TECHNICAL MEMO:

FAR-FIELD SURVEYS OF SUSPENDED SEDIMENT PLUMES ASSOCIATED WITH HARBOR DEEPENING DREDGING IN ARTHUR KILL

S-AK-2 Contract Area

Prepared for

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List of Acronyms

ADCP – Acoustic Doppler Current Profiler
ASTM – American Society for Testing and Materials
BMP – Best Management Practices
CY – Cubic Yard
GPS – Global Positioning System
HDP – Harbor Deepening Project
NTU – Nephelometric Turbidity Units
OBS – Optical Backscatter Sensor
TSS – Total Suspended Solids
USACE-NYD – Unites States Army Corps of Engineers – New York District
WQ – Water Quality

1.0 INTRODUCTION

The resuspension of bottom sediments within aquatic habitats may be induced by a variety of events both natural and anthropogenic. Naturally occurring storms or tidal flows, for example, will influence suspended sediment concentrations within the water column although the timing, duration and intensity of the resuspension may differ from that caused by human activities (Wilber & Clarke 2001). Information on the extent and nature of suspended sediment plumes generated by dredge activities, therefore, is critical to enhance the understanding of sediment transport processes and associated environmental concerns (Puckette 1998).

As part of United States Army Corps of Engineers New York District's (USACE-NYD) Harbor-wide Water Quality/Total Suspended Solids (WQ/TSS) Monitoring Program, two far-field WQ/TSS surveys were conducted consecutively between 9 March and 13 March 2012 (Survey #1), and 14 March and 20 March 2012 (Survey #2) within the S-AK-2 contract area of the Harbor Deepening Project (HDP) in the North of Shooters Island Reach of the Arthur Kill, between Elizabeth, New Jersey and Staten Island, New York (Figure 1). The objective of these far-field surveys was to assess the spatial extent and temporal dynamics of suspended sediment plumes associated with mechanical dredging of fine-grained sediment within the navigation channel. The methodologies employed for this survey were similar to those used previously to survey environmental or "closed" (i.e. with seals and flaps, as per contract specifications) clamshell bucket dredging of fine-grained sediment within the Arthur Kill (USACE 2007), Newark Bay (USACE 2008 and USACE 2009), Port Elizabeth Channel (USACE 2010), the Upper Bay (USACE 2011), and South Elizabeth Channel (USACE 2013a); as well as to survey cutterhead dredging operations in the Kill Van Kull (USACE 2012 and USACE 2013b).

Mobile surveys were conducted using an Acoustic Doppler Current Profiler (ADCP) mounted off a 25-foot Parker research vessel, and consisted of parallel transects running perpendicular to the longitudinal axis of the suspended sediment plume. Transects were conducted adjacent to and down-current of the active dredging operation and were run such that the entire spatial extent of the plume's acoustic signature (i.e. the detectable signature above ambient backscatter) was recorded. To establish the calibration for the ADCP backscatter, water samples were collected to directly measure TSS concentration (via gravimetric analysis) and turbidity across the broadest possible range of tidal and concentration gradients. Note that because of the high volume of vessel traffic in the S-

AK-2 contract area, and because of United States Coast Guard concerns about deploying fixed sampling gear in this area, the fixed station surveys using an anchored array of optical backscatter sensors (OBS) turbidity meters could not be conducted during these surveys as in previous monitoring events.

1.1 Study Area

Far-field WQ/TSS surveys were conducted between 9 and 13 March 2012 (S-AK-2 Survey #1), and 14 and 20 March 2012 (S-AK-2 Survey #2) in the vicinity of an active dredging operation in the S-AK-2 Contract Area. Figure 1 shows the S-AK-2 Contract Area, the area of WQ/TSS surveys, and the approximate position of the dredge *Delaware Bay* during each survey. During both surveys, the *Delaware Bay* was located along the southern edge of the North of Shooters Island Reach of the Arthur Kill Channel, to the east of the green and red "A" navigation buoy. Water depths in this area generally ranged from approximately 10 to 15 meters. The *Delaware Bay* moved eastward along the edge of the channel as dredging operations progressed during the far field surveys. In addition, the backhoe dredge *J.P. Boisseau* equipped with an 11.8 CY bucket was also operating nearby in the channel but was generally beyond the range of influence to the surveys unless otherwise noted.

1.2 Dredge Operational Setup

The dredge contractor for this study was Donjon Marine Company, Inc. (Donjon), operating the dredge *Delaware Bay,* configured with a 15 cubic-yard capacity Cable Arm environmental bucket. This bucket features an over-square design with greater width than length to reduce sediment loss during bucket closing. In contrast to conventional "grab" buckets, the cable arm environmental bucket produces a relatively level cut when removing bottom sediment, thereby enhancing vertical as well as horizontal control. In addition, overlapping steel side plates with rubber seals reduce sediment squeezing out of the side (known as windrowing). Rubber flaps on the face of the bucket allow air to escape during descent while sealing the top during ascent, thereby slowing the inflow of water and reducing the loss of material due to washout. In addition to the use of an environmental bucket, best management practices (BMPs) were employed by the dredge contractor to reduce overall sediment resuspension. BMPs included restriction of bucket hoist speed to no more than two feet per second and the use of dredging instrumentation and software to ensure full bucket closure.

2.0 METHODS

2.1 Hydrodynamic Surveys

Hydrodynamic conditions within the Arthur Kill Channel were assessed during both ebb and flood tides using a vessel-mounted Teledyne RD Instruments 1200-kHz Workhorse Monitor Series ADCP. The mobile transects were conducted perpendicular to the Arthur Kill Channel.

ADCP data provided a characterization of prevailing hydrodynamic conditions within the Study Area. Raw data from the hydrodynamic surveys were processed and examined for evidence of stratified flows, tidal eddies, and other patterns that could influence plume dispersion.

For each survey, the observed hydrodynamic conditions were cross-referenced against predicted currents generated from NobleTec Tides & Currents™ software for Elizabethport. The predicted currents data show the water speed (in m/s; blue bars) and direction (negative values for ebb, positive for flood) and are useful to place a particular survey within the context of the daily tide cycle.

2.2 Mobile ADCP Suspended Sediment Surveys

Suspended sediment plumes were also characterized using the Workhorse model ADCP. In the field, RD Instruments WinRiver software was used for the display of plume acoustic signatures and data recording. The ADCP operates by emitting acoustic pulses into the water column at set time intervals. Each group of pulses, referred to as an "ensemble," is vertically stratified into discrete, fixed-depth increments, or "bins." The number of bins and size of each bin is a configurable operation parameter of the instrument. In this study, 40 bins of 0.5-meter depth were used, for a maximum profile range of 20 meters. After the instrument emits a pulse, the ADCP then "listens" for the return of any sound (i.e. backscatter) that has been reflected from particles in the water column (in this case, a "particle" is any acoustic reflector, including sediment, plankton, fish, air bubbles etc.).

Once the instrument receives the reflected signals, the WinRiver software can calculate the three-dimensional movement of particles in the water column and thus determine water velocity in each bin. When water samples are collected concurrently, suspended sediment concentration can be determined using additional software and analyses (see *Section 2.4 - ADCP Calibration* below). Similarly, navigation data (i.e. GPS positions) collected throughout the monitoring period by the dredge contractor were integrated during post-processing of the ADCP data to determine the distance each transect was from the dredge. To cover a range of tidal conditions, ADCP backscatter data were collected during various stages of ebb and flood tides during the survey periods.

It is important to note that the ADCP cannot simultaneously receive and emit an acoustic pulse. Thus, when emitting a pulse, the ADCP cannot obtain data from immediately in front of its transducers (in addition to the water above the immersion depth of the instrument itself). This "blanking distance" is a user-defined parameter with limitations imposed by the operating frequency of the ADCP. For the 1200-kHz ADCP used in this survey, the blanking distance is approximately 0.5 meters (i.e. one bin depth).

In addition, acoustic "echoes" reflected from the seabed may interfere with the ADCP signal. The ADCP emits most of its acoustic energy in a very narrowly confined beam; however, a small amount of energy is emitted at angles far greater than that of the main lobe. These "side lobes", despite their low power, can contaminate the echo from the main lobe, typically in the area directly above the seabed. The net effect of this side lobe interference is to show artificially high backscatter from the near-seabed areas. This effect is exacerbated in vessel-mounted surveys when the seabed elevation changes rapidly (e.g. during the transition from the shallows to the channel areas or vice-versa). In general, the side lobe distance above the seafloor is equal to approximately 6% of the water depth at that point.

2.2.1 Mobile ADCP Survey Design

Prior to initiating the mobile plume surveys, circular transects using the ADCP were conducted around the actively operating dredge to assess the location and acoustic signal of the plume. Subsequent ADCP transects were then conducted across the plume, generally oriented in a direction perpendicular to the channel and extending down-current until the plume's acoustic signatures could no longer be detected against background conditions. Background conditions on the days of the surveys were determined by conducting ambient transects up-current of the plume and outside the active dredging area. Individual transect length was generally determined by bathymetry at the site, but always with the objective of extending beyond the detectable boundaries of the plume. The number, and consequently the spacing, of cross-plume transects were maximized within each designated tidal phase in order to provide complete spatial coverage of the detectable plumes and optimal resolution of internal plume structure.

2.2.2 Mobile ADCP Data Presentation

Results for the mobile ADCP plume transects are presented graphically in three ways:

- **Vertical Profile Plots** – Vertical cross-section profiles representing individual transects are examined in detail for TSS concentration gradient structure of the plume at fixed distances from the source.

- **Plan-View Plots** – TSS concentrations are presented as composite horizontal "slices" through the plume signature at surface (0-5 meters), middle (5-10 meters), and bottom (10-15 meters) depth intervals.

- **Isometric Plot Depiction** – Selected transects are plotted three dimensionally and superimposed on the existing bathymetry to show the spatial extent of the plume within the channel (note: the depth (Z) axis is exaggerated to show detail better since the X,Y spatial extents are much larger than the Z extents). Channel bathymetry is generated using NOAA sounding data.

For all figures, unless otherwise noted, estimates of TSS concentrations above ambient concentration are assumed to be associated with dredging activities.

2.3 Water Sample Collection

During the far-field surveys, water samples were collected to measure TSS concentrations (mg/L) and turbidity (NTU) throughout the water column, in order to correlate the ADCP backscatter data into estimates of TSS. The water samples were collected from the research vessel using a custom made pump sampler which consisted of a Rule model 2000 submersible impeller pump with ¾-inch polyester braid reinforced PVC tubing, to which a Campbell Scientific, Inc. OBS-3A optical backscatter sensor (OBS) was mounted. The OBS unit was configured to measure and record depth, temperature, salinity, and turbidity values at one second intervals throughout the entire water profile. The OBS unit was connected via RS-232 serial link to an onboard computer which logged these data using HDR's proprietary Water Sample Collection Control software. This software is designed to time-stamp collections of TSS/Turbidity water samples with one second accuracy, and easily cross-reference these samples with simultaneously logged OBS and ADCP data for use in establishing the ADCP backscatter correlation to TSS concentrations during post-processing.

Water samples collected in the field were processed in the laboratory by Test America Laboratories, Inc. for optical turbidity (Method SM 2130-B) and for the gravimetric analysis of TSS concentration (Method SM 2540-D) except where noted. Some samples could not be analyzed for turbidity because they exceeded the 48 hour holding time for this parameter during weekend closures at the analytical lab. All samples were analyzed for TSS which is the critical parameter used to provide a robust calibration data set to convert the raw ADCP backscatter measurements to estimates of TSS concentration. See Sediview methodology and software as further described in Section 2.4 below.

2.4 ADCP Calibration

Following the field data collection effort, the raw acoustic backscatter measurements collected by the ADCP were converted to estimates of suspended sediment concentration using Sediview Software provided by Dredging Research, Ltd. The Sediview Method (Land and Bray 2000) derives estimates of suspended solids concentration in each ADCP data bin by converting relative backscatter intensity to TSS concentration. This process requires collecting a calibration data set consisting of discrete water samples and concurrently recorded ADCP acoustic backscatter data. The degree of confidence that can be placed in the estimates of TSS is directly proportional to the quality of the calibration data set. The quality of the calibration is in turn dependent on the collection of adequate water samples to represent sediments in suspension at all depths in the water column and across the entire gradient of concentrations occurring in ambient as well as plume conditions.

Water samples were collected at known locations within the water column, so that individual gravimetric results could be directly correlated with ADCP acoustic backscatter data for a "bin" of water as close to the water sample as possible. Following the Sediview calibration, the results were then applied to all of the ADCP files recorded during each of the far-field surveys, resulting in an ADCP-derived estimate of TSS concentration for each recorded ADCP bin for an individual far-field survey. Note, because of the continuously changing ambient conditions present in estuaries, it was important to collect water samples frequently. It was also important to collect enough samples to constitute a robust sample size as it is occasionally necessary for some outlier water samples to be excluded. This is due to the dynamic nature of the sampling environment where it is often difficult to achieve perfect spatial and temporal synchronization of the water samples and ADCP data. For example, outlier samples may exhibit artificially high TSS based on the disturbance of bottom sediments by the sampling apparatus (i.e. the apparatus impacts on the sea floor resulting in localized elevated TSS concentrations that are not reflected in the concurrent ADCP data). Similarly, ADCP backscatter data can be influenced by air entrainment in the water column in which air bubbles will show as extremely high backscatter/TSS estimates but the corresponding water sample for that time/position has relatively low TSS concentration.

Because air is injected into the water column as the dredge bucket breaks the air-water interface, and air bubbles are acoustic reflectors, care was exercised in converting acoustic data derived very close to the operating bucket to TSS estimates. Air bubbles dissipate by rising to the surface with time. The distance down-current of bubble interference of the signal is therefore influenced by current velocities. Previous experiments were conducted during the monitoring of a closed bucket during maintenance dredging operations in the Providence River, in which the bucket was intentionally plunged through the air-water interface without removing sediment from the bottom (Reine *et al*. 2006). These experiments were conducted under slow to moderate current flow conditions, and determined that the "bubble signature" pattern dissipated within approximately 50 meters of the source. Beyond 50 meters estimates of TSS concentration for the calibrated ADCP should be accurate.

2.5 Sediment Sample Collection

To determine the sediment characteristics of the survey area, a sample was collected once per day from both the sediment bed in the vicinity of the dredge using a ponar grab, and from the dredge scow during down periods of active dredging operations. All of the sediment samples were analyzed by Test America Laboratories, Inc. for sediment grain size distribution (ASTM D-422 Method), density (ASTM D-2937 Method) and Atterberg Limits (ASTM D-4318 Method).

3.0 RESULTS

3.1 S-AK-2 Survey #1 (9 - 13 March 2012)

3.1.1 Hydrodynamic Surveys

To assess hydrodynamic conditions within the Arthur Kill Channel and its immediate vicinity hydrodynamic surveys were conducted throughout the areas surveyed in mobile ADCP TSS surveys during an ebb tide (9 March) and two separate flood tides (12 and 13 March). Transects were conducted approximately perpendicular to the Arthur Kill Channel. Additionally, hydrodynamic conditions during each mobile ADCP survey were also recorded to aid in the interpretation of plume dynamics, and place the corresponding TSS data in a hydrodynamic context. These results are included as part of the discussion of each mobile ADCP survey in Section 3.1.3 below. The results of the hydrodynamic surveys are presented in Figures 2 through 4. In these figures, the "Direction of Travel" arrow indicates the direction in which the research vessel progressed through the survey area while conducting transects.

3.1.1.1 9 March 2012 - Ebb Tide

Figure 2 presents the results of the 9 March 2012 ebb tide hydrodynamic survey. During this survey, depth-averaged current velocities within the area ranged from near 0 m/s to approximately 0.45 m/s. Currents in the western portion of the survey area were oriented parallel to the Arthur Kill Channel and flowed to the west with little variation. The greatest current velocities (greater than 0.2 m/s) were also detected in this area. To the east of the point where the South of Shooter's Island Channel joins the main Arthur Kill Channel, current direction was more variable, in general falling between southwesterly and southeasterly and velocities were lower, at 0.2 m/s or less. During this survey the *Delaware Bay* was operating near the boundary between these two areas of differing currents.

3.1.1.2 12 & 13 March 2012 - Flood Tide

Figures 3 and 4 present the results of the hydrodynamic surveys conducted on 12 and 13 March 2012 from the middle through the second half of two separate flood tides, from approximately 10:13 to 11:30 on 12 March and from approximately 12:02 to 13:17 on 13

March. The area surveyed covered the width of the Arthur Kill Channel, and extended from near the eastern end of Shooter's Island westward to near the red "22" and green "21" navigation buoys. During these surveys, currents flowed eastward into the North of Shooters Island Reach of the Arthur Kill Channel and southeastward into the South of Shooters Island reach. Another current flowed southward into the survey area from the flats at the mouth of Newark Bay, at a point just west of Shooter's Island. In the portion of the Arthur Kill directly to the north of Shooter's Island currents were observed to flow generally towards the west to west-southwest. Where these three currents met, they created eddies, or areas of swirling current. Depth averaged current velocities observed during this surveys ranged from near 0 m/s to near 0.5 m/s. In general, the highest current velocities (approximately 0.2 m/s or greater) were observed along the edges of the channel.

3.1.2 Ambient Conditions

A total of 25 ambient water samples were collected at various depths from 9 to 13 March 2012, and later analyzed in the laboratory for TSS and turbidity except where noted (Table 1). Ambient turbidity values ranged from 4.9 to 11.9 NTU, and the corresponding TSS concentrations ranged between 16 to 36 mg/L.

Because of the naturally heterogeneous distribution of suspended sediment, ambient conditions are often associated with a range of TSS concentrations and the distribution of these values is rarely symmetric and is often stratified within the water column. As a result, using average ambient TSS will often underestimate the ambient condition and thus using a percentile approach as a measure of central tendency is more applicable. Choice of which percentile to use is largely a matter of which one most clearly demarcates the plume from the background condition (i.e., removes the natural "noise" of the ambient condition), but typically it ranges from the 50^{th} percentile (median) to 95^{th} percentile. For this study, the 50th percentile value of 30 mg/L was used as the critical cutoff between ambient and plume conditions. Thus, acoustically estimated TSS concentrations greater than 30 mg/L are herein considered above background and attributable to the dredge-induced plume unless otherwise noted, e.g., clearly attributable to air entrainment, vessel prop wash, or from other sources of re-suspension such as tug and ship plumes, or from side-lobe interference (see ADCP calibration methods, Section 2.5, for further information).

3.1.3 Mobile ADCP Surveys

3.1.3.1 10 March 2012 - Flood Tide #1

Two mobile ADCP plume characterization surveys were conducted on 10 March 2012 during a flood tide. The first was conducted during the middle of the tide cycle from approximately 8:37 to 9:17 (Figures 5a-m). The survey consisted of three circle transects to locate the plume (Figures 5a through 5c), four up-current transects (Figures 5d through 5g), and six down-current transects (Figures 5h through 5m). A summary of each of the graphically represented transects is presented in Table 2.

To examine the spatial extent of the plume, a series of plan-view layouts are given in Figures 6a through 6c. During this survey, the dredge *Delaware Bay* was located on the southern side of the Arthur Kill Channel approximately 100 meters east-northeast of the charted position of the green and red “A” navigation buoy. The *J.P. Boisseau* was approximately 325 meters to the north and east of the *Delaware Bay* in the center of the Arthur Kill Channel. Up-current transects were conducted to the west of the *Delaware Bay* and down-current transects were conducted to the east of the dredge. Up- and down-current transects were oriented perpendicular to the channel.

Up-current conditions presented in transects A01 through A04 (Figures 5d through 5g) show background ADCP estimated TSS concentrations between 0 and 30 mg/L in the top one quarter of the water column, and strata of naturally occurring suspended sediment below this with estimated TSS concentrations from 30 to 200 mg/L.

Down-current transects T01 through T05 (Figures 5h through 5l) show the extent of the TSS plume associated with dredging operations of the dredge *Delaware Bay*. Peak TSS concentrations within the plume reached as high as approximately 250 mg/L in a very small area close to the bottom at the edge of the channel side slopes and within 98 meters of the source (Transect T01). Plume TSS concentrations up to 200 mg/L persisted along the bottom to within 164 meters down-current of the dredge (Transect T03). TSS concentrations ranging between 30 and 100 were detected throughout the water column within 324 meters down-current of the dredge (Transects T03 through T06). Though natural background TSS concentrations were similar to those in the plume in these further down current transects, the plume signature can be distinguished from the background, as it is nearer to the channel slope and throughout the water column, while the ambient suspended sediment forms strata with increasing concentrations lower in the water column. Plume width varied from approximately 40 to 70 meters across its extent, being narrower when higher in the water column and further from the dredge. Because some transects in this survey extended over shallower slopes (less than approximately 10 meters), side lobe reflectivity can be observed near the bottom in these transects.

Figure 7 presents the hydrodynamic conditions recorded during the 10 March 2012 flood tide mobile ADCP survey discussed above. During this survey, depth-averaged current velocities within the area ranged from near 0 m/s to approximately 0.5 m/s. Current direction across most of the survey area was towards the east or east-southeast, generally parallel to the Arthur Kill Channel. Along the northern edge of the survey area, current directions flowed more to the southeast or south-southeast, from the flats to the north of the channel. The highest current velocities (greater than approximately 0.2 m/s) were detected in the southwestern portion of the survey area.

3.1.3.2 10 March 2012 - Flood Tide #2

The second flood tide mobile ADCP plume characterization survey conducted on 10 March 2012 was completed during the end of the flood tide from approximately 11:49 to 12:07 (Figures 8a through 8h). The survey consisted of three up-current transects (Figures 8a through 8c), and five down-current transects (Figures 8d through 8h). A summary of each of the graphically represented transects is presented in Table 3.

To examine the spatial extent of the plume, a series of plan-view layouts are given in Figures 9a through 9c. During this survey, the dredge *Delaware Bay* was located on the southern side of the Arthur Kill Channel approximately 100 meters east-northeast of the charted position of the green and red “A” navigation buoy. The *J.P. Boisseau* was approximately 300 meters to the north and east of the *Delaware Bay* in the center of the Arthur Kill Channel. Up-current transects were conducted to the west of the *Delaware Bay* and down-current transects were conducted to the east of the dredge. Up- and down-current transects were oriented perpendicular to the channel.

Up-current conditions presented in transects A01 through A03 (Figures 8a through 8c) show background ADCP estimated TSS concentrations between 0 and 30 mg/L in approximately the top one-third of the water column, and strata of naturally occurring suspended sediment below this with estimated TSS concentrations ranging from 30 to 100 mg/L. As recorded in the field notes presented in Table 3, Transect T03 (Figure 8c) shows heavy propwash from a passing tugboat at the top of the water column.

Down-current transects T01 through T05 (Figures 8d through 8h) show the extent of the TSS plume associated with operations of the dredge *Delaware Bay.* Peak TSS concentrations within the plume reached as high as approximately 400 mg/L in a very small area close to the bottom at the edge of the channel side slopes and within 149 meters of the source (Transects T01-T02). Plume concentrations as high as 200 mg/L were present for at least 267 meters down-current of the dredge (T05). Overall plume width was approximately 40 to 70 meters across its extent, but areas of the plume containing TSS concentrations greater than 200 mg/L were limited in width to no more than 10 meters. As lighter portions of the plume spread out in the bottom of the water column, it merged into a strata where estimated suspended sediments were comparable and indistinguishable from ambient conditions.

Figure 10 presents the hydrodynamic conditions recorded during the second 10 March 2012 flood tide mobile ADCP survey discussed above. During this survey, depth-averaged current velocities within the area ranged from near 0 m/s to approximately 0.3 m/s. Current direction across most of the survey area was generally between east-southeast and south-southeast, flowing across the Arthur Kill Channel diagonally from the flats to the north towards Shooter’s Island. The highest current velocities (approximately 0.2 to 0.3 m/s) were detected in a small area near the middle of the Arthur Kill Channel.

3.1.3.3 12 March 2012 - Ebb Tide

A mobile ADCP plume characterization survey was conducted on 12 March 2012 during the middle portion of an ebb tide from approximately 14:55 to 16:29 (Figures 11a-11j). The survey consisted of three up-current transects (Figures 11a through 11c), and seven down-current transects (Figures 11d through 11j). A summary of each of the graphically represented transects is presented in Table 4.

To examine the spatial extent of the plume, a series of plan-view layouts are given in Figures 12a through 12c. During this survey, the dredge *Delaware Bay* was located along the southern side of the Arthur Kill Channel approximately 120 meters east of the charted position of the green and red “A” navigation buoy. The *J.P. Boisseau* was approximately 100 meters to the north and east of the *Delaware Bay* in the center of the Arthur Kill Channel. Up-current transects were conducted to the east of the *Delaware Bay* and down-current transects were conducted to the west of the dredge. Up- and down-current transects were oriented perpendicular to the channel. Figure 13 provides a three-dimensional depiction of average TSS values for selected representative transects.

Up-current conditions presented in transects A01 through A03 (Figures 11a through 11c) show background ADCP estimated TSS concentrations between 0 and 30 mg/L in the top two-thirds of the water column, and strata of naturally occurring suspended sediment with concentrations ranging between 30 and 75 mg/L below this. A small area of higher TSS from an unknown source was recorded near the bottom at the end of transect A03 but was not representative of typical ambient conditions observed during these three transects.

Down-current transects T01 through T06 (Figures 11d through 11i) show the extent of the TSS plume associated with dredging operations of the dredge *Delaware Bay*. Peak TSS concentrations within the plume reached as high as approximately 300 mg/L in areas along the bottom and within 147 meters of the source (Transects T01-T02). Plume TSS concentrations were detected within at least 489 meters down-current from the dredge (T06), but had returned to background conditions by 637 meters down-current (T07). The plume detected in this survey was approximately 160 to 200 meters wide, but remained confined to the Arthur Kill Channel for its entire extent. Portions of the plume extended to the surface closer to the *Delaware Bay* (T01 in Figures 11d and 12a), but descended to the bottom half of the water column and narrowed by 212 meters down-current (T03). The lateral extent of the plume observed in this survey may be enhanced due in part to the addition of TSS plume from the operations of the excavator dredge *J. P. Boisseau*, which was located directly up-current of the plume transects as indicated by the black square in Figures 12a through 12c and to the northeast of the *Delaware Bay*. Though the plumes from the two dredges eventually merged further down current and along the bottom of the channel, it may be possible to distinguish the two plumes in the closest down-current transects (T01 through T02).

Figure 14 presents the hydrodynamic conditions recorded during the 12 March 2012 ebb tide mobile ADCP survey discussed above. During this survey, depth-averaged current velocities within the area ranged from near 0 m/s to approximately 0.4 m/s. Current direction across most of the survey area was generally towards the west, flowing parallel to the Arthur Kill Channel. Towards the middle of the survey area, current direction was somewhat more towards the west-southwest or southwest, flowing towards the smaller channel to the south of Shooter’s Island. The highest current velocities (greater than 0.2 m/s) were generally detected at the eastern and western ends of the survey area.

3.1.3.4 13 March 2012 - Flood Tide

A mobile ADCP plume characterization survey was conducted on 13 March 2012 during the middle portion of a flood tide from approximately 9:57 to 11:05 (Figures 15a-15m). The survey consisted of one circle transect to locate the plume (Figure 15a), four up-current transects (Figures 15b through 15e), and eight down-current transects (Figures 15f through 15m). A summary of each of the graphically represented transects is presented in Table 5.

To examine the spatial extent of the plume, a series of plan-view layouts are given in Figures 16a through 16c. During this survey, the dredge *Delaware Bay* was located along the southern side slope of the Arthur Kill Channel approximately 240 meters east of the charted position of the green and red "A" navigation buoy. The *J.P. Boisseau* was approximately 125 meters to the north of the *Delaware Bay* in the center of the Arthur Kill Channel. Up-current transects were conducted to the west of the *Delaware Bay* and down-current transects were conducted to the east of the dredge. Up- and down-current transects were oriented perpendicular to the channel.

Up-current conditions presented in transects A01 through A04 (Figures 15b through 15e) show background ADCP estimated TSS concentrations between 0 and 30 mg/L in the top one-quarter of the water column, along with surface prop wash from crew boats. A stratum of naturally occurring suspended sediment was present in the bottom three-quarters of the water column with concentrations ranging between 30 and 150 mg/L.

Down-current transects T01 through T07 (Figures 15f through 15l) show the extent of the TSS plume associated with dredging operations of the dredge *Delaware Bay*. Peak TSS concentrations within the plume reached as high as approximately 400 mg/L in small areas along the bottom and within 155 meters of the source (Transect T02). Plume TSS concentrations as high as 200-300 mg/L were detected within at least 340 meters down-current from the dredge (T07), but conditions had returned to background by 400 meters down-current (T08). The plume generated by the *Delaware Bay* was detected along the southern side of the Arthur Kill Channel, and can generally be seen on the right side of the down-current vertical profiles. The larger and heavier plume signature to the left in Figures 15k and 15l is likely attributable to the excavator dredge *J. P. Boisseau*, which was positioned to the due north of the *Delaware Bay* during this survey, so that the end of the down-current transects were within its plume as well. However, the two plumes can be distinguished from each other for their entire extent. The plume generated by the *Delaware Bay* varied in width from approximately 20 to 50 meters over its length, narrowing and sinking in the water column farther down-current from the dredge. Because some transects in this survey extended over shallower slopes (less than approximately 10 meters), side lobe reflectivity can be observed near the bottom in these transects.

Figure 17 presents the hydrodynamic conditions recorded during the 13 March 2012 flood tide mobile ADCP survey discussed above. During this survey, depth-averaged current velocities within the area ranged from near 0 m/s to near approximately 0.5 m/s. Current direction across the survey area was towards the southeast overall, flowing diagonally across the Arthur Kill Channel from the flats to the north towards Shooter's Island. The highest current velocities (greater than 0.2 m/s) were detected along the southern end of the survey area.

3.1.4 Laboratory Analysis of Water Samples

A total of 96 water samples were collected in the project area during the S-AK-2 Far Field Survey #1. The laboratory results of the optical turbidity and the gravimetric analysis of TSS concentration of these samples are presented in Table 1. To provide a robust data set for calibration of the ADCP backscatter, samples were taken from locations to represent the broadest possible concentration gradient from ambient to the highest TSS concentrations that could be safely collected in the area of the active dredging operation. The TSS concentrations of the 96 water samples ranged from 16 to 158 mg/L and corresponding turbidity concentrations ranged from 4.9 to 46.0 NTU.

3.1.5 Sediment Samples

A total of eight sediment samples (four from the dredge scow and four from the seabed in the dredging area) were collected during the S-AK-2 Far Field Survey #1. The laboratory results of these sediment collections for grain size distribution, density and Atterberg Limits are presented in Table 6. Sediment samples collected during this survey were comprised mostly of silt, which made up over 50% of each sample collected and an average of 75% of all samples. Clay and sand made up the most of the remainder of the samples, with an average of approximately 18% and 7% composition, respectively. Only two samples, both from the dredge scow, contained any gravel, and this averaged only 0.6%. The in-place density of the sediment samples ranged between 0.486 and 0.892 g/cc and averaged 0.589 g/cc, and the Atterberg Limits averaged 87.9, 39.3, and 48.5 for Liquid Limit, Plastic Limit, and Plasticity Index, respectively.

3.1.6 Dredging Operations — Bucket Cycles

To examine the bucket cycle sequence, a video record was obtained of 19 complete cycles during an ebb tide on 12 March, 2012. The video was then analyzed for time increments for each component of the cycle (Figure 18). The average total elapsed time per cycle was one minute, thirty four seconds. A certain degree of variability in cycle component elapsed times can be seen across the 19 cycles in Figure 18. The shortest cycle was one minute, twelve seconds, whereas the longest cycle was one minute, fifty-eight seconds.

Average time for each component of the dredge cycle was: Descent (20 seconds), Grab (13 seconds), Raise (14 seconds), Slew Over (14 seconds), Dump (24 seconds), and Slew Back (11 seconds).

3.2 S-AK-2 Far Field Survey #2 (14 – 20 March 2012)

3.2.1 Hydrodynamic Surveys

Hydrodynamic conditions within the Arthur Kill Channel and its immediate vicinity were assessed during both a flood (15 March) and an ebb (19 March) tide. Transects were conducted approximately perpendicular to the Arthur Kill Channel. Additionally, the specific hydrodynamic conditions during each mobile ADCP survey were also recorded to aid in the interpretation of plume dynamics, and place the corresponding TSS data in a hydrodynamic context. These results are included as part of the discussion of each mobile ADCP survey in Section 3.2.3 below. The results of the hydrodynamic surveys for the flood and ebb tides are presented in Figures 19 and 20, respectively.

3.2.1.1 15 March 2012 (Flood Tide)

Figure 19 presents the results of the hydrodynamic survey conducted on 15 March 2012 during the middle of a flood tide, from approximately 12:14 to 13:32. The area surveyed covered the width of the Arthur Kill Channel, beginning near the red “22” and green “21” navigation buoys and moved eastward to the area north of Shooters Island. In the western half of the survey area, currents flowed eastwards out of the Arthur Kill. Along the southern edge of the survey area, currents flowed south-eastwards toward the channel to the south of Shooter’s Island. At the eastern end of the survey area, adjacent to the northern point of Shooter’s Island, currents formed an eddy, flowing in from the west on the north side of the Arthur Kill Channel and turning 180° to flow east on the south side of the channel. Where the prevailing eastward current met this eddy it turned the south and southeast. Depth averaged current velocities observed during this survey ranged from near 0 m/s to approximately 0.4 m/s. In general, the highest current velocities (approximately 0.2 m/s or greater) were observed in the western half of the survey area.

3.2.1.2 19 March 2012 (Ebb Tide)

Figure 20 presents the results of the hydrodynamic survey conducted on 19 March 2012 during the middle of an ebb tide, from approximately 10:33 to 11:38. The area surveyed covered the width of the Arthur Kill Channel, beginning near the red “22” and green “21” navigation buoys and moved eastward to the area north of Shooters Island. Overall, currents flowed westward across the survey area. Along the southern edge of the survey area, currents flowed north-west from the areas south of Shooters Island into the main westward current in the Arthur Kill Channel, and along the north edge of the channel, currents flowed southwest into the survey area from the flats to the north. Depth averaged current velocities observed during this survey ranged from near 0 m/s to approximately 0.4 m/s. Current velocities were greater than approximately 0.2 m/s over most of the survey area, except for towards the northeast part of the area. The highest current velocities of 0.3 to 0.4 m/s were observed in the middle of the channel and at the western end of the survey area.

3.2.2 Ambient Conditions

A total of 40 ambient water samples were collected at various depths from 14 to 20 March 2012, and later analyzed in the laboratory for TSS and turbidity except where noted (Table 7). Ambient turbidity values ranged from 3.85 to 20 NTU, and the corresponding ambient TSS concentrations ranged between 23 to 47 mg/L.

For this survey, the 50th percentile was used resulting in an ambient cutoff value of 30 mg/L when analyzing data from this survey and was the same cutoff value as Survey #1.

3.2.3 Mobile ADCP Surveys

3.2.3.1 14 March 2012 (Flood Tide)

A mobile ADCP plume characterization survey was conducted on 14 March 2012 during the middle portion of a flood tide from approximately 11:36 to 12:07 (Figures 21a-21m). The survey consisted of one circle transect to locate the plume (Figure 21a), three up-current transects (Figures 21b through 21d), and nine down-current transects (Figures 21e through 21m). A summary of each of the graphically represented transects is presented in Table 8.

To examine the spatial extent of the plume, a series of plan-view layouts are given in Figures 22a through 22c. During this survey, the dredge *Delaware Bay* was located on the southern side of the Arthur Kill Channel approximately 330 meters east of the charted position of the green and red "A" navigation buoy. The *J.P. Boisseau* was approximately 100 meters to the north and west of the *Delaware Bay* in the center of the Arthur Kill Channel. Up-current transects were conducted to the east of the *Delaware Bay* and down-current transects were conducted to the west of the dredge. Up- and down-current transects were oriented perpendicular to the channel.

Up-current conditions presented in transects A01 through A03 (Figures 21b through 21d) show background ADCP estimated TSS concentrations ranging between 0 and 100 mg/L throughout the water column and up to approximately 200 mg/L along the very bottom, along with surface prop wash from vessel traffic as noted in field observations presented in Table 8.

Down-current transects T01 through T06 (Figures 21e through 21j) show the extent of the TSS plume associated with dredging operations of the dredge *Delaware Bay*. Peak TSS concentrations within the plume reached as high as approximately 500 mg/L in some very small areas along the bottom and within 100 meters down-current of the source (Transect T02). The plume was largely isolated to the bottom half to two-thirds of the water column, with TSS concentrations as up to 200 mg/L within 185 meters down-current (Transect T05). The plume had dissipated to background conditions by 272 meters down-current (Transect T07). The plume varied in width from approximately 50 to 150 meters over its length. Heavy prop wash from vessel traffic was detected in transects T07-T09.

Figure 23 presents the hydrodynamic conditions recorded during the 14 March 2012 flood tide mobile ADCP survey discussed above. During this survey, depth-averaged current velocities within the area ranged from near 0 m/s to near approximately 0.5 m/s. Current direction in the western part of the survey area flowed in from the northwest compared to the eastern part of the survey area where currents flowed from the northeast. Where these currents met they turned to flow southeast towards Shooter’s Island and this central part of the survey area showed the highest current velocities at approximately 0.5 m/s or greater.

3.2.3.2 15 March 2012 (Flood Tide)

A mobile ADCP plume characterization survey was conducted on 15 March 2012 during the second half of a flood tide from approximately 14:21 to 14:54 (Figures 24a-24o). The survey consisted of one circle transect to locate the plume (Figure 24a), five up-current transects (Figures 24b through 24f), and nine down-current transects (Figures 24g through 24o). A summary of each of the graphically represented transects is presented in Table 9.

To examine the spatial extent of the plume, a series of plan-view layouts are given in Figures 25a through 25c. During this survey, the dredge *Delaware Bay* was located on the southern side of the Arthur Kill Channel approximately 380 meters east of the charted position of the green and red “A” navigation buoy. The *J.P. Boisseau* was approximately 100 meters to the north and east of the *Delaware Bay* in the center of the Arthur Kill Channel. Up-current transects were conducted to the west of the *Delaware Bay* and down-current transects were conducted to the east of the dredge. Up- and down-current transects were oriented perpendicular to the channel.

Up-current conditions presented in transects A01 through A05 (Figures 24b through 24f) show background ADCP estimated TSS concentrations between 0 and 30 mg/L in the top half to three-quarters of the water column, and a strata of higher ambient TSS concentrations ranging from approximately 30 to 200 mg/L near the bottom of the water column.

Down-current transects T01 through T08 (Figures 24g through 24n) show the extent of the TSS plume associated with dredging operations of the dredge *Delaware Bay*. Peak TSS concentrations within the plume reached as high as approximately 300 mg/L within 130 meters down-current of the source (Transect T01 and T02). The plume was present throughout the water column in a band approximately 10 to 20 meters wide, but otherwise spread out in the bottom half to two-thirds of the water column. Plume TSS concentrations were as high as approximately 150 mg/L from 157 to 271 meters down-current from the dredge, before returning to largely background conditions within 312 meters down-current. The acoustic signature visible on the left of Transects T03 through T06 likely comes from the excavator dredge *J. P. Boisseau,* which was also operating up current of these transects (Figure 25a-c). Plume generated by the *Delaware Bay* ranged from 30 to 60 meters in width across the extent of the plume.

Figure 26 presents the hydrodynamic conditions recorded during the 15 March 2012 flood tide mobile ADCP survey discussed above. During this survey, depth-averaged current velocities within the area ranged from near 0 m/s to near approximately 0.5 m/s. Current direction was generally towards the east or east-southeast for most of the survey area, with some currents coming in from the northeast in the northeastern part of the survey area. The greatest current velocities detected in this survey (greater than 0.2 m/s) were along the southern edge of the channel.

3.2.3.3 16 March 2012 (Ebb Tide)

A mobile ADCP plume characterization survey was conducted on 16 March 2012 during the middle portion of an ebb tide from approximately 7:40 to 8:55 (Figures 27a-27x). The survey consisted of one circle transect to locate the plume (Figure 27a), three up-current transects (Figures 27b through 27d), and twenty down-current transects (Figures 27e through 27x). A summary of each of the graphically represented transects is presented in Table 10.

To examine the spatial extent of the plume, a series of plan-view layouts are given in Figures 28a through 28c. During this survey, the dredge *Delaware Bay* was located on the southern side of the Arthur Kill Channel approximately 380 meters east of the charted position of the green and red “A” navigation buoy. The *J.P. Boisseau* was approximately 175 meters to the north and west of the *Delaware Bay* in the center of the Arthur Kill Channel. Up-current transects were conducted to the east of the *Delaware Bay* and down-current transects were conducted to the west of the dredge. Up- and down-current transects were oriented perpendicular to the channel.

Up-current conditions presented in transects A01 through A03 (Figures 27b through 27d) show background ADCP estimated TSS concentrations between 0 and 30 mg/L in the top half of the water column, and a stratum of higher ambient TSS concentrations ranging from approximately 30 to 100 mg/L in the bottom half.

Down-current transects T01 through T17 (Figures 27e through 27u) show the extent of the TSS plume associated with dredging operations of the *Delaware Bay.* Peak TSS concentrations within the plume reached as high as approximately 700 mg/L in very small areas within 142 meters down-current of the source (Transect T01). The plume was almost entirely concentrated in the lower half of the water column with the highest TSS concentrations confined to the channel side slope. Plume TSS concentrations were approximately 300 mg/L or less within 199 meters down-current from the dredge (Transect T05), and 200 mg/L or less within 237 meters down-current (Transect T08). Beyond 237 meters down-current, the plume settled to form a layer in the bottom half of the water column with TSS concentrations of 150 mg/L or less. Plume width ranged from 50 to 90 meters across its length. The plume signature visible on the left side of figures 27p through 27t (Transects T12 to T16) was likely generated by excavator dredge *J. P. Boisseau,* which was also operating up-current of these transects (Figure 28a-c). Both plumes dissipated to background conditions within 1,070 meters down-current of the *Delaware Bay* (Transect T18).

Figure 29 presents the hydrodynamic conditions recorded during the 16 March 2012 ebb tide mobile ADCP survey discussed above. During this survey, depth-averaged current velocities within the area ranged from approximately 0.1 to near 1.0 m/s. In general, currents during this survey were strongly oriented parallel to the Arthur Kill Channel, and flowed westward with little variation. Currents were fastest (0.5 m/s or greater) in the western part of the survey area, and lowest in the eastern part along the southern edge of the channel.

3.2.3.4 19 March 2012 (Ebb Tide)

A mobile ADCP plume characterization survey was conducted on 19 March 2012 during the middle portion of an ebb tide from approximately 12:04 to 13:26 (Figures 30a-30l). The survey consisted of one circle transect to locate the plume (Figure 30a), three up-current transects (Figures 30b through 30d), and eight down-current transects (Figures 30e through 30l). A summary of each of the graphically represented transects is presented in Table 11.

To examine the spatial extent of the plume, a series of plan-view layouts are given in Figures 31a through 31c. During this survey, the dredge *Delaware Bay* was located on the southern side of the Arthur Kill Channel approximately 240 meters east-northeast of the charted position of the green and red "A" navigation buoy. The *J.P. Boisseau* was approximately 300 meters to the north and east of the *Delaware Bay* on the northern side of the Arthur Kill Channel. Up-current transects were conducted to the east of the *Delaware Bay* and down-current transects were conducted to the west of the dredge. Up- and down-current transects were oriented perpendicular to the channel. Figure 32 provides a three-dimensional depiction of average TSS values for selected representative transects.

Up-current conditions presented in transects A01 through A03 (Figures 30b through 30d) show background ADCP estimated TSS concentrations between 0 and 40 mg/L throughout most of the water column with several small areas of higher concentrations near the very bottom (Transects A01 – A03). Surface prop wash from vessel traffic was also detected in these transects.

Down-current transects T01 through T08 (Figures 30e through 30l) show the extent of the TSS plume associated with dredging operations of the dredge *Delaware Bay*. Peak

TSS concentrations within the plume reached as high as approximately 250 mg/L in small areas at least 130 meters down-current of the source (Transects T01 – T02). Within 179 meters from the source (Transect T03), plume TSS concentrations of no more than 150 mg/L were largely confined to the lower half of the water column and were faintly detected up to 455 meters down current (Transect T08). Plume width ranged from approximately 75 to 120 meters over the length of the plume, which widened and sank lower in the water column farther from the dredge. Those parts of the plume that were closer to the surface had TSS concentrations of only approximately 30 to 75 mg/L. Prop wash from vessel traffic was detected near the surface in Transects T01, T02, and T08, as noted in the field observations presented in Table 11, and merged with the plume signature in some cases.

Figure 33 presents the hydrodynamic conditions recorded during the 19 March 2012 ebb tide mobile ADCP survey discussed above. During this survey, depth-averaged current velocities within the area ranged from approximately 0.1 to 1.0 m/s. Current direction throughout the survey area was generally towards the west, parallel with the Arthur Kill Channel. Current velocities were fastest at the western edge of the survey area, where velocities were greater than 0.5 m/s over a considerable portion of the survey area.

3.2.4 Laboratory Analysis of Water Samples

A total of 104 water samples were collected in the project area during S-AK-2 Far Field Survey #2. The laboratory results of the optical turbidity and the gravimetric analysis of TSS concentration of these samples are presented in Table 7. The TSS concentrations of the 104 water samples from Survey #2 ranged from 23 to 337 mg/L and turbidity values ranged from 3.85 to 210 NTU.

3.2.5 Sediview Calibration

To provide a robust data set for calibration of the ADCP backscatter, water samples from Surveys #1 and #2 were combined into one set containing 200 samples. Figure 35a plots the paired gravimetric measurements and ADCP acoustic estimates of TSS arranged in concentration versus time order for the 163 water samples used in the Sediview calibration. Note that some of the 200 water samples collected were excluded if they exhibited clear signs of air bubble contamination, interference with the water sampler apparatus, or contact with the sea bottom (see ADCP calibration methods described in

Section 2.4). Overall, there was a strong agreement (R^2 = 0.95) between the acoustic estimates of TSS concentration and the gravimetric measurements (Figure 35b).

3.2.6 Sediment Samples

A total of nine sediment samples (four from the dredge scow and five from the seabed in the dredging area) were collected during S-AK-2 Far Field Survey #2. The laboratory results of these sediment collections for grain size distribution, density and Atterberg Limits are presented in Table 12. Sediment samples collected during this survey had characteristics very similar to those collected in during S-AK-2 Survey #1. Samples were comprised mostly of silt, which made up over 60% of each sample collected and an average of 75% of all samples. Clay and sand made up the most of the remainder of the samples, with an average of approximately 18% and 6% composition, respectively. Four out of nine samples, three of which were from the dredge scow, contained gravel, and this averaged only 1% composition. The in-place density of the sediment samples ranged between 0.489 and 0.718 g/cc and averaged 0.556 g/cc, and the Atterberg Limits averaged 86.4, 37, and 49.2 for Liquid Limit, Plastic Limit, and Plasticity Index, respectively.

3.2.7 Dredging Operations — Bucket Cycles

To examine the bucket cycle sequence, a video record was obtained of 15 complete cycles during an ebb tide on 19 March, 2012. The video was then analyzed for time increments for each component of the cycle (Figure 34). The average total elapsed time per cycle was one minute, thirty seconds. A certain degree of variability in cycle component elapsed times can be seen across the 15 cycles in Figure 34. The shortest cycle was one minute, fourteen seconds, whereas the longest cycle was two minutes, eleven seconds.

Average time for each component of the dredge cycle was: Descent (18 seconds), Grab (8 seconds), Raise (20 seconds), Slew Over (13 seconds), Dump (19 seconds), and Slew Back (9 seconds).

4.0 DISCUSSION

During the course of normal dredging operations, some sediment is resuspended into the water column. In many cases, this suspended sediment is evident as a turbidity plume within the immediate vicinity of the dredge operation. Because suspended sediment plumes are dynamic rather than static phenomena and because they vary over large areas in short periods of time, particularly when driven by tidal currents, characterizing plumes can present a difficult challenge. Data collected at arbitrarily determined points in time at fixed locations are inadequate to assess dredge plume structure. However, advanced acoustic technologies offer advantages in capturing data at appropriate spatial and temporal scales to allow more accurate interpretation of plume dynamics (Tubman & Corson 2000).

As part of USACE-NYD's Harbor-wide WQ/TSS Monitoring Program, two far-field WQ/TSS surveys were conducted in March 2012 within the S-AK-2 contract area of the HDP in the North of Shooters Island Reach of the Arthur Kill. The objective of these far-field surveys was to assess the spatial extent and temporal dynamics of suspended sediment plumes associated with mechanical dredging of fine-grained sediment using an environmental or "closed" (i.e. with seals and flaps, as per contract specifications) clamshell bucket. Sediments in the S-AK-2 contract area, as sampled in these surveys, were predominantly composed of silt, with some clay and sand. Fine grained sediments such as silt can remain in suspension longer than coarser sediments might. Therefore, direct comparisons between other studies with different sediment types and under varying hydrodynamic conditions is inexact.

In both S-AK-2 Surveys, ambient suspended sediment conditions in the survey area were observed to be stratified within the water column, usually with concentrations of 0 to 30 mg/L near the surface, with concentrations increasing with depth to reach a maximum near the bottom of the water column. Maximum observed ambient TSS concentrations ranged from 40 to 200 mg/L. In some instances, the maximum ambient suspended sediment concentrations were similar to concentrations observed down-current within the plume from the *Delaware Bay*. A TSS plume generated by the excavator dredge *J. P. Boisseau* was also detected in some ADCP surveys, as this dredge was often operating in proximity to the *Delaware Bay*.

Peak estimates of TSS concentrations directly attributable to the dredging operation of the *Delaware Bay* ranged from approximately 250 mg/L to as high as approximately 700 mg/L in one ebb tide survey. These peak concentrations were usually detected only in very small areas near the bottom of the channel, and, at the most, 212 meters down-current from the dredge. In general for both surveys, TSS concentrations were 200 mg/L or less for most of the plume's extent.

With one exception, the sediment plume dissipated to essentially background conditions within 659 meters down-current or less. During an ebb tide mobile ADCP survey conducted on 16 March, 2012, the plume returned to background conditions within 1,070 meters down-current of the dredge. Current velocities as high as approximately 1.0 m/s were also observed during this survey, and the fact that the *J.P. Boisseau* was operating approximately 175 meters to the north and west of the *Delaware Bay* may have contributed to the down-current extent of the observed plume in this survey. On average across all surveys, the dredging-generated plume had become indistinguishable from background conditions within approximately 441 meters down-current from the source.

Maximum plume width varied between 50 and 200 meters, and averaged approximately 99 meters, across S-AK-2 Surveys #1 and #2. In all surveys, the widest portions of the plume were detected in the bottom two-thirds to one half of the water column. In some surveys, for example the 15 March 2012 flood tide survey and the 16 March 2012 ebb tide survey, the plume was observed to extend throughout the water column in the transects conducted closer to the dredge. However, the portions of the plume present in the upper parts of the water column tended to contain lower suspended sediment concentrations (less than approximately 100 mg/L) and be narrower (less than 50 meters) than portions near the bottom. In general, the dredge plume descended in the water column and widened along the bottom as distance from the source increased. In one survey, conducted during an ebb tide on 12 March 2012, the plume spread along the bottom of the Arthur Kill Channel, however in all other surveys the plume generally remained confined to the side of the channel closest to the dredge, and along the channel side slopes to just above the toe of the slope. During no survey was the dredge plume observed to extend beyond the slopes of the channel.

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