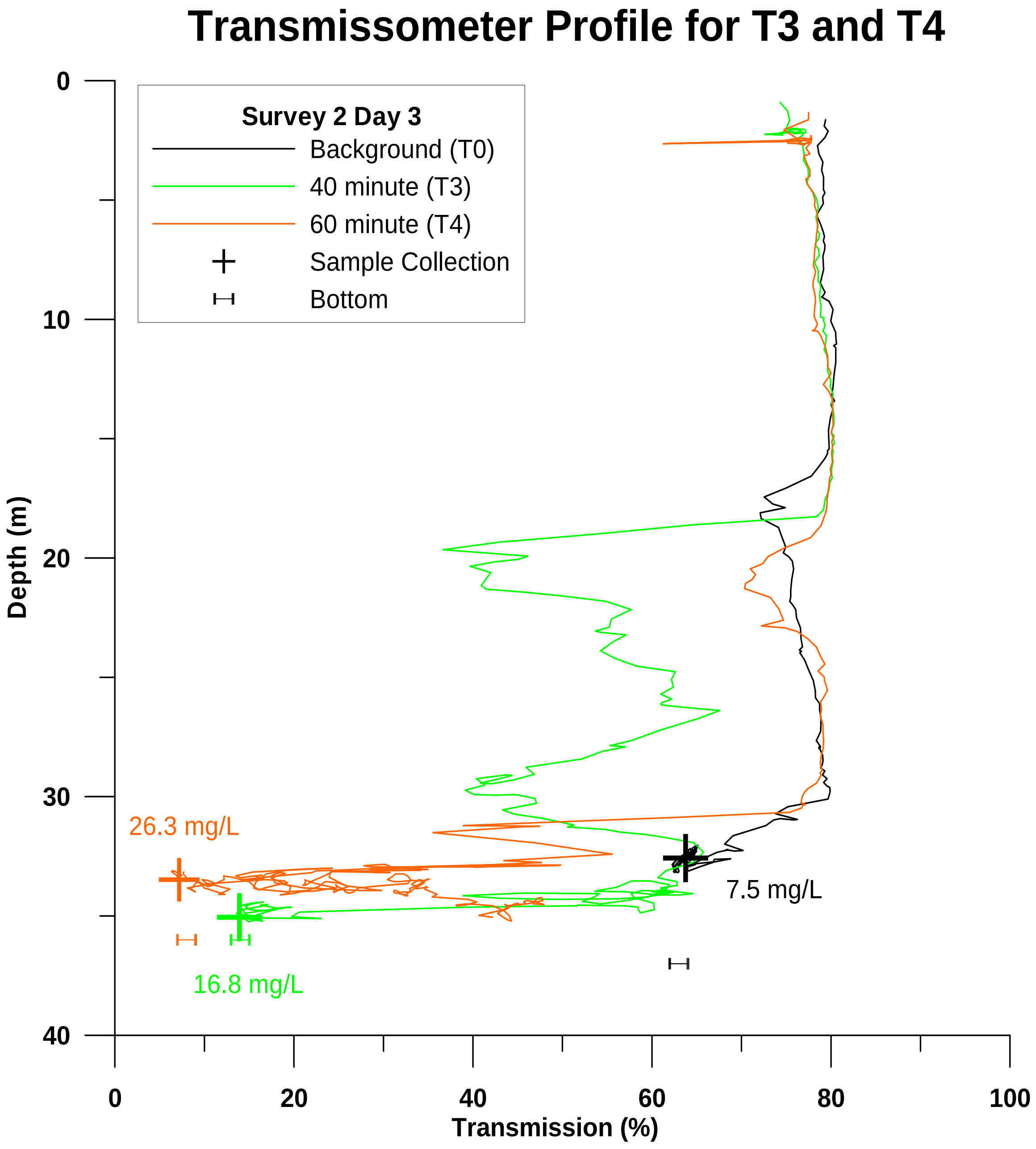


Figure 3-50. Profile plot of percent light transmission and sensor depth acquired during CTD sample intervals T3 and T4 for Plume 3. Locations of water sample collections within the plume are also shown.

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 sample were collected approximately 325 m southwest of the observed disposal point (Figure 3-41). The CTD data showed the presence of background transmittance levels to a depth of nearly 20 m, where a mid-depth pulse of turbidity similar to those observed in the T4 and background profiles was present (Figure 3-51). Displaying transmittance levels of 65 to 70%, this mid-depth pulse of turbidity extended to a depth of 25 m before transmittance returned to background transmission levels (80%). Turbidity increased sharply at a depth of 31 m marking the presence of the near-bottom disposal plume, with transmittance values decreasing with depth until reaching a minimum of 11%, approximately 3 m above the seafloor. The water sample for TSS analysis was collected at this location (32.8 m depth) prior to upcast.

At the 120-minute sampling interval (T6), the vessel monitoring real-time ADCP data directed the water-sampling vessel to the location of the approximate plume centroid, 25 m east of the position of the mid-depth drogue, to collect a CTD cast (Figure 3-41). The transmissometer profile displayed background levels of light transmittance occurring to a depth of 20 m, where the pulse of turbidity detected in earlier profiles existed. When compared to the T5 and background profiles, the record for T6 suggested slightly higher suspended sediment concentrations within the mid-depth turbidity pulse. Between the 25 and 30 m water depth, the percentage of light transmittance remained comparable to background levels (75 to 80%). A sharp increase in turbidity, similar to what was detected in the T5 profile, was documented at 32 m depth. Transmittance values decreased rapidly from 77% to a minimum value of 8%. The water sample was collected at a depth of 32 m (transmission 17%).

The 150-minute (T7) sample profile was conducted at a location directed by the ADCP vessel, while the 210-minute (T8) sample interval was collected in proximity to the mid-water drogue. Although the profiles were attained in different locations (Figure 3-41) and one hour apart, the plume morphology was very similar for both profiles, indicating background levels of transmittance to a depth of 23 m, and low transmittance below 32 m depth indicating the presence of strong near-bottom turbidity (Figure 3-52). Minimum light transmission values for profiles T7 and T8 reached 26% and 16%, respectively, at 33 m depth. The water samples for both sampling intervals were collected within the near-bottom portion of the plume at a depth of 33 m.

3.2.3.1 Total Suspended Solids (TSS)

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

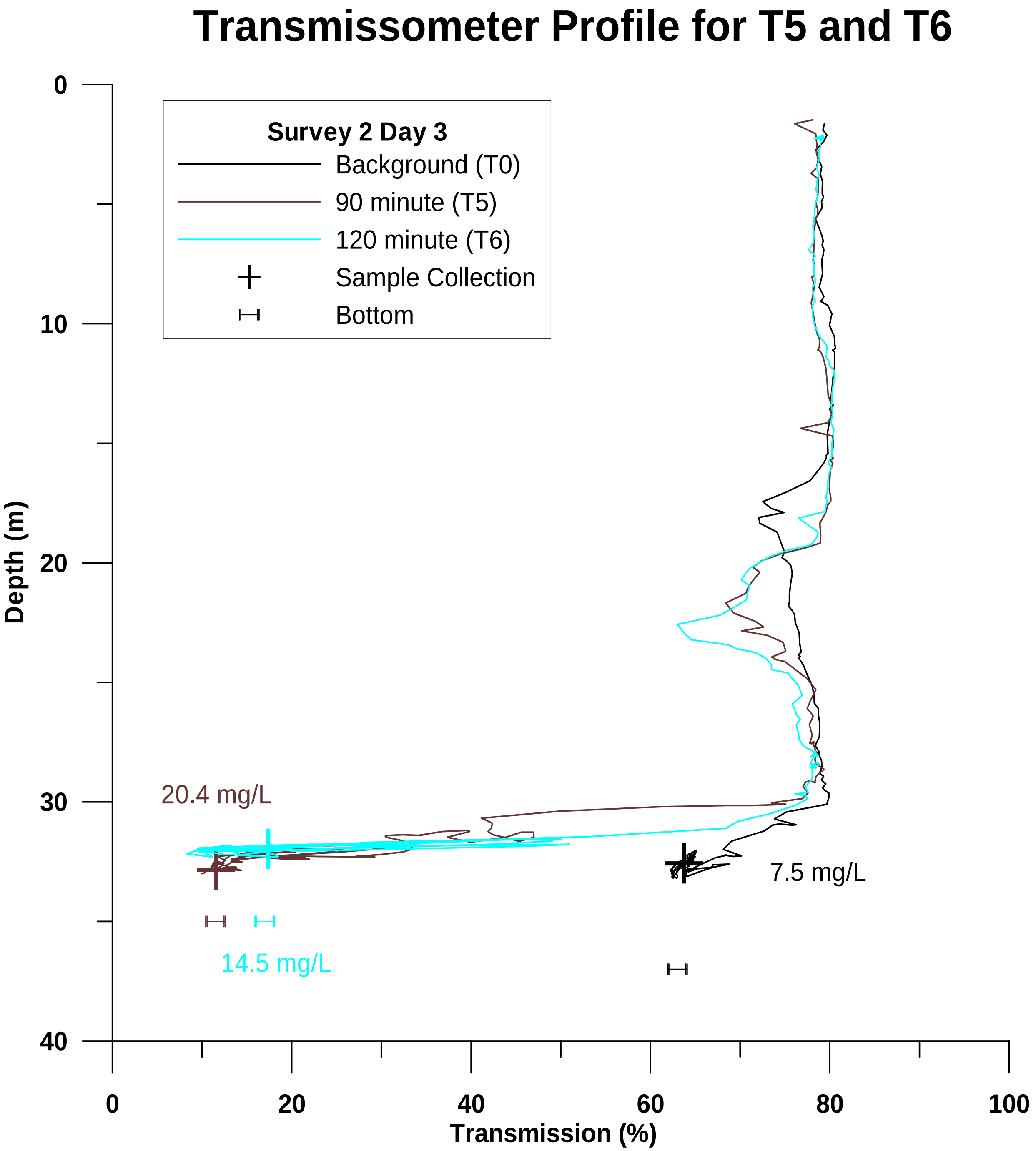


Figure 3-51. Profile plot of percent light transmission and sensor depth acquired during CTD sample intervals T5 and T6 for Plume 3. Locations of water sample collections within the plume are also shown.

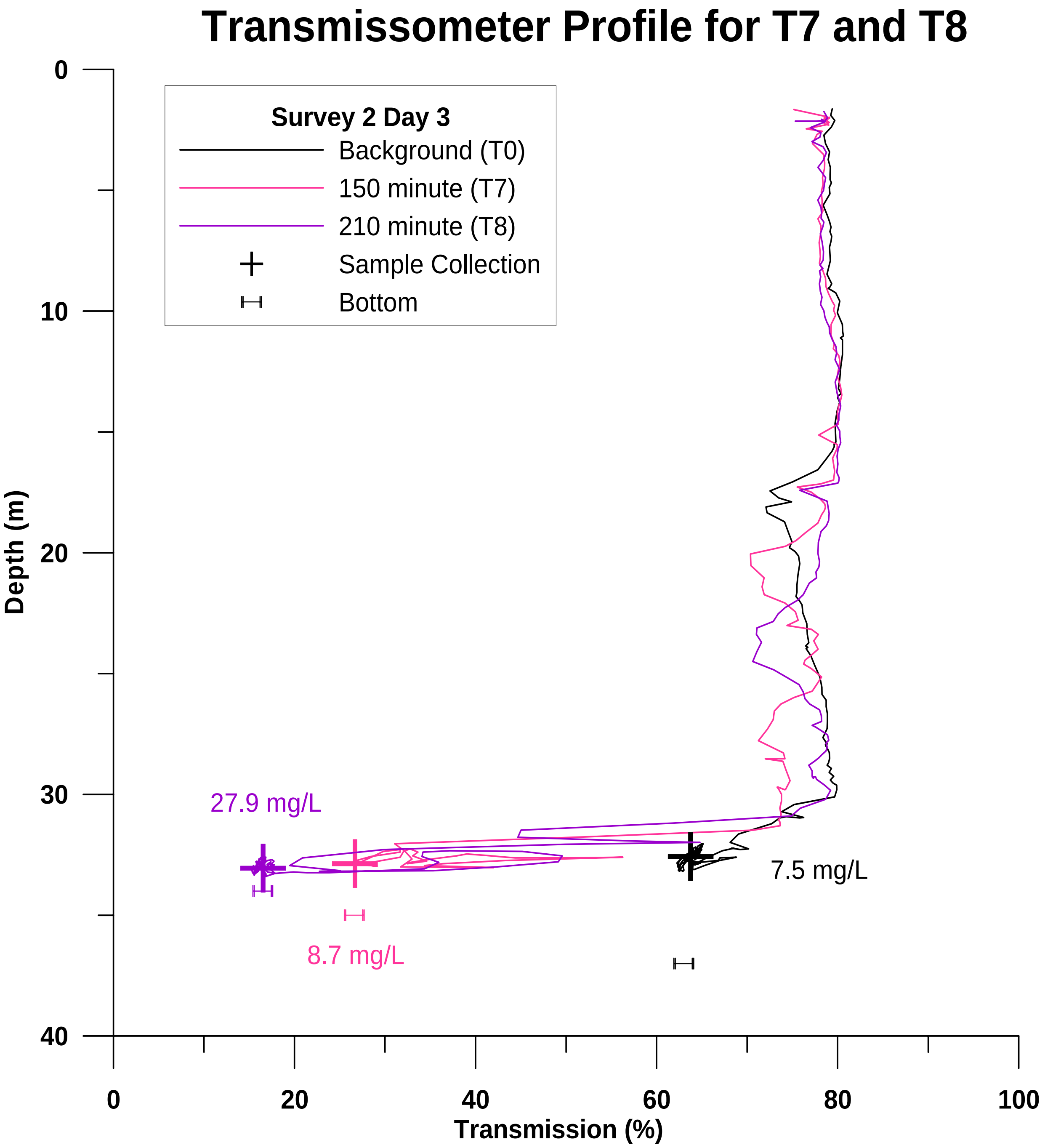


Figure 3-52. Profile plot of percent light transmission and sensor depth acquired during CTD sample intervals T7 and T8 for Plume 3. Locations of water sample collections within the plume are also shown.

Table 3-7

Results of Total Suspended Solids (TSS) Analysis from Discrete Water Samples collected during CTD Profiling Operations during 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
S2D3_T0	0	0:00	32.6	63.8	12.2	11.2	8.6	2.6	7.5	4.41
S2D3_T1	10	0:10	10.6	2.1	40.9	50.8	51.2	45.2	49.1	3.35
S2D3_T2	20	0:23	24.7	5.8	28.7	64.8	54.8	54.4	58.0	5.89
S2D3_T3	40	0:42	35.1	13.9	23.2	19.2	14.8	16.4	16.8	2.23
S2D3_T4	60	1:13	33.5	7.9	27.5	23.2	30.4	25.2	26.3	3.72
S2D3_T5	90	1:31	32.8	11.6	24.4	21.6	19.6	20.0	20.4	1.06
S2D3_T6	120	1:57	32.0	17.4	22.0	19.2	14.4	10.0	14.5	4.60
S2D3_T7	150	2:34	32.9	26.7	17.1	8.6	9.4	8.0	8.7	0.70
S2D3_T8	210	3:23	33.1	16.5	22.6	26.8	35.2	21.6	27.9	6.86

Plume tracked from the disposal of material from a 4,600 m^3-capacity split-hull disposal barge, loaded only to 2,300 m^3.

tracking survey were obtained prior to disposal operations in the southeast quadrant of the disposal site near Disposal Target D. The background TSS sample for Plume 3 was 7.5 mg·L^{-1}, slightly less than the values reported from Plume 1, but higher than the background value for Plume 2. With the exception of the T1 and T2 sample intervals, TSS samples were generally collected approximately 3 to 5 m above the seafloor within the apparent plume centroid.

TSS values indicated relatively high turbidity during the early stages of the plume. A TSS value of 49.1 mg·L^{-1} was reported ten minutes after plume tracking commenced (T1), but the highest TSS value corresponded to the sample collected 20 minutes after disposal operations (T2; average of 58.0 mg·L^{-1}) at a depth of 24.7 m. Consistent with the inverse relationship between transmissometer and TSS values, higher TSS values observed at the 10 and 20 minute (T1 and T2) sample intervals corresponded to the lowest percent transmission of light recorded in the CTD profiles (Table 3-7). The transmissometer record indicated the highest turbidity levels were found at mid-depth in the early stages of the Plume 3 survey. As a result, both the T1 and T2 samples were obtained at shallower depths than the remaining samples; the T1 sample appeared to capture the leading edge of the mid-water plume, while the water captured as part of the T2 sample characterized the leading edge of the near-bottom plume.

The TSS concentrations decreased considerably between the T2 and T3 sample intervals, with a reported average value of 16.8 mg·L^{-1} 40 minutes post-placement. Values were somewhat variable for the remaining sample intervals, but showed an overall trend of decreasing turbidity over time. The T7 sample, obtained approximately 154 minutes post-placement, yielded an average TSS value of 8.7 mg·L^{-1}, approaching the background levels detected prior to sediment deposition (7.5 mg·L^{-1}). However, TSS values showed a significant increase for the next sample interval (T8), increasing to 27.9 mg·L^{-1} nearly 3.5 hours after disposal operations (Table 3-7). This increase in TSS suggested that the sample was obtained within a somewhat denser portion of the near-bottom plume, which was supported by the recording of lower transmissometer values at the T8 sampling interval, in comparison to T7 interval.

3.2.3.2 ADCP Backscatter

On the third and final day of survey operations, the vessel-mounted ADCP showed currents were flowing west-southwestward in the surface layers, and west-northwestward in the mid-depth and near-bottom layers prior to the disposal event. Thus, a survey grid with lanes running from northeast to southwest was chosen, with hopes that this orientation would be perpendicular to the general flow direction during subsequent plume sampling operations. However, as will be shown below, current patterns shifted during the course of the survey, and ultimately, three different transect orientations were necessary to adequately characterize the plume extent. Data on background acoustic backscatter collected prior to disposal showed fairly consistent backscatter within the majority of the water column (75 counts), with the exception of a band of reduced backscatter intensity in the near-bottom layers (Figure 3-53).

The disposal event occurred at 17:16 UTC at Point D, in the southeastern corner of the disposal site. The first transect was run on Lane S in a southwest-northeast direction, which lied directly over the disposal point (Figure 3-54A). Consistent with the results from prior surveys, a very distinct plume was observed in the acoustic backscatter data. The sediment plume, comprised of entrained sediments and gas bubbles, measured approximately 300 m in width and showed consistent residual backscatter values of greater than30 counts throughout. As the observed currents at the time of disposal were flowing predominantly west-northwestward, the next survey lane to the northwest was chosen (Lane R). This transect was occupied for 640 m from northeast to southwest and displayed the plume at approximately 10 minutes post-disposal (Figure 3-54B). At the time Line R was first occupied, currents near the surface of the water column were stronger than those at depth and flowing to the southwest, yielding substantial shear. The near-surface layers of the water column trended toward the southwest, while the mid-depth and near-bottom layers trended more northward. (See current meter data from moored ADCP in Figure 3-44.) Backscatter intensity was still high in the center of the plume (above 30 counts); however, it appeared to be diminishing on the margins, to values less than 22 counts in the lower water column.

Following Line R, the survey vessel occupied Line Q, which was located 200 m northwest of the disposal location. The appearance of the sediment plume was quite reduced in this transect in comparison to Lines R and S (Figure 3-54C). Given the weak currents in the mid and lower water column, it is likely that the majority of the plume had simply not traveled 200 m from the disposal location within the first 15 minutes of the survey. As a result, the data from Line Q was likely representative of the leading edge of the sediment plume. To confirm this hypothesis, Line R was reoccupied.

The second occupation of Line R (R2) revealed a more cohesive plume structure in the water column, relative to Line Q. The plume feature was approximately 240 m wide within the lower water column and displaying residual backscatter values in excess of 30 counts nearly 30 minutes post-placement (Figure 3-55A). In addition, measurable turbidity (14-16 counts) was also present in the upper water column between the surface and 7 m water depth. The shear in water column currents noted in the earlier transects was also observed in the data obtained from Line R2, as the water mass lying between 7 to 15 m water depth was trending toward the southwest, while the portion of the sediment plume below 15 m remained in proximity to the original disposal location.

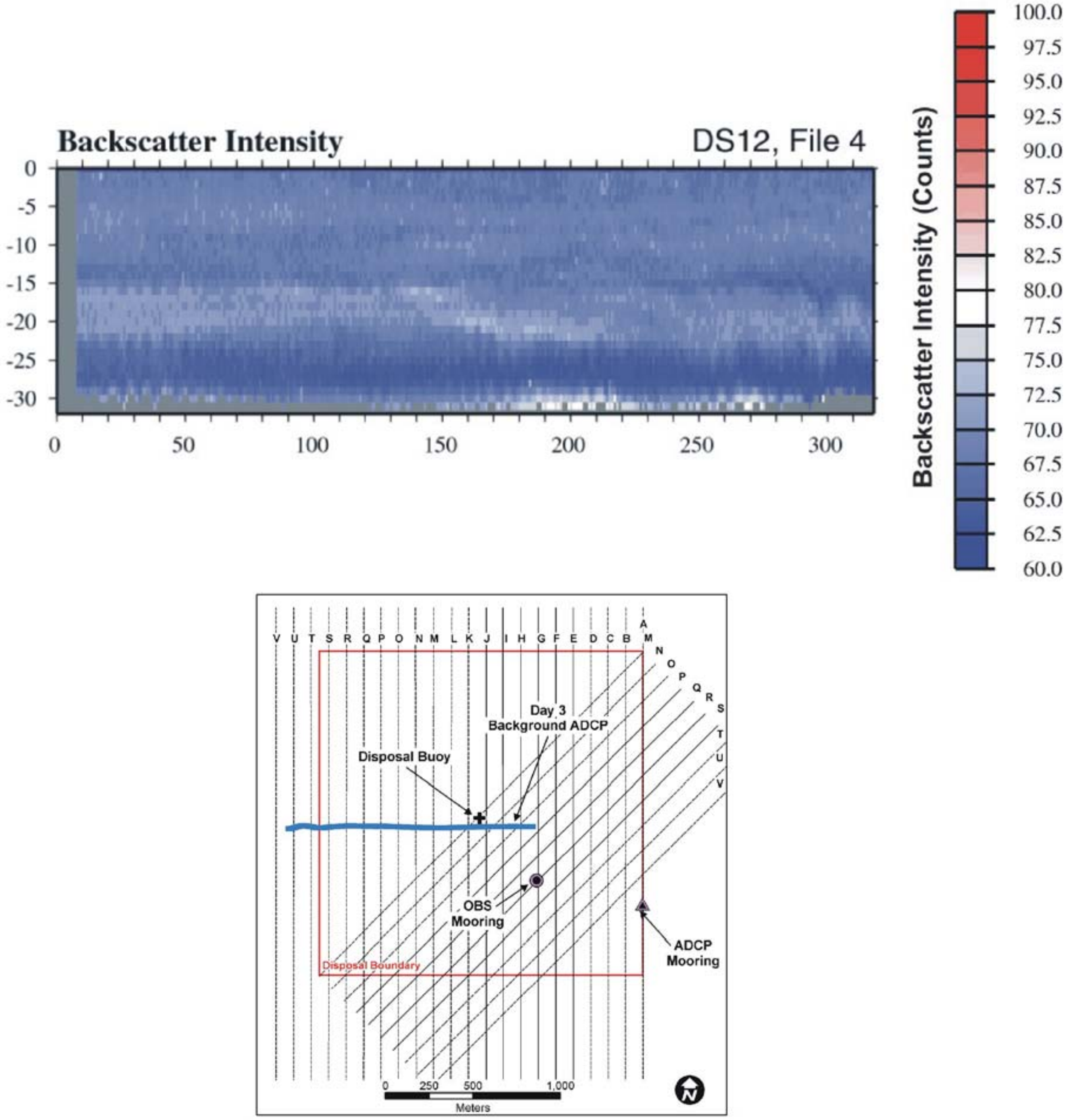


Figure 3-53. Profile plot of raw ADCP backscatter data collected on 3 September 2004 to characterize background conditions at RISDS.

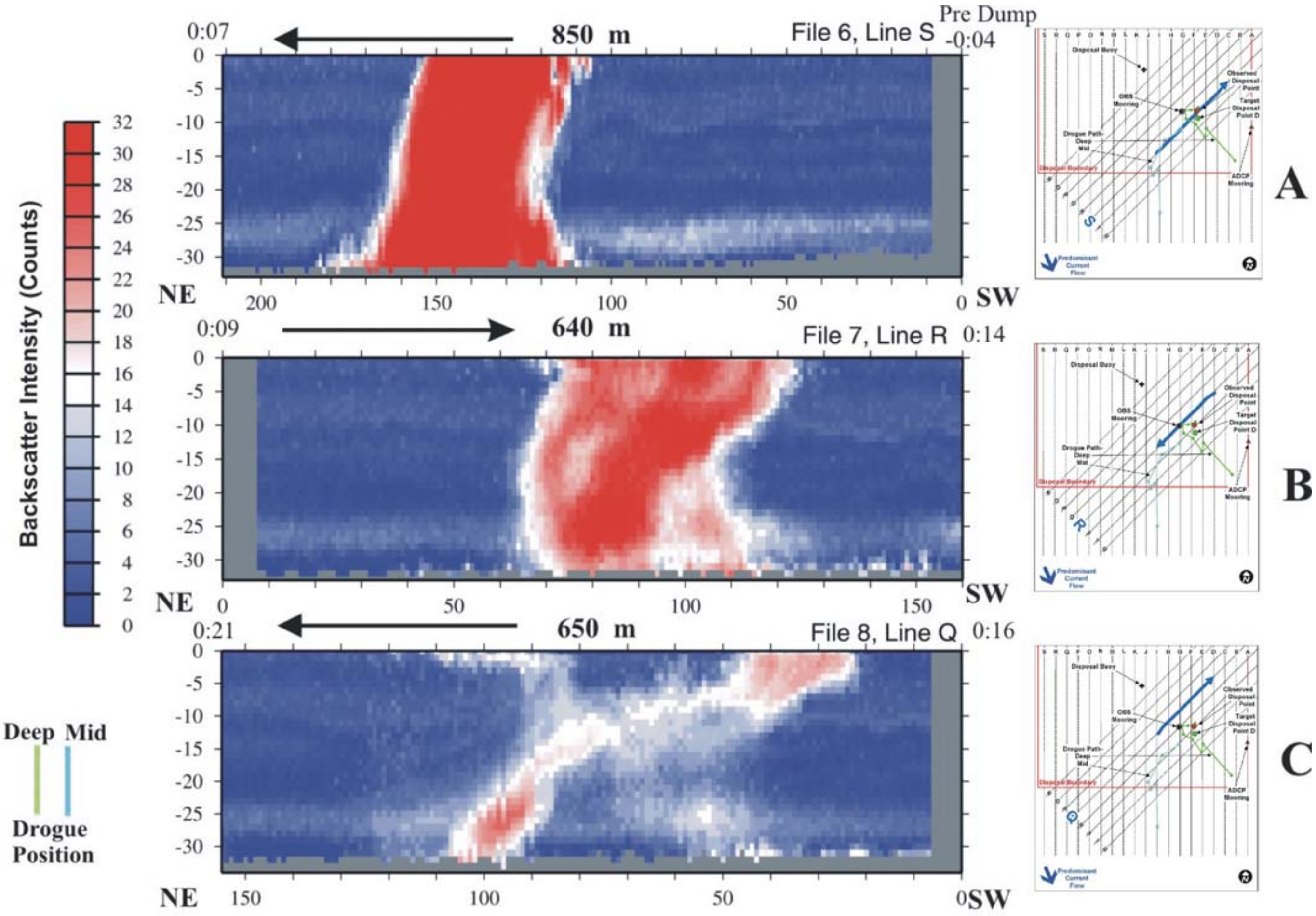


Figure 3-54. Profile plots of data collected from ADCP transects S, R, and Q on 3 September 2004 displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to illustrate plume morphology prior to disposal and 21 minutes after the dredged material disposal event at Point D.

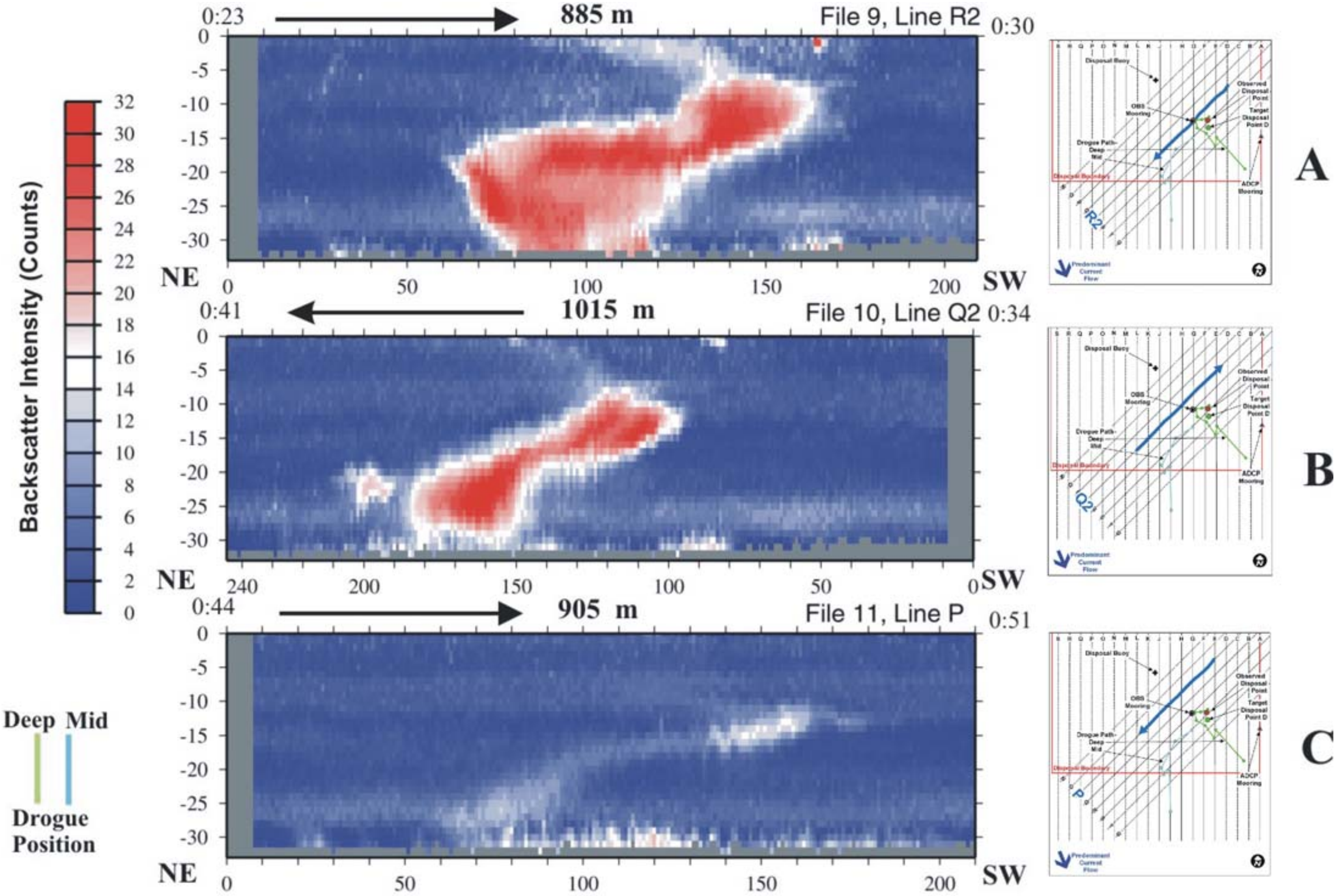


Figure 3-55. Profile plots of data collected from ADCP transects R2, Q2, and P on 3 September 2004 displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to illustrate plume morphology 51 minutes after the dredged material disposal event at Point D.

Following the second occupation of Line R, the ADCP vessel returned to Line Q once again. At approximately 35 minutes post-placement, a relatively intense plume feature was detectable in the water column (Figure 3-55B). The plume morphology documented on Line Q2 had similar shape to that of Line R2, but was smaller in overall size. The majority of the plume feature existed in the mid- and lower portions of the water column and was approximately 170 m in width. The residual backscatter values near the center of the plume remained in excess of 30 counts, but decreased rapidly with distance from the center to levels of 14 to 16 counts at the periphery.

The survey continued with the occupation of Line P, lying 300 m northwest of the disposal location, to document the northwestern extent of the plume approximately 50 minutes post-placement. The residual backscatter data indicated a small increase in suspended particulates over background with values less than 14 counts (Figure 3-55C). The general shape of this weak plume feature was similar to the morphology noted in Lines R2 and Q2, suggesting that this feature represented the edge of the sediment plume. Overall, this sediment plume experienced less horizontal transport during the first 50 minutes after disposal than was observed for plumes during the previous survey days.

Since it appeared the entrained sediments in the majority of the water column had not been advected far from the original disposal location, the survey vessel returned to Line R, (100 m northwest from the disposal location) for a third occupation. This transect (Line R3) showed a fairly dense plume in the lower 10 to 15 m of the water column, approximately 410 m in width, and displayed backscatter intensities above 26 counts (Figure 3-56). These data indicated that the majority of the plume remained within 200 m of the disposal location approximately one hour post-placement. However, evidence of current shear and differences in the rate of advection were also documented as the mid-depth element of the plume had moved to the south and west in response to the higher current velocities within the upper water column.

At this point in the survey, the orientation of the survey lines was switched to examine the north-south axis of the sediment plume. The first two transects in this orientation were Lines G and H, lying 100 m and 200 m to the west of the original disposal location, respectively (Figure 3-57 A&B). The residual backscatter data obtained from these two transects showed the majority of the sediment plume in the lower 12 to 15 m of the water column, but at reduced intensity in relation to the last northeast-southwest transect (Line R3; Figure 3-56). Residual backscatter values were 20 counts or lower within the central portion of the plume detected along on these two transects.

In order to characterize the leading edge of the sediment plume, the next transect to the west (Line I) was skipped and Line J was occupied. The data collected 400 m to the west of the original disposal location displayed some measurable residual backscatter

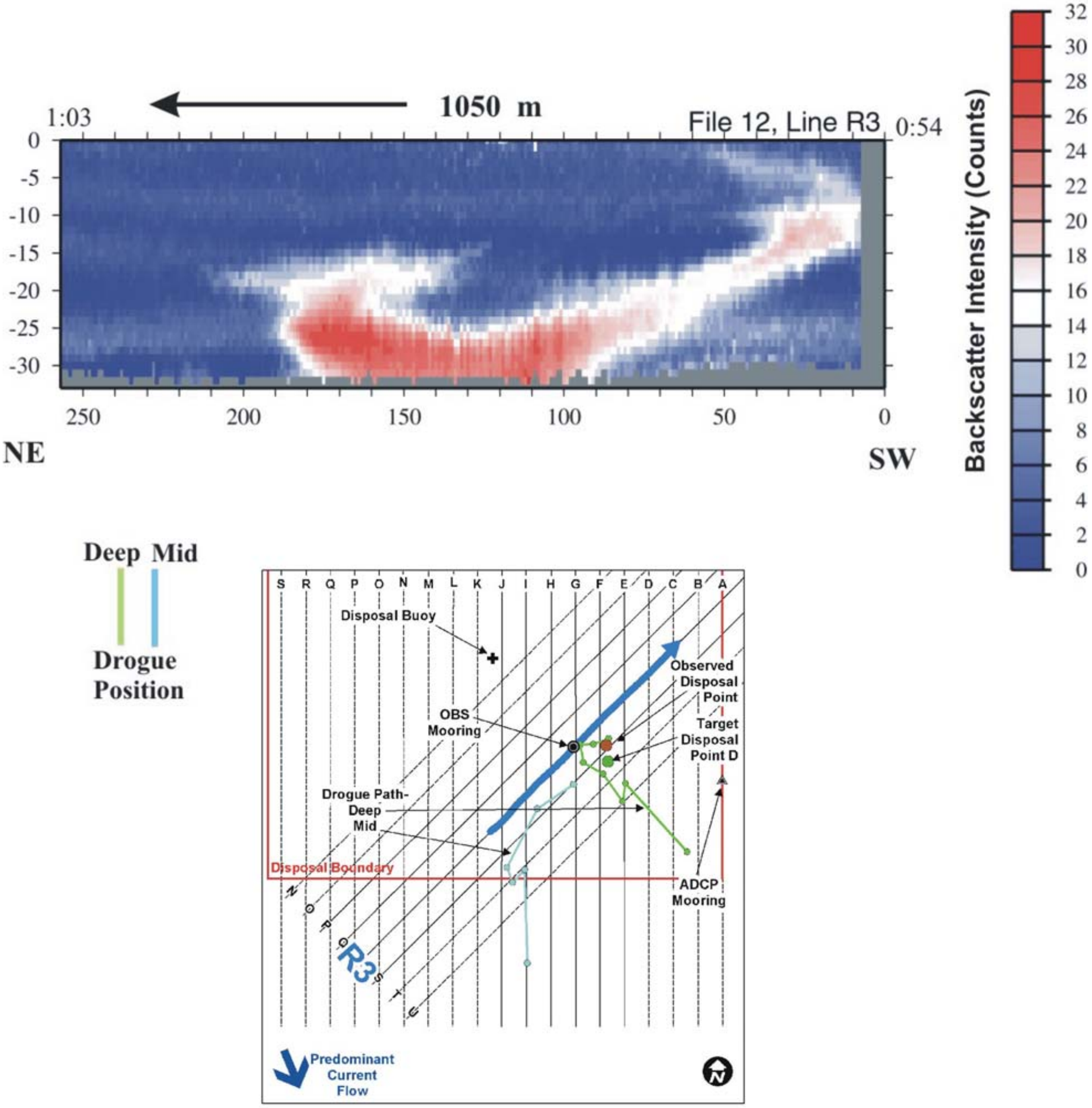


Figure 3-56. Profile plots of data collected from ADCP transects R3 on 3 September 2004 displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to emulate plume morphology one hour and 3 minutes after the dredged material disposal event at Point D.

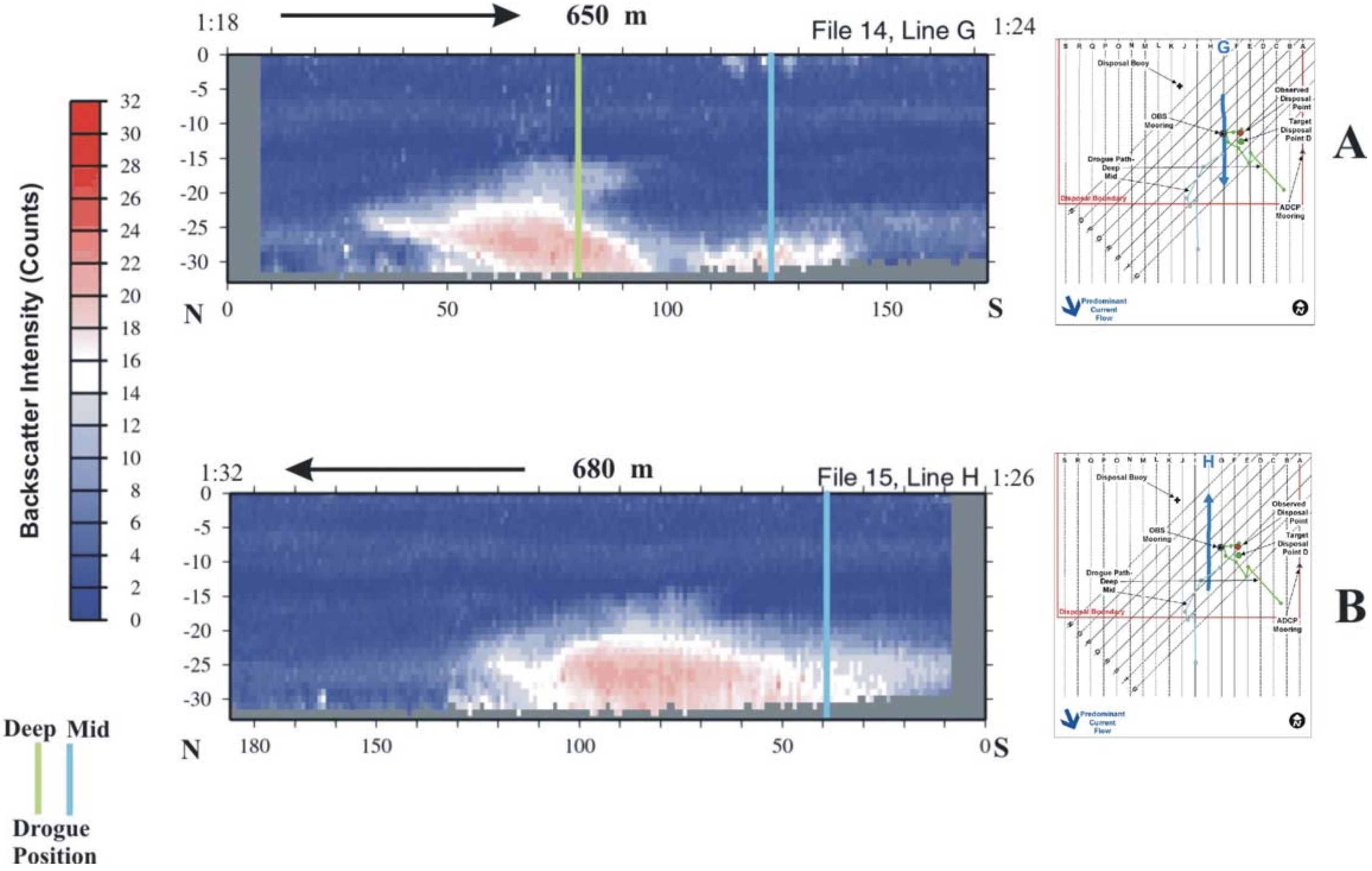


Figure 3-57. Profile plots of data collected from ADCP transects G and H on 3 September 2004 displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to illustrate plume morphology one hour and 32 minutes after the dredged material disposal event at Point D.

(12 counts) at a depth of 15 m and greater (Figure 3-58A). This water column turbidity was likely associated with the western edge of the sediment plume 100 minutes post-placement. The residual backscatter information collected from Line I (300 m west of the original disposal location) showed similar results to Line J, with somewhat higher intensities and a larger plume feature overall (Figure 3-58B). Continuing eastward, the data from Line H depicted an even broader plume in the lower 10 m of the water column (530 m in width), with maximum residual backscatter values of 18 counts near bottom, and average intensities of 14 to 16 counts higher in the water column (Figure 3-58C).

A transect was next run in the north-south direction directly over the original disposal location (Line F) 130 minutes post-placement and captured a broad disperse plume in the lower 10 m of the water column (Figure 3-59A). More than two hours after the disposal event, this transect displayed residual backscatter values in the lower water column approaching 18 counts, indicative of the weak plume observed below 15 m water depth. These data indicate that a significant portion of the turbidity generated by the disposal event remained at or near the original disposal location and gradually dispersed over time, presumably due to particle settling.

Although the predominant current direction at the surface and mid-depth levels during the first two hours of the survey operation was to the southwest and south, survey Line E, lying 100 m to the east of the disposal location, was occupied 140 minutes post-placement to assess conditions along the eastern margin of the sediment plume. The data collected along this line displayed a coherent plume below 20 m water depth in proximity to the disposal location (and the deep drogue) with a gradual reduction in residual backscatter intensities as the transect continued toward the southern boundary of the disposal site (Figure 3-59B). Subsequent to Line E, Lines H and G were reoccupied, showing residual turbidity in the near-bottom layers (Figures 3-60 A and B, respectively). The residual backscatter signal was weak, with levels of 8 to 10 counts common at mid-depth and near-bottom nearly three hours post-placement.

At the end of the survey day, the final two transects were occupied in an east-west orientation along the southern boundary of RISDS to examine the morphology of the plume as it was transported beyond the site boundary. Line S, 500 m south of the original disposal location, showed the remains of a sediment plume in the lower 7 m of the water column with acoustic backscatter values of 12 counts or less (Figure 3-61A). The next transect, Line T situated on the RISDS boundary, also showed some residual turbidity in the lower layers, presumably due to southward plume advection and mixing by currents in the mid- to lower water column (Figure 3-61B).

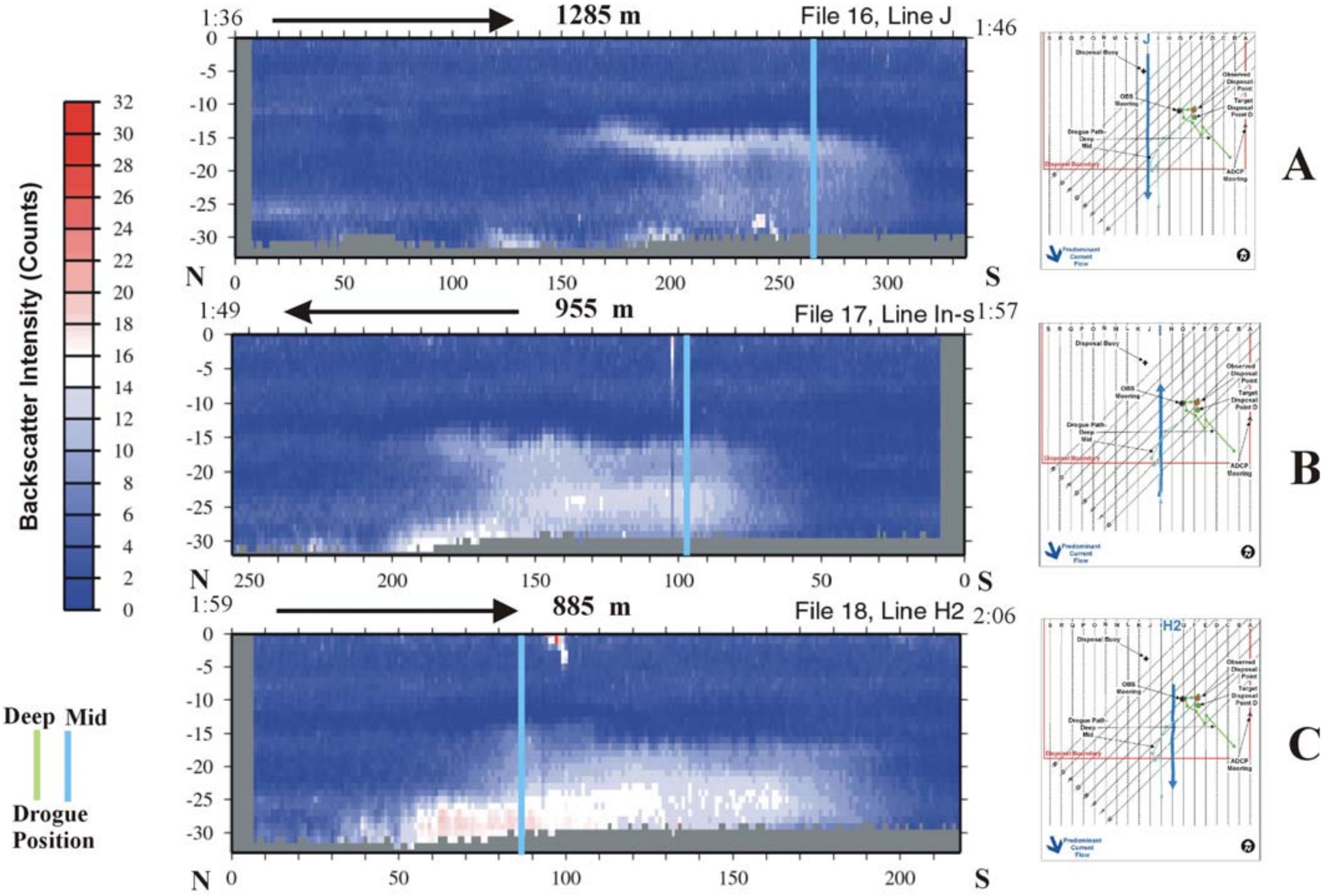


Figure 3-58. Profile plots of data collected from ADCP transects J, I, and H2 on 3 September 2004 displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to illustrate plume morphology two hours and 6 minutes after the dredged material disposal event at Point D.

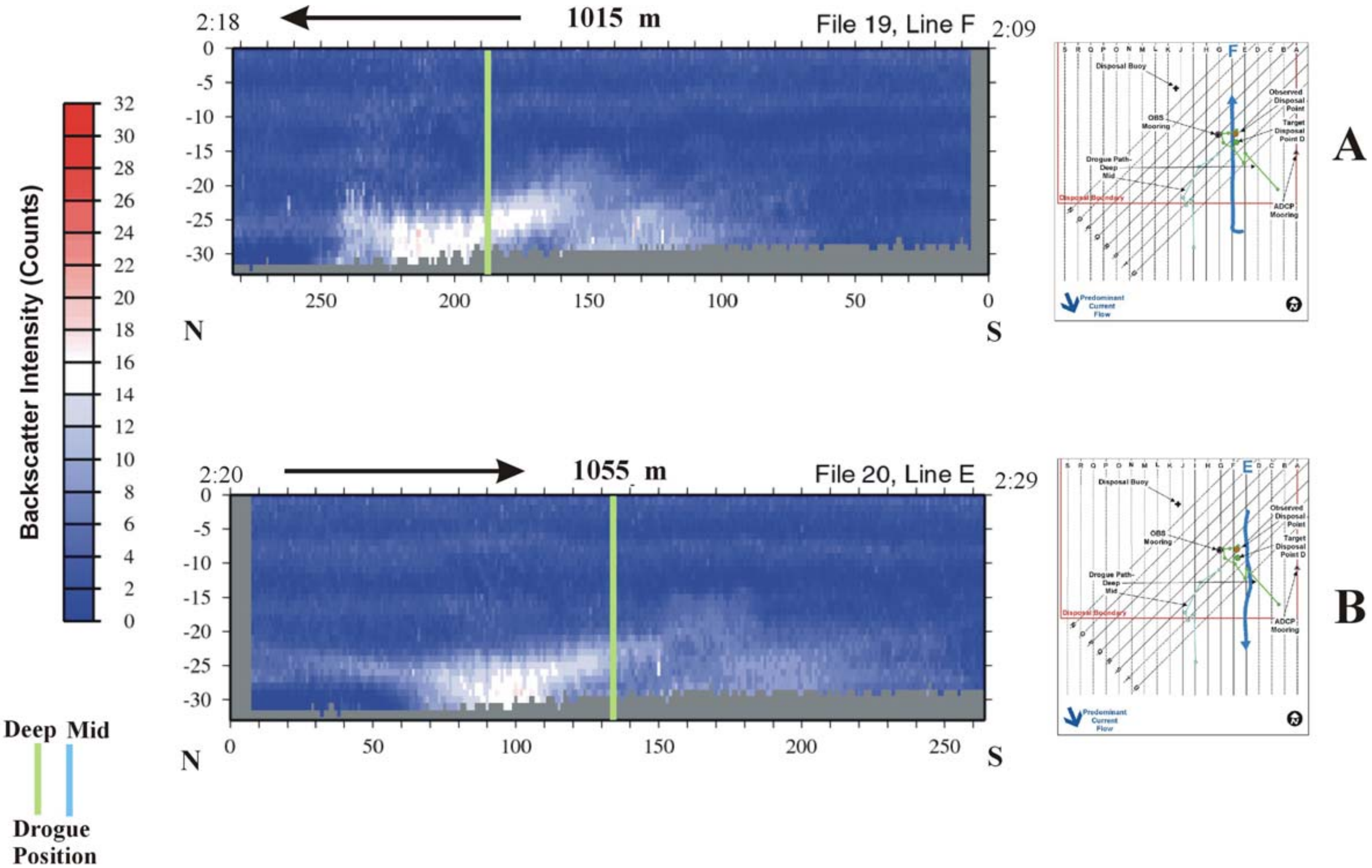


Figure 3-59. Profile plots of data collected from ADCP transects F and E on 3 September 2004 displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to illustrate plume morphology two hours and 29 minutes after the dredged material disposal event at Point D.

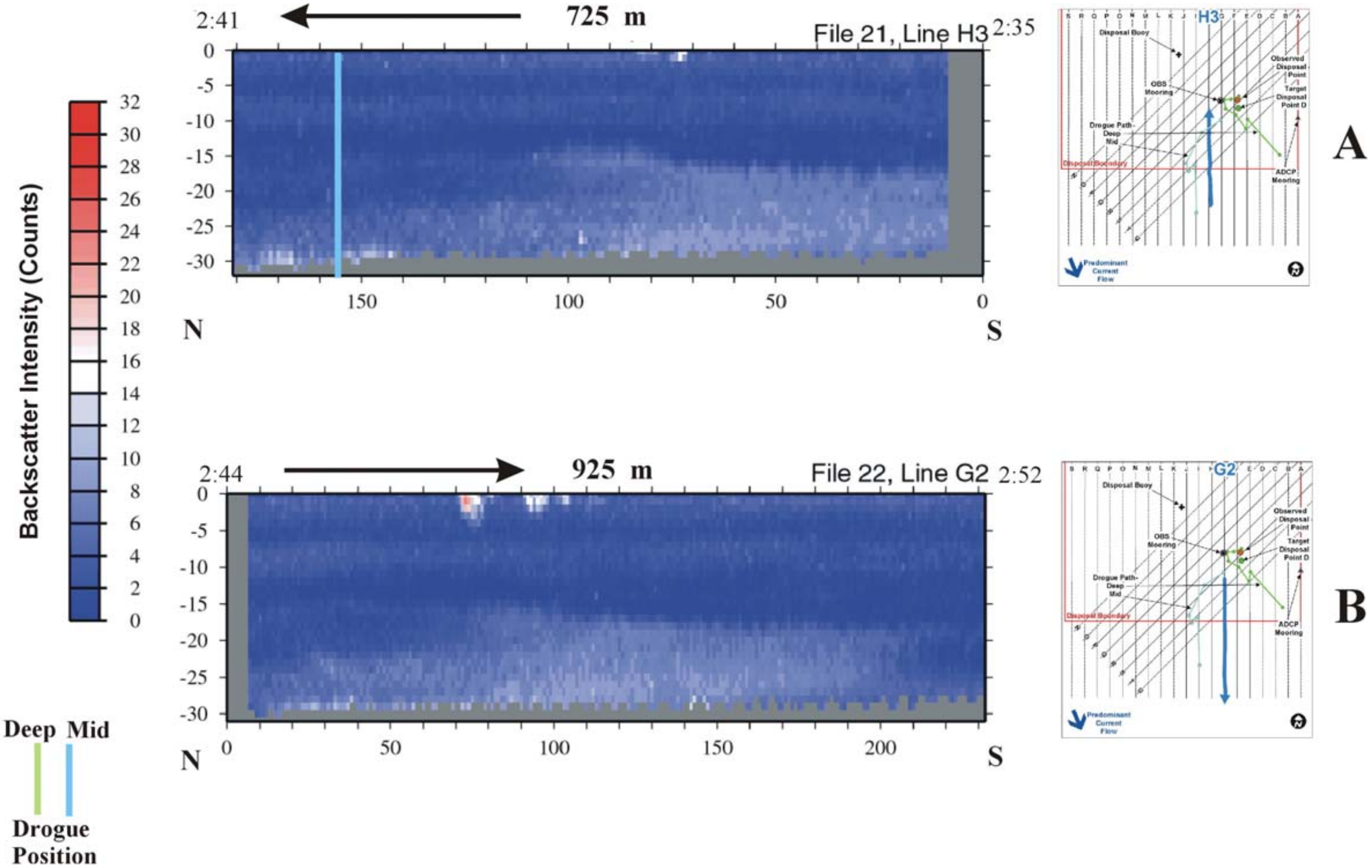


Figure 3-60. Profile plots of data collected from ADCP transects H3 and G2 on 3 September 2004 displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to illustrate plume morphology two hours and 52 minutes after the dredged material disposal event at Point D.

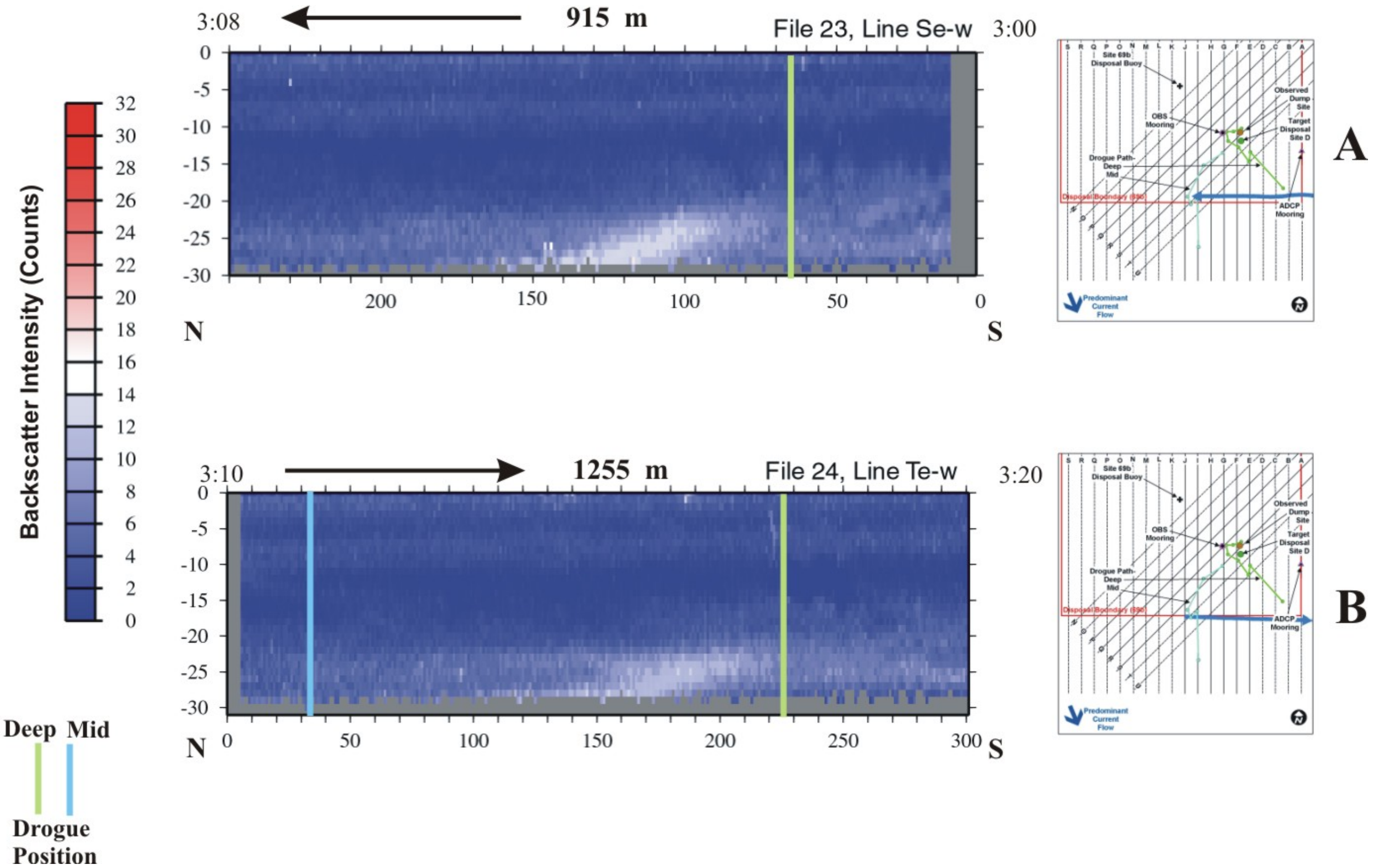


Figure 3-61. Profile plots of data collected from ADCP transects S and T on 3 September 2004 displaying acoustic backscatter intensity within the water column minus the raw backscatter intensity to illustrate plume morphology three hours and 20 minutes after the dredged material disposal event at Point D.

3.2.3.3 Water Column Optical Backscatter

As part of the Plume 3 survey, the OBS sensor mooring was placed approximately 150 m west of the target disposal position (Figure 2-5). As in the previous surveys, the OBS data obtained for the Plume 3 survey indicated background turbidity was low in the upper two sensors (5 FTU or less), and somewhat higher (10 to 12 FTU) at the deep sensor located at 32 m water depth (Figure 3-62). These data generally agreed with the transmissometer records obtained within the disposal site boundary prior to the disposal event that indicated a clear water column from the surface to a depth of 30 m, followed by a distinct increase in turbidity within 5 to 7 m of the seafloor.

The disposal event occurred at 17:16 UTC, and a sharp increase in turbidity was noted in the near-bottom OBS sensor at 17:22 UTC, or 6 minutes after the beginning of the disposal event (Figure 3-62). The strong increase in turbidity lasted one minute and reached a peak turbidity value of 782 FTU, after which turbidity returned to background values. At 17:41, an increase in turbidity to approximately 25 FTU was recorded by the uppermost sensor (13 m depth) signifying interaction with the plume. A corresponding increase was noted at the mid-depth sensor four minutes later with turbidity levels fluctuating between 15 and 25 FTU. The passage of the plume as recorded by the 13 m sensor lasted only nine minutes, while the mid-depth sensor documented the presence of the sediment plume for 56 minutes. These findings were most likely attributable to the significant difference in water column current speeds that existed at the uppermost (13 m depth) and middle OBS sensors (18 m depth). Variations in plume width at the two sensor levels would also contribute to the observed differences in plume residence times at the sensor depths, but such spatial mapping this was not resolved in this study.

Following the initial spike in turbidity within a few minutes of the disposal event, an increase in suspended sediment concentrations was not recorded by the near-bottom sensor until 19:01 UTC, approximately 105 minutes post-placement (Figure 3-62). After 19:01 UTC, turbidity values remained elevated and variable throughout the remainder of the deployment. The OBS sensor recorded values ranging from 15 FTU to greater than 50 FTU, never settling down to background values for the duration of the survey period. This long-term increase in near-bottom turbidity was the result of the slow advection of the sediment plume within the bottom waters. The plume eventually reached the mooring location (150 m west of the disposal location) 105 minutes after the disposal event and lingered in close proximity to the mooring location for at least two hours.

3.2.3.4 Toxicity

No toxicity testing was conducted for the Plume 3 survey in accordance with the study objectives.

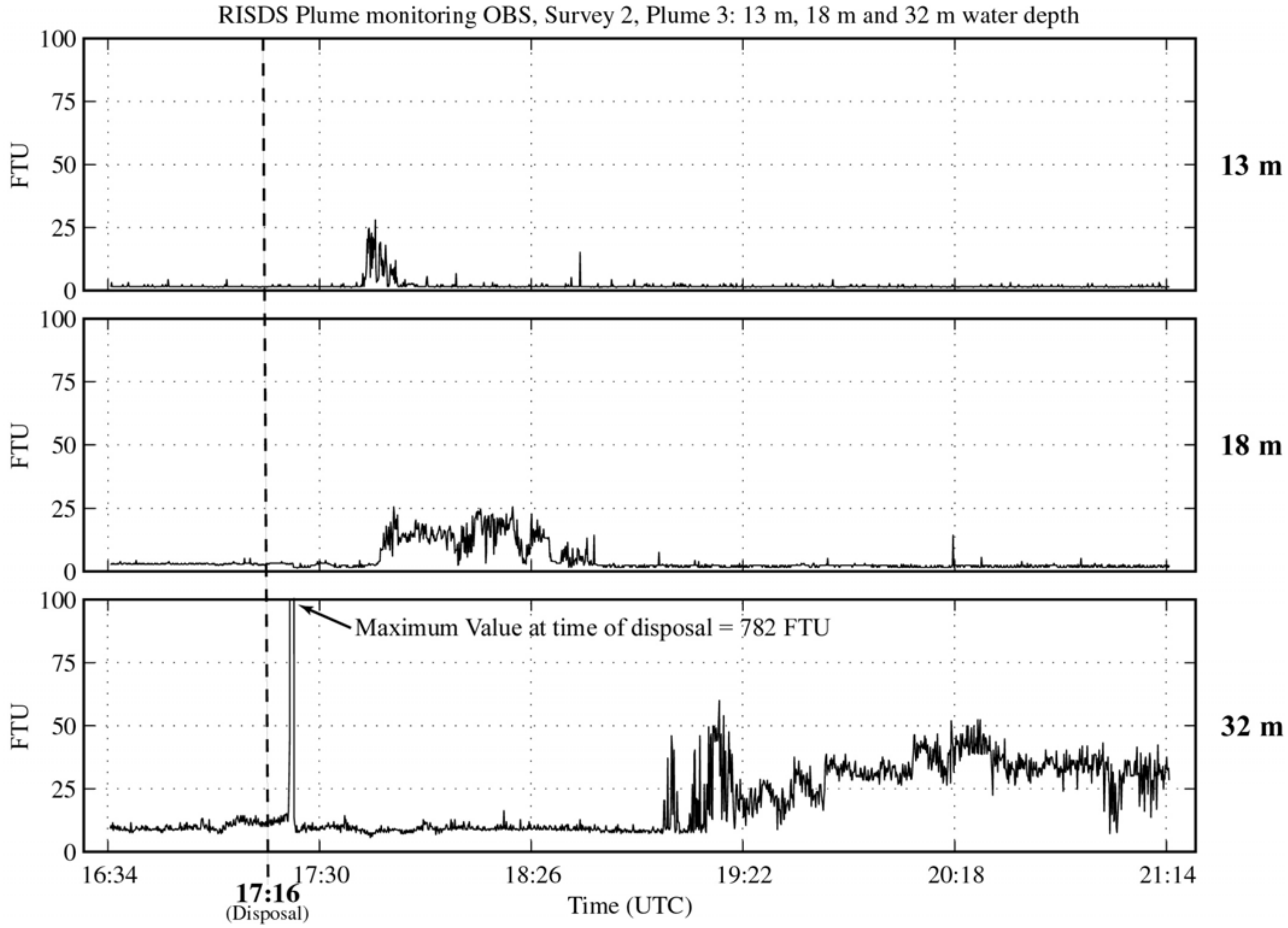


Figure 3-62. Time-series plot of OBS data collected on 3 September 2004 from three levels in the water column (13 m, 18 m, and 32 m), displaying changes in turbidity over time resulting from sediment plume passage.

4 PLUME MORPHOLOGY AND CHARACTERISTICS

The abundance of data collected as part of the second plume monitoring survey confirmed that the morphology and characteristics of each sediment plume are the end results of multiple physical 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 all govern the formation, transport, diffusion, and settlement of sediments entrained within the water column during and after disposal. Section 3 of this report presented detailed results for each survey completed during the September 2004 field effort relative to the individual disciplines used to characterize elements of plume behavior.

The methods employed during the September 2004 survey were identical to those used during the April 2004 survey. The only difference between the two surveys was the source of the dredged material and the disposal strategy used to minimize environmental risk. As stated in Section 1.5, the dredged material tracked as part of the September 2004 effort was removed from the lower Fox Point and upper Fuller Rock Reaches of the Providence River federal navigation channel. The results of geochemical and toxicity testing performed on the in-place sediments prior to dredging determined that these sediments were suitable for unconfined open water disposal with a stipulation that individual disposal events be restricted to 2,300 m^3. Disposal barges with capacities of 4,600 m^3 were utilized to transport these smaller volumes (2,300 m^3) of material to the disposal site. The placement of smaller volumes of dredged material by a large-capacity disposal barge was expected to result in a relatively dilute sediment plume and minimize any issues associated with acute toxicity in the water column.

The following subsections offer a synthesis of these data to chronicle the observations made during the course of the September 2004 survey. 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 Eulerian and Lagrangian data sets.

4.1 Plume One (1 September 2004)

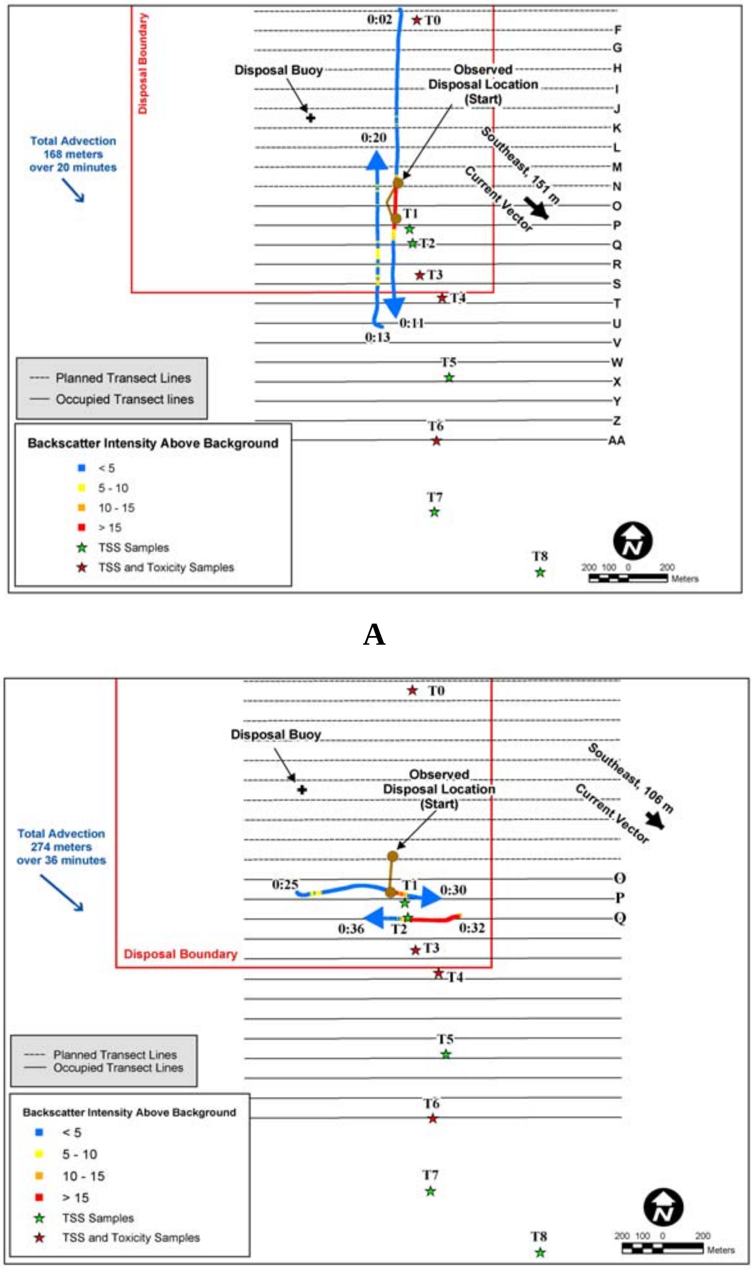
Prior to the start of the Plume 1 sediment plume survey, 2,300 m^3 of fine-grained maintenance material dredged from Fuller Rock Reach was loaded into a 4,600 m^3 split-hull barge (GL-65) and transported to RISDS for disposal. Following a four-hour transit, the disposal barge entered RISDS from the north, deposited Load 1282 at Point D within the southeastern 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 south-southeast with ambient currents, with consistent and coherent flow documented in the surface, mid-water and near-bottom waters.

The figures referred to in this section display the vessel-mounted ADCP data obtained during the Plume 1 (1 September 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 4-1 through 4-4 indicate: 1) the ADCP transects occupied over distinct time intervals following the disposal event, 2) the current vector determined by the moored ADCP over distinct time intervals (from 2 to 185 minutes) following the disposal event, 3) the current vector (total advection distance of a water parcel) during that specific portion of the survey operation starting from initial time of disposal, and 4) locations of both TSS and toxicity water samples.

The T1 profile and water samples were collected 12 minutes following the placement event, approximately 225 m south of the observed disposal point (Figure 4-1). The transmissometer profile exhibited distinct increases of turbidity in the upper (4 to 10 m depth) and lower (21 to 23 m depth) water column separated by a layer of water at mid-depth displaying background turbidity levels (Figure 3-7). A strong increase in turbidity was also detected near the seafloor, triggering the collection of water samples for TSS analysis from the deepest turbid layer (33 m depth). The triplicate samples yielded an average TSS value of 66.5 $mg \cdot L^{-1}$, suggesting the sample was collected in proximity to, but possibly not within, the central core or centroid of the plume (Figure 3-7).

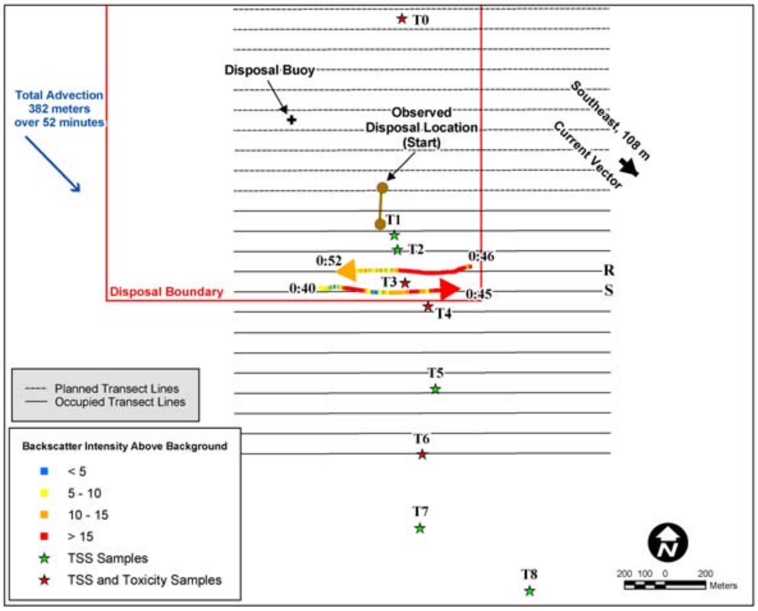
The acoustic data recorded seven to eight minutes after the disposal event detected the presence of a discrete, intense residual backscatter signal on north-south oriented Line F. The sediment plume extended from the surface to the seafloor, with entrained sediments, gas bubbles, and turbulence within the water column acoustically detectable over a 240 m portion of the initial 1500 m long cross-section (Figure 3-12A). The subsequent ADCP survey line (south-north Line G) captured the western margin of the sediment plume.

The T2 (20-minute) profile and water samples were obtained 75 m down-current (south-southeast) of the T1 sample location and yielded a similar profile to that of T1. Once again, a substantial amount of entrained sediment was observed within a well-defined layer in the upper water column, as well as lower in the water column. However, the

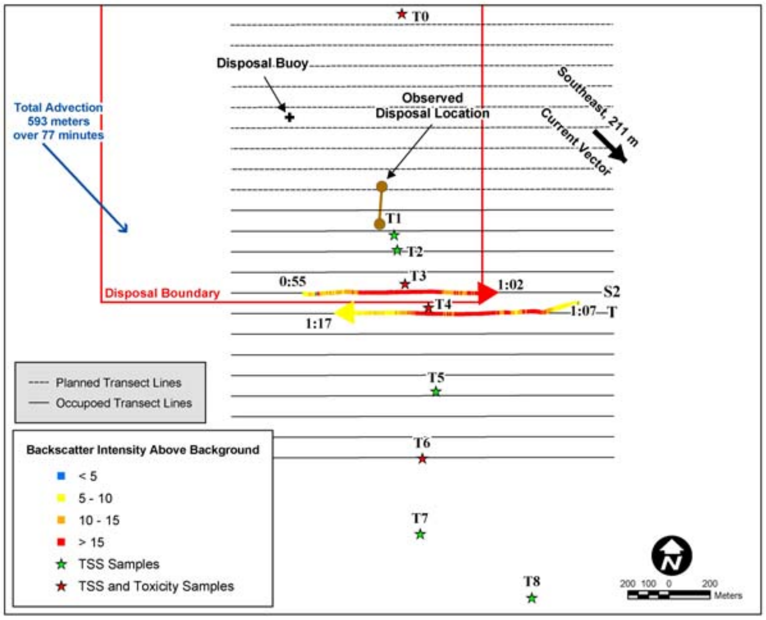


B

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, 2 to 20 (A) and 25 to 36 (B) minutes after the disposal event.



A



B

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, 40 to 52 (A) and 55 to 77 (B) minutes after the disposal event.

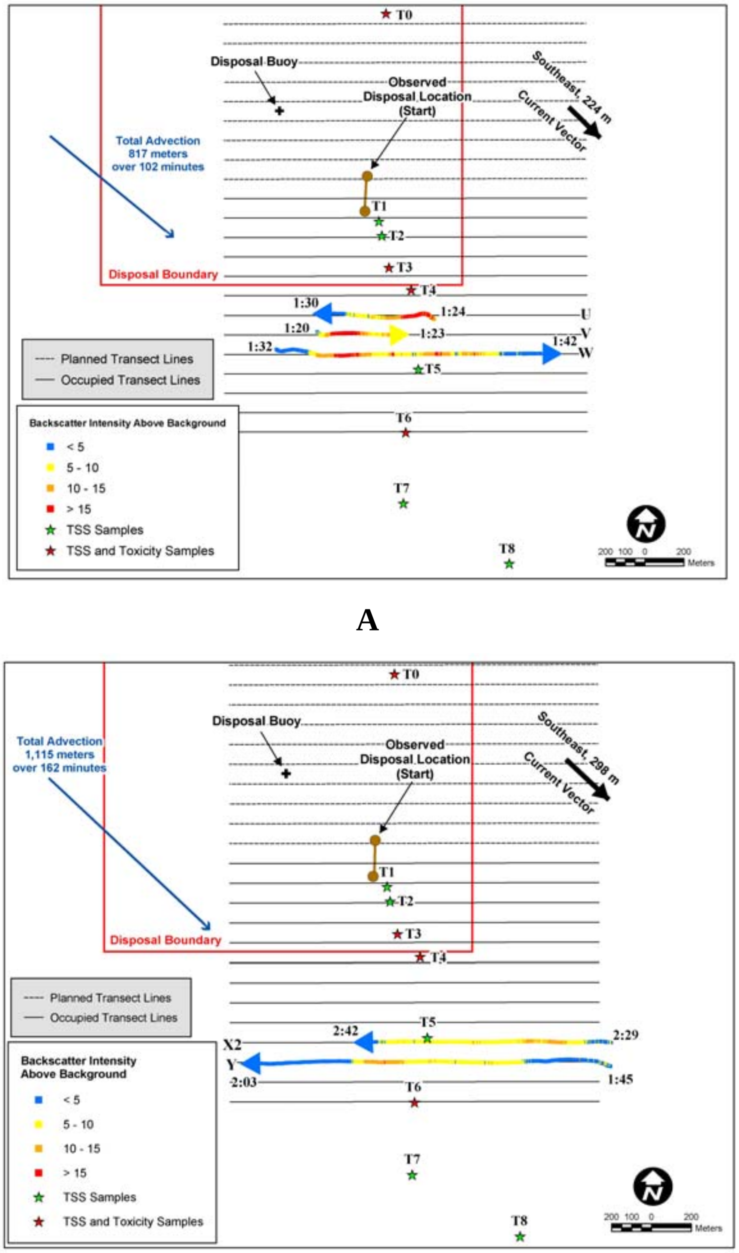


Figure 4-3. Residual acoustic backscatter intensity values from the 32 m depth interval representing suspended sediment concentrations along individual survey lines occupied during the Plume 1 monitoring survey, 80 to 102 (A) and 105 to 162 (B) minutes after the disposal event.

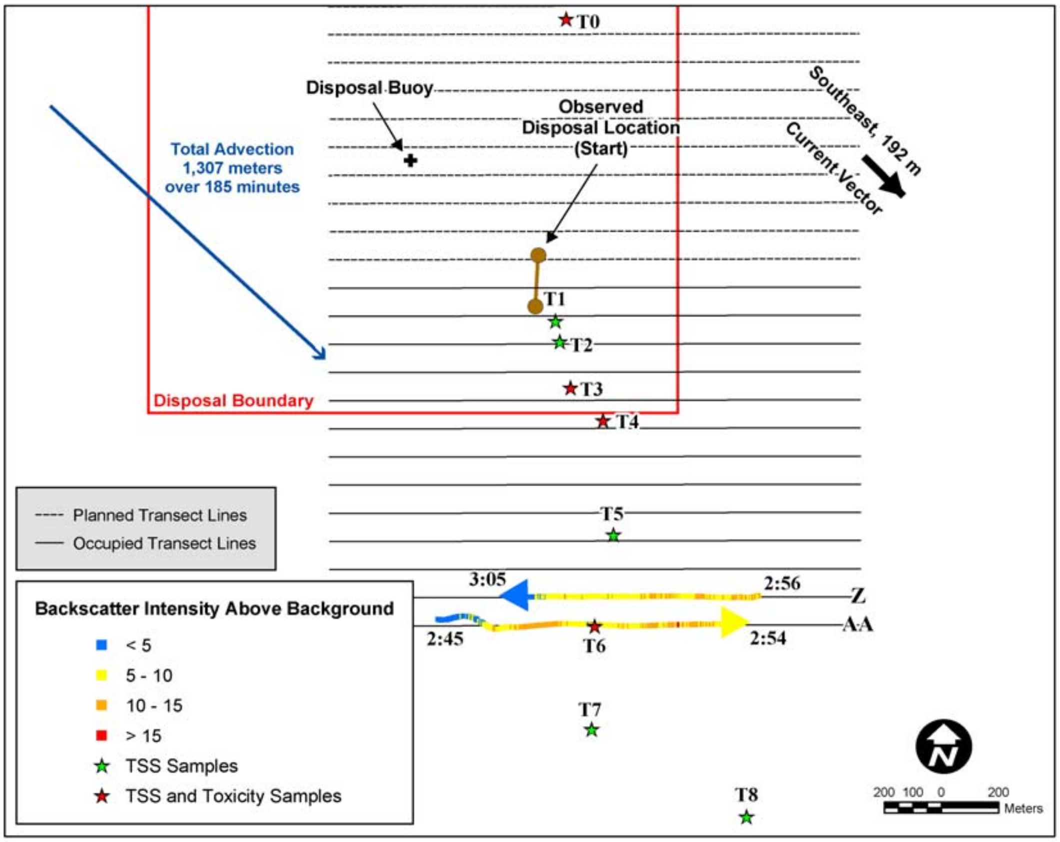


Figure 4-4. Residual acoustic backscatter intensity values from the 32 m depth interval representing suspended sediment concentrations along individual survey lines occupied during the Plume 1 monitoring survey, 165 to 185 minutes after the disposal event.

transmissometer values within the upper and lower water column were slightly higher in comparison to the T1 profile, indicating a minor decrease in turbidity over the 10 minutes that elapsed between profiles. Maximum turbidity within the water mass was encountered at a depth of 33 m, with TSS analysis indicating a sediment load of 111.6 $mg \cdot L^{-1}$ (Figure 3-7). These results suggested the T2 CTD cast and TSS replicate samples were likely closely aligned with the plume centroid.

During the early stages of the Plume 1 survey, the near-bottom currents (32 m depth) flowed southeast at velocities of 10 to 15 cm s^{-1}, resulting in a net transport of 151 m between the start of north-south Line F and the end of south-north Line G. Total advection from the original disposal location was estimated at 168 m within the near-bottom layer during the first 20 minutes of the survey (Figure 4-1A). As the near-bottom portion of the plume was carried by relatively strong 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 east-west Line Q (Figure 3-13B) approximately 35 minutes post-placement provided evidence of the plume element below 18 m water depth becoming slightly larger (300 m wide) and more diffuse. Residual acoustic backscatter values along Line Q ranged from 5 counts to well in excess of 15 counts, with the higher values detected along the eastern half of the line (Figure 4-1B).

The transmissometer data obtained as part of the T3 profile provided the last evidence of the sediment plume in the upper water column, as it was rapidly advected to the southeast by currents in the upper 18 m of the water column. The transmissometer record indicated elevated turbidity in the upper 10 m of the water column, with decreased turbidity at depth (Figure 3-8). Light transmittance levels similar to background were observed within the mid-water column (depths ranging between 12 m and 27 m), indicating lack of a mid-water plume element and a significant change in morphology relative to the T1 and T2 profiles. Suspended sediment concentrations increased once again at depths below 27 m with the highest turbidity detected at a depth of 34 m. The acoustic data obtained in proximity to the T3 profile location confirmed the findings of the transmissometer record, displaying the bulk of the entrained sediments below 15 m depth. Data from Lines R and S indicated the bulk of the suspended sediments existed below a depth of 15 m, with the highest concentrations detected near-bottom (Figure 3-14). Residual acoustic backscatter values along Lines R and S ranged from 5 counts to over 15 counts, with the highest values detected along the eastern portions of each line (Figure 4-2A).

The T3 profile was obtained nearly 475 m south-southeast of the observed disposal location 42 minutes post-placement. Based on the water column current data, the near-bottom element of the sediment plume was subject to total advection of 300 to 350 m prior to the completion of the profile. As a result, the current and acoustic data indicate the highest turbidity water was located 100 m north of the T3 profile location 42 minutes after the disposal event, suggesting this profile was more characteristic of the leading edge than the plume centroid (Figure 4-2A). The significant decrease in average TSS concentration between the T2 and T3 (111.6 to 15 mg·L^{-1}) samples provided further evidence of this conclusion (Table 3-4).

The southeast flow of ambient currents continued to transport the sediment plume away from the original disposal point, towards the southern 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 550 m (Figure 4-2B). The T4 profile and water samples were obtained 625 m down-current of the observed disposal point in proximity to an area that exhibited a substantial amount of near-bottom turbidity based upon acoustic records (Figure 4-2B). The T4 transmissometer profile displayed very little turbidity over the background signal in the upper and mid-water column, but a substantial increase in suspended sediments near-bottom. The water samples for TSS analysis were collected from the 32 m depth interval, which displayed the lowest light transmittance value and an average sediment load of 30 mg·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 in excess of 15 counts were commonly detected in proximity to the T4 sampling station. The acoustic data collected along Lines S2 and T indicated relatively high residual backscatter existed both up-current and down-current, indicating the CTD profile and water samples were obtained within the plume (Figure 4-2B). But based on the flow information provided by the bottom-mounted ADCP data, the centroid of the sediment plume was likely 50 to 75 m up-current of the recorded T4 profile location at the time the CTD data and the water samples were collected. As a result, the transmissometer and TSS values were not representative of the absolute centroid, but probably provide insight into the conditions within the majority of the plume one hour after the disposal event.

Following the T4 sample interval, the ADCP data indicated the plume was broadening somewhat, but maintaining several areas with residual backscatter values in excess of 15 counts. Acoustic records collected along Lines U, V, and W (Figure 4-3A) displayed entrained sediments throughout much of the lower water column, with the data from Line W suggesting multiple parcels of turbid water existed at depth separated by relatively clear water (Figure 3-16C). Residual backscatter values ranging from 5 to 15 counts were detected within these areas of turbidity, with the more coherent and concentrated areas located outside the southern boundary of the disposal site (Figure 4-3A).

The T5 (90-minute) sampling event was completed approximately 400 m south of the southern disposal site boundary, with water samples collected from a layer of relatively turbid water detected at a depth of 32 m. The transmissometer profile indicated that most of the surface water turbidity was near background levels, but also displayed several discrete layers of turbid water in the top 15 m of the water column. Below a depth of 25 m, 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 3-9). A replicate-averaged TSS value of 15.1 $\mathrm{mg \cdot L^{-1}}$ was calculated for the T5 sample interval, which was obtained from a parcel of seawater located 1 km south-southeast of the observed disposal point. The ADCP records obtained 100 m south of the T5 sampling station at the time of the CTD profile exhibited residual backscatter values of 10 to 15 counts over much of the survey line, with values in excess of 15 counts (Figure 4-3B). The calculated total advection distance from the original disposal point (based on current flow) was approximately 800 m, suggesting the T5 sample was collected toward the leading edge of the sediment plume, ahead of the absolute centroid.

The acoustic data collected after the T5 (90-minute) sampling interval of the Plume 1 survey indicated the plume was becoming broader and more diffuse, with turbidity levels decreasing within the sediment plume. Residual backscatter values were ranging from less than 5 counts along the margins of the survey lines occupied, to in excess of 10 counts in isolated parcels (Figure 4-3B). Isolated segments of each survey line exhibited acoustic backscatter signatures indicative of concentrated plume sediments, but were constrained in both size and intensity. The most coherent area of elevated turbidity was detected along Line Y approximately 120 minutes post-placement, suggesting the centroid of the plume existed 550 m south of the RISDS boundary. The T6 transmissometer profile that was collected within that time interval displayed turbidity analogous to background conditions throughout the top 30 m of the water column. Below 30 m water depth, turbidity levels increased with depth with the highest levels detected 2 m above the seafloor. The water sample obtained as part of the T6 profile was collected from a depth of 33 m and yielded an average TSS value of 8.6 $\mathrm{mg \cdot L^{-1}}$, which was less than the value calculated for background prior to the disposal event (Figure 3-9).

Based on the speed and direction of near-bottom currents, the centroid of the plume would have been advected over 1 km south-southeast of the disposal point by the ambient currents 120 minutes post-placement (Figure 4-3B). The T6 samples were obtained 1300 m down-current of the observed disposal point, suggesting the 120-minute samples were collected within the diffuse sediment plume, but likely ahead of the absolute centroid.

The T7 (150-minute) sampling interval was completed at a station located nearly 1.6 km south of the observed disposal point (Figure 4-4). The transmissometer record indicated that the top 25 m of the water column exhibited turbidity quite similar to background conditions. Below 25 m, the record indicated that suspended particulate concentrations generally increased with depth based on the consistent decrease in percent transmission values. A minimum transmissometer (maximum turbidity) reading of 50% was detected within the water column profile, which corresponded to the 32 m depth interval from which the TSS samples were collected (Figure 3-10). An average TSS value of 9 mg·L^{-1} indicated turbidity levels were quite comparable to background as the sediment plume continued to travel south-southeast with the ambient currents.

The acoustic data collected during the final hour of the Plume 1 survey focused on bounding the diffuse sediment plume 300 to 400 m north of the T7 sample location. In general, a broad and diffuse element of the sediment plume was detected in the lower portion of the water column. Residual backscatter readings of less than 5 counts dominated the survey area, with residual backscatter values of 10 counts measured along isolated segments of the individual survey lines.

The collection of the T8 water column profile occurred over 2 km south-southeast of the observed disposal point in proximity to the deep drogue prior to recovery (Figure 3-2). The transmissometer profile and TSS samples both suggested that plume sediments had become mixed with the ambient seawater surrounding RISDS. Relatively high transmissometer values in the surface layers were indicative of low turbidity values. Similar to prior casts, transmissometer readings began to decrease with depth below 25 m depth to eventually reach a minimum value of 49% at a depth of 31.8 m. TSS samples collected from this depth yielded an average value of 11.7 mg·L^{-1}, slightly above the background levels detected 3.5 hours earlier and indicative of continued dissipation of the sediment plume within the water column (Figure 3-10).

4.2 Plume Two (2 September 2004)

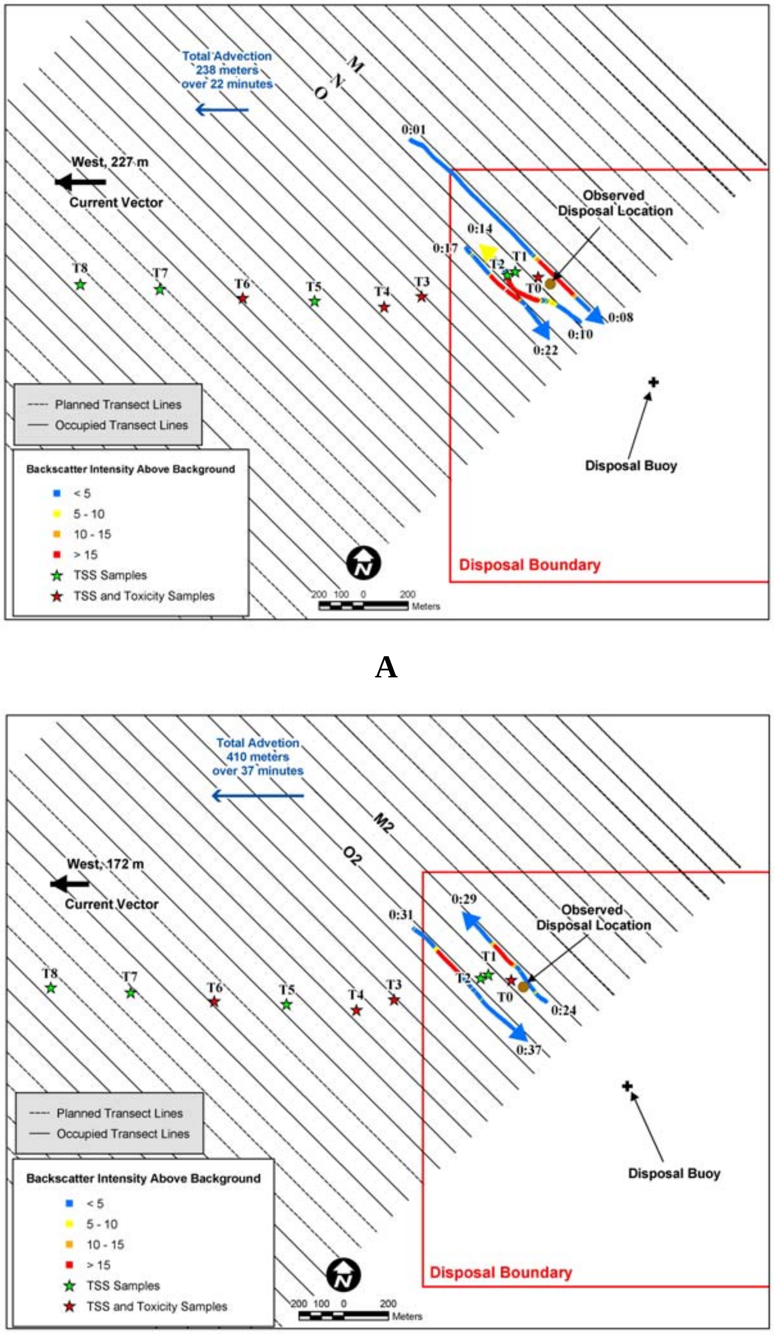
Barge GL-63 was loaded with 2,300 m^3 of fine-grained sediment dredged from Fuller Rock Reach and transported to the northwestern quadrant of RISDS for disposal. The barge entered the disposal site from the north, stopped at Disposal Point A for the disposal event, then continued south, eventually turning to the east and north for the return transit. The acoustic backscatter information acquired along the first survey line (Line M) 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 160 m wide on the surface and nearly 300 m wide at depth (Figure 3-31A).

The surface drifter and current drogues served as visual references of plume location for the CTD/water sampling vessel, indicating plume transport was primarily westward for the majority of the Plume 2 survey period. Transmissometer profiles and discrete water samples were consistently collected in proximity to the deep drogue location; however, several investigative casts were also conducted along the mid-depth drogue track (Figure 3-21). With the exception of the hydrocast conducted during the T1 sampling interval, water samples were consistently collected below 30 m water depth, as the most turbid water appeared to remain near the seafloor.

The figures referred to in this section display the vessel-mounted ADCP data obtained during the Plume 2 (2 September 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 4-5 through 4-7 indicate: 1) the ADCP transects occupied over distinct time intervals following the disposal event, 2) the current vector determined by the moored ADCP over distinct time intervals (from 1 to 199 minutes) following the disposal event, 3) the current vector (total advection distance of a water parcel) during that specific portion of the survey operation starting from initial time of disposal, and 4) locations of both TSS and toxicity water samples.

Figure 4-5A indicates that 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 150 m west-northwest of the observed disposal point and corresponded to an area displaying high residual backscatter values in the ADCP data. The transmissometer record indicated light transmittance was reduced within discrete layers of the water column existing at the surface, mid-depth, and near-bottom. The minimum transmittance value detected (representing maximum turbidity) within the T1 transmissometer profile was 14% at a water depth of 11 m. The water samples obtained from that depth horizon yielded an average TSS value of 34.6 $mg \cdot L^{-1}$, suggesting that the profile was obtained on the periphery of the tightly constrained sediment plume (Figure 3-26).

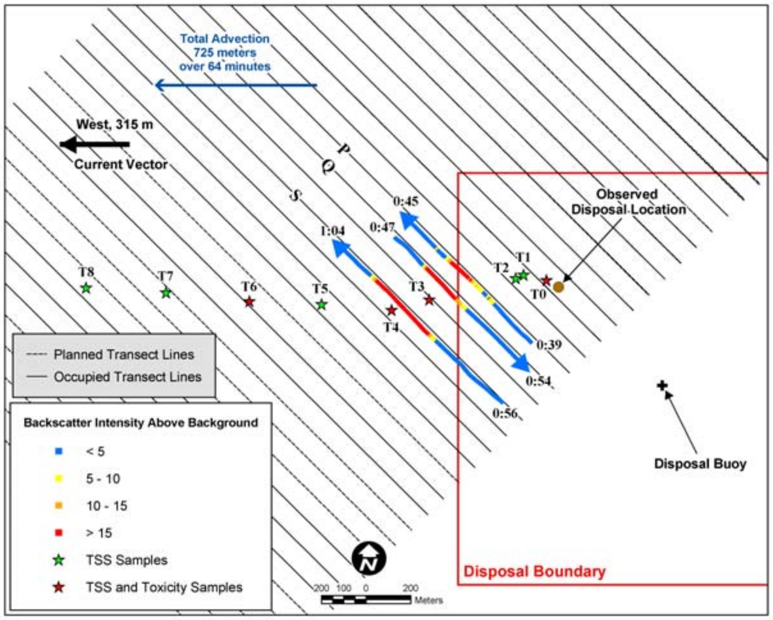
The water column profile for the T2 (20-minute) sample interval was similar in structure to that of T1, but maximum turbidity was documented near the seafloor. The T2 profile and samples were obtained approximately 200 m west of the observed disposal point and displayed an increase in suspended particulate concentrations within both the surface and near-bottom layers of the water column relative to T1. An average TSS value of 47.2 $mg \cdot L^{-1}$ was determined from the sample obtained from a depth of 32 m, which correlated to a minimum transmittance value of 3.5%. Based on the near-bottom current velocities obtained by the bottom-mounted ADCP, the water mass carrying the core of the sediment plume was transported 238 m to the west between the time of the disposal event and the end of the T2 sampling event. Given the location of the T2 profile relative to the calculated transport distance, the data obtained at the T2 interval may be more representative of the trailing edge of the constrained sediment plume, rather than its absolute centroid (Figure 4-5A).



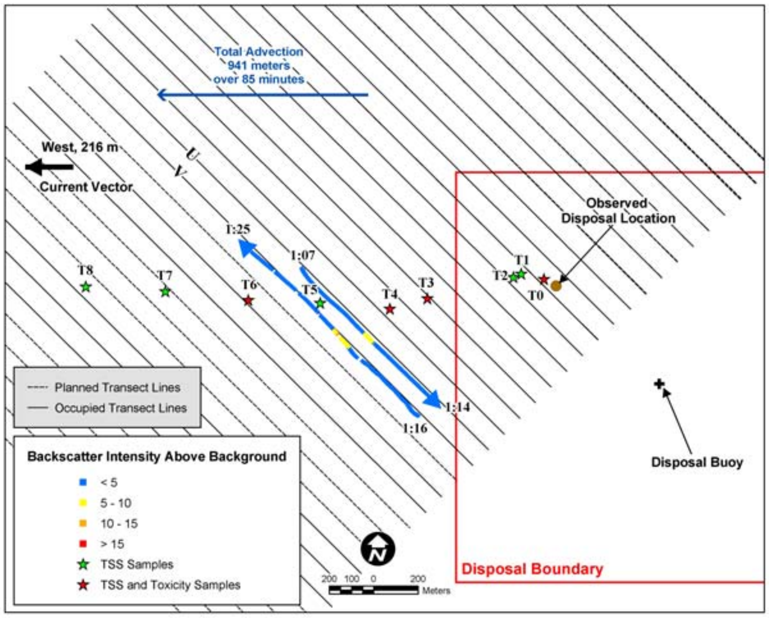
A

B

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, 1 to 22 (A) and 24 to 37 (B) minutes after the disposal event.

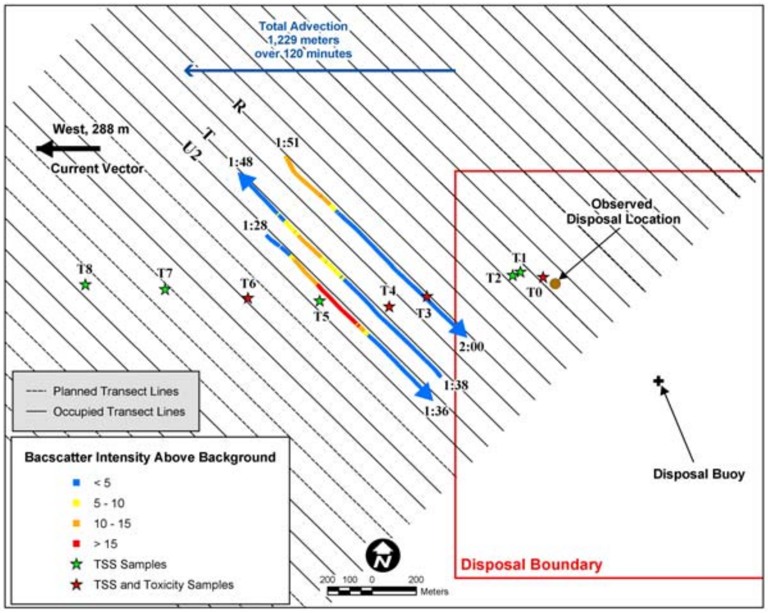


A

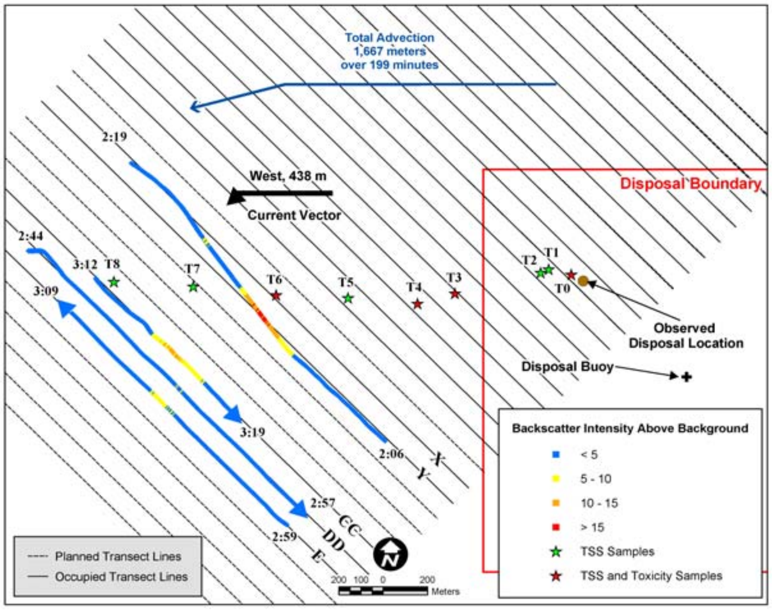


B

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, 39 to 64 (A) and 67 to 85 (B) minutes after the disposal event.



A



B

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, 88 to 120 (A) and 126 to 199 (B) minutes after the disposal event.

The second occupation of Lines M and O suggested the core of the sediment plume had continued to move to the west and northwest in response to the near-bottom currents (Figure 4-5B). The acoustic data indicated that suspended sediment concentrations within the near-bottom element of the plume remained relatively concentrated, as residual backscatter intensities in excess of 15 counts were detected as far as 400 m west-northwest of the observed disposal point 37 minutes following the disposal event. This finding correlated well with the transport distance of 410 m calculated from the current records obtained by the bottom-mounted ADCP (Figure 4-5B).

The T3 (40-minute) profile and water samples were collected approximately 550 m west of the observed disposal point and displayed a substantial difference in the distribution and concentration of entrained sediments relative to the earlier casts. The transmissometer data indicated waters from the surface to 20 m depth displayed suspended sediment concentrations near background levels, while intervals of turbid water were detected at mid-depth and near-bottom that were separated by relatively clear water (Figure 3-27). Maximum turbidity was detected at approximately 32 m depth (4 m above the seafloor), with the T3 water sample yielding an average TSS value of 29.6 $mg \cdot L^{-1}$. This lower TSS value relative to the T2 sample, and the location of the 40-minute profile suggests that the profile and water sample were collected 100 m to 150 m ahead of the centroid and was more characteristic of the leading edge of the plume (Figure 4-5B).

During the 20 minutes that elapsed between the T3 (40-minute) and T4 (60-minute) sampling intervals, the water mass at the 32 m depth interval moved an estimated 315 m west in response to near-bottom currents (Figure 4-6A). The T4 samples were collected 175 m west-southwest of the T3 sample location and 750 m down-current from the observed disposal point. Total calculated advection during the one-hour period following the disposal event was 725 m, suggesting the T4 profile and sample were closely aligned with the core of the disposal plume. With the exception of an apparent reduction in suspended sediment concentrations, the transmissometer profile obtained during the T4 sampling interval was quite similar in structure to that of T3. The water sample obtained for TSS analysis during the T4 profile was collected from a depth 34 m (approximately 2 m above the seafloor) and yielded an average value of 12.3 $mg \cdot L^{-1}$.

The acoustic data collected along Lines U and V, situated 100 and 200 m down-current from the T4 sample location respectively, detected low residual backscatter values at 32 m depth (Figure 4-6B). These findings suggest the ADCP transects re-acquired the leading edge of the sediment plume as it was transported west by the ambient currents. Following the completion of Line V, Line U was re-occupied at the time corresponding to the T5 (90-minute) sampling interval. The acoustic data from the 32 m depth interval detected an area of high residual backscatter with intensities in excess of 15 counts 950 m down-current from the observed disposal location. The size of this plume feature and reduced intensities in the subsequent survey lines suggests the absolute plume centroid was in close proximity to Line U 90 minutes post-placement.

The T5 transmissometer profile and water sample were collected 1,050 m down-current from the observed disposal location 97 minutes post-placement. Despite the high acoustic returns in the ADCP data set, the transmissometer profile depicted a suspended particulate load approaching background levels in both the upper and lower water column (Figure 3-28). Similar to the transmissometer records from prior casts, percent transmittance values remained near 80% in the top 20 m of the water column. Below 20 m, transmissometer values decreased with depth indicating an increase in suspended sediment concentrations, eventually reaching a minimum transmittance of 50% at 33.9 m depth. However, the increase in turbidity that was documented in the lower water column was much more gradual in the T5 profile relative to the earlier casts. The T5 water sample was obtained from the densest portion of the near-bottom plume element, and yielded an average TSS value of 9.1 $mg \cdot L^{-1}$, slightly lower than the T4 value. Since it is assumed that both the T5 and T4 sample were collected in close proximity to the plume centroid, the decrease in the average TSS value was indicative of a slow, continuous reduction in suspended sediment load within the centroid due to diffusion and settlement.

The remaining two hours of monitoring captured the slow decay of the sediment plume as turbidity levels within the centroid gradually returned to near background conditions. The T6 (120-minute) profile and water sample were collected adjacent to the deep-drogue position at a point that was 1,350 m west of the observed disposal point (Figure 3-21). The transmissometer data indicated a slightly lower transmittance throughout the majority of the water column relative to the T5 profile, indicative of a small-scale increase in turbidity levels. In addition, a relatively distinct increase in turbidity was detected at a depth of 25 m as light transmission values decreased sharply from 76% to 53%, then rebounded to approximately 70%, which may have been a function of the physical properties of the water column (i.e., density; Figure 3-28). A transmittance of 55% was also recorded at a depth of 34 m, approximately 2 m above the seafloor. A water sample obtained from this interval yielded an average TSS value of 6.5 $mg \cdot L^{-1}$ suggesting that the near-bottom element of the plume had dissipated somewhat between the T5 (90-minute) and T6 (120-minute) sample intervals.

The acoustic data collected after the T6 sample interval was successful at tracking the progression of the sediment plume as it was advected west and then southwest in response to the counter-clockwise rotation of near-bottom currents that began flowing in a southerly direction three hours after the disposal event (Figure 3-23). The centroid of the disposal plume was apparently detected within the 32 m depth interval along Line Y 1500 m down-current of the observed disposal position 130 minutes post-placement (Figure 4-7B). Residual backscatter values in excess of 15 counts were measured within a

75 m wide segment of Line Y, which was bounded on either side by a gradient of decreasing backscatter intensities that eventually returned to background. Based on the current meter data, total advection of the plume centroid was estimated at 1,400 m to 1,500 m to the west, indicating strong agreement with the field observations.

The T7 sample interval was completed 1,750 m west of the observed disposal location 152 minutes post-placement (Figure 4-7B). The T7 transmissometer profile and water samples both indicated only a minor increase in near-bottom turbidity relative to the background profile. The water sample for the T7 interval was obtained from a depth of 33.5 m and yielded an average TSS value of 8.1 $mg \cdot L^{-1}$, which was slightly higher but comparable to the background turbidity value (5.6 $mg \cdot L^{-1}$) for the Plume 2 survey (Figure 3-29). No acoustic data were collected in proximity of the T7 sampling position at the time the transmissometer profile was obtained. However, the T7 sampling was completed prior to the southerly rotation in the near-bottom currents. Given the distribution of plume sediments 15 minutes prior to the T7 sample and the consistent direction of flow, the transmissometer record and water sample likely captured a portion of the sediment plume at the 32 m depth interval, but not the absolute centroid.

Following the T7 sample interval, the sediment plume remained acoustically detectable in the water column as a decreasing mass of turbid water, displaying a discernable centroid approximately 195 minutes post-placement (Figure 4-7B). The acoustic data collected along Line CC documented the core of the plume as an area of turbid water with a moderate acoustic backscatter signature over background (10 to 15 counts). The apparent centroid of the residual plume was documented over 1,800 m west-southwest of the observed disposal point. However, the lateral extent of the plume (perpendicular to direction of transport) appeared to be gradually decreasing from continued dilution at the periphery, resulting in further reduction in acoustic backscatter intensity.

The T8 transmissometer profile and water sample were collected over 2.1 km west of the observed disposal point 212 minutes post-placement. The transmissometer record displayed suspended sediment concentrations analogous to background in the upper water column, as well as remnant turbidity near-bottom (Figure 3-29). A hydrocast obtained from a depth of 32 m yielded an average TSS value of 4.6 $mg \cdot L^{-1}$, which was actually lower than the background turbidity values prior to the Plume 2 disposal event (5.6 $mg \cdot L^{-1}$). A comparison of the recorded position of the T8 water sample (adjacent to the deep drogue; Figure 3-21) and the location of the sediment plume, as detected acoustically along Line CC, indicates that the final water sample and transmissometer profile were collected 400 m northwest of the centroid (Figure 4-7B). This offset in position was likely due to the effects of the change in water column current flow three hours post-placement and the continued settlement of material from the upper water column.

4.3 Plume Three (3 September 2004)

On the afternoon of the Plume 3 survey, the loaded 4,600 m^3 barge (GL-65) was towed from Narragansett Bay toward the disposal site within the outbound traffic lane. The loaded barge was towed approximately 2 km beyond RISDS prior to turning and entering the site from the south. Once inside the boundaries of the disposal site, GL-65 was positioned over Disposal Point D, deposited 2,300 m^3 of dredged material, and then proceeded north to begin its return transit. Current following drogues (mid-depth and near-bottom) deployed at the time of disposal event slowly tracked to the northwest and west during the early stages of the survey then eventually assumed a southerly heading in response to the relatively weak water column currents, while the surface drifter displayed a southerly track for the duration of the survey period (Figure 3-41).

Based on the initial acoustic measurements made by the ADCP along a northeast-southwest axis through the plume (Line S) approximately five minutes post-placement, the resulting sediment plume was nearly 300 m in width and existed as a well-defined column of turbid water, gas bubbles, and turbulence when initially formed (Figure 3-54A). The subsequent survey line (Line R) was completed 100 m to the northwest of the observed disposal location, capturing the sediment plume at 12 minutes post-placement. The acoustic profile information indicated a somewhat weaker and more diffuse acoustic signature in the water column (Figure 3-54B). Due to weak and variable water column currents during the 3.5 hour survey period, subsequent acoustic survey lines were run in northeast-southwest, north-south, and east-west orientations to best define the nature and extent of the sediment plume. Throughout this process, the elements of sediment plume residing below 15 m water depth remained the most turbid and coherent regardless of the direction of transport. Water samples for TSS were commonly collected from depths greater than 15 m, and most often from levels 3 to 5 m above the seafloor.

The figures referred to in this section display the vessel mounted ADCP data obtained during the Plume 3 (3 September 2004) survey. Particular emphasis was placed on the attributes of the plume at 32 m depth (the 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 transects occupied over distinct time intervals following the disposal event, 2) the current vector determined by the moored ADCP over distinct time intervals (from 4 to 200 minutes) following the disposal event, 3) the current vector (total advection distance of a water parcel) during that specific portion of the survey operation

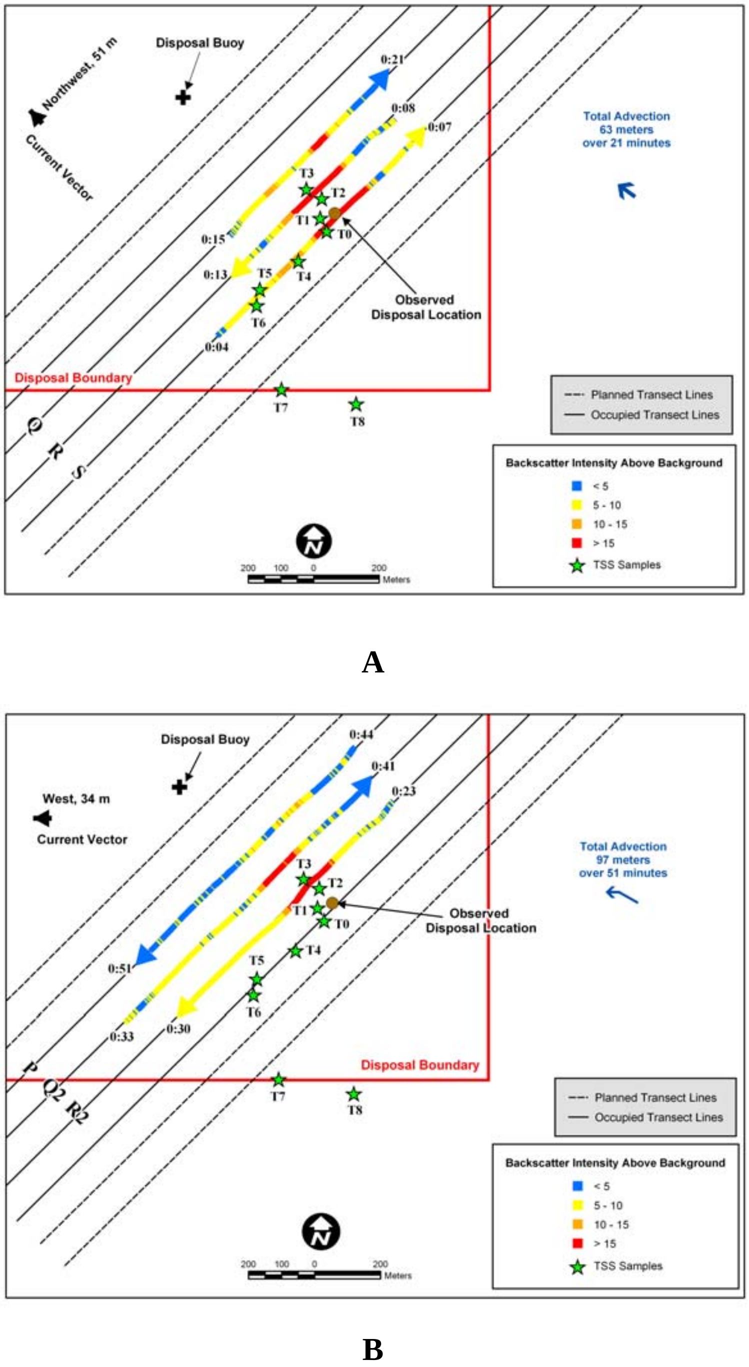
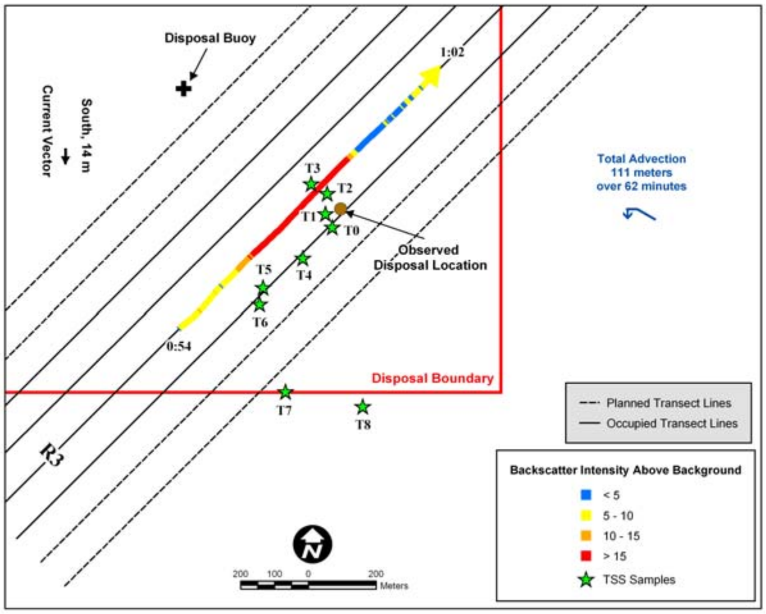
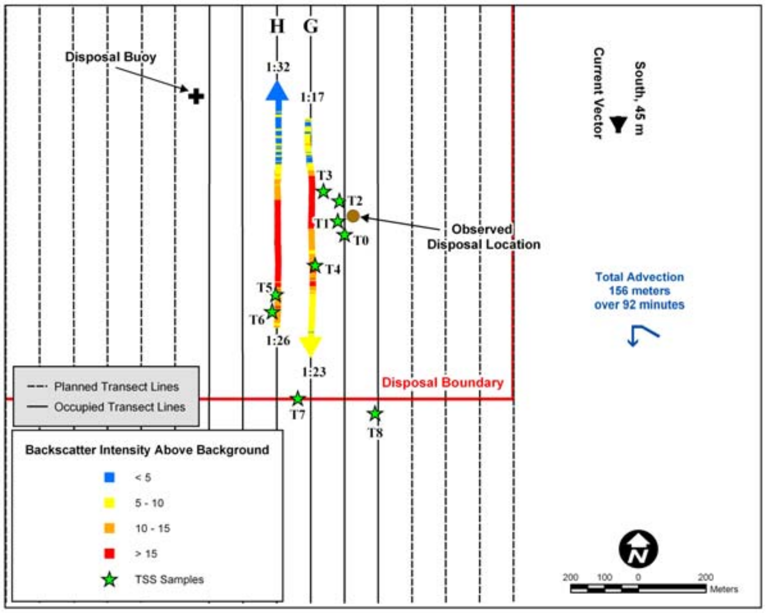


Figure 4-8. Residual acoustic backscatter intensity values from the 32 m depth interval representing suspended sediment concentrations along individual survey lines occupied during the Plume 3 monitoring survey, 4 to 21 (A) and 23 to 51 (B) minutes after the disposal event.



A



B

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, 54 to 62 (A) and 77 to 92 (B) minutes after the disposal event.

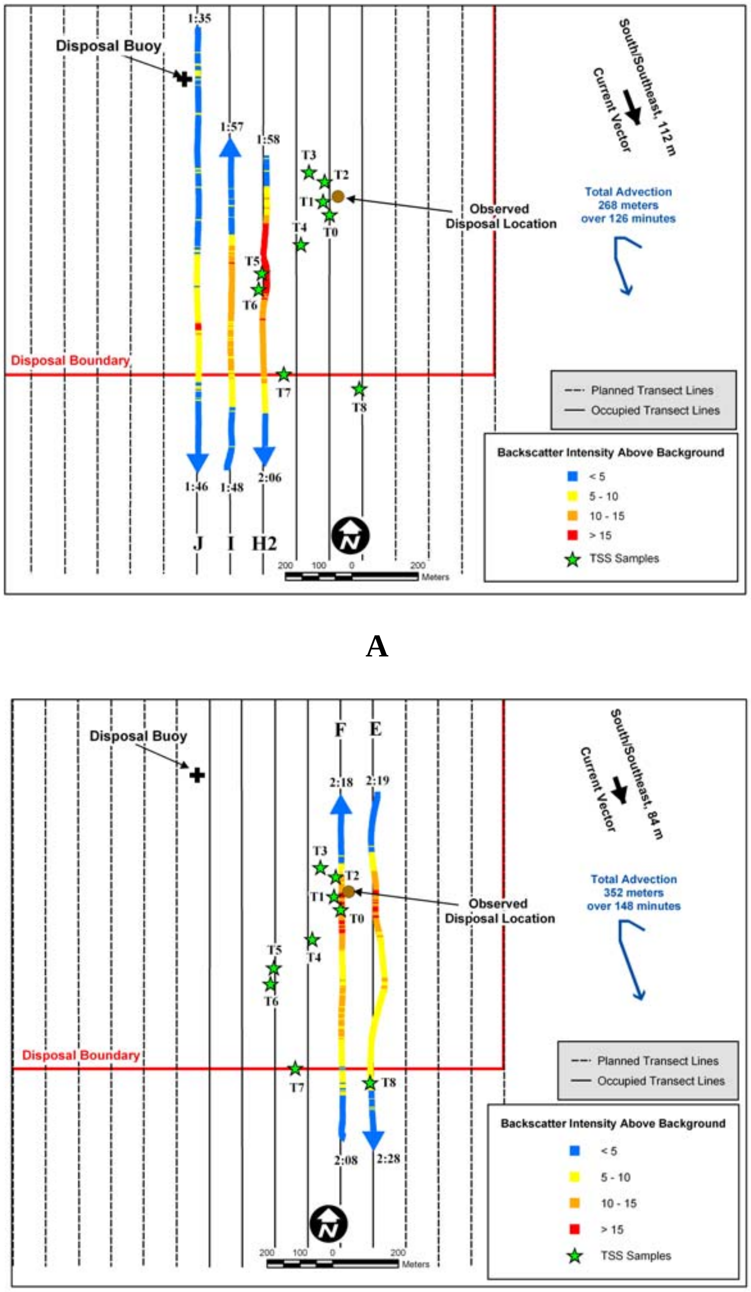


Figure 4-10. Residual acoustic backscatter intensity values from the 32 m depth interval representing suspended sediment concentrations along individual survey lines occupied during the Plume 3 monitoring survey, 95 to 126 (A) and 128 to 148 (B) minutes after the disposal event.

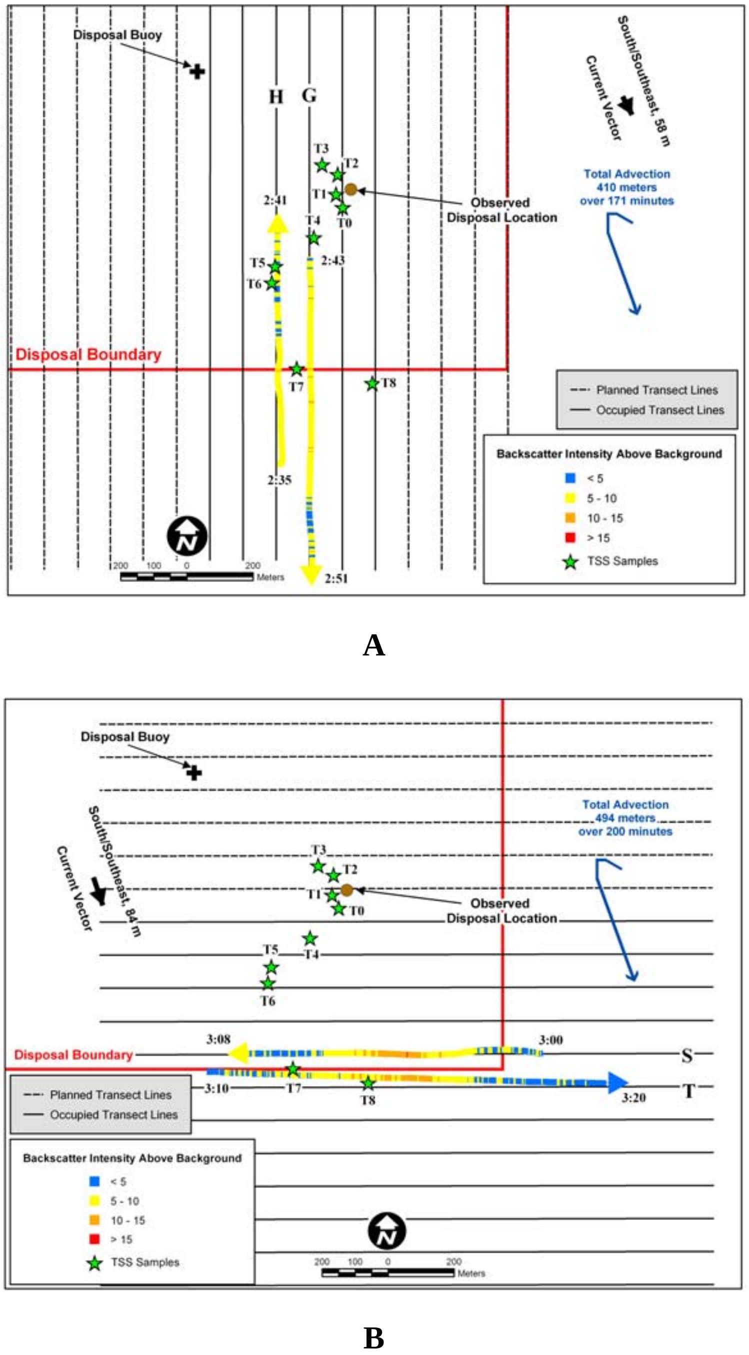


Figure 4-11. Residual acoustic backscatter intensity values from the 32 m depth interval representing suspended sediment concentrations along individual survey lines occupied during the Plume 3 monitoring survey, 155 to 171 (A) and 180 to 200 (B) minutes after the disposal event.

starting from initial time of disposal, and 4) locations of both TSS and toxicity water samples.

During the early stages of the survey (first 40 minutes), the near-bottom element of the sediment plume displayed gradual transport to the west and northwest, remaining within 200 m of the observed disposal point (Figures 4-8A and B). Water samples from the T1 through T3 sample intervals collected within the same 200 m radius from the disposal point were thus acquired in close proximity to the plume centroid. Figure 4-8A illustrates that the near-bottom portion of the sediment plume (at 32 m depth) possessed the highest backscatter intensity above background levels immediately surrounding the observed disposal point approximately five minutes post-placement. Similar residual backscatter intensities were documented 100 m down-current (to the northwest) ten minutes post-placement, along Line R.

Based on the moored current meter data, the water mass and initial sediment plume moved approximately 63 m to the northwest during the first 21 minutes of the survey, yielding an average transport rate of 5 $cm \cdot s^{-1}$. The T1 transmissometer profile and water samples were obtained 50 m southwest of the observed disposal point in an area with a significant amount of suspended particulate matter (which was confirmed by the vessel-mounted ADCP backscatter data). The average TSS value of 49 $mg \cdot L^{-1}$ ten minutes post-placement suggests that the profile and water sample were likely collected in an area of elevated turbidity, but just outside the tightly constrained core of the sediment plume (Figures 3-49 and 4-8A). The T2 transmissometer profile and TSS sample were obtained approximately 75 m northwest of the observed disposal point 23 minutes post-placement and yielded a higher average TSS value of 58 $mg \cdot L^{-1}$ at a depth of 24 m, indicating the T2 profile was successful in locating the plume centroid within the water column.

Between the T2 and T3 sample intervals, additional ADCP survey lines were completed to the northwest of Disposal Point D (Figure 4-8B). The location of the residual backscatter intensities within these lines indicated that the transport of the near-bottom element of the sediment plume had diminished, with the bulk of the suspended sediment at the 32 m depth level remaining within a 200 m radius northwest of the observed disposal point. The T3 water sample was obtained approximately 125 m northwest of the observed disposal point (50 m to the northwest of the T2 sampling location) from a water depth of 35 m, but yielded a relatively low average TSS value of 16.8 $mg \cdot L^{-1}$ (Figure 3-50). At the time of the survey, this rapid decline in suspended sediment concentrations served as an indicator that the centroid of the plume was moving in a direction other than northwest.

The third occupation of Line R, located 100 m northwest of the observed disposal point, was the final survey line run in a northeast-southwest orientation (Figure 4-9A). The acoustic backscatter acquired over Line R 60 minutes post-placement suggested that ambient currents were now transporting the most turbid portion of the sediment plume to the west and southwest. The data from the bottom mounted ADCP later confirmed a counter-clockwise rotation in the near-bottom currents and a change in direction of plume transport beginning at approximately 17:50 UTC (34 minutes post-placement; Figure 3-43). Over the 62 minutes that had elapsed between the disposal event and the third occupation of Line R, total transport distance of the plume centroid was calculated as only 111 m due to weak near-bottom currents. However, it was determined that the counter-clockwise rotation of these currents in response to the change in tidal phase resulted in the net change in location of the centroid of approximately 75 m to the west.

In an effort to reacquire the centroid of the sediment plume, the T4 profile and water sample were obtained 200 m southwest of the observed disposal location (Figure 4-9A). The transmissometer profile obtained as part of the T4 sample interval displayed a minimum value of 8%, which indicated a moderate increase in suspended sediment concentrations near bottom vs. those observed at T3. However, the same profile also indicated a substantial decrease in suspended material concentrations at mid-depth relative to the T3 profile, which may have been associated with differences in the rate or direction of transport between mid-water column and near bottom (Figure 3-50). The T4 water sample for TSS was collected from a depth of 33.5 m 73 minutes post-placement and displayed an average suspended sediment concentration of 26 $\mathrm{mg \cdot L^{-1}}$. The acoustic data collected along north-south Lines G and H indicated that more turbid water existed 100 m to the north and 100 m to the west of the T4 sample location at the time the TSS sample was obtained (Figure 4-9B). The increase in suspended sediment suggested the T4 sample was obtained closer to the core of the plume, in comparison to T3, but the moderate TSS value suggested that the T4 profile and water sample were likely acquired prior to the arrival of the centroid.

Between the T4 and T5 sample intervals, the near-bottom water mass continued to display current velocities of 5 $\mathrm{cm \cdot s^{-1}}$, yielding a calculated transport distance of 54 m to the south over the 13 minutes that elapsed. The T5 profile and water sample were collected approximately 120 m southwest of the T4 sample location. The acoustic data collected along Line H just prior to the T5 sample indicated an area of turbid water displaying residual backscatter values in excess of 15 counts was present to the north of the T5 sample location (Figure 4-9B). This plume feature was approximately 300 m wide along the north-south axis, but the CTD profile and water sample were apparently obtained less than 50 m from this area of elevated turbidity. As result, the TSS sample (20.4 $\mathrm{mg \cdot L^{-1}}$) and transmissometer profile (11% minimum transmittance) likely characterized the margin of this feature and were not representative of the plume centroid.

Following the T5 sample interval, near-bottom currents displayed a more southeasterly flow, but remained quite weak with velocities of 6 to 7 $\mathrm{cm \cdot s^{-1}}$ common throughout the remainder of the survey period (Figures 3-44). The residual backscatter data collected with the vessel mounted ADCP between the T5 and T6 sample intervals indicated the extents of the sediment plume generally remained 500 to 600 m southwest of the observed disposal location before the southeasterly flow began to influence overall transport (Figure 4-10A). Total transport of the centroid was calculated as 268 m over the two-hour period following the disposal event. But due to the variability in the direction of flow, the net transport of the sediment plume was approximately 175 m to the south-southwest.

The T6 profile and water sample were obtained less than 50 m south of the T5 location, in an effort to re-occupy the centroid following 26 minutes of transport to the south-southeast. The transmissometer profile for the T6 sample interval displayed strong similarities to that of the T5 interval, with the majority of the turbidity in the water column existing at a depth of 32 m (approximately 3 m above the seafloor; Figure 3-51). However, the T6 transmissometer profile indicated water with slightly higher turbidity existed 0.5 m deeper in the water column (9% transmittance), but it likely existed in finite layers or as pulses of seawater with elevated turbidity passing by the instrument. A water sample with an average TSS value of 14.5 $mg \cdot L^{-1}$ was collected from a depth of 32 m at a point where light transmission values were approximately 17%. These data indicate near-bottom turbidity was lower than that of the T5 sample interval, suggesting the centroid of the plume had not reached the T6 sample location despite the 26 m of elapsed time.

The acoustic backscatter data collected during the third hour of the survey indicated that the near-bottom element of the sediment plume became broad, diffuse and less defined, essentially lingering within the southeast quadrant of RISDS for the remainder of the survey. This finding was supported by the moored OBS data, which displayed a substantial increase in near-bottom turbidity 105 minutes after the disposal event followed by a period of elevated turbidity conditions over two hours in duration (Figure 3-62). Residual backscatter data that were collected along north-south Lines F and E between the T6 (120-minute) and T7 (150-minute) sample intervals indicated the presence of suspended particulates in the southeast quadrant of the disposal site, with the most concentrated areas (15 counts) identified within a 100 m radius of the observed disposal location (Figure 4-10B). Estimates of advection based on near-bottom current velocities between the T6 and T7 sample intervals suggest the core of the sediment plume was transported 84 to 100 m to the south-southeast within the 37 minutes elapsed time.

The T7 transmissometer profile and water sample were collected 300 m south-southeast of the T6 profile from a location along the southern boarder of RISDS. This location was selected based on the anticipated path of the plume given the track of the current-following drogues. The transmissometer data indicated light transmittance values were lower in comparison to background, indicative of a small-scale increase in suspended particulates (Figure 3-52). Small vertical-scale deflections in the transmissometer record provided evidence of independent layers of turbid water existing at mid depth, with the bulk of the turbidity detected near-bottom. The T7 water sample was captured at a depth of nearly 33 m, but displayed an averaged TSS value of only 8.7 $mg \cdot L^{-1}$, approaching the background TSS value of 7.5 $mg \cdot L^{-1}$. Acoustic survey lines completed in the vicinity of this sampling location immediately following the T7 sample interval indicated the broad scale presence of plume sediments in the water column (Figure 4-11A). However, the residual backscatter values 5 to 10 counts above background indicated the data from the T7 interval were representative of conditions within the majority of the large-scale sediment plume, but not necessarily the plume centroid.

The T8 transmissometer profile and TSS water samples were collected 203 minutes after the disposal event from a location that was 300 m southeast of the T7 sampling location and 600 m due south of the observed disposal location. The ADCP backscatter data collected along east-west Lines S and T several minutes prior to the T8 sampling event suggested that turbid water with residual backscatter values approaching 15 counts existed along the seafloor just beyond the southern disposal site boundary (Figure 4-11B). The transmissometer profile for T8 was similar to that of the T7 sampling event, but displayed a lower light transmission value at depth (16.5%; Figure 3-52). The average TSS value for the T8 water samples indicated near-bottom turbidity was nearly 28 $mg \cdot L^{-1}$, and higher than the TSS values for all samples obtained between the T3 and T7 sample intervals (Table 3-7).

Given the slow rate of horizontal transport during the Plume 3 survey, near-bottom currents that existed at RISDS following the 3 September disposal event transported the centroid of the plume a total of 500 m over the course of 203 minutes. Due to the counter-clockwise rotation in the direction of flow, net advection for the densest portion of the sediment plume was estimated at 400 m south of the observed disposal point. The recorded position of the T8 samples was 600 m south of the disposal point; therefore, the T8 transmissometer profile and TSS results were likely characteristic of the leading edge of the broad and diffuse sediment plume. Based on the data collected in prior survey efforts, it was theorized that the absolute centroid of the sediment plume would have been observed approximately 150 m farther to the north at 200 minutes post-placement. But given the broad and diffuse nature of this sediment plume, the centroid may not have displayed TSS value markedly different from those documented in the T8 profile.

5 DISCUSSION

This report documents the second of two comprehensive sediment plume monitoring studies performed within RISDS in association with the placement of material generated by the Providence River and Harbor Maintenance Dredging Project. The first plume monitoring survey was conducted in April 2004 to evaluate the morphology, suspended sediment concentrations, and acute toxicity associated with three disposal plumes formed by the placement of sediments dredged from the Sabin Point Reach (SAIC 2005). The more recent survey consisted of the same monitoring goals and techniques, but focused on sediment plumes formed by the disposal of sediment dredged from the upper Fuller Rock Reach of the Providence River federal navigation channel.

5.1 Accomplishment of Study Objectives

The primary objectives of the September 2004 study were to track the extent and concentration of the disposal plume generated during three separate disposal events at RISDS during the placement of smaller volumes (2,300 m^3) of sediment than those monitored in April (3,200 to 4,600 m^3), 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 the upper Fuller Rock Reach were investigated. This sediment was characteristic of most maintenance material, composed primarily of high water content, unconsolidated estuarine silts and clays. However, concerns related to the results of suspended/liquid phase toxicity testing of the in-place sediments from this reach prior to dredging prompted some concern in the federal regulatory community regarding impacts to water quality within RISDS upon disposal.

The sediments tracked during the September 2004 study were deemed suitable for unconfined open water disposal with a stipulation that individual disposal events be restricted to 2,300 m^3 or less. This material was mechanically dredged with a closed 26 yd^3 (20 m^3) clamshell bucket, transported to RISDS via 4,600 m^3-capacity split-hull disposal barges, and placed on the seafloor as a single deposit. Based on the results of the April 2004 plume study, it was theorized that the disposal of a partially filled 4,600 m^3 disposal barge would result in a more dilute plume upon its initial formation in comparison to the use of a fully loaded 3,050 m^3 barge (SAIC 2005). The generation of a less concentrated sediment plume would reduce the impacts to the water column with regards to turbidity, as well as minimize the potential for toxic response by water column organisms interacting with the sediment plume.

Similar to the April 2004 study, all study objectives were accomplished within three sequential days of field sampling. 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.

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). Much of the history pertaining to investigations of sediment plumes conducted under DAMOS has been summarized in DAMOS Contribution 166 (SAIC 2005). The results of both the April and September 2004 surveys have reinforced the findings of prior studies, indicating the cloud of turbidity that comprised each sediment plume generally existed in the water column for several hours. Each sediment plume tended to broaden and diffuse as the turbid water was advected from the point of disposal by ambient water column currents.

The results of the September 2004 survey were generally consistent with those obtained during the April 2004 survey effort, with some minor differences noted when directly comparing the results of the two survey efforts. In both surveys, the most turbid conditions were detected within the tightly constrained plume centroid during the first 20 minutes of each plume monitoring survey. Although a reduction in suspended particulate matter was documented within each survey, each sediment plume remained a distinct feature in the water column and remained detectable in both the underway acoustic backscatter transect data and the transmissometer profile data for the entire survey period. Despite the increased concern regarding the quality of the material dredged from the upper Fuller Rock Reach of the Providence River federal navigation channel, toxicity within the water obtained in proximity of the centroid was not an issue within any of the samples collected during two plume surveys of the September 2004 monitoring study.

In September 2004, the water samples collected within the three plumes during the first 20 minutes following disposal yielded TSS concentrations that ranged from 35 to 112 $mg \cdot L^{-1}$; a range that was generally higher than those documented in April 2004 (23 to 64 $mg\ L^{-1}$; SAIC 2005). The findings of the three plume monitoring efforts performed in September 2004 indicated that suspended sediment concentrations within each plume decreased substantially within 60 minutes of the disposal event via a combination of particle settlement and diffusion (plume decay), exhibiting TSS values of 30 mg L^{-1} or less near the centroid of each plume (Figure 5-1). With the exception of Plume 3, TSS concentrations were below 10 mg L^{-1} in proximity of the centroid within three hours. The dashed blue and yellow lines on Figure 5-1 represent the inferred change in average TSS concentrations within the plume centroid between the T2 and the T4 samples for Plumes 1 and 3, as well as the T4 and T8 samples for Plume 3. Each line represents the likely concentrations of suspended sediment within the centroid of the plumes during that elapsed period of time (T2 to T4 - 40 minutes; T4 to T8 – 150 minutes). It is highly probable that the relatively low TSS values obtained at 40 minutes for both Plumes 1 and 3 were associated with water samples collected outside of the plume centroid containing the maximum TSS concentration. The higher TSS concentrations at 60 minutes for both of these plumes confirms spatial sampling problems for the 40-minutes samples, as the near-bottom plumes would not be capable of TSS enhancement at this late stage in the plume evolution.

In agreement with the general findings of the April 2004 survey, the September 2004 data supported the finding that distance, direction, and rate of plume transport was highly dependent upon the characteristics of the water column currents over the dredged material disposal site at the time of the disposal event. Despite the smaller volumes of material disposed in September versus April, each plume monitored in September existed as a concentrated column of turbidity that occupied the water column at the location where the disposal barge was opened during the early stages of each monitoring event. This column of turbid water was then advected by ambient currents acting within the various depth levels of the water column. The actual morphology of each sediment plume was primarily a function of vertical current shear, or the differences in the speed and direction of water movement between the various depth levels within the water column.

The April 2004 effort was conducted during flood tides such that the sediment plumes were transported to the west or northwest in response to the water column currents. In contrast, the sediment plumes monitored during the September 2004 surveys were transported in a variety of directions (Plume 1 - southeastward; Plume 2 - westward, and Plume 3 – variable/southward) based upon the stage of the ebb tide at which the disposal events occurred. Figure 5-2 illustrates the locations of water samples collected during monitoring operations for all three plumes in September 2004. Although this figure does not present the exact location and boundary of the plumes sampled, it does give a general indication of plume transport as multiple surveying techniques were used to direct the water sampling operations at, or near the centroid of each plume at the specific sampling time. Thus, the water sampling positions indicate the general direction of plume transport during the 3.5-hr sampling period for each plume surveyed.

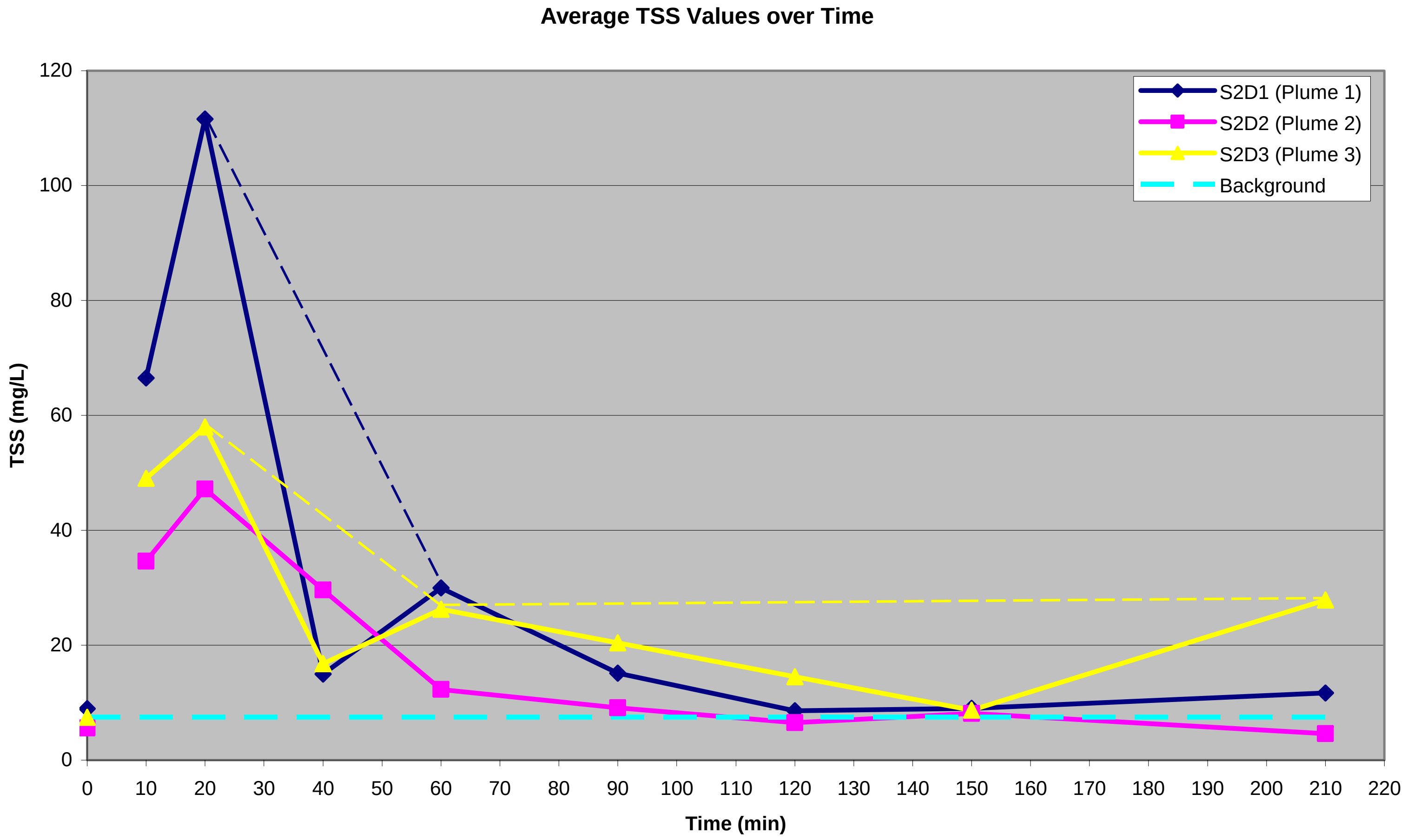


Figure 5-1. Plot of total suspended solids (TSS) concentration versus time since disposal for discrete water samples collected during CTD profiling operations of the RISDS plume monitoring in September 2004.

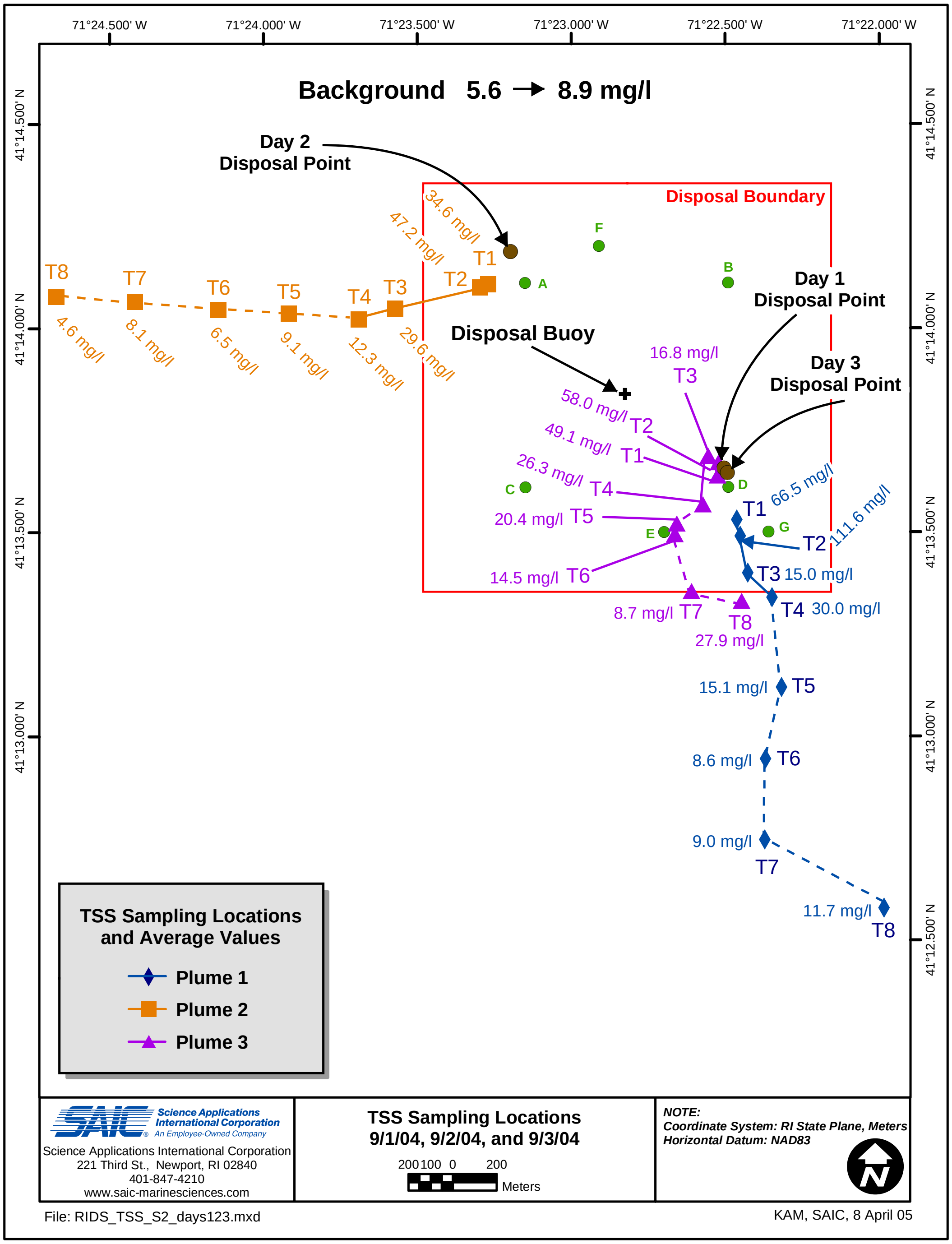


Figure 5-2. Graphic displaying the various positions of the centroid and direction of transport of the three sediment plumes tracked during the September 2004 plume monitoring survey relative to RISDS boundaries.

As Figures 3-4, 3-23, and 3-43 indicate, the September 2004 plume tracking surveys were conducted at different phases of ebb tide, resulting in different rates and directions of plume transport. The bottom-mounted ADCP records indicated that currents display a westerly flow direction during the later stages of the flood tide (and early ebb) as observed during Plume 2 monitoring. As the ebb progressed, currents rotated counter-clockwise to flow southwest and south during the middle stages of the ebb (Plume 3). As water levels at the site continued to decrease in response to the ebb tide, water column currents became southeasterly and the flow more coherent (Plume 1). As anticipated, total transport distances within the 3.5 to 4 hour survey windows were highly dependent on the timing of disposal versus the stage of the tide, with total plume transport distances ranging from 600 m to 2.1 km.

As with the April 2004 study, all three September 2004 plume monitoring surveys were relatively equal in duration, such that the observed total transport distances of the plumes were solely a function of current velocities and consistency in flow within the water column post–placement. The distances for Plume 1 and Plume 2 were quite comparable (2 km and 2.1 km, respectively) despite the difference in direction of transport (westerly versus southeast; Figure 5-2). The results from the Plume 3 survey indicated that the majority of the plume, which was formed by a disposal event approximately one hour into the ebb tide, lingered within the southeast quadrant of RISDS for an extended period (>2 hours) before being transported beyond the boundaries of the disposal site.

Overall, the results of the Plume 3 survey differed from those generated from Plumes 1 and 2 in September 2004. Inter-comparison between the plumes indicated the concentration of entrained sediment observed during the early stages of the Plume 3 survey were analogous to Plume 1 and Plume 2, but Plume 3 did not display the same rate of plume decay over time. Turbidity levels remained relatively high throughout the Plume 3 survey, displaying an average TSS value slightly below 30 $mg \cdot L^{-1}$ 210 minutes post-placement (Figures 5-1 and 5-2). The primary explanation for the differences in plume characteristics in the latter stages of Plume 3 could be linked to the differences in current velocities (transport rate) and a reduction in the volume of ambient seawater mixed into the sediment plume. The decreased influx of low-turbidity seawater likely resulted in reduced mixing following the formation of Plume 3. This allowed near-bottom turbidity levels to remain elevated for an extended period of time in comparison to Plumes 1 and 2. Based on the data collected as part of the Plume 2 survey regarding current flow in the late stages of the ebb tide over RISDS, near-bottom current velocities would have likely increased to 10 to 12 $cm \cdot s^{-1}$ approximately 30 minutes following the conclusion of the Plume 3 survey. The increase in flow to the southeast would have served to provide a sufficient volume (mixing zone) of seawater to rapidly dissipate the remnants of the sediment plume.

The analysis of the results generated as part of the April 2004 plume monitoring surveys identified a disparity between suspended sediment concentrations predicted by the STFATE modeling results for sediment plumes formed over RISDS after the deposition of 4,600 m^3 of dredged material in comparison to observations (SAIC 2005). The TSS observations during the first 90 minutes of each plume monitoring survey performed in April 2004 were approximately 10% of those predicted by STFATE. The major difference between model predictions and observations were attributed to the tendency of STFATE to over-predict the impacts of disposal activity within the water column.

Based on information included within the Final Environmental Impact Statement for the Providence River and Harbor Maintenance project, it was theorized that the smaller load volume of dredged material (2,300 m^3 per disposal event) placed at RISDS during the September 2004 survey period would result in a sediment plume with TSS concentrations of approximately 250 $mg \cdot L^{-1}$ within the plume centroid 30 minutes post-placement. Suspended sediment concentrations were predicted to rapidly decrease to 65 $mg\ L^{-1}$ 60 minutes post-placement, then decrease again to approximately 7.5 $mg \cdot L^{-1}$ 120 minutes post-placement before returning to near background conditions (3 to 5 $mg\ L^{-1}$) 2.5 to 3 hours following each disposal event. Figure 5-3 presents these model predictions superimposed with the observed temporal evolution of TSS concentrations for the three plumes monitored in September 2004. The TSS concentrations observed at, or near the centroid during the first 60 minutes of each plume monitoring survey performed in September 2004 were less than 50% of those predicted by STFATE. However, the observed TSS concentrations in the later stages of the survey (>2 hours) appear to better align with the model predictions, with some observed turbidity values actually exceeding predictions (Figure 5-3).

5.2 Characteristics of Dredged Material Disposed and Tracked

The April 2004 study suggested that a correlation existed between the dimensions of the disposal barge employed to deposit dredged material at the open water disposal site and the morphology of the resulting sediment plume (SAIC 2005). It appeared that larger barges promoted the formation of a more dilute plume at the time of disposal by discharging the sediment into a larger volume of water (e.g., a function of the footprint of the barge). The deposition of sediment from smaller barges was expected to form a sediment plume relatively constrained in areal size, but more concentrated than those formed by larger volume disposal barges. As a result, it was recommended that disposal barges with a relatively large footprint be utilized for the open water placement of dredged material to address regulatory concerns with regard to short-term impacts to water quality.

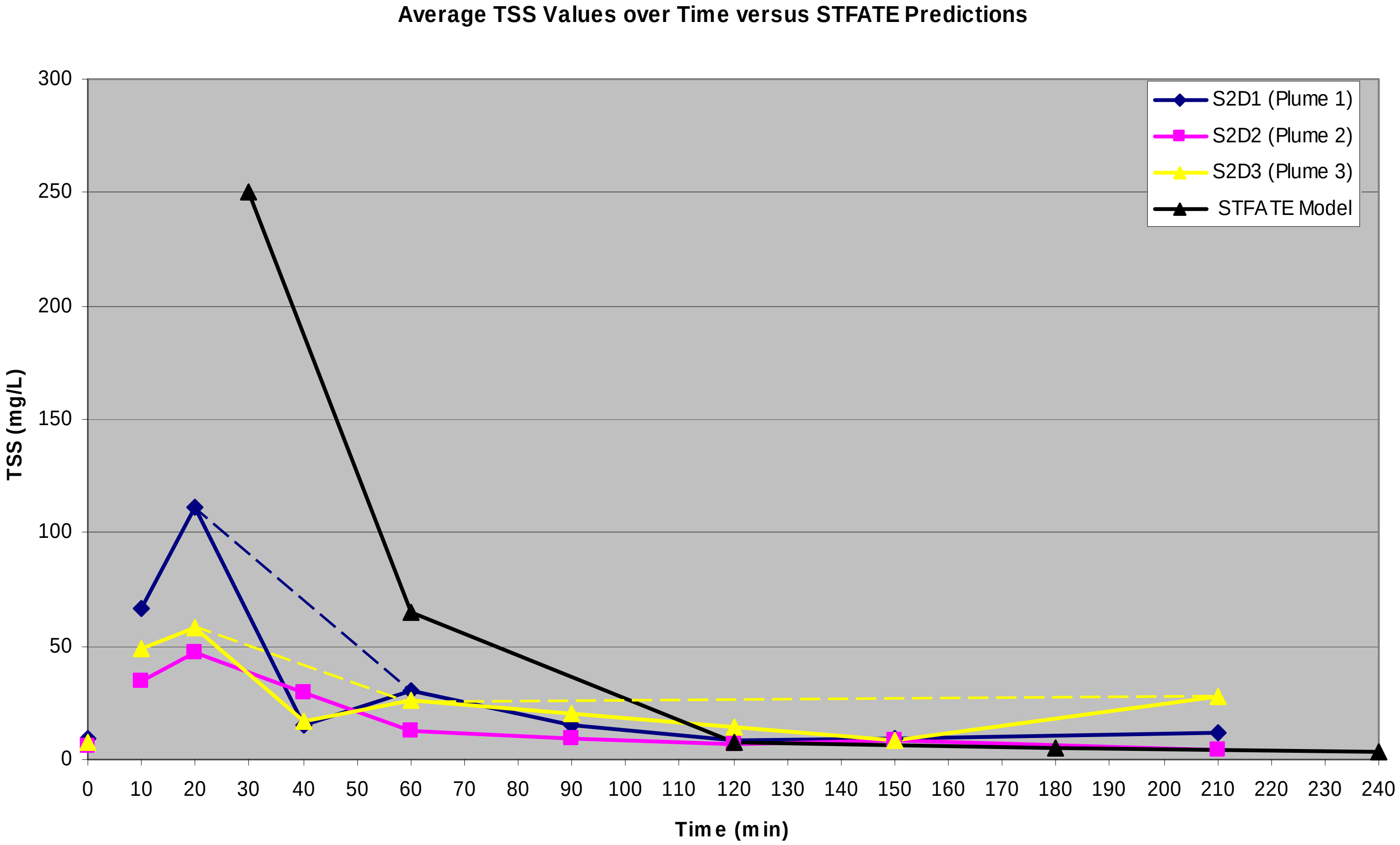


Figure 5-3. Plot of total suspended solids (TSS) concentration versus time for discrete water samples collected during CTD profiling operations for RISDS plume monitoring in comparison to TSS concentrations predicted for the disposal of 2,300 m³ of material dredged from the Providence River (USACE 2001).

All of the sediment plumes tracked during the September 2004 plume monitoring survey consisted of maintenance material removed from the upper Fuller Rock Reach. The composition of the material was quite similar among the three loads and consisted primarily of silt and clay, with a high water content, in excess of 200% (Table 3-2). The plume morphology and concentration of entrained sediment observed during the early stages of the Plume 2 and Plume 3 surveys were quite similar, while the concentration of sediment detected at, or near the Plume 1 centroid was substantially higher (Figure 5-3). Given the similarities in material type, barge dimensions, and sea conditions, the differences in the suspended sediment concentrations may have been attributable to the ability to identify and sample the exact centroid of Plume 1. The sampling performed during the early stages of Plumes 2 and 3 provided samples from the core of the sediment plume, but likely missed the tightly-constrained centroid, yielding lower average TSS values in the first 40 minutes of the individual surveys.

Comparisons between the TSS results from the September 2004 and April 2004 plume monitoring surveys indicated that plume turbidity measured in September was generally higher than that observed in April (Figure 5-4). For the disposal events employing a 4,600 m^3 barge, the discrete water samples collected during the three events in September 2004 study (blue) were consistently higher than those obtained for the two events monitored in April 2004 (pink). The turbidity values observed during the early stages of September 2004 - Plume 1 exceeded those of any other monitoring survey of the RISDS studies. The results for September 2004 - Plumes 2 and 3 were lower, but remained comparable to the turbidity detected in April 2004 following the disposal of 3,200 m^3 of material by a 3,050 m^3 barge (yellow; Figure 5-4). Consequently, these results indicate that barge volume and dredged material volume were not the primary factors governing TSS concentrations in plumes generated from disposal at RISDS. While they had an effect on plume characteristics, other factors may have been more significant as discussed below.

The observed differences in the turbidity levels detected within plumes during the September 2004 and April 2004 studies were most likely attributed to a combination of four factors: physical characteristics of the dredged material; seawater properties; efficiency of locating and sampling within the centroid of the disposal plume; and/or the sampling design and procedures for collection of the discrete water samples. Regarding this last factor, it is important to note that, because a single 5-L water sample was collected at each sampling event (at the instant when the CTD/carousel sampler was positioned at the depth of highest observed turbidity for that vertical profile), this means that replicate water samples were not collected. Rather, triplicate samples were drawn from the single Niskin sample and processed for TSS analysis.

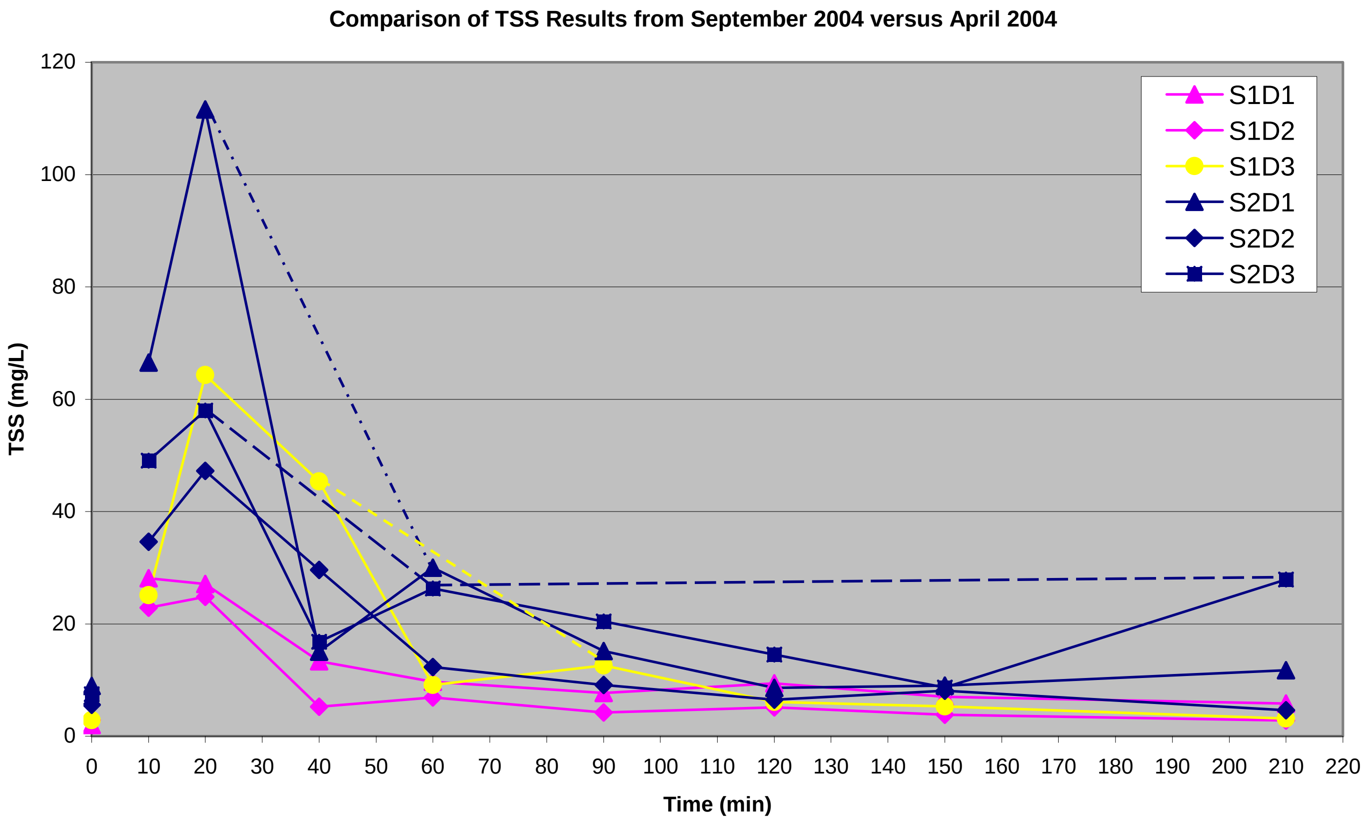


Figure 5-4. Comparison plot of total suspended solids (TSS) concentration versus time for discrete water samples collected during the September 2004 (blue) and April 2004 (pink/yellow) plume monitoring studies performed over RISDS. The yellow line represents the TSS concentrations measured following the placement of 3,200 m³ of dredged material by a 3,050 m³ barge.

The grain size distribution of the sediment in both studies was similar, with the dredged material in the barges primarily comprised of high water content (>200%), fine-grained sediment. However, minor differences in grain size were noted in these data sets, as the sediment dredged from the upper Fuller Rock Reach in September displayed a slightly lower percentage of sand and a slightly higher percentage of silt and clay in comparison to the sediments removed from Sabin Point in April. The resulting net increase in the fine-grained component could have contributed to higher localized turbidity during the first hour of each survey despite the reduced disposal volume (2,300 m^3 in September versus 4,600 m^3 in April).

Although described in detail within Section 5.3, the physical properties and movement of the water mass over RISDS was quite different between the September and April surveys. In April, the water column reflected late-winter to early spring conditions with cold (3.6 to 3.4°C), dense (26.02 to 26.06 sigma-t) water residing over RISDS. A slight pycnocline existed within the water column primarily due to vertical gradients in temperature, but stratification was generally weak. In September, mid-summer conditions were in place with warmer (21.0 to 12.1°C), less dense (21.7 to 24.2 sigma-t) seawater residing over the disposal site. Water temperatures decreased with depth and density was closely correlated with temperature. Distinct pycnoclines were observed within the density profile and corresponded to the depths of the strong temperature stratification. The presence of strong pycnoclines in the water column may have factored into the mechanics associated with particle settlement and the subsequent development of the plume centroid. Although the speed and direction of current flow was different in September in comparison to April, these parameters appeared to have more of an impact on turbidity and plume morphology over the long-term and likely had no major influence during the initial formation of the plume.

The final factor pertaining to the apparent increase in turbidity during the early stages of the September surveys may be related to the increase in the efficiency of sampling operations. The sheer repetition of the survey operations may have improved the ability of the sampling crew and vessel operators to rapidly identify the core of the plume in the water column and sample the centroid with the Carousel sampling device. The net result was somewhat better vessel positioning at the T1 (10 minute) sampling event, although the small horizontal scales of the plume early in its formation certainly poses a challenge to vertical sampling operations. Twenty minutes after the disposal event (at T2) the plume was considerably larger and sampling operations appear to have been effective at hitting the centroid for all plumes sampled in September (Figure 5-3). Curiously, the T3 sampling interval (at 40 minutes) was again problematic with regard to positioning of the vessel above the plume centroid. This is most likely because the direction of near-bottom plume transport during the first hour of sampling operations was not well understood for

Plumes 1 and 3 of the September survey, as the currents rotated southward during the late stages of the ebb flow.

5.3 Characteristics of the Receiving Water at RISDS

Previous studies have shown that the size, configuration (split-hull versus pocket-type), footprint, and speed of the barge during disposal influence the initial formation of a sediment plume (SAIC 2005; SAIC 2004b). However, water column currents and the physical properties of the receiving 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 during the September 2004 plume study exhibited flow to the west, south, and southeast during the three 3.5-hour surveys conducted at RISDS due to the influences of an ebb tide. The direction and velocity of flow varied greatly depending upon which part of the ebb phase was encountered. During Plume 1 sampling, currents throughout the water column generally flowed in the same direction, without significant vertical shear, but during Plumes 2 and 3, considerable shear in current speed and direction was encountered, thus creating divergence of plume elements residing at different levels in the water column.

The background TSS concentrations measured in September (5.6 to 8.9 $\mathrm{mg \cdot L^{-1}}$) were higher than those documented in April 2004 (2.0 to 2.9 $\mathrm{mg \cdot L^{-1}}$), which could be attributed to the September receiving water mass having moved into the survey area from nearby coastal estuaries rather than from the continental shelf, or it could have been associated with an increased phyto- and zooplankton abundance in the warmer waters of late summer. The elevated background turbidities in September could also have been the result of residual plume material from disposal events that had preceded the water sampling operations, but this hypothesis would be valid only if the plumes generated in September were able to persist and reside in the vicinity of RISDS longer than plumes generated in April.

Prior to the start of the Plume 3 monitoring survey, an expanded-area CTD survey was conducted to assess background turbidity within and surrounding RISDS. Stations were occupied along lines extending up to 6 km to the east, west and north of RISDS boundaries (Figure 2-2). The transmissometer profiling results illustrated that near-bottom turbidities were significantly higher than the mid-depth background levels at nearly all stations, suggesting that a near-bottom turbid layer existed throughout the general region of RISDS on 3 September 2004. Additionally, even higher turbidities were observed in the lower 5 m of the water column at two stations, each situated 2 km from the site boundaries (one west and one south). One could speculate that this turbid layer was a remnant of the repeated disposal of dredged material at RISDS because its turbidity values approximated those observed within the near-bottom dredged material plumes within a few hours after disposal but, in the absence of laboratory-based analysis of the particulate characteristics of the suspended material, we cannot determine whether the lingering near-bottom turbidity was associated with dredged material or naturally occurring particulates (e.g., biological material or suspended bottom sediments) from the general vicinity of the RISDS.

The background CTD profile data collected prior to each disposal event revealed a significant pycnocline extending from roughly 10 m depth to the seafloor. A pronounced thermocline was governing the density stratification, as vertical salinity gradients were relatively small. Despite this resident pycnocline in September, there was no indication that the density stratification was trapping suspended sediments within the upper water column. Furthermore, the September survey results illustrated that, beyond one hour post-disposal, the only significant plume turbidity resided in the lower 10 m of the water column, in agreement with the April results when density stratification was much less pronounced (SAIC 2005).

Although the pycnocline in September 2004 was more pronounced than that observed in April, it had less effect on the underway acoustic backscatter data than was encountered in April. During the April survey, sharp vertical density gradients (microstructure) apparently acted as significant reflectors of the acoustic signal of the ADCP profiler, causing a false plume signature near mid-depth which had to be subtracted from the results in order to view actual plume characteristics. Despite the stronger pycnocline in September, it apparently lacked the microstructure to reflect much of the acoustic ADCP signal. Consequently, only a weak background signal at mid-depth in the water column needed to be subtracted from the raw backscatter data from September to allow focus on the plume characteristics.

Currents throughout the water column were considerably stronger in September (5 to 40 $cm \cdot s^{-1}$) than observed in April (15 to 25 $cm \cdot s^{-1}$) and they were governed by the semidiurnal tide, which was ebbing during all three plume surveys conducted in September. The vertical shear in horizontal currents also was strong in September, causing suspended sediments at different levels of the water column to diverge as time after disposal progressed. The underway acoustic backscatter profile data from the ADCP proved very useful for three-dimensional mapping of the transport and divergence of the plume at different levels in the water column. Although the current shear posed real-time challenges during location of the plume centroid, especially during the first half-hour after disposal when the plume had limited horizontal scales, the shear did not prevent accomplishment of the primary survey objective to track and collect samples from within the plume centroid for 3.5 hours following disposal.

A subtle but very important observation that was made during this plume study was the high turbidity contained within an annulus of water that spread outward, radially and rapidly along the seafloor, immediately after the dredged material impacted the seafloor during the descent phase. Monitoring the near-bottom current speed of this spreading annulus was a key monitoring objective of the Palos Verdes Pilot Cap Monitoring Program in 2000 (SAIC, 2002), because it was suspected to cause significant erosion of contaminated seafloor sediments. During that study, multiple near-bed observations were made within the annulus formed from individual hopper dredge disposal operations, and high current speeds and very high turbidity were documented. In the September 2004 study at RISDS, no near-bottom current measurements were made in close proximity to the disposal points but the optical backscatter (turbidity) data acquired near the seafloor by the moored OBS sensor revealed very high turbidities for very short durations shortly after disposal operations for Plumes 2 and 3 (Figures 3-39 and 3-62, respectively). Although the annulus contains extremely high turbidity and a pulse of strong horizontal currents, its horizontal scale, volume, and suspended sediment load are all small compared to the overall dimensions and suspended load of the primary dredged material plume (see schematic diagram in Figure 5-5).

5.4 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 changes in bottom topography by selectively distributing the sediment on the RISDS seafloor. 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 (formerly WES) provided recommended disposal points 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 sufficient 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 surveys on 1 to 3 September 2004 were conducted during different stages of the ebb tide over RISDS. As shown in Figure 5-2, disposal operations were directed to Point D for Plumes 1 and 3, and to Point A for Plume 2. Unfortunately, these were not optimal selections for disposal points because they were close to the segment of the RISDS boundary across which the near-bottom plumes were observed to transport. This indicates that more research must be done on the behavior of near-bottom currents at RISDS and subsequent modeling for prediction of plume transport if there is a future regulatory need to maximize the time that plumes reside within the site boundaries.

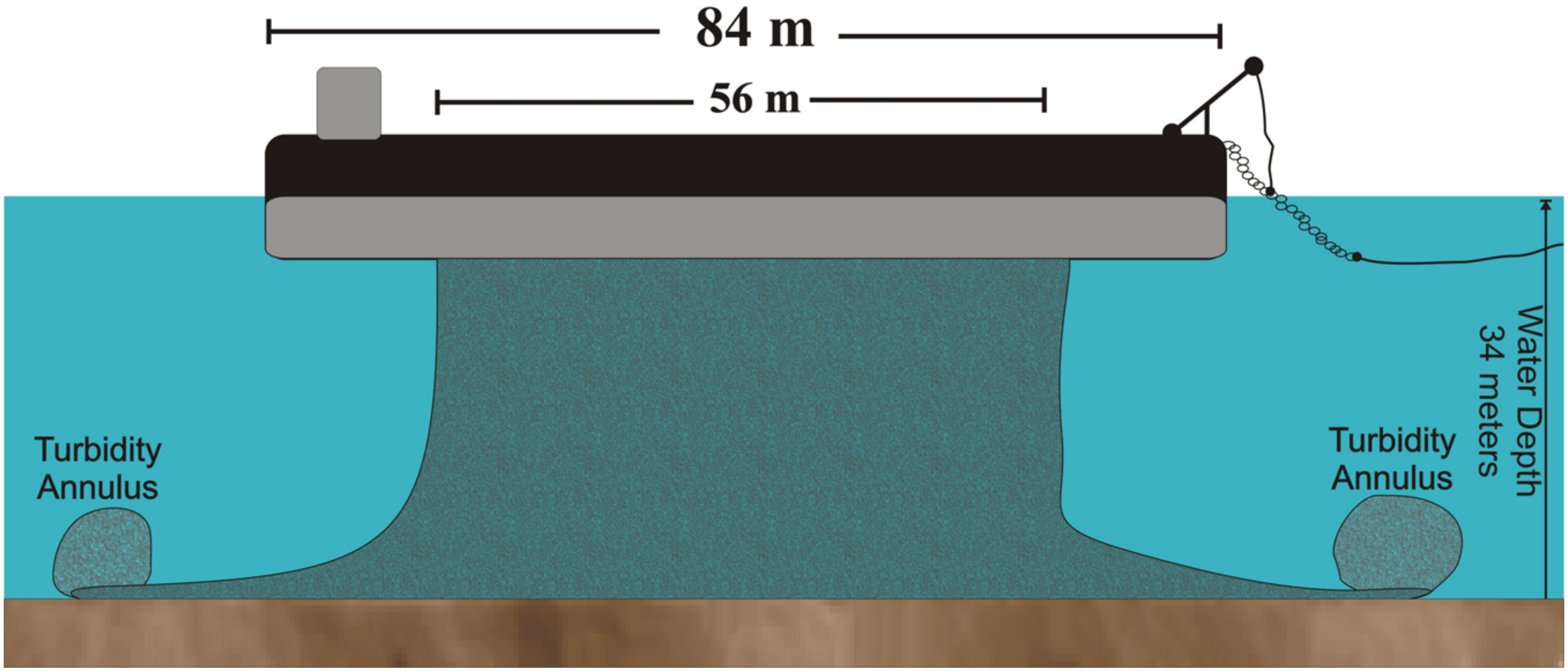


Figure 5-5. Schematic representation of a sediment plume formed over RISDS immediately following disposal displaying the column of turbid water created during the convective descent phase of disposal, as well as the annulus of turbidity generated in proximity to the seafloor during the translation of flow from the vertical plane to the horizontal plane.

5.5 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 amount of dilution that occurred within the water column during the formation of the sediment plumes and subsequent advection by ambient currents.

The chemistry results from the September 2004 barge sampling were compared to the pre-dredging sediment analyses from the most representative samples for the Fuller Rock reach of the river, which consisted of Samples G and H (Table 5-1). Bulk sediment chemistry data were available for stations G and H from 1992, 1993 (G and H composited together), and 1994 (top and bottom sections of cores analyzed for metals only).

Barge sample metal concentrations were all within the ranges of concentrations reported for the pre-dredging samples (right-most columns in Table 5-1 and Figure 5-6), with the exception of minor deviations for arsenic and mercury. Arsenic concentrations in the barge samples (14-16 mg/kg) slightly exceeded the two pre-dredge sample concentrations of 13 mg/kg. Mercury concentrations from the barge samples, 0.6 to 0.8 mg/kg, were slightly lower than the range detected in the pre-dredge samples, 0.74 to 0.86 mg/kg. All other metal concentrations of barge samples were within the pre-dredge concentration ranges.

In contrast to the metals comparison, the data pertaining to PAH compounds exhibited substantially lower concentrations in the barge samples than the pre-dredge samples from 1992, 1993, and 1994 for Stations G and H (Table 5-2, Figure 5-7). 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 and acenaphthylene were the only compounds for which the barge samples yielded a comparable concentration to the pre-dredge samples; in both cases the maximum barge sample concentration was the same as the minimum reported pre-dredge concentration. For the remaining PAHs for which pre-dredge data are available, the barge sample ranges of concentrations were lower than the pre-dredge ranges of concentrations, with barge sample means ranging from 26-85% of the pre-dredge means.

For the pre-dredge samples, many PAH concentrations were qualified “J” in Table 5-2, indicating that they were estimated values due to detected concentrations lower than the practical quantization limit (i.e., translating to 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

Table 5-1

Trace Metals Results of Fuller Rock Barge Samples, September 2004, and Comparison to Pre-Dredge Samples from Stations G and H

	Barge Sample Results			Pre-Dredge Sample Results							Pre-Dredge Summary	
				1992	1992	1993	Nov. 1994					
Metals (mg/kg)	**Min**	**Max**	**Mean**	**G**	**H**	**G/H**	**G-Top**	**G-Bottom**	**H-Top**	**H-Bottom**	**Min**	**Max**
Arsenic	14	16	15	13	13						13	13
Chromium	170	200	183	220	220	180	180	280	170	230	170	280
Copper	400	480	430	490	480	390	290	570	250	410	250	570
Lead	160	170	163	41	260	170	150	230	140	180	41	260
Mercury	0.6	0.8	0.7	0.8	0.74	0.86					0.74	0.86
Nickel	41	48	44	47	46		35	67	32	46	32	67
Zinc	300	350	323	360	370	310	300	490	260	360	260	490

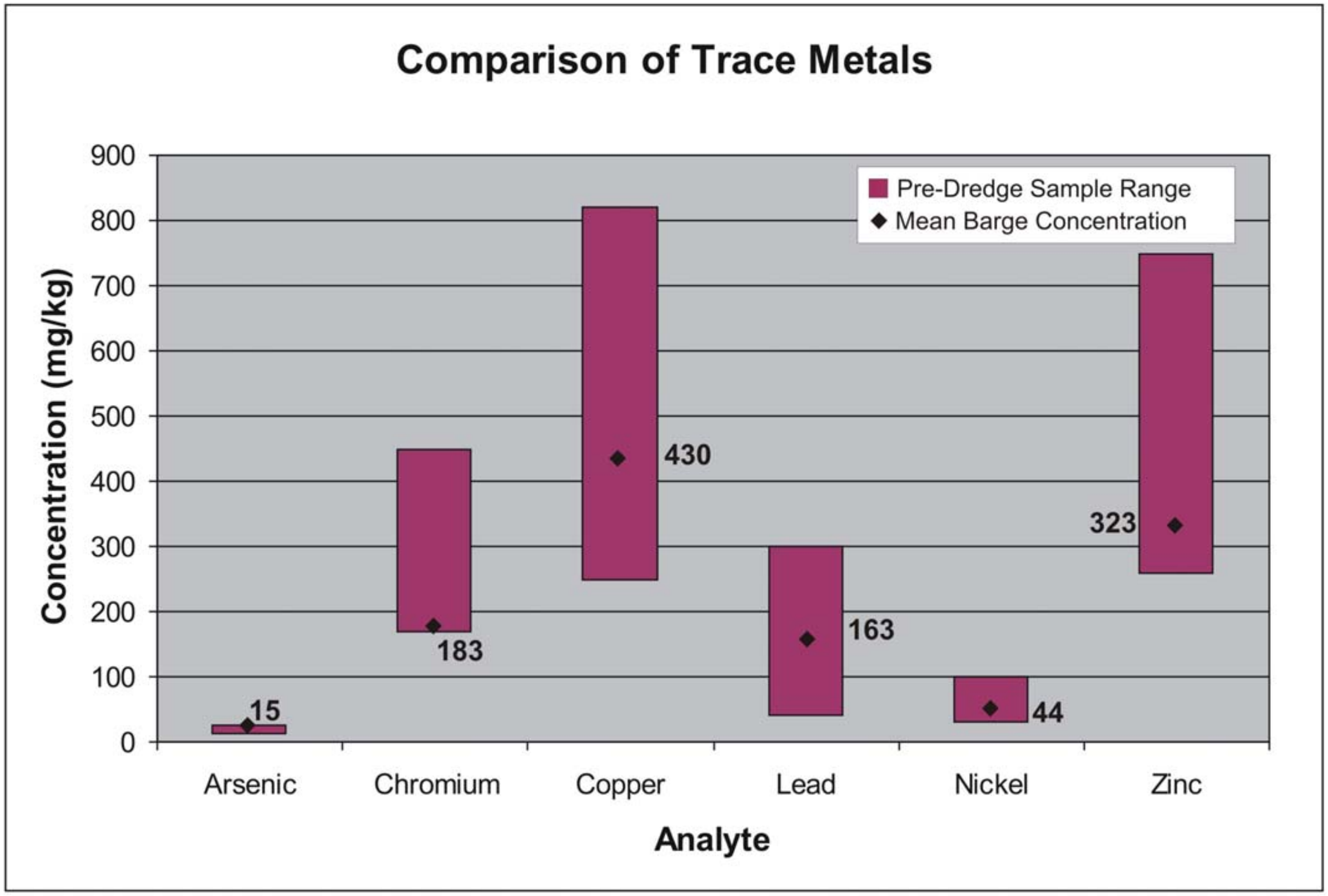


Figure 5-6. Chart showing the relationship between the mean concentration of trace metals in the September 2004 disposal barge samples to the range of concentrations detected in the 1992 and 1994 pre-dredge samples of in-place sediments within Fuller Rock Reach.

Table 5-2

PAH Results of Fuller Rock Barge Samples, September 2004, and Comparison to Pre-Dredge Samples from Stations G and H

	Barge Sample Results			Pre-Dredge Sample Results						Pre-Dredge Summary	
				1992		1992		1993			
PAHs (µg/kg)	Min	Max	Mean	G		H		G/H		Min	Max
Naphthalene	36.0	140.0	90.7	150	j	140	j	250		140	250
Acenaphthylene	25.0	62.0	48.7	77	j	62	j	130		62	130
Acenaphthene	ND	33.0	25.5	50	j	39	j			39	50
Fluorene	19.0	58.0	38.3	84	j	89	j	90	j	84	90
Phenanthrene	97.0	280.0	192.3	560	j	430	j	700		430	700
Anthracene	35.0	90.0	68.0	140	j	130	j	210	j	130	210
Fluoranthene	210.0	500.0	390.0	1000		780		1160		780	1160
Pyrene	200.0	450.0	363.3	2600		2300		1720		1720	2600
Benz[a]anthracene	88.0	200.0	159.3	520	j	450	j	670		450	670
Chrysene	120.0	270.0	220.0	570	j	480	j	810		480	810
Benzo[b]fluoranthene	130.0	290.0	236.7	520	j	450	j	950		450	950
Benzo[k]fluoranthene	100.0	240.0	193.3	560	j	480	j	630	j	480	630
Benzo[a]pyrene	130.0	290.0	233.3	500	j	350	j	770		350	770
Benzo[g,h,i]perylene	100.0	220.0	180.0	630	j	480	j			480	630

“j” = Associated value estimated

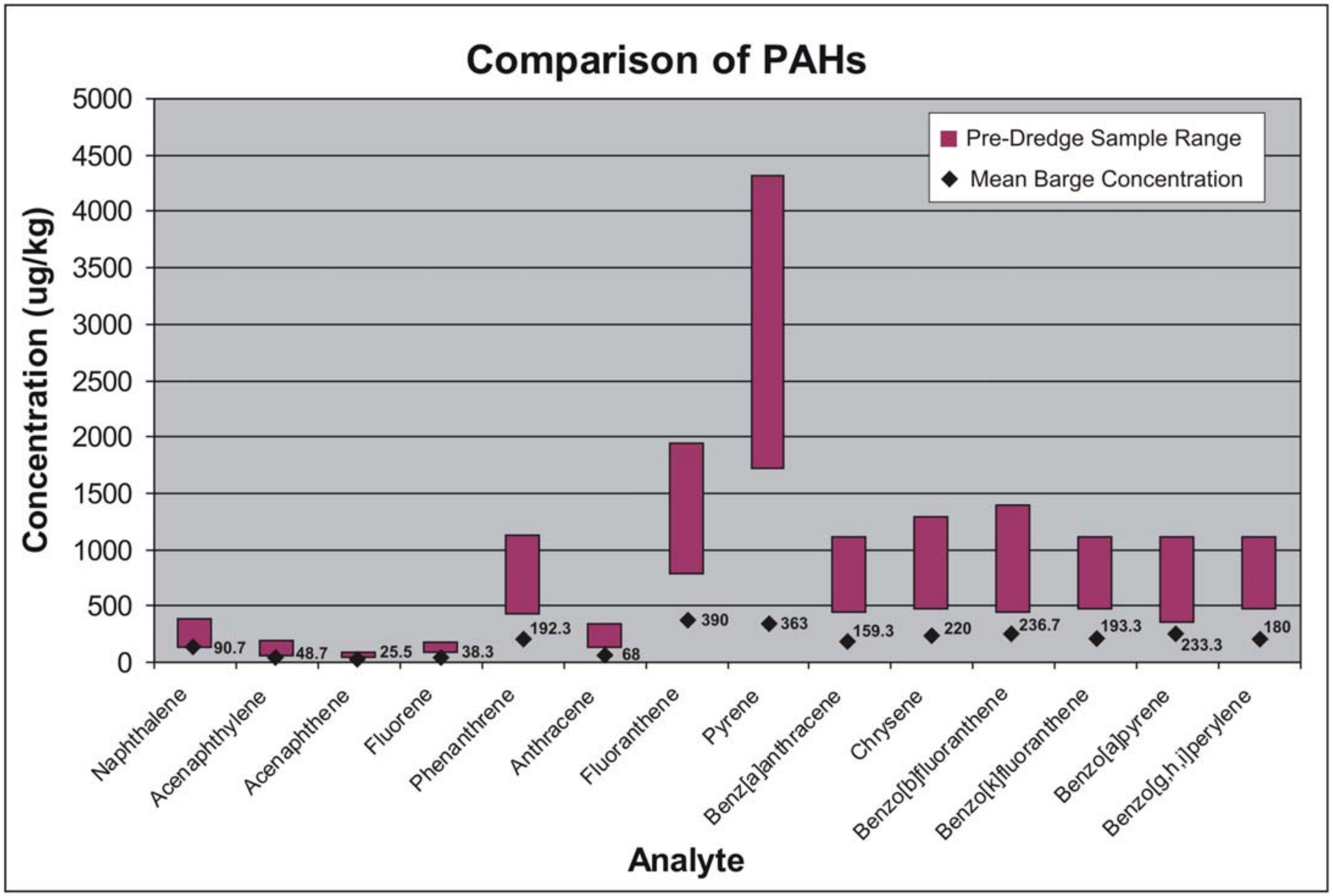


Figure 5-7. Chart showing the relationship between the mean concentrations of PAH compounds in the September 2004 disposal barge samples to the range of concentrations detected in the 1992 and 1994 pre-dredge samples of in-place sediments within Fuller Rock Reach.

data sets was reported as Method 3540/8270; the 2004 barge samples were analyzed using Method 8270-SIM. Improvements in analytical equipment over this 10+ year time-frame could result in as much as a hundred-fold (i.e., two decimal places) increase 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 5-7).

In summary, these results suggest metals concentrations in the barge were consistent with pre-dredge sediment characterization data, while PAH concentrations in barge samples could not be reliably compared, which is likely primarily attributable to improved analytical techniques. As presented in the results section, comparison with ecological screening benchmarks indicated barge concentrations of contaminants would generally be considered low.

When the September 2004 and April 2004 disposal barge chemistry data sets were compared, concentrations for metals and PAHs in Fuller Rock samples tended to be slightly greater than the Sabin Point Reach sample results (Table 5-3). The minimum concentrations of copper, lead, nickel, and zinc for Fuller Rock samples were greater than the maximum concentrations from the Sabin Point Reach samples, and comparison of mean concentrations from the two data sets generally showed greater mean concentrations for the Fuller Rock samples (Figure 5-8). For the PAH compounds, Sabin Point and Fuller Rock samples exhibited comparable minimum concentrations, with Fuller Rock maximum concentrations typically slightly greater than the corresponding Sabin Point maximum. Comparison of mean concentrations indicated consistently higher mean concentrations for Fuller Rock samples (Figure 5-9).

The metals results are consistent with characterization of the channel sediments from pre-dredging surveys, which indicated a down-channel decrease in metal concentrations in the Providence River (USACE 2001). PAH concentration data from the barge surveys support a similar trend for PAHs, with evidence of decreased concentrations down-channel.

Table 5-3

Comparison of trace metal and PAH concentrations in barge samples collected from Sabin Point (April 2004) and Fuller Rock (September 2004) Reaches of the Providence River navigational channel.

	Sabin Point			Fuller Rock		
Metals (mg/kg)	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
Arsenic	13.0	15.0	14.3	14	16	15
Chromium	140	170	157	170	200	183
Copper	290	350	320	400	480	430
Lead	120	140	130	160	170	163
Nickel	34	40	37	41	48	44
Zinc	260	290	273	300	350	323
PAHs (µg/kg)						
Acenaphthylene	29.0	41.0	35	25.0	62.0	44
Acenaphthene	ND	12.0	12	ND	33.0	33
Fluorene	20.0	28.0	24	19.0	58.0	39
Phenanthrene	110	160	135	97.0	280.0	189
Anthracene	41.0	58.0	50	35.0	90.0	63
Fluoranthene	230.0	350.0	290	210.0	500.0	355
Pyrene	220.0	330.0	275	200.0	450.0	325
Benz[a]anthracene	92.0	130.0	111	88.0	200.0	144
Chrysene	120.0	180.0	150	120.0	270.0	195
Benzo[b]fluoranthene	130.0	200.0	165	130.0	290.0	210
Benzo[k]fluoranthene	120.0	190.0	155	100.0	240.0	170
Benzo[a]pyrene	140.0	200.0	170	130.0	290.0	210
Benzo[g,h,i]perylene	120.0	170.0	145	100.0	220.0	160

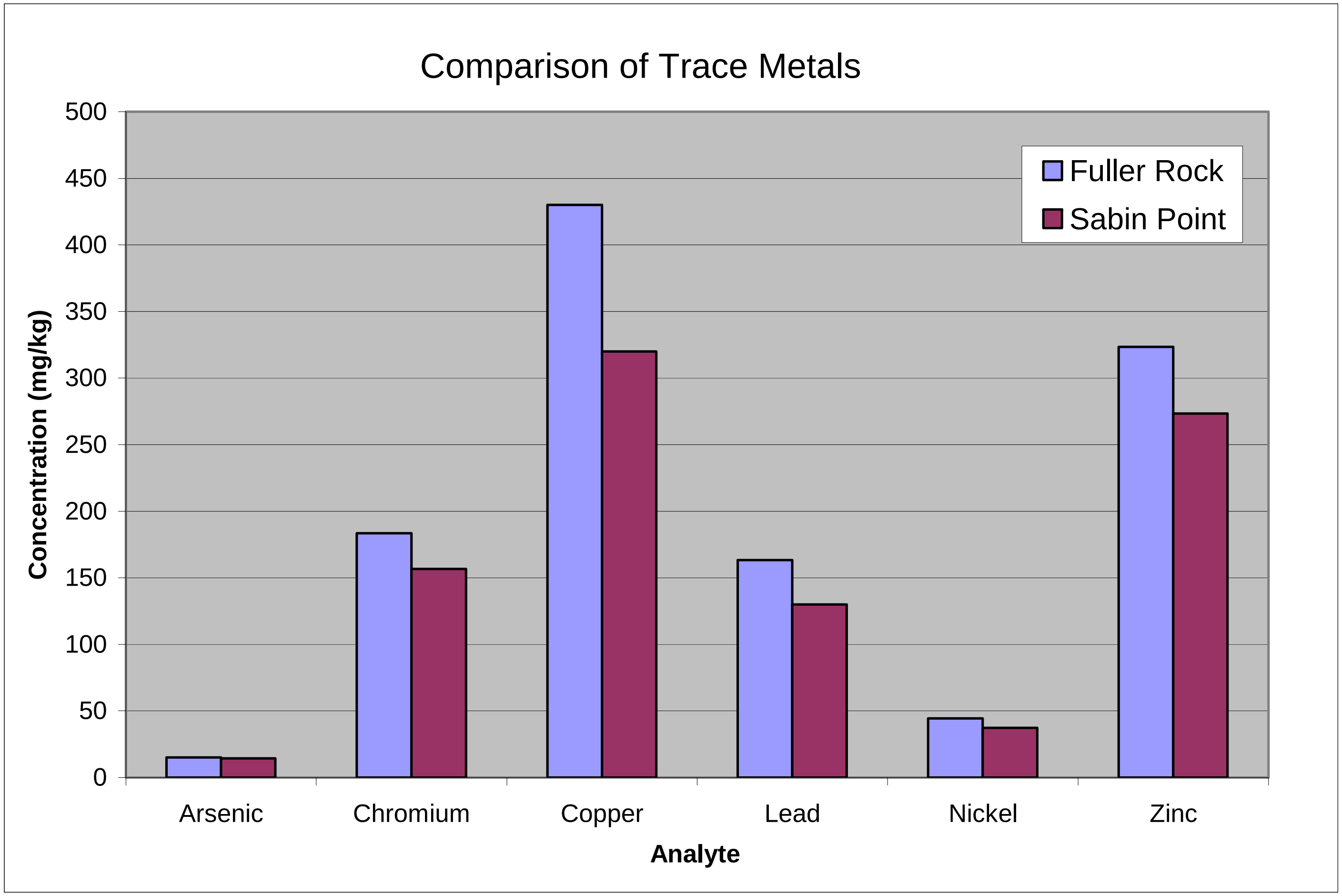


Figure 5-8. Comparison of mean trace metal concentrations from barge samples collected from the Fuller Rock (September 2004) and Sabin Point (April 2004) Reaches of the Providence River navigational channel.

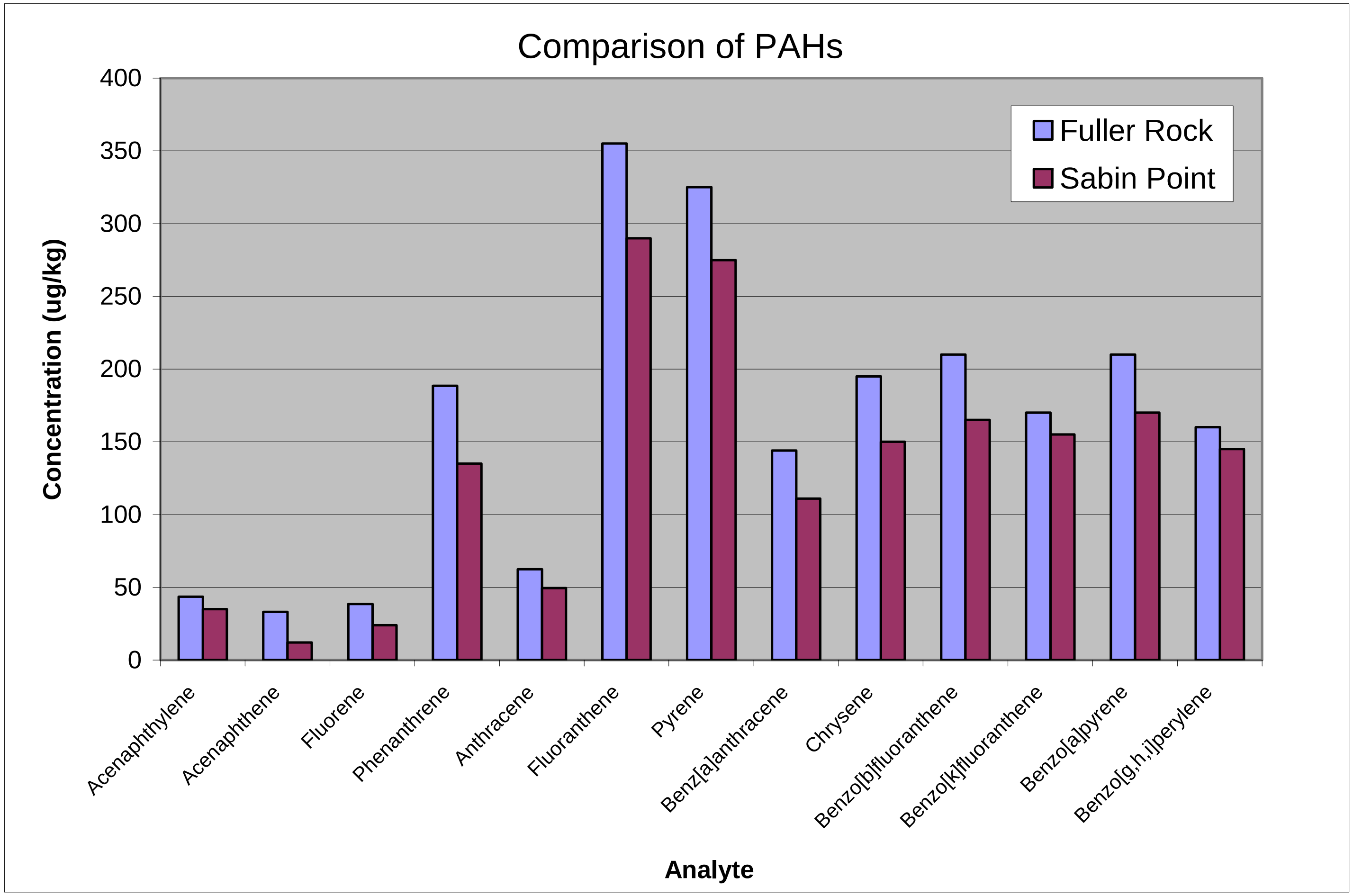


Figure 5-9. Comparison of mean PAH concentrations from barge samples collected from the Fuller Rock (September 2004) and Sabin Point (April 2004) Reaches of the Providence River navigational channel.

6 CONCLUSIONS

This report presents the results of a marine environmental survey performed within RISDS during September 2004, representing the second phase of a sediment plume tracking and assessment study. The information acquired from this survey is compared to estimates of sediment plume transport and dilution contained within the Environmental Impact Statement developed for the Providence River and Harbor Maintenance Dredging Project, as well as with results of the first phase of the study conducted in April 2004. Furthermore, findings 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.

SAIC conducted a comprehensive plume tracking survey involving water sampling, turbidity analysis, and plume transport measurements. Survey operations over RISDS were conducted on 1, 2 and 3 September, tracking sediment plumes generated by the disposal of maintenance material dredged from the upper Fuller Rock Reach of the federal navigation channel.

Accomplishment of the two primary study objectives is discussed below:

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

This objective was accomplished, with detailed results provided in Section 3 and discussion presented in Sections 4 and 5. Overall, the results of the September 2004 monitoring survey at the RISDS demonstrated that sediment plumes generated by open water disposal of dredged material remain detectable in the water column for periods of at least three hours following individual disposal events. Multiple acoustic and optical remote sensors used aboard survey vessels and from moored platforms 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.

During the first half-hour after disposal, the sediment plumes typically existed as a concentrated vertical column of turbid water at the dredged material placement location. 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 majority of the dredged material reached the seafloor rapidly during the descent phase of plume formation, but a small fraction of the material remained suspended in the water column. 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. Settling of the particulate matter contributed to deepening of the central mass of the plume, referred to as the centroid.

During the first three hours after a disposal event, mixing and dissipation occurred throughout the water column, but the most turbid and most persistent element of each sediment plume was situated in close proximity to the RISDS seafloor. Data from the optical and acoustic remote sensors, as well as from the discrete water samples, illustrated that the centroid of each sediment plume remained relatively concentrated for the first 40 to 60 minutes following disposal, after which turbidity and suspended solids concentrations approximated the low, background levels. Suspended solids 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, suspended solids concentrations of approximately 10 $mg \cdot L^{-1}$ were typical within 1 to 1.5 hours of each disposal event.

Comparisons between the suspended sediment concentrations observed during the September 2004 plume monitoring surveys to those predicted by STFATE as part of the Final Environmental Impact Statement, suggested the model output significantly over-estimated the suspended solids concentrations that would exist within the plume centroid during the first 90 to 120 minutes following a disposal event. These field observations demonstrated that 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.

It is noteworthy that all three plume surveys in September 2004 were conducted during the ebb tide. Water column currents over RISDS displayed differences in velocity and direction, with the water mass flowing to the west, south, and/or southeast depending upon the stage of the tide at which the disposal event occurred. As a result, the sediment plumes were transported to the west, south or southeast in response to the water column currents.

Similar to the results of the April 2004 study, the sediment plumes tracked during the September 2004 survey did cross the boundaries of RISDS during the survey operations. Residence time within RISDS varied from 30 to 180 minutes, depending upon the target disposal point utilized, as well as the direction and magnitude of water column currents. Although the toxicity results obtained from this survey suggest the movement of a detectable sediment plume beyond the RISDS boundary is of little environmental significance, it does indicate the need to refine the model used to predict plume behavior at RISDS, and to select optimum target disposal positions in order to maximize plume residence times in the site.

Objective 2: Assess the acute toxicity of the sediment plume to water column organisms

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 beryllina*) test organisms exhibited a lethal response. Therefore, the water obtained from the plume centroid did not exhibit toxicity that was significantly different from background conditions within two hours of disposal. This was the anticipated outcome given the amount of dilution that occurs within the water column during the formation of the sediment plume and its subsequent mixing and transport by ambient currents.

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APPENDIX

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

Note: Sample collection times in minutes correspond 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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