APPENDIX B
INTERIM REPORT FOR THE 2005 RESUSPENSION STUDY

NY & NJ Harbor Deepening Project - Total Suspended Solids (TSS) Monitoring

Interim Report

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For:

U.S. Army Corps of Engineers

Submitted by:

HDR | LMS

One Blue Hill Plaza
Pearl River, NY 10965

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I. INTRODUCTION

Water column total suspended solids (TSS) concentrations and turbidity were monitored during dredging operations in the Kill Van Kull. Monitoring was conducted in the portions of the S-KVK Dredging Project Area dominated by fine-grained sediments. Monitoring efforts focused on operations of the clamshell dredge Bean 2, which was equipped with an eight cubic yard cable arm environmental bucket.

The objectives of the monitoring effort were:

1) Define the extent of the suspended solids plume resulting from dredging operations through TSS and turbidity sampling; and

2) Correlate turbidity readings with TSS concentrations to facilitate future dredge operations monitoring.

II. SAMPLING METHODOLOGY

Sampling was conducted on four occasions, July 1, July 19, August 1, and August 15, 2005. Each sampling event included one ebb and one flood tidal stage, with the exception of August 15, which only included the flood tidal stage. On July 19, sampling was also conducted during slack low tide. For each sampling event, TSS concentrations and turbidity were measured at different locations relative to the dredge. TSS concentrations were measured directly at three discrete depths and turbidity was measured through the water column (profile) by taking readings at regular intervals from the surface to the bottom.

During each tidal stage, current speed and direction were established with a General Oceanics Electronic Flowmeter. One station up-current of dredging operations (background) was sampled first, followed by up to nine down-current stations. Station distance from the dredge was established using a range finder and a Trimble global positioning system (GPS). The up-current station was located approximately 250 ft from the dredge. The down-current stations were located approximately 250 ft, 500 ft, and 1000 ft from the dredge (station locations were labeled A, B and C, respectively for data summary and graphing purposes).

Three locations were sampled at each distance, one in the anticipated center of the plume, in line with the dredge and the current (center station), and two on anticipated edges of the plume (north and south, relative to the center stations). Some locations were not sampled during each survey due to tidal conditions, vessel traffic in the channel or in-water obstructions (e.g., bulkheads, piers).

At each sampling station the position coordinates were recorded after the boat was anchored. Depth was measured using a Hummingbird Wide Paramount depth finder. Turbidity, temperature and salinity (as conductivity) profiles were collected using a conductivity-temperature-depth recorder (CTD) equipped with an optical backscatter meter (OBS). The CTD/OBS was lowered through the water column until it made contact with the bottom. Measurements were recorded approximately once per second during each CTD/OBS cast, where downcast refers to the instrument descending through the water column and upcast refers to the instrument ascending through the water column. One downcast and upcast was performed at each station.

At each station, discreet water samples were collected for TSS analysis using a Niskin bottle. Grab samples were collected 18 in below the surface (near-surface), at mid-depth, and approximately 3 ft above the bottom (near-bottom). For shallow stations (< 15 ft. deep), only near-bottom samples were collected. Grab samples were collected in duplicate on July 1 and in triplicate on July 19, August 1, and August 15. One water sample from each depth was analyzed for temperature, conductivity and turbidity. Temperature and conductivity were measured using a YSI Model 85 multiple parameter meter and turbidity was measured using an HF Scientific Portable Turbidimeter. Water samples were poured from the Niskin sampler into Nalgene sample bottles and placed on ice until delivery to the analytical laboratory.

Samples were analyzed for TSS using EPA Method 160.2 and concentrations were reported as mg/L. Turbidity readings were correlated to TSS concentrations using both field measurements and a laboratory calibration of the OBS sensor, described in Section VI.

III. STATION LOCATIONS

1. JULY 1, 2005

The Bean 2 dredge was located at the east end of Shooters Island in the Kill Van Kull. Sampling began on the ebb tide. The direction of the tidal current was generally southeast. Sampling was conducted at ten locations; one location 250 ft up-current of the dredge and three locations at each distance of 250 ft (A), 500 ft (B) and 1000 ft (C) down-current of the dredge.

Sampling was not conducted during slack low water due to maintenance of the dredge at this time. Dredging and sampling resumed during the flood tide. The direction of the tidal current during the flood tide was generally northwest. Although current speed was not measured on this date, visual observation indicated that the flood tidal current speed was faster than the ebb tidal current speed. Sampling was conducted at nine locations; one location 250 ft up-current of the dredge, two locations 250 ft down-current of the dredge and three locations at each distance of 500 ft and 1000 ft down-current of the dredge.

A summary of station information is provided in Table 1. Locations of the sampling stations in the Kill van Kull relative to the dredge are shown in Figure 1.

2. JULY 19, 2005

The Bean 2 dredge was located east of Shooters Island in the Kill Van Kull. The dredge Tauracavor was positioned approximately 1500 ft away from the Bean 2, dredging material comprised of approximately 65% rock and 35% glacial till and clay. However, the dredge Tauracavor was out of service for the entire sampling period and thus did not influence TSS concentrations or turbidity at this location.

Sampling began on the ebb tide. The direction of the tidal current was generally southeast. Sampling was conducted at eight locations; one location 250 ft up-current of the dredge, three locations approximately 250 ft down-current of the dredge, and two locations at each distance of 500 ft and 1000 ft down-current of the dredge. The dredge stopped working before the second and third locations at each approximate distance of 500 ft and 1000 ft could be sampled. When dredging resumed, the tidal stage was slack low water. Two locations were sampled during slack low tide, both were approximately 250 ft from the dredge.

The direction of the flood tidal current was generally northwest and as previously noted, the current was faster than the ebb tidal current. Sampling was conducted at one location 250 ft up-current of the dredge, three locations approximately 250 ft down current of the dredge, two locations approximately 500 ft down-current of the dredge, one location 750 ft down-current of the dredge and one location 1000 ft down-current of the dredge. In-water obstructions and the position of the dredge Tauracavor prevented sampling at all 1000 ft locations. The 750 ft location was sampled instead of a 500 ft location in order to obtain samples on the shoal.

A summary of station information is provided in Table 2. Locations of the sampling stations in the Kill van Kull relative to the dredge are shown in Figure 2. The dredge spuds were retracted a couple of times during the sampling event and the dredge moved approximately 100 ft each time. The sampling transect was shifted to follow the potential suspended sediment plume.

3. AUGUST 1, 2005

The Bean 2 dredge was located east of Shooters Island in the Kill Van Kull. The dredge Tauracavor was positioned approximately 1500 ft away from the Bean 2. The Tauracavor was operating during the sampling event, dredging material comprised of approximately 30% rock and 70% glacial till and clay. Operations of the Tauracavor may have influenced TSS concentrations and turbidity readings at the background station on the ebb tide.

Sampling began on the ebb tide. As previously observed, the direction of the tidal current was generally southeast. Sampling was conducted at seven locations; one location 250 ft up-current of the dredge and three locations at each approximate distance of 250 ft and 500 ft down-current of the dredge. Instrumentation maintenance of the CTD/OBS delayed initiation of sampling, and the end of the ebb tidal phase occurred before sampling at the 1000 ft stations could be completed. Sampling was not conducted at slack low tide.

Flood tide sampling began at the background sampling location approximately 250 ft up-current of the dredge. After sampling was completed at this station, the dredge went out of service for two hours for repairs to the clamshell bucket. Dredging and sampling resumed during the flood tidal stage. As previously noted, the direction of the flood tidal current was generally northwest and the speed of the current was greater than that of the ebb tide. Maintenance of the CTD/OBS prevented turbidity profiles from being sampled at down-current stations during the flood tide. Only four locations could be sampled for TSS due to time constraints. Sampling for TSS was conducted at three locations 250 ft down current of the dredge and one location 700 ft down-current of the dredge. A location 700 ft down-current of the dredge was chosen because two locations at distances of 500 ft could not be sampled due to in-water obstructions and the position of the dredge Tauracavor, and stations at distances of 1000 ft could not be sampled due to heavy vessel traffic in the channel.

A summary of station information is provided in Table 3. Locations of the sampling stations in the Kill van Kull, relative to the dredge are shown in Figure 3

4. AUGUST 15, 2005

The Bean 2 dredge was located between the Bayonne Bridge and Shooters Island in the Kill Van Kull. The dredge Tauracavor was positioned approximately 3000 ft away from the Bean 2. The Tauracavor was operating during the sampling event, dredging material comprised of approximately 50% rock and 50% glacial till and clay. However, due to the relative locations of the dredges and the tidal conditions, this additional dredging activity did not appear to influence TSS concentrations or turbidity in the vicinity of the Bean 2.

Sampling was conducted on the flood tide. As previously observed, the direction of the tidal current in the channel was generally northwest. However, at this sampling location, the flood tidal current was not very strong and surface currents appeared to be moving in the opposite direction even though a flood tidal current was evident in the main channel.

Flood tide sampling began at the background sampling location 250 ft up-current of the dredge. Sampling was conducted at three locations 250 ft down current of the dredge and two locations 500 ft down-current of the dredge. The dredge stopped working for approximately one hour for maintenance. When dredging resumed, two additional locations were sampled up-current of the dredge, due to the apparent tidal eddies at this location. Due to the generally weak strength of the tidal current, sampling was not conducted at 1000 ft intervals.

A summary of station information is provided in Table 4. Locations of the sampling stations in the Kill van Kull relative to the dredge are shown in Figure 4.

IV. DATA ANALYSIS

The presence or absence of suspended sediment plumes was determined through statistical comparison of background and down-current TSS concentrations and turbidity. A plume was considered present when down-current values were significantly higher than background levels.

Mean TSS concentrations were calculated for each depth (near-surface, mid-depth and bottom) for each station. For each sample date and each tide (flood or ebb) a two-way analysis of variance (ANOVA) was performed with depth and station as independent variables and TSS concentration as the dependent variable. Tests were conducted at the α=0.05 significance level.

Due to significant interaction terms between the two variables in many cases, it was not possible to make conclusions as to the significance of the main effects (depth and station). Therefore, a one-way ANOVA was conducted for depth and station separately as the independent variables. When the one-way ANOVA indicated a significant effect, Tukey's

Studentized Range (HSD) Test was performed in order to determine which depths and/or stations were significantly different using pairwise comparisons.

For each sampling station, mean turbidity values were calculated for the following depth ranges: 0 to 10 ft, 10 to 20 ft, 20 to 30 ft, 30 to 40 ft and 40 to 50 ft. ANOVAs were then performed as previously described for TSS data, with depth range and Station ID as independent variables and turbidity as the dependent variable. For both TSS and turbidity data, when a significant difference was indicated in the near-bottom depths, a separate one-way ANOVA was performed to compare near-bottom TSS and turbidity values between stations.

V. RESULTS

Turbidity and TSS concentration results from the four sampling events are presented below. For CTD/OBS data, only the results of downcasts (instrument descending through the water column) are presented due to the potential effect of instrument contact with the bottom on upcast turbidity readings.

1. JULY 1, 2005

Salinity ranged from 18.98 to 20.64 ppt on the ebb tide and from 19.12 to 21.70 ppt on the flood tide and was relatively uniform throughout the water column. Temperature ranged from 22.98 to 24.53 ^{o}C on the ebb tide and from 22.19 to 26.38 ^{o}C on the flood tide and was also similar throughout the water column.

During the ebb tide, background (up-current) turbidity ranged from 3 to 4 NTU and mean background TSS concentrations ranged between 5.5 and 6.8 mg/L (Figure 5). Mean turbidity was similar to background for all stations except Station A-Down-C, the center station located in the channel, 250 ft down-current of the dredge. At this station, turbidity ranged from 3 to 35 NTU and was significantly higher ($p<0.0001$) than at the up-current station (Figure 5). During the ebb tide, turbidity in the depth range of 40 to 50 ft was significantly higher ($p<0.0001$) than turbidity at all other locations in the water column, and turbidity in the depth ranges of 30 to 40 ft and 20 to 30 ft was significantly higher ($p<0.0001$) than turbidity in the surface water (0 to 10 ft). This was likely caused by the increase in turbidity with depth at Station A-Down-C, as there was an interaction between depth range and station. Comparison of near-bottom turbidities between stations did not produce a different result from comparison of turbidity over all depths (Figure 5).

Mean TSS concentrations at Station A-Down-C (in the channel, 250 ft down-current of the dredge) were also significantly higher ($p<0.0003$) than mean TSS concentrations at the up-current station, and ranged between 4.7 mg/L in the near-surface water samples and 51.8 in the near-bottom water samples (Figure 5). Mean TSS concentrations at all other stations were similar to the up-current station. During the ebb tide, TSS concentrations were not significantly different between near-surface, mid-water, and near-bottom samples.

During the flood tide, background (up-current) turbidity ranged from 3 to 14 NTU and mean background TSS concentrations were between 6.3 and 13.8 mg/L (Figure 6). Mean turbidity was significantly higher than background ($p<0.0001$) at Stations A-Down-C, B-Down-C, B-Down-S, and C-Down-C. At Stations A-Down-C and C-Down-C, center stations located in the channel, 250 ft and 1000 ft down-current of the dredge, turbidity readings ranged from 6 to 40 NTU, and increased in the near-bottom water (Figure 6). At Stations B-Down-C and B-Down-S, the center and south stations located in the channel, 500 ft down-current of the dredge, turbidity readings ranged from 6 to 15 NTU and increased slightly with depth. During the flood tide, turbidity readings in the depth range of 30 to 40 ft and 40 to 50 ft were significantly higher ($p<0.0001$) than turbidity readings at the shallower locations in the water column. There was an interaction between depth range and station, likely caused by the increase in turbidity with depth at all downstream stations except for those on the north track (Figure 6). Comparison of near-bottom turbidities between stations did not produce a different result from comparison of turbidity over all depths.

Mean TSS concentrations at Station B-Down-S (in the channel, 500 ft down-current of the dredge) were significantly higher ($p<0.0003$) than mean TSS concentrations at the up-current station, and ranged between 15 mg/L in the near-surface water and 32.5 mg/L in the near-bottom water (Figure 6). Mean TSS concentrations at all other stations were similar to the up-current station, when all depths were compared together. During the flood tide, TSS concentrations were significantly higher in the near-bottom water ($p<0.008$) than in mid-depth and near-surface water. When only near-bottom TSS concentrations were compared between stations, mean concentrations at Stations B-Down-S, C-Down-C and C-Down-S, located in the channel, 500 ft (B) and 1000 ft (C) down-current of the dredge, were significantly higher than mean concentrations at the up-current station (Figure 6).

Summary: During the ebb tide, significantly higher turbidity and TSS concentrations were measured at the station in the channel, 250 ft down-current from the dredge, in line with the dredge and current. Turbidity and TSS concentrations at all other ebb tide stations were similar to the up-current station. During the flood tide, significantly higher turbidity was measured at all center stations in the channel (250 ft, 500 ft and 1000 ft down-current of the dredge) and at one south station located in the channel, 500 ft down-current of the dredge. Mean TSS concentrations at this south station were significantly higher than background concentrations. When only near-bottom depths were compared, two stations 1000 ft down-current of the dredge (center and south tracks) had mean TSS concentrations significantly higher than background concentrations. Two stations had elevated TSS concentrations that corresponded with elevated turbidity readings.

2. JULY 19, 2005

Salinity ranged from 19.2 to 20.7 ppt during the ebb tide, from 18.8 to 19.9 ppt during slack low tide, and from 18.9 to 21.1 ppt during flood tide and was relatively uniform throughout the water column. Temperature ranged from 24.8 to 25.9 ^{o}C during ebb tide, from 24.9 to 26.4 ^{o}C during slack low tide, and from 24.8 to 25.1^{o}C during flood tide and was also similar throughout the water column.

During the ebb tide, background (up-current) turbidity ranged from 5 to 10 NTU and mean background TSS concentrations ranged between 9.0 and 14.5 mg/L (Figure 7). Mean turbidity readings were similar to background readings for all stations down-current of the dredge when turbidity was compared across all depth ranges. During the ebb tide, turbidity readings in the depth range of 40 to 50 ft were significantly higher ($p<0.0001$) than turbidity readings at all other locations in the water column. When turbidity in the bottom depth range was compared between stations, turbidity at Station A-Down-C (in the channel, 250 ft down-current of the dredge) was significantly higher than turbidity at the up-current station (Figure 7).

Mean TSS concentrations at Station A-Down-S (in the channel, 250 ft down-current of the dredge) were significantly higher ($p<0.0001$) than mean TSS concentrations at the up-current station, and ranged between 12.9 mg/L in the near-surface water samples and 18.9 mg/L in the near-bottom water samples (Figure 7). Mean TSS concentrations at all other stations were similar to the up-current station. During the ebb tide, TSS concentrations were significantly higher in the near-bottom water ($p<0.001$) than in the near-surface water, but when near-bottom TSS concentrations were compared between stations, mean concentrations at the down-current stations were not significantly different from mean TSS concentrations at the up-current station.

During the flood tide, background (up-current) turbidity readings ranged from 5.4 to 18 NTU and mean background TSS concentrations were between 11 and 16.5 mg/L (Figure 8). Mean turbidity was significantly higher than background ($p<0.0001$) at Stations A-Down-C, A-Down-S, B-Down-C, B-Down-N, and C-Down-N. Turbidity was greatest at Stations A-Down-C and A-Down-S (both in the channel, 300 ft and 250 ft down-current of the dredge), ranging between 8.8 and 29.5 NTU and increasing in the near-bottom water. Turbidity also increased in the near-bottom water at Station C-Down-N (in the channel, 1100 ft down-current of the dredge), up to 25.9 NTU. Field notes indicated that a large container ship passed just prior to sampling at Station C-Down-N. Turbidity at Stations B-Down-C and B-Down-N (in the channel, 500 ft and 450 ft down-current of the dredge) ranged from 10 to 20 NTU and was relatively constant throughout the water column. During the flood tide, turbidity in the depth range of 30 to 40 ft and 40 to 50 ft was significantly higher ($p<0.0001$) than turbidity at the shallower locations in the water column. There was an interaction between depth range and station, likely caused by the increase in turbidity with depth at Stations A-Down-C, A-Down-S, and C-Down-N (Figure 8). Comparison of near-bottom turbidities between stations did not produce a different result from comparison of turbidity over all depths.

Mean TSS concentrations at Station A-Down-S (in the channel, 250 ft down-current of the dredge) were significantly higher ($p<0.0001$) than mean TSS concentrations at the up-current station, and ranged between 25.3 mg/L in the near-surface water samples and 75.6 mg/L in the near-bottom water samples (Figure 8). Mean TSS concentrations at all other stations were similar to the up-current station, when all depths were compared together. During the flood tide, TSS concentrations were significantly higher in the near-bottom water ($p<0.008$) than in near-surface water. There was an interaction between depth and station, which was likely caused by the high TSS concentrations in the bottom water of Station A-Down-S, as comparison of mean near-bottom TSS concentrations between stations did not produce a different result from comparison of TSS concentrations over all depths.

Turbidity at slack low tide ranged between 3.4 and 7.5 NTU and mean TSS concentrations ranged between 9 and 11 mg/L. Both turbidity and TSS concentrations were similar to both the flood tide and ebb tide up-current stations (Figure 9).

Summary: During the ebb tide, significantly higher mean TSS concentrations relative to background were measured at the south station located in the channel, 250 ft down-current from the dredge. However, these concentrations were less than 20 mg/L. Significantly higher turbidity was measured in the near-bottom water at the center station located 250 ft down-current of the dredge, but this difference was not reflected in the measured TSS concentrations. During the flood tide, turbidity was higher than background at five down-current stations, which were all located in the channel. Two stations were located approximately 250 feet from the dredge (250 ft and 300 ft, center and south tracks), two were located approximately 500 ft from the dredge (450 ft and 500 ft, center and north tracks) and one was located 1100 ft from the dredge (north track). At the station 1000 ft down-current of the dredge turbidity may have been influenced by the passage of a large container ship. Mean TSS concentrations were higher than background concentrations at only one station, 250 ft down-current of the dredge (in the channel, south track).

3. AUGUST 1, 2005

Water column salinity, temperature and turbidity were only measured on the ebb tide due to maintenance of the CTD/OBS during the flood tide. Salinity ranged from 21.4 to 22.5 ppt on the ebb tide and temperature ranged from 24.9 to 26.2 ^{o}C and both were generally uniform throughout the water column.

Background (up-current) turbidity ranged from 5 to 10 NTU on the ebb tide to a depth of approximately 39.8 ft (Figure 10). From 39.8 ft to 46 ft, turbidity ranged from 27 to 59.5 NTU. Turbidity measurements at this location may have been influenced by the dredge Tauracavor. Mean TSS concentrations at the up-current station were 12 to 13 mg/L in the near-surface and mid-water, and 36.5 in the near-bottom water. The flood tide up-current station was included in statistical analysis of turbidity due to the potential influence of the second dredge on the ebb tide up-current station. Turbidity at the flood tide up-current station ranged from 3.5 to 8.0 NTU. When turbidity was compared between all ebb tide stations and the up-current flood tide station, turbidity at the ebb tide up-current station was significantly higher ($p<0.0001$) than all other stations. Turbidity at the ebb tide down-current stations was not significantly different from the flood tide up-current station when compared across all depths. Turbidity readings in the depth range of 40 to 50 ft were significantly higher ($p<0.0001$) than turbidity readings at all other locations in the water column. There was an interaction between depth range and station, and when turbidity in the bottom depth range was compared between stations, near-bottom turbidities at the ebb tide up-current station and at Station A-Down-N (in the channel, 285 ft down-current of the dredge) were significantly higher than turbidity at the flood tide up-current station. Mean TSS concentrations were not significantly different between any of the ebb tide stations.

During the flood tide, mean TSS concentrations at the up-current station were between 11 and 17.5 mg/L (Figure 11). Mean TSS concentrations were not significantly different between the down-current stations and the up-current station. Mean TSS concentrations were not significantly different between near-surface, mid-depth and near-bottom water samples.

Summary: During the ebb tide, turbidity at the up-current station was significantly higher than at all of the down-current stations, likely due to the influence of the dredge Tauracavor.

Significantly higher near-bottom turbidity, relative to the flood tide up-current station, was measured at Station A-Down-N, the north station located 285 ft down-current from the dredge. This difference was not reflected in the mean TSS concentrations, which were less than 20 mg/L at all depths at this sampling station.

4. AUGUST 15, 2005

During the flood tide, salinity ranged from 20.0 to 24.2 ppt and temperature ranged from 24.8 to 26.5 ^{o}C. Both were relatively uniform throughout the water column. Background (up-current) turbidity readings ranged from 5 to 14 NTU and background TSS concentrations ranged between 25 and 27 mg/L (Figure 12). However, turbidity was significantly lower than the "background" station, ranging between 5 and 11.5 NTU, at Stations A-Down-C, B-Down-C, located in the channel, 250 ft and 525 ft down-current of the dredge, and Up-Current 300', located in the shallows. Turbidity at Station A-Down-S (on the side-slope, 300 ft down-current of the dredge) was significantly higher than all other stations, ranging from 8.3 NTU to 26.7 NTU. Turbidity in the depth range of 0 to 10 ft was significantly lower ($p<0.0001$) than turbidity at all other locations in the water column. There was an interaction between depth and station, which is probably due to turbidity changing with depth at some stations (increasing or decreasing) and not at others (Figure 12).

Mean TSS concentrations at Station A-Down-S (side-slope, 300 ft down-current of the dredge) were significantly higher ($p<0.0025$) than mean TSS concentrations at the up-current station, and ranged between 25.5 mg/L in the near-surface water samples and 45.1 mg/L in the near-bottom water samples (Figure 12). During the flood tide there was no significant difference between mean TSS concentrations in near-surface, mid-depth and near-bottom waters.

<u>Summary:</u> During the flood tide, both turbidity and mean TSS concentrations were significantly higher than background at one south station (A-Down-S), located on the side-slope, 300 ft down-current of the dredge.

VI. CORRELATION OF TSS CONCENTRATIONS AND TURBIDITY

Correlation between TSS concentrations and turbidity data was established using both field data and laboratory calibration of the OBS sensor. For field data, the mean TSS concentrations at a particular depth were compared to the mean turbidity reading at that depth. The mean turbidity value was calculated over the range of depths equal to the TSS sample collection depth $\pm$ 3 ft. Turbidity was then plotted as a function of TSS concentration and linear regression was used to derive a relationship (Figure 13). The regression was significant ($p<0.0001$) and both the regression coefficient (0.393) and intercept (2.24) were significantly different from zero with p-values of 0.0001 and 0.004, respectively. The R^2 value was 0.43.

Laboratory calibration of the OBS sensor with sediment was performed following the methods in the D&A Instrument Company operations manual for OBS 1 and OBS 3 sensors. Sediment was collected from within dredging area during each sampling event using a Ponar Grab. As the sediment properties were similar on all collection dates, only sediment collected on August 15, 2005 was used for the calibration. Calibration was first performed using dried sediment. The sediment was homogenized and a subsample was placed in a drying oven at 106°C. Large debris were removed by hand prior to drying. Calibration was performed with a constant volume of deionized water in a black bucket using a hand-drill equipped with a stainless steel stirrer. Dry sediment was weighed into individual weigh boats and disaggregated in a small amount of water (1 ml). The sediment was added to the bucket incrementally and the OBS recorded turbidity (through the CTD) for a period of 2 minutes after each addition. The mean turbidity value was calculated over the time period, plotted against the concentration of suspended solids (TSS), and linear regression was used to derive a relationship (Figure 14). The regression was significant ($p<0.0001$) and both the regression coefficient (0.144) and intercept (0.834) were significantly different from zero with p-values < 0.0001. The R^2 value was 0.998.

Due to the properties of the sediment ("sticky" black mud) complete disaggregation was difficult after drying. Since incomplete disaggregation can affect the correlation between turbidity and TSS concentrations, calibration was also performed using wet sediment. The sediment was homogenized and three subsamples were weighed into crucibles and placed in a drying oven for percent moisture analysis. Percent moisture was determined to be 50%. Wet sediment was then weighed into individual weigh boats and disaggregated in a small amount of water (1 ml). As described for the dried sediment, wet sediment was added to the deionized water incrementally and the OBS recorded turbidity (through the CTD) for a period of 2 minutes after each addition. The mean turbidity value was calculated over the time period, plotted against the dry weight-based concentration of suspended solids (TSS), and linear regression was used to derive a relationship (Figure 15). The regression was significant ($p<0.0001$) and both the regression coefficient (0.253) and intercept (0.899) were significantly different from zero with p-values of 0.0001 and 0.0002, respectively. The R^2 value was 0.999.

VII. CONCLUSIONS

Generally, significantly higher turbidity and TSS concentrations relative to background were limited to within 250 ft of dredging operations. For the ebb tide sampling events on July 1, July 19 and August 1, 2005 significantly higher turbidity and TSS concentrations relative to background were only present at stations located in the channel, approximately 250 ft from the dredge (Track A). For the flood tide sampling events on July 1 and July 19, significantly higher turbidity and TSS concentrations relative to background were measured at stations in the channel, up to 1000 ft down-current of the dredge (Tracks A, B and C). However, on July 19 the elevated turbidity at one station 1000 ft down-current of the dredge may have been caused by a passing container ship. On August 15 during the flood tide, significantly higher turbidity and TSS concentrations relative to background were only measured at one station located on the side-slope, 300 ft down-current of the dredge. On July 1 (observed) and July 19 (measured), the flood tidal current was much faster than the ebb tidal current, which indicates the effect of tidal current on spatial distribution of the suspended solids plume. This is further supported by the limited distribution of the plume on August 15, when dredging and sampling occurred at a location with a weak flood tidal current.

Background turbidity generally ranged from 5 to 18 NTU and background TSS concentrations generally ranged between 5 and 18 mg/L. The highest turbidity values measured were between 35 and 40 NTU, with the exception of the up-current measurement that was likely influenced by the dredge Tauracavor (up to 60 NTU). The two greatest mean TSS concentrations measured were 45 and 77 mg/L. Generally, higher turbidity and TSS concentrations occurred in near-bottom water in channel areas. This suggests that the suspended solids plume is primarily concentrated in the bottom water of the navigation channel, with generally decreasing concentrations with decreasing depth in the water column (shallower). These results correspond to other studies of turbidity and TSS in the NY/NJ Harbor. Ambient TSS concentrations have been reported to range from 4 to 44 mg/L with generally higher TSS concentrations in the near-bottom water (LMS 1997, USACE 2002). Concentrations over an order of magnitude higher than background concentrations (up to 952 mg/L) have been observed following passage of container ships (LMS 1997, USACE 2002).

Generally, significantly higher TSS concentrations were reflected in the turbidity measurements. However, significantly higher turbidity was not necessarily reflected in the measured TSS concentrations, especially during the flood tidal stage. This suggests that the suspended solids plume may be highly variable over short time periods and may dissipate relatively quickly depending on the current speed. Also, elevated turbidity/TSS concentrations were not necessarily consistent along one track (e.g. higher measurements were not concentrated to one track or transect). This suggests that the suspended solids plume may also show high spatial variation.

The correlation between TSS and turbidity measurements with the OBS was very strong in the laboratory calibration. This demonstrates that the OBS does effectively measure increasing concentrations of suspended solids, and that relative comparisons of turbidity will provide an indirect measure of relative concentrations of suspended solids. The field correlation between turbidity and TSS concentrations was significant, but was likely affected by temporal variability of the plume. The laboratory-derived coefficient was approximately one half of the field-derived coefficient. Therefore, field turbidity measurements converted to TSS concentrations using the coefficient derived from the laboratory calibration will be approximately two times the TSS concentrations measured in the field. Although the laboratory calibration will always represent "ideal" conditions, both the field and laboratory correlations can be optimized in an attempt to produce a stronger relationship between them.

VIII. RECOMMENDATIONS FOR FUTURE MONITORING EFFORTS

- Characterize the backscatter from suspended solids and current velocity throughout the water column using an Acoustic Doppler Current Profiler (ADCP) to assist in assessing movement of the suspended solids plume and temporal variability.
- Use the ADCP to take continuous measurements while the vessel is underway in order to capture potential spatial variability of the suspended solids plume
- Continue to take TSS grab samples at fixed stations in triplicate in order to provide statistically comparable concentrations and to aid in correlation of relative measures (OBS, ADCP) with actual concentrations
- Continue to use the CTD/OBS to measure conductivity (salinity), temperature, depth and turbidity to characterize the water column

- Optimize the field correlation of turbidity and TSS concentrations by taking concurrent OBS measurements with grab samples
- Optimize the laboratory correlation of turbidity and TSS concentrations by using filtered site water or artificial seawater and performing grain size analysis on grab samples to characterize the suspended material and mimic the composition in the calibration.

IX. REFERENCES

LMS. 1997. Water quality monitoring of Howland Hook dredge operation. Lawler, Matusky and Skelly Engineers, Pearl River, NY.

USACE. 2002. 2001 Total suspended sediment and turbidity monitoring for Newark Bay, Kill van Kull, and Port Jersey. U.S. Army Corps of Engineers, New York District, New York, NY.

Table 1. Station information for sampling conducted on July 1, 2005.

Date	ID	Tide	Distance ft	Location	Track	Depth ft
7/1/2005	Up-Current	Ebb	250	Upstream	Center	33
7/1/2005	A-Down-C	Ebb	250	Downstream	Center	45
7/1/2005	A-Down-S	Ebb	250	Downstream	South	13
7/1/2005	A-Down-N	Ebb	250	Downstream	North	43
7/1/2005	B-Down-C	Ebb	500	Downstream	Center	25
7/1/2005	B-Down-S	Ebb	500	Downstream	South	20
7/1/2005	B-Down-N	Ebb	500	Downstream	North	44
7/1/2005	C-Down-C	Ebb	1000	Downstream	Center	30
7/1/2005	C-Down-S	Ebb	1000	Downstream	South	15
7/1/2005	C-Down-N	Ebb	1000	Downstream	North	44
7/1/2005	Up-Current	Flood	250	Upstream	Center	44
7/1/2005	A-Down-C	Flood	250	Downstream	Center	37
7/1/2005	A-Down-N	Flood	250	Downstream	North	46
7/1/2005	B-Down-C	Flood	500	Downstream	Center	42
7/1/2005	B-Down-S	Flood	500	Downstream	South	36
7/1/2005	B-Down-N	Flood	500	Downstream	North	47
7/1/2005	C-Down-C	Flood	1000	Downstream	Center	42
7/1/2005	C-Down-S	Flood	1000	Downstream	South	44
7/1/2005	C-Down-N	Flood	1000	Downstream	North	48

* Current speed and wind conditions were not recorded on this date

Table 2. Station information for sampling conducted on July 19, 2005.

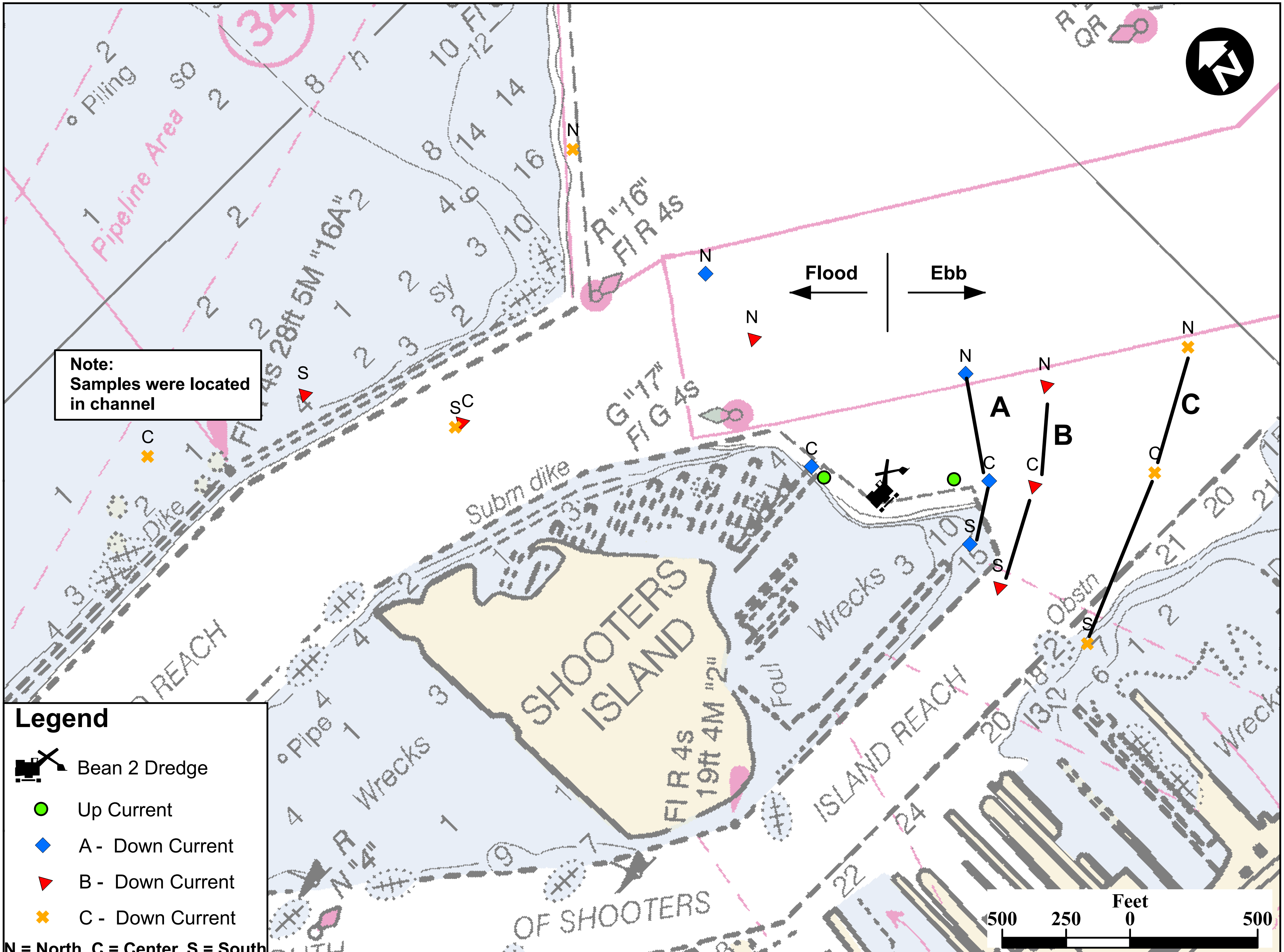
Date	ID	Tide	Distance ft	Location	Track	Depth ft	Current cm/s	Wind speed mph	Wind Dir	Precip
7/19/2005	Up-Current	Ebb	250	Upstream	Center	45	9	0 - 5	SW	NO
7/19/2005	A-Down-C	Ebb	250	Downstream	Center	46	20	0 - 5	SW	NO
7/19/2005	A-Down-S	Ebb	250	Downstream	South	41	10	0 - 5	SW	NO
7/19/2005	A-Down-N	Ebb	250	Downstream	North	45	15	0 - 5	SW	NO
7/19/2005	B-Down-C	Ebb	500	Downstream	Center	45	22	0 - 5	SW	NO
7/19/2005	B-Down-S	Ebb	500	Downstream	South	44	13	0 - 5	SW	NO
7/19/2005	C-Down-C	Ebb	1000	Downstream	Center	45	20	0 - 5	SW	NO
7/19/2005	C-Down-N	Ebb	900	Downstream	North	45	25	0 - 5	SW	NO
7/19/2005	Slack 300'	Slack Low	300	Slack	North	43	5	5 - 10	SW	NO
7/19/2005	Slack 250'	Slack Low	250	Slack	North	43	0	10 - 15	SW	NO
7/19/2005	Up-Current	Flood	300	Upstream	Center	45	5	15 - 20	SW	NO
7/19/2005	A-Down-C	Flood	300	Downstream	Center	41	40	15 - 20	SW	NO
7/19/2005	A-Down-S	Flood	250	Downstream	South	47	15	15 - 20	SW	NO
7/19/2005	A-Down-N	Flood	250	Downstream	North	46	35	15 - 20	SW	NO
7/19/2005	B-Down-C	Flood	500	Downstream	Center	46	30	15 - 20	SW	NO
7/19/2005	B-Down-N	Flood	450	Downstream	North	45	45	15 - 20	SW	NO
7/19/2005	C-Down-S	Flood	750	Downstream	South	6	15	15 - 20	SW	NO
7/19/2005	C-Down-N	Flood	1100	Downstream	North	47	25	15 - 20	SW	NO

Table 3. Station information for sampling conducted on August 1, 2005.

Date	ID	Tide	Distance ft	Location	Track	Depth ft	Current cm/s	Wind speed mph	Wind Dir	Precip
8/1/2005	Up-Current	Ebb	300	Upstream	Center	44	0	0 - 5	SE	NO
8/1/2005	A-Down-C	Ebb	300	Downstream	Center	43	5	0 - 5	SE	NO
8/1/2005	A-Down-S	Ebb	300	Downstream	South	12	5	0 - 5	SE	NO
8/1/2005	A-Down-N	Ebb	285	Downstream	North	46	10	0 - 5	SE	NO
8/1/2005	B-Down-C	Ebb	600	Downstream	Center	43	10	0 - 5	SE	NO
8/1/2005	B-Down-S	Ebb	500	Downstream	South	13	10	0 - 5	SE	NO
8/1/2005	B-Down-N	Ebb	550	Downstream	North	45	5	0 - 5	SE	NO
8/1/2005	Up-Current	Flood	275	Upstream	Center	42	5	0 - 5	SE	NO
8/1/2005	A-Down-C	Flood	320	Downstream	Center	48	25	0 - 5	SE	NO
8/1/2005	A-Down-S	Flood	270	Downstream	South	11	20	5 - 10	E	NO
8/1/2005	A-Down-N	Flood	285	Downstream	North	53	50	5 - 10	SE	NO
8/1/2005	B-Down-C	Flood	700	Downstream	Center	49	40	5 - 10	SE	NO

Table 4. Station information for sampling conducted on August 15, 2005.

Date	ID	Tide	Distance ft	Location	Track	Depth ft	Current cm/s	Wind Speed mph	Wind Dir	Precip
8/15/2005	Up-Current	Flood	350	Upstream	Center	51	10	5 - 10	N	NO
8/15/2005	Up-Current 300'	Flood	300	Upstream	South	14	0	5 - 10	N	NO
8/15/2005	Up-Current 550'	Flood	550	Upstream	Center	26	5	10 - 15	N	NO
8/15/2005	A-Down-C	Flood	250	Downstream	Center	50	10	10 - 15	N	NO
8/15/2005	A-Down-S	Flood	300	Downstream	South	28	10	5 - 10	N	Lt. Rain
8/15/2005	A-Down-N	Flood	250	Downstream	North	49	15	5 - 10	N	Lt. Rain
8/15/2005	B-Down-C	Flood	525	Downstream	Center	50	10	5 - 10	NE	NO
8/15/2005	B-Down-S	Flood	500	Downstream	South	13	10	5 - 10	NE	NO



	July 1 2005 TSS Sample Locations	Job No.	Date	Figure No.
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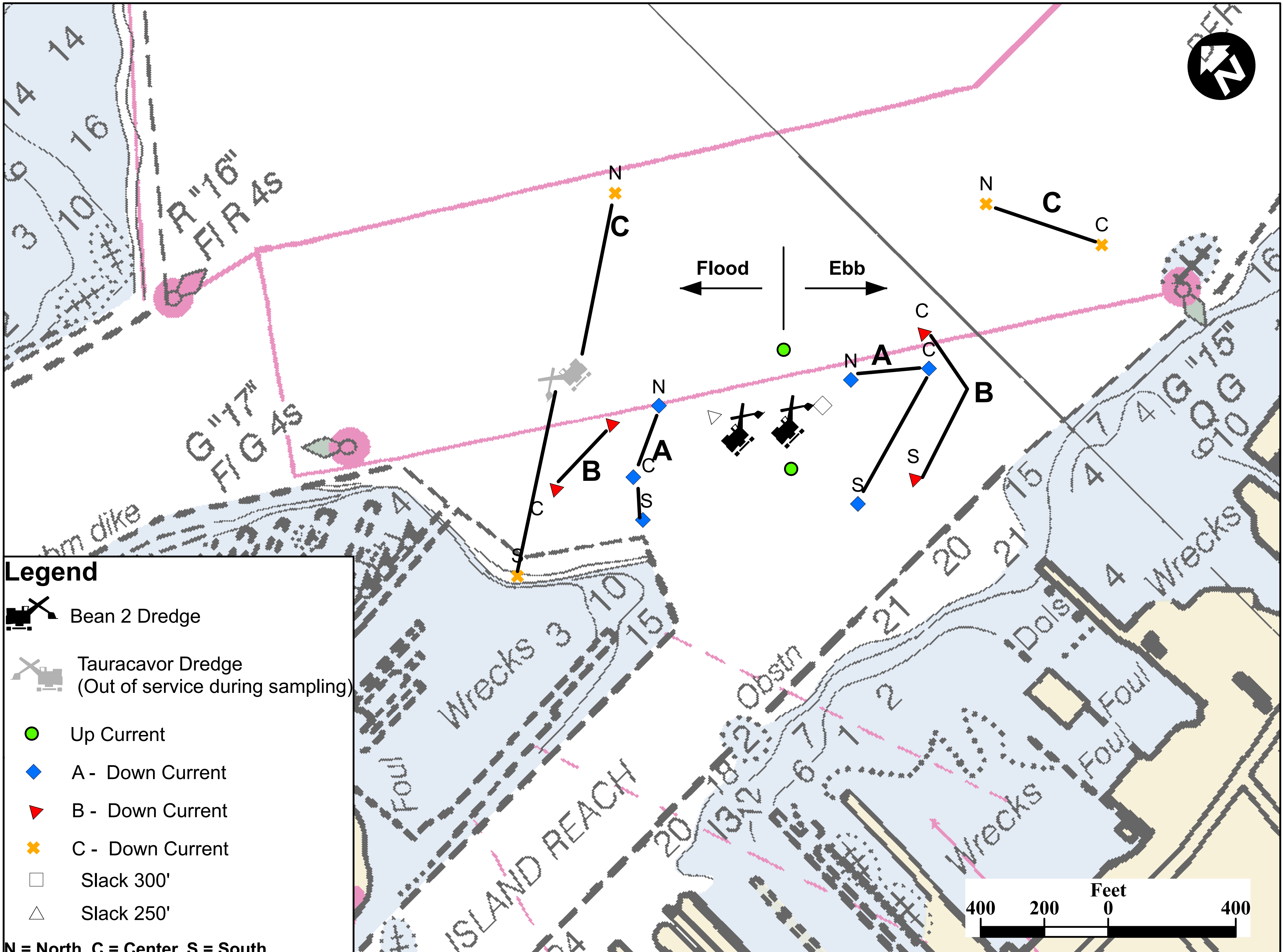

July 19 2005 TSS Sample Locations

Job No.	Date	Figure No.
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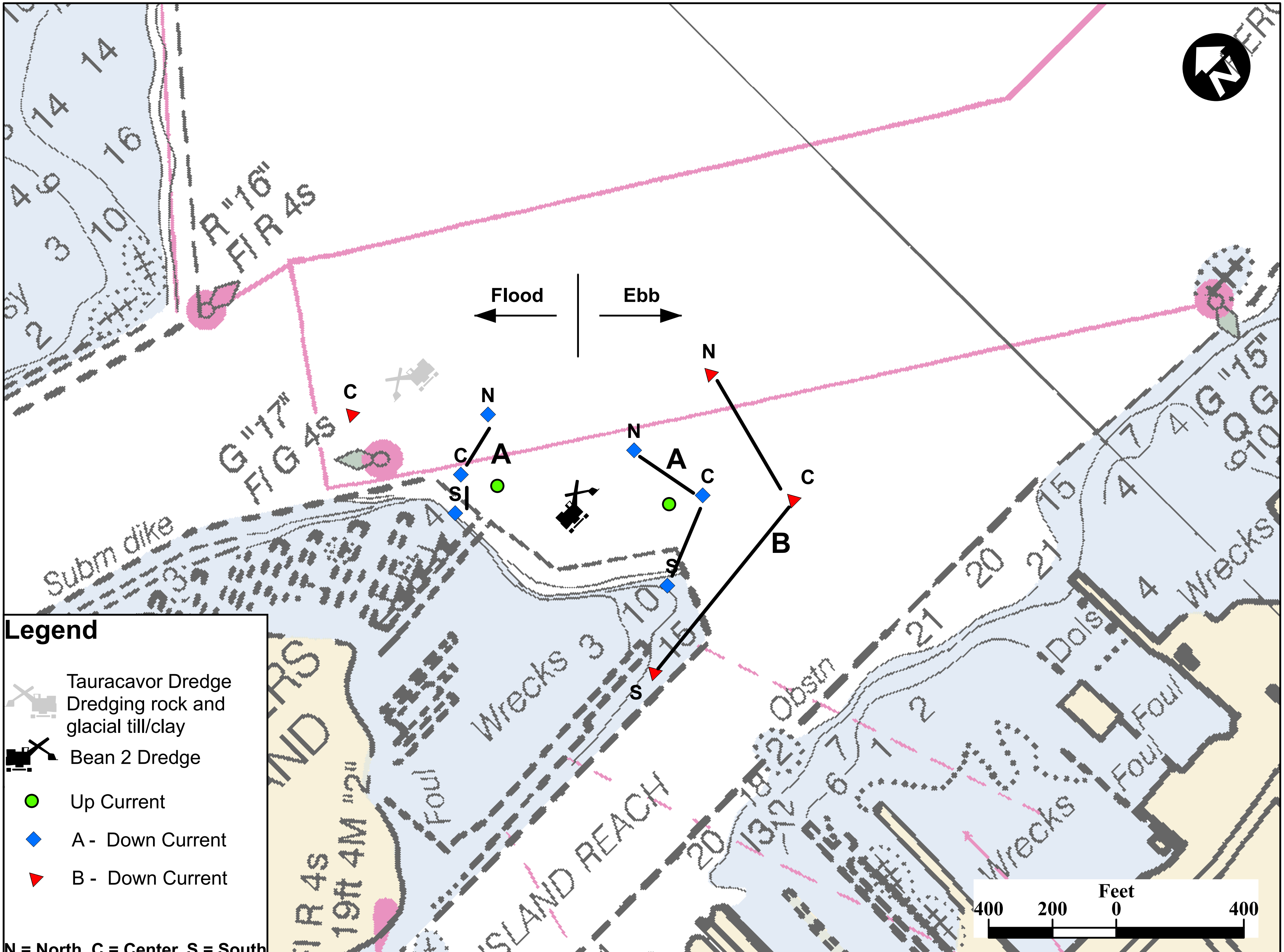

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August 1 2005 TSS Sample Locations

Job No.	Date	Figure No.
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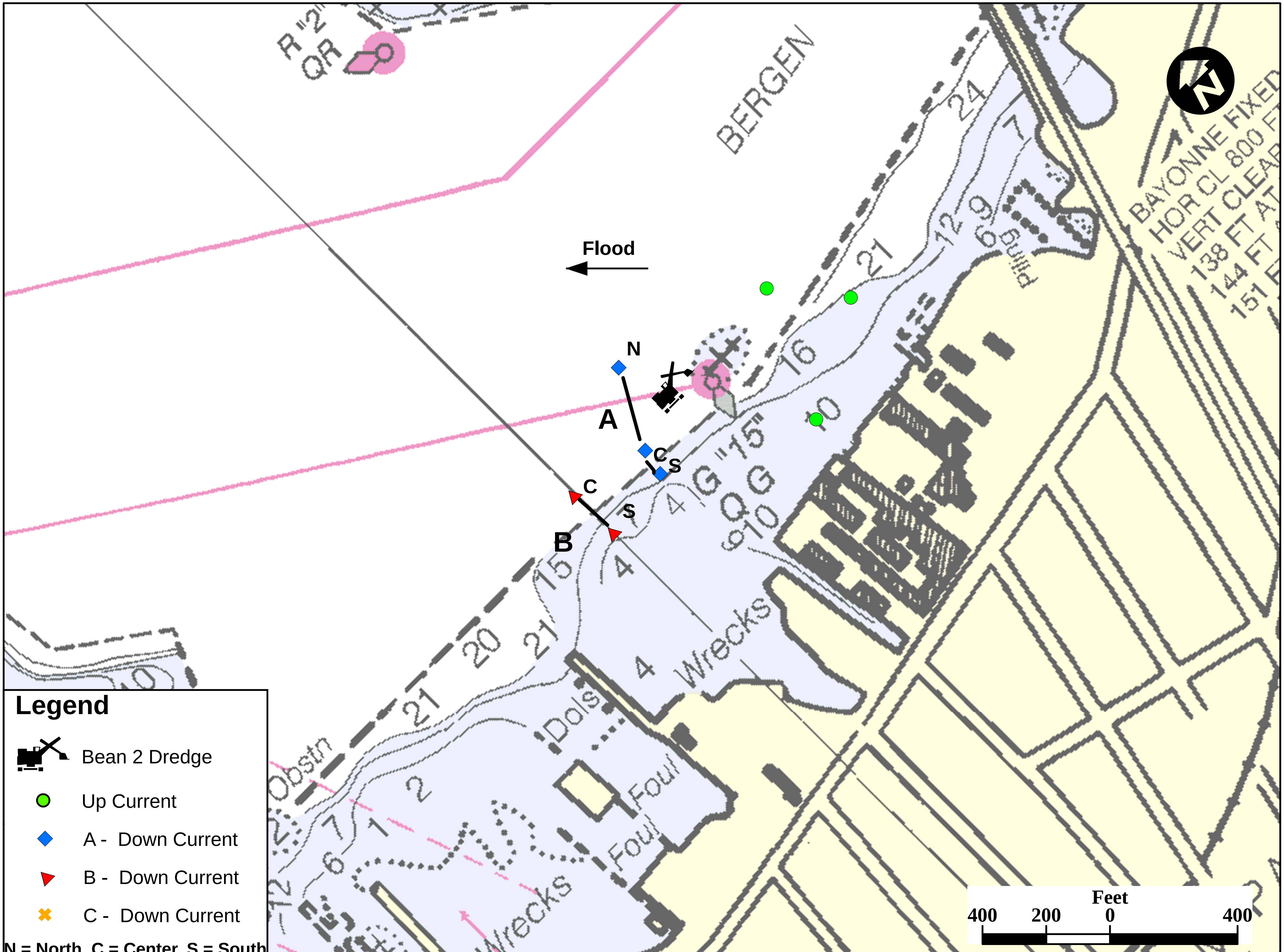

August 15 2005 TSS Sample Locations

Job No.	Date	Figure No.
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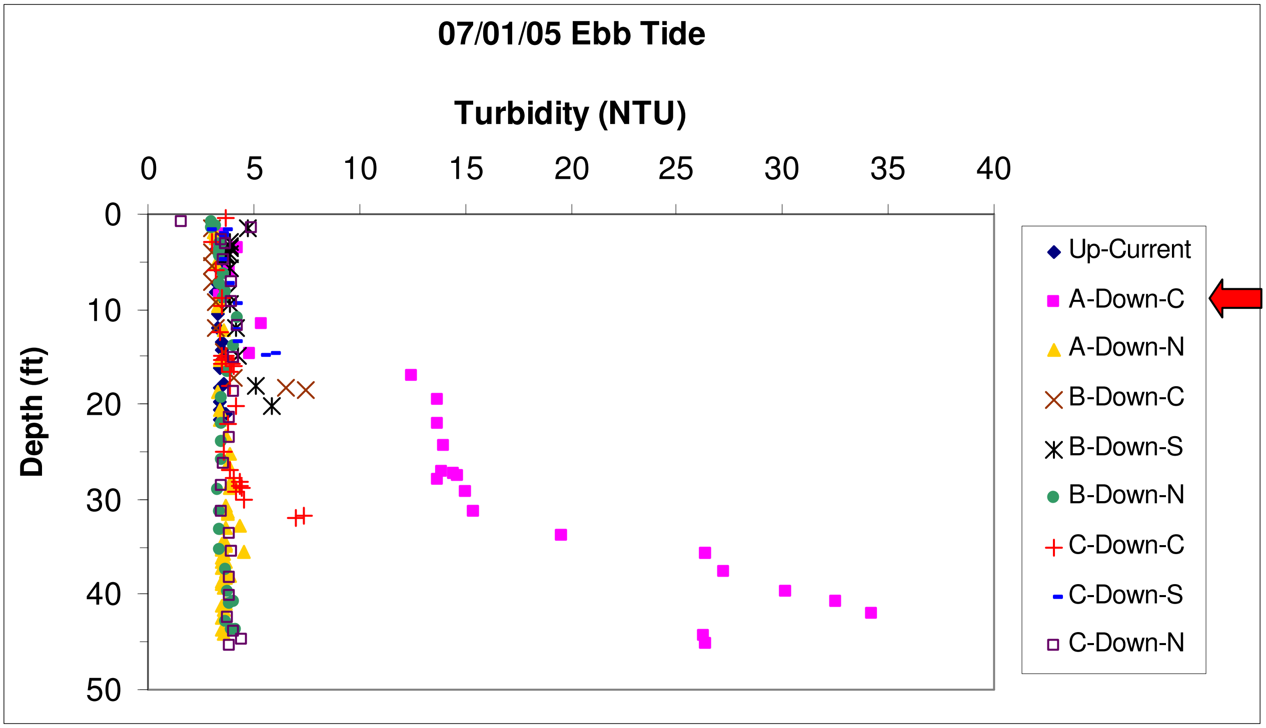


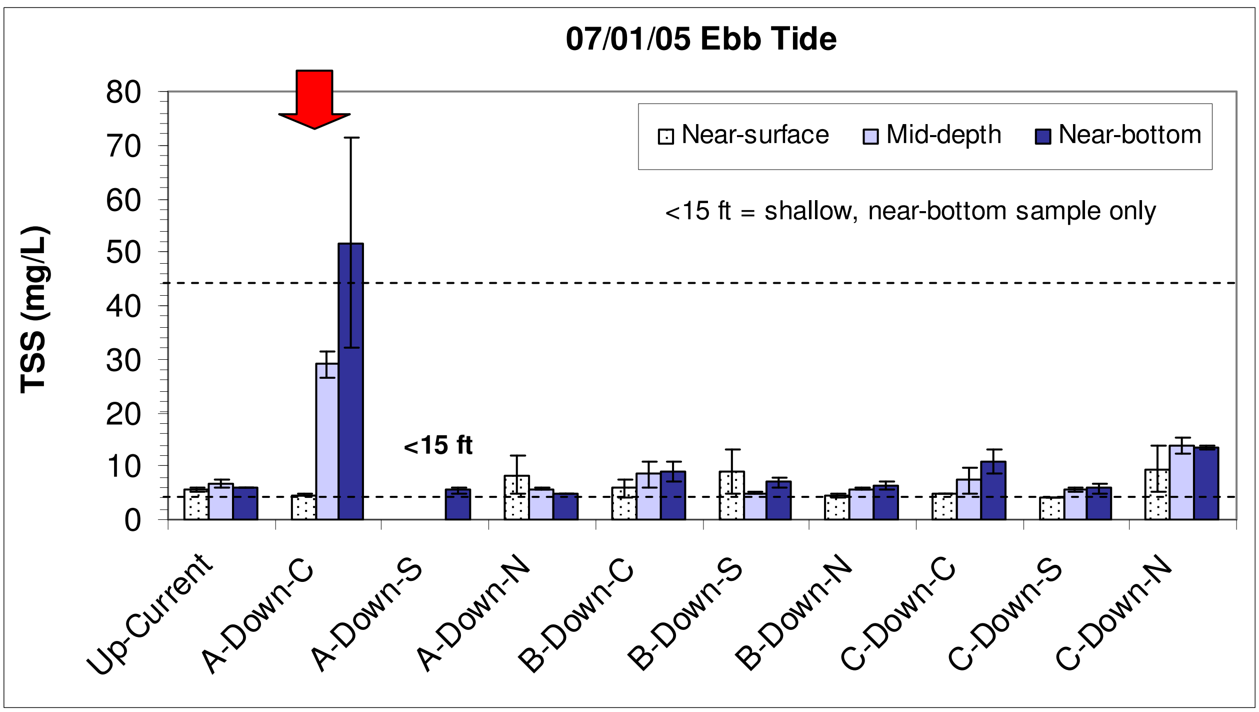
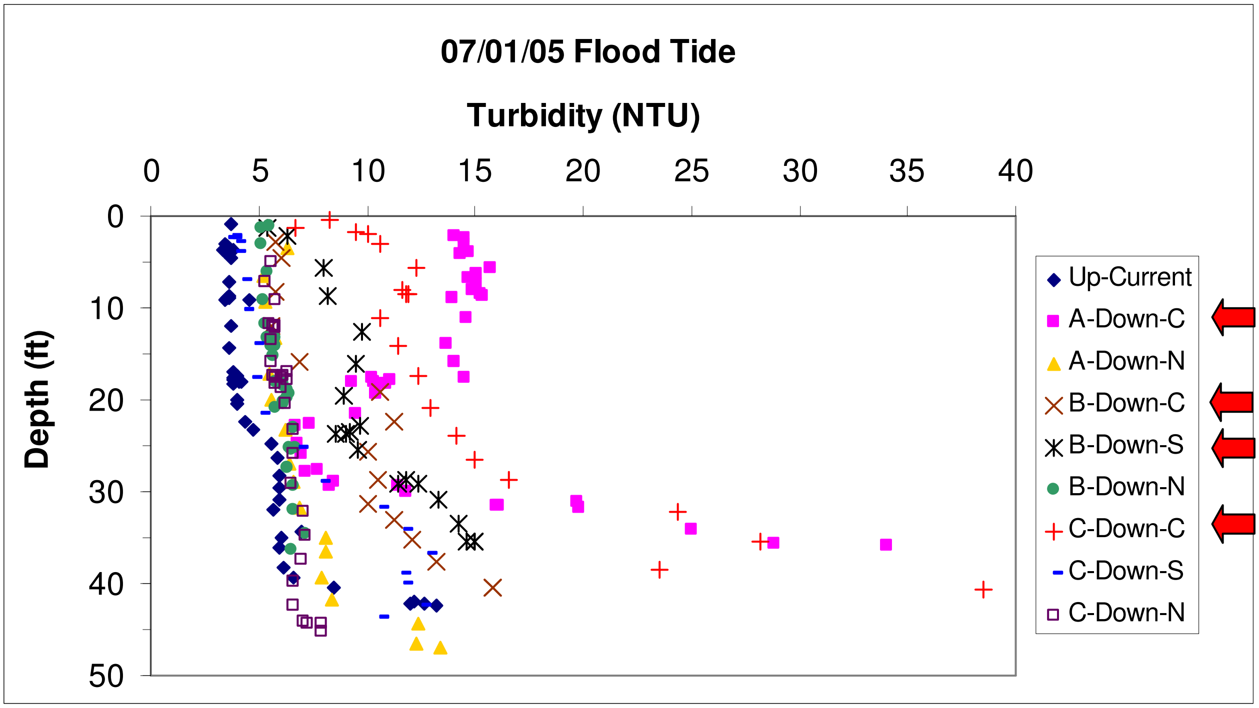


Figure 5. Turbidity (top) and TSS concentrations (bottom) at all stations sampled during ebb tide on July 01, 2005. Track A represents stations approximately 250' from the dredge, Track B represents stations approximately 500' from the dredge and Track C represents stations approximately 1000' from the dredge. Turbidity was measured throughout the water column and TSS samples were collected at discrete depths. TSS concentrations represent the mean of two replicates and error bars represent standard error of the mean. The dashed lines on the graph of TSS concentrations represent the low (4 mg/L) and high (44 mg/L) limits for measured ambient conditions in the NY/NJ Harbor (LMS 1997, USACE 2002). On both graphs, a red arrow indicates a significant difference (α=0.05) from the station up-current of the dredge (background conditions) over all depths.



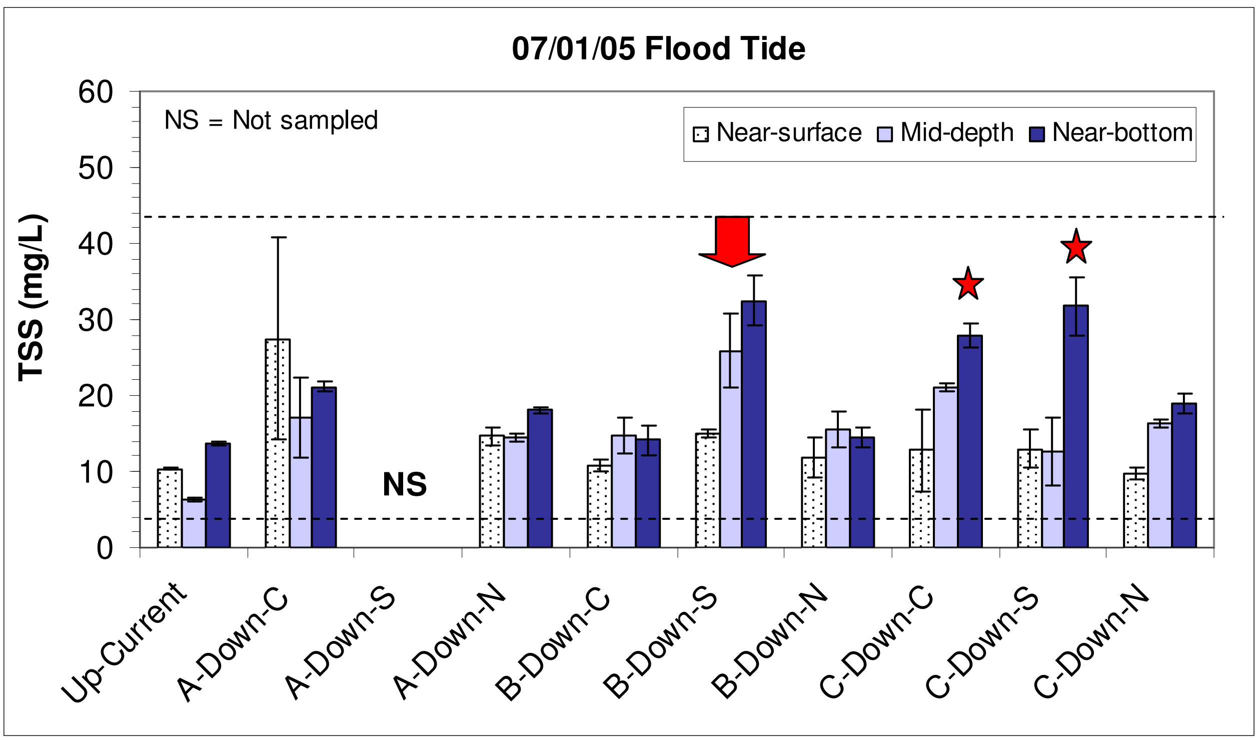
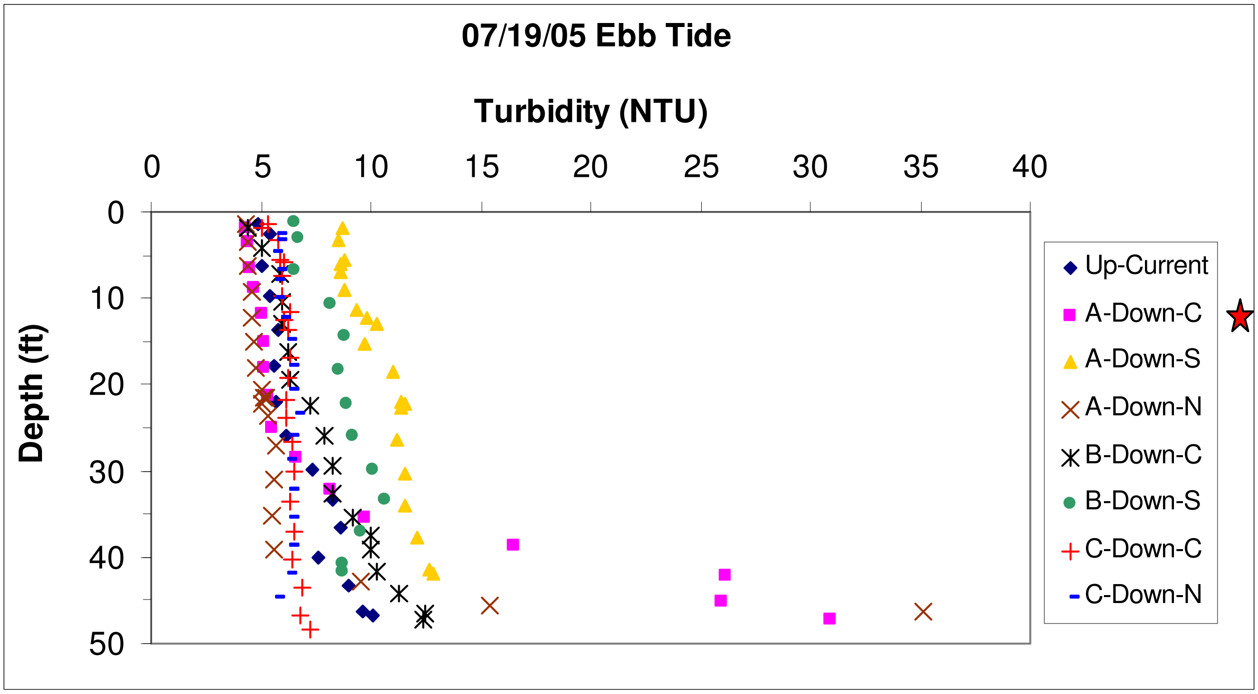


Figure 6. Turbidity (top) and TSS concentrations (bottom) at all stations sampled during flood tide on July 01, 2005. Track A represents stations approximately 250' from the dredge, Track B represents stations approximately 500' from the dredge and Track C represents stations approximately 1000' from the dredge. Turbidity was measured throughout the water column and TSS samples were collected at discrete depths. TSS concentrations represent the mean of two replicates and error bars represent standard error of the mean. The dashed lines on the graph of TSS concentrations represent the low (4 mg/L) and high (44 mg/L) limits for measured ambient conditions in the NY/NJ Harbor (LMS 1997, USACE 2002). On both graphs, a red arrow indicates a significant difference (α=0.05) from the station up-current of the dredge (background conditions) over all depths. On the graph of TSS concentrations, a red star indicates a significant difference (α=0.05) in the near-bottom concentrations from the station up-current of the dredge.



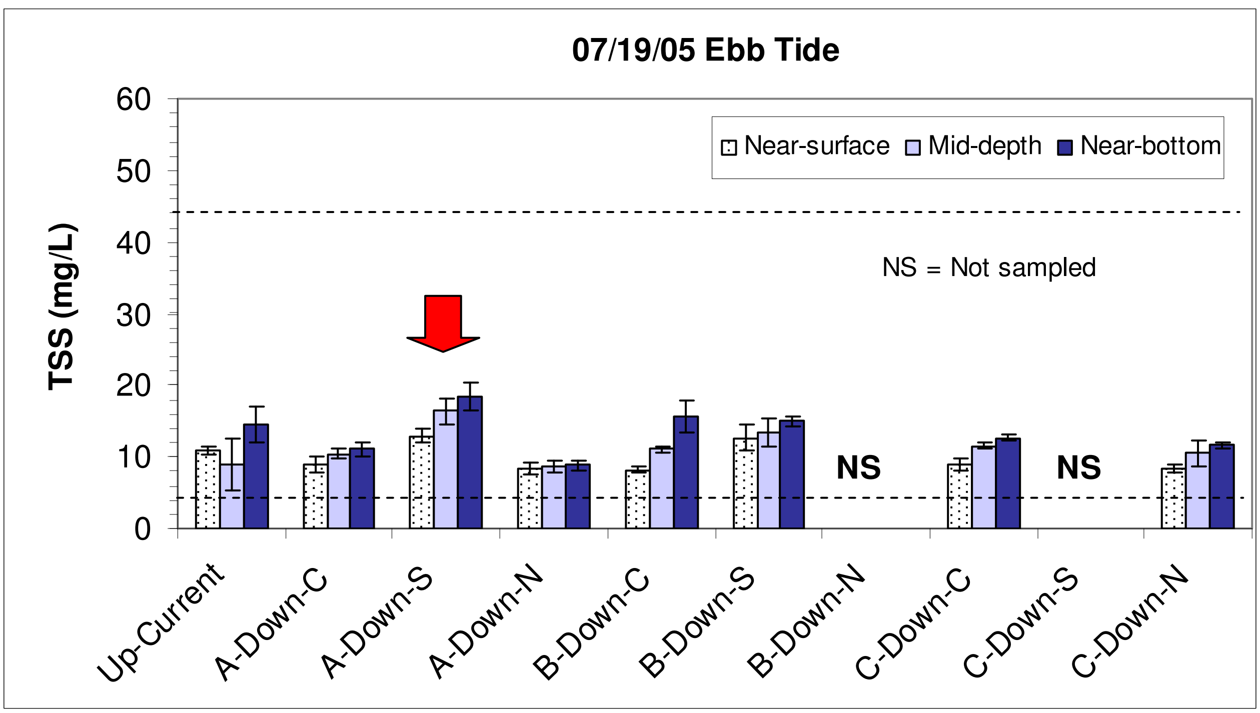
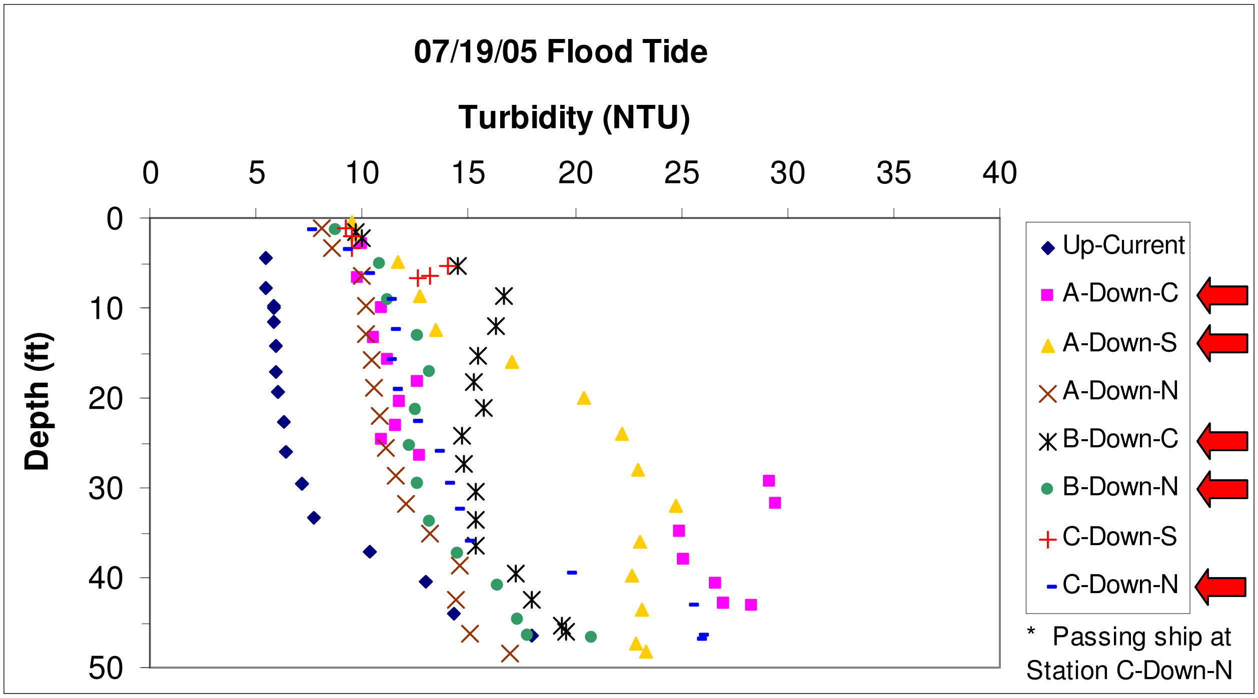


Figure 7. Turbidity (top) and TSS concentrations (bottom) at all stations sampled during ebb tide on July 19, 2005. Track A represents stations approximately 250' from the dredge, Track B represents stations approximately 500' from the dredge and Track C represents stations approximately 1000' from the dredge. Turbidity was measured throughout the water column and TSS samples were collected at discrete depths. TSS concentrations represent the mean of three replicates and error bars represent standard error of the mean. The dashed lines on the graph of TSS concentrations represent the low (4 mg/L) and high (44 mg/L) limits for measured ambient conditions in the NY/NJ Harbor (LMS 1997, USACE 2002). A red arrow indicates a significant difference ($\alpha=0.05$) from the station up-current of the dredge (background) over all depths. A red star indicates a significant difference ($\alpha=0.05$) in near-bottom concentrations from the station up-current of the dredge.



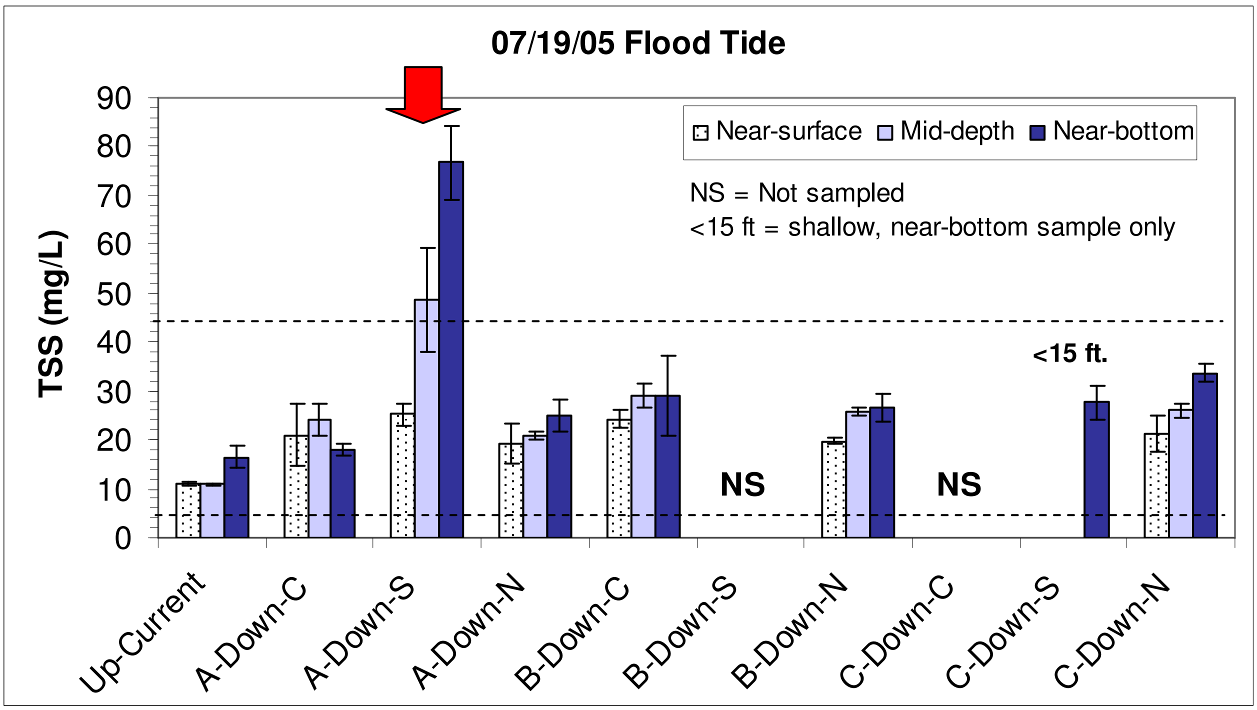
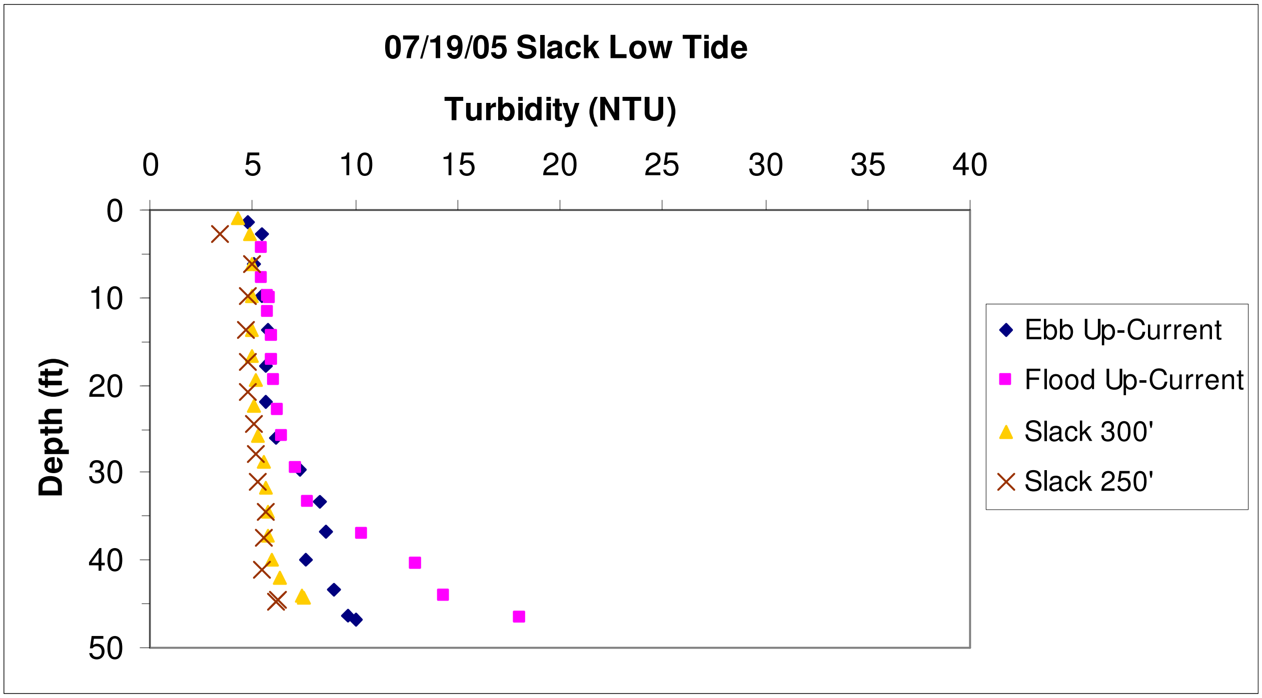


Figure 8. **Turbidity (top) and TSS concentrations (bottom) at all stations sampled during flood tide on July 19, 2005**. Track A represents stations approximately 250' from the dredge, Track B represents stations approximately 500' from the dredge and Track C represents stations approximately 1000' from the dredge, except for Station C-Down-S, which was 750' from the dredge. Turbidity was measured throughout the water column and TSS samples were collected at discrete depths. TSS concentrations represent the mean of three replicates and error bars represent standard error of the mean. The dashed lines on the graph of TSS concentrations represent the low (4 mg/L) and high (44 mg/L) limits for measured ambient conditions in the NY/NJ Harbor (LMS 1997, USACE 2002). On both graphs, a red arrow indicates a significant difference (α=0.05) from the station up-current of the dredge (background conditions). Turbidity at Station C-Down-N may have been affected by a passing container ship.



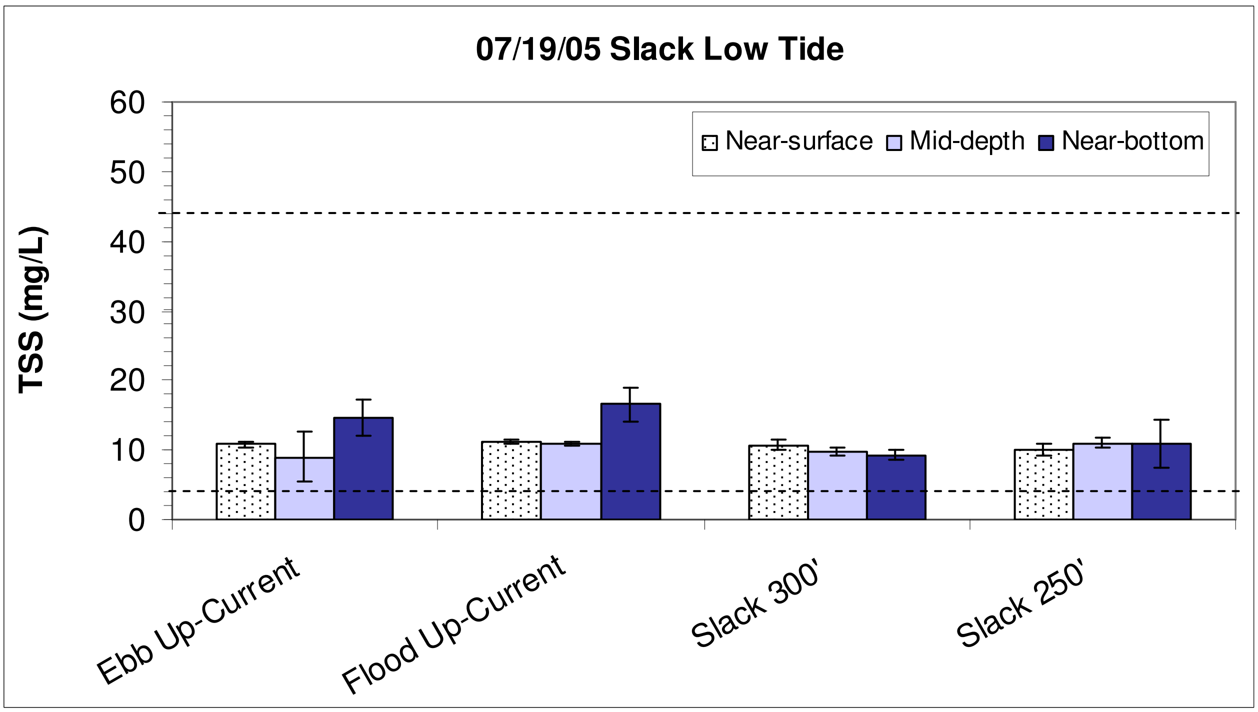
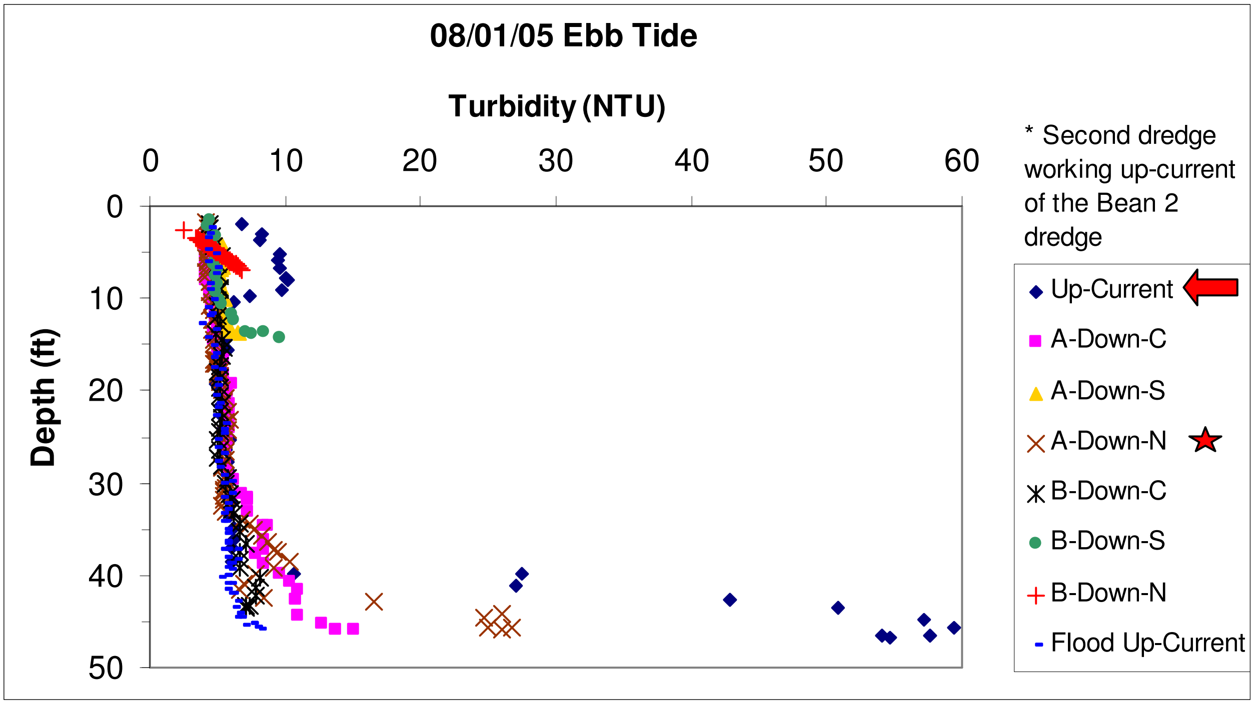


Figure 9. Turbidity (top) and TSS concentrations (bottom) at all stations sampled during slack low tide on July 19, 2005. Turbidity was measured throughout the water column and TSS samples were collected at discrete depths. TSS concentrations represent the mean of three replicates and error bars represent standard error of the mean. The dashed lines on the graph of TSS concentrations represent the low (4 mg/L) and high (44 mg/L) limits for measured ambient conditions in the NY/NJ Harbor (LMS 1997, USACE 2002).



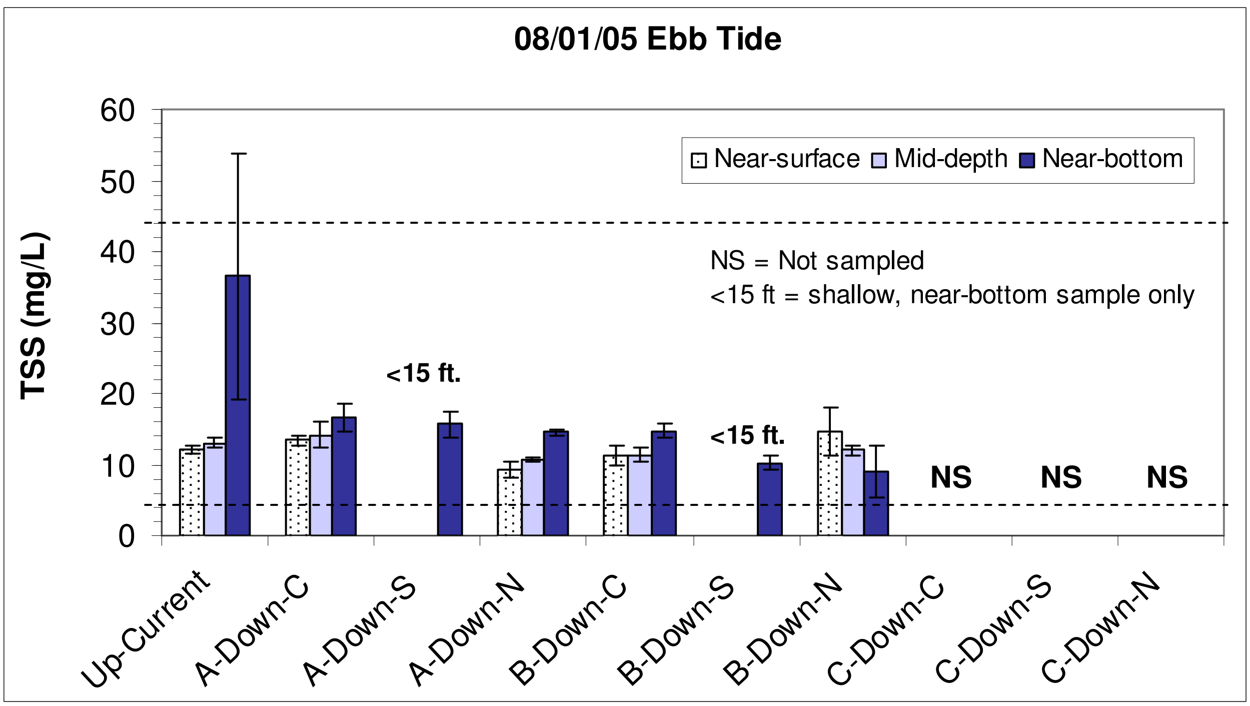


Figure 10. **Turbidity (top) and TSS concentrations (bottom) at all stations sampled during ebb tide on August 01, 2005.** Track A represents stations approximately 250' from the dredge, Track B represents stations approximately 500' from the dredge and Track C represents stations approximately 1000' from the dredge. Turbidity was measured throughout the water column and TSS samples were collected at discrete depths. TSS concentrations represent the mean of three replicates and error bars represent standard error of the mean. The dashed lines on the graph of TSS concentrations represent the low (4 mg/L) and high (44 mg/L) limits for measured ambient conditions in the NY/NJ Harbor (LMS 1997, USACE 2002). The red arrow indicates a significant difference ($\alpha=0.05$) between the ebb tide up-current station and the stations down-current of the dredge. A second dredge (dredging rock and glacial till/clay) in the area appeared to affect the turbidity at the station up-current of the Bean 2 dredge on the ebb tide. Thus, the flood-tide up-current station turbidity values were included for reference. A red star indicates a significant difference ($\alpha=0.05$) in near-bottom concentrations from the flood tide up-current station.

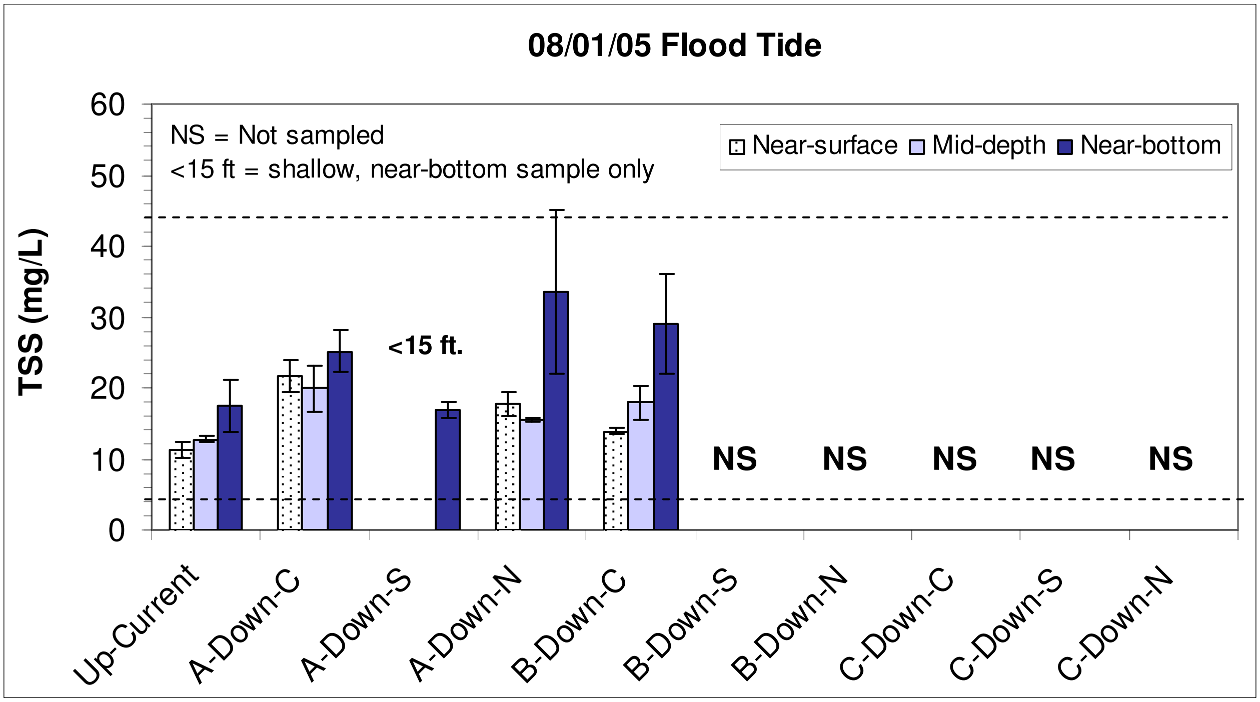
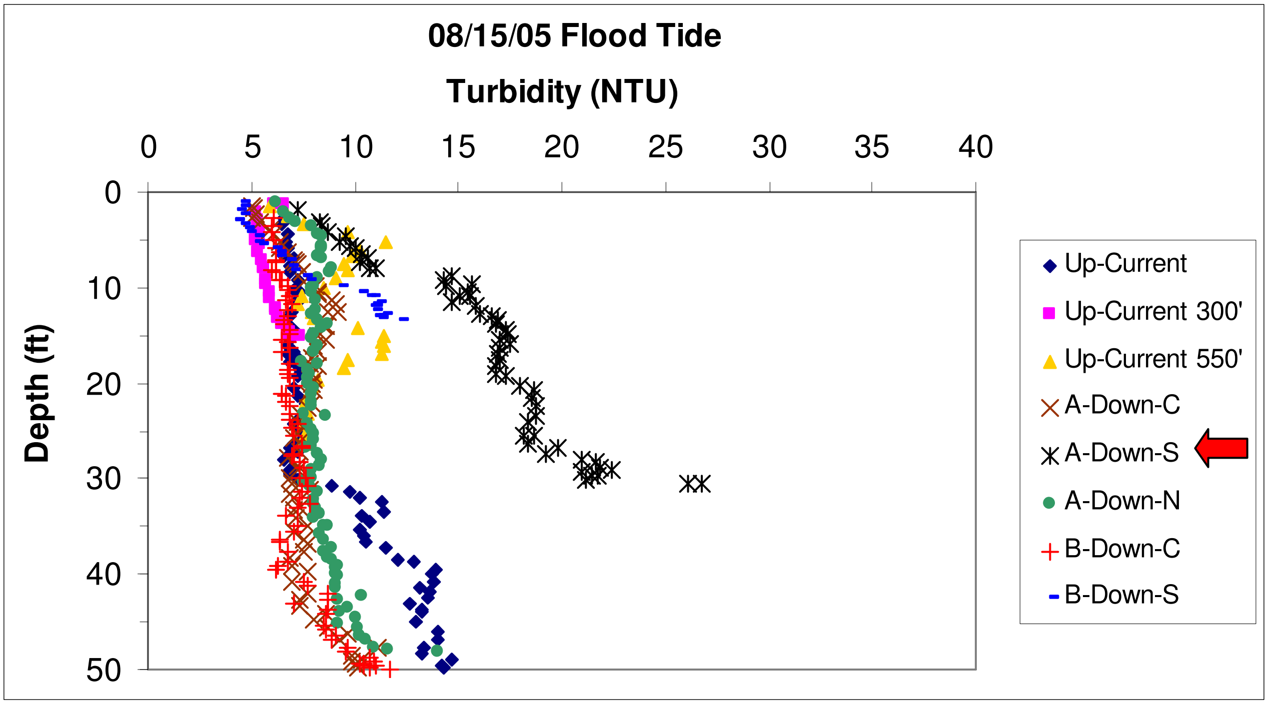


Figure 11. **TSS concentrations at all stations sampled during flood tide on August 01, 2005.** Track A represents stations approximately 250' from the dredge and Station B-Down-C was located approximately 700' from the dredge. Other stations at distances of 500' (Track B) and 1000' (Track C) from the dredge were not sampled due to logistical considerations. TSS concentrations represent the mean of three replicates and error bars represent standard error of the mean. The dashed lines on the graph represent the low (4 mg/L) and high (44 mg/L) limits for measured ambient conditions in the NY/NJ Harbor (LMS 1997, USACE 2002). Turbidity measurements (other than at the up-current station) were not collected on the flood tide due to loss of communication with the instrument.



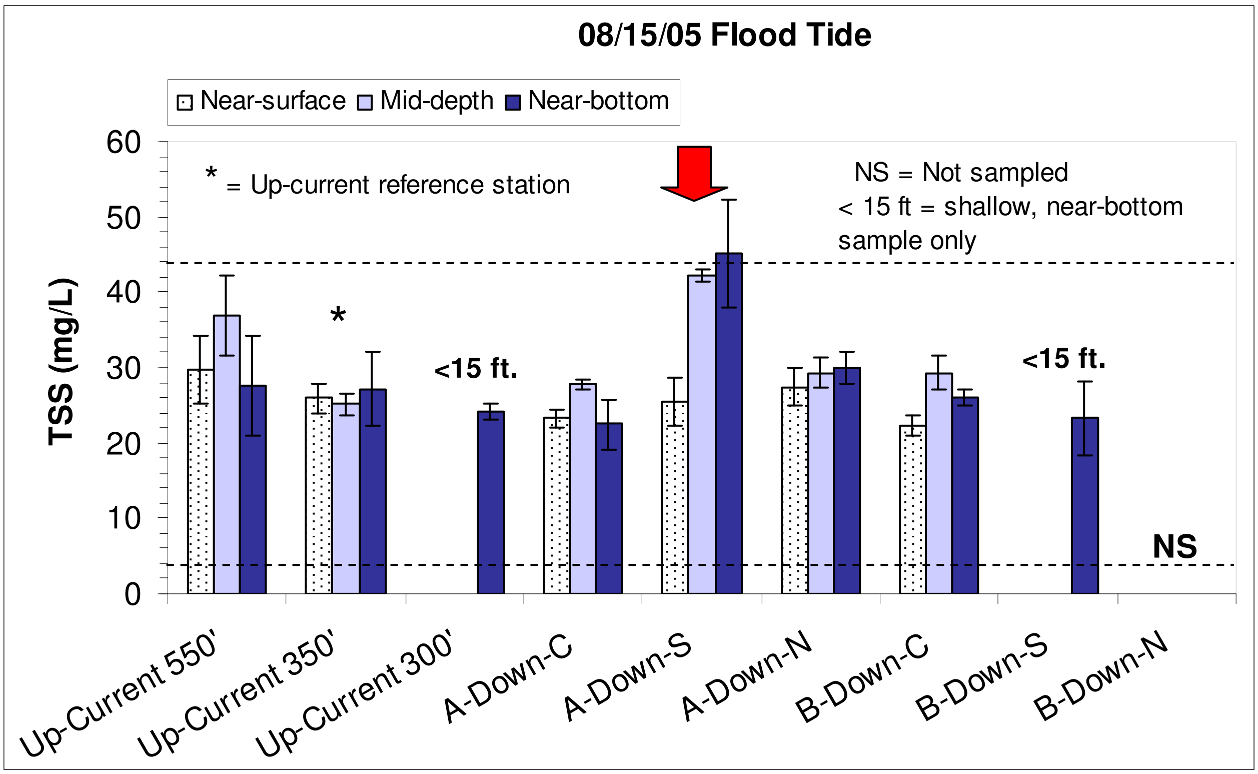


Figure 12. Turbidity (top) and TSS concentrations (bottom) at all stations sampled during flood tide on August 15, 2005. Track A represents stations approximately 250' from the dredge, Track B represents stations approximately 500' from the dredge. Samples were not collected at distances greater than 500' from the dredge (Track C) due to very weak tidal currents. Turbidity was measured throughout the water column and TSS samples were collected at discrete depths. TSS concentrations represent the mean of three replicates and error bars represent standard error of the mean. The dashed lines on the graph of TSS concentrations represent the low (4 mg/L) and high (44 mg/L) limits for measured ambient conditions in the NY/NJ Harbor (LMS 1997, USACE 2002). On both graphs, a red arrow indicates a significant difference (α=0.05) from the station up-current of the dredge (background conditions).

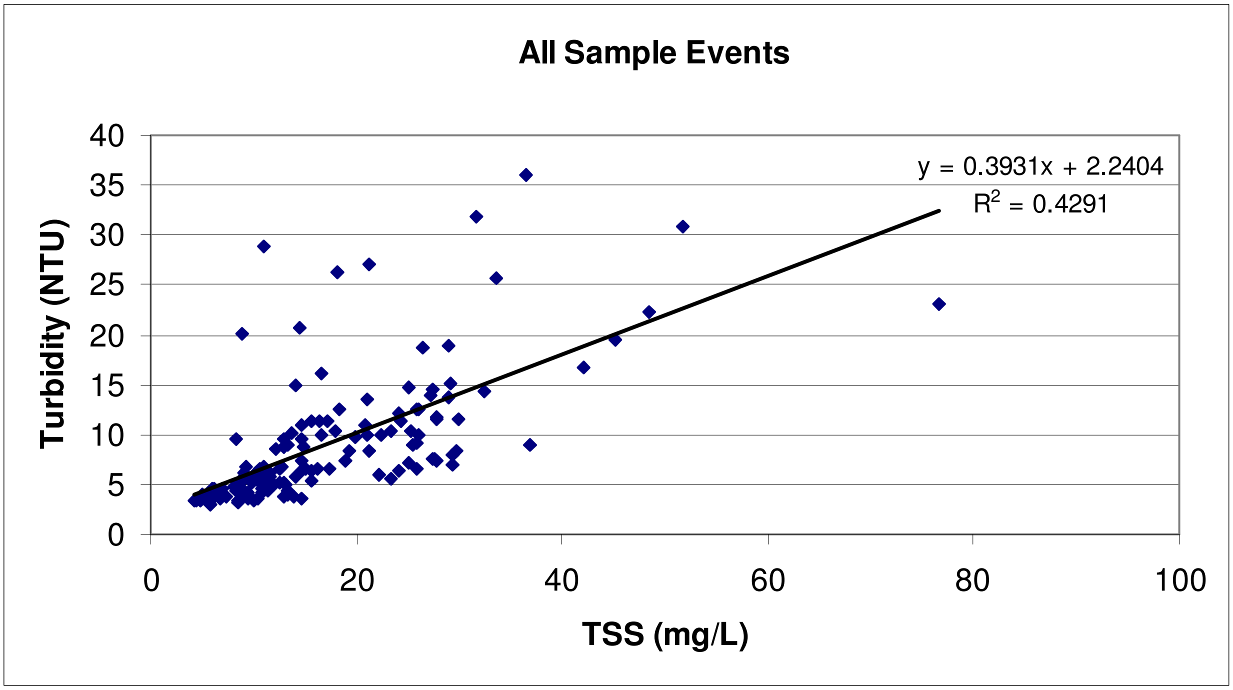


Figure 13. **Correlation of TSS concentrations and turbidity measurements collected during all field sampling events.** The TSS concentrations represent the mean of all replicates collected at a particular depth. A turbidity value for the TSS sample collection depth was derived by calculating the mean turbidity over the range of depths equal to TSS sample collection depth ± 3 ft. Turbidity was then plotted as a function of TSS concentration and linear regression was used to derive a relationship. The regression coefficient and intercept were significantly different from zero at the α=0.05 level, with p-values of 0.0001 and 0.004, respectively.

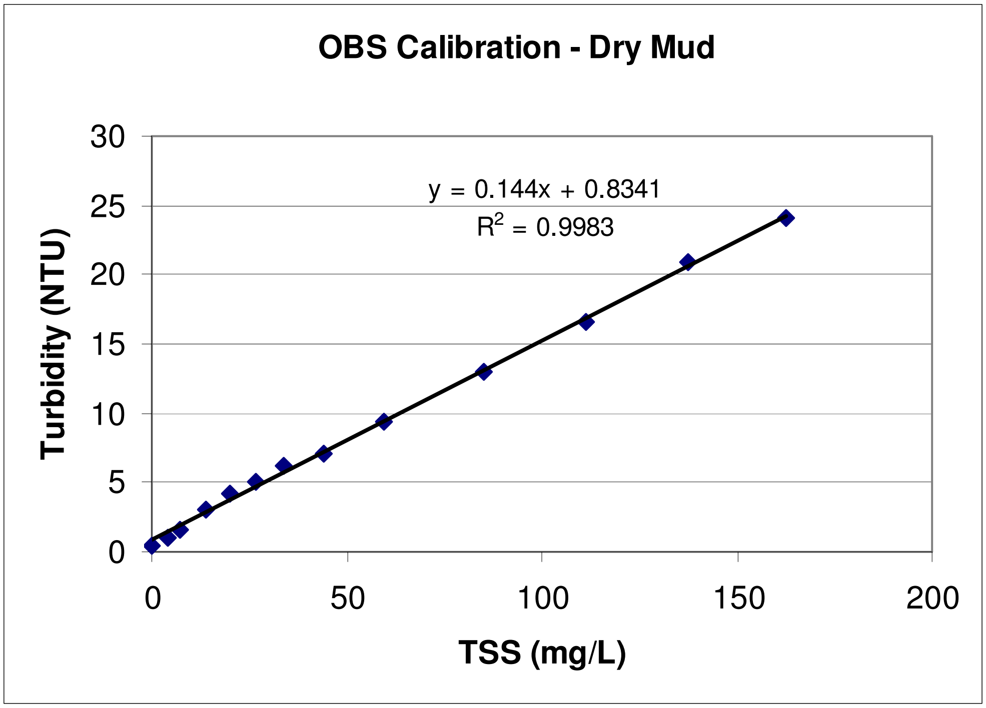


Figure 14. **Results of the laboratory calibration of the OBS in order to correlate TSS concentrations and turbidity measurements**. Aliquots of dry mud were added to a fixed volume of water in order to produce known TSS concentrations and turbidity measurements were collected. Turbidity was then plotted as a function of TSS concentration and linear regression was used to derive a relationship. The regression coefficient and intercept were significantly different from zero at the $\alpha=0.05$ level, with p-values<0.0001.

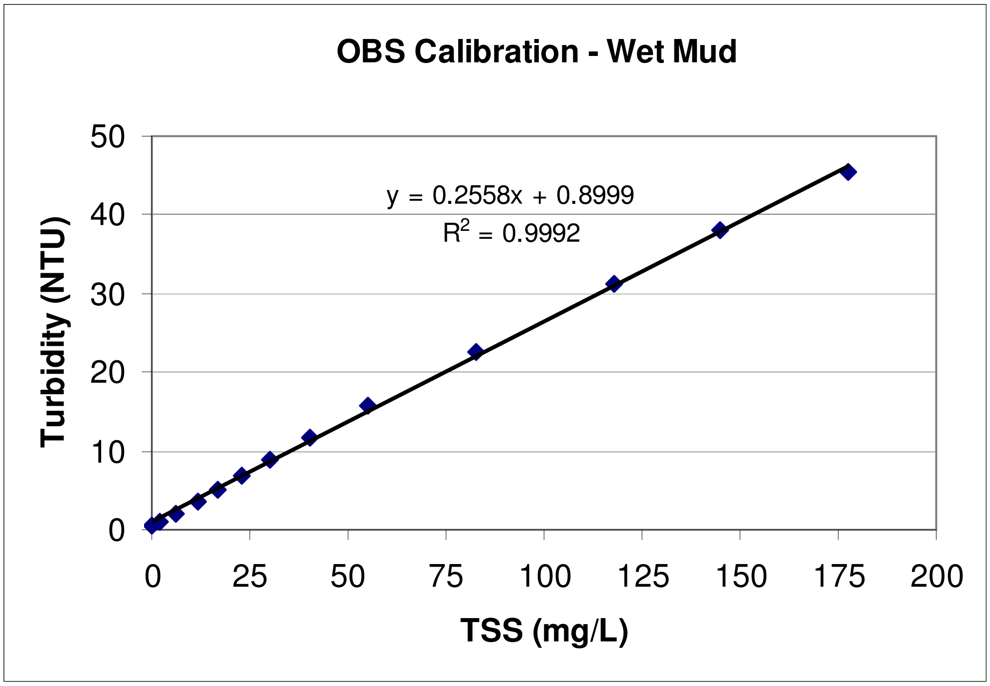


Figure 15. **Results of the laboratory calibration of the OBS in order to correlate TSS concentrations and turbidity measurements.** Aliquots of wet mud were added to a fixed volume of water in order to produce known TSS concentrations and turbidity measurements were collected. Turbidity was then plotted as a function of TSS concentration and linear regression was used to derive a relationship. The regression coefficient and intercept were significantly different from zero at the α=0.05 level, with p-values of 0.0001 and 0.0002, respectively.