TECHNICAL MEMO:

FAR-FIELD SURVEYS OF SUSPENDED SEDIMENT PLUMES ASSOCIATED WITH HARBOR DEEPENING DREDGING IN UPPER BAY

S-KVK-1 Contract Area (Kill Van Kull)

U.S. Army Corps of Engineers - New York District

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Table of Contents

List of Tables

List of Figures

Figure 24a-b: Comparison of Gravimetric and ADCP Estimates of TSS Concentration, S-KVK-1 Far Field Survey (15-23 June 2009)

a) Concentration vs. Time

b) ADCP Concentration vs. Gravimetric Concentration

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 U.S. Army Corps of Engineers New York District's (USACE-NYD) Harbor-wide Water Quality/Total Suspended Solids (WQ/TSS) Monitoring Program, a far-field WQ/TSS survey was conducted between 15 June and 23 June 2009 within the S-KVK-1 contract area of the Harbor Deepening Project (HDP) in the Constable Hook Reach of the Kill Van Kull in Upper Bay, New York (Figure 1). The objective of the far-field survey was to assess the spatial extent and temporal dynamics of suspended sediment plumes associated with cutterhead dredge operations. The methodologies employed for this survey were similar to those used previously and subsequently 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 2013).

Mobile surveys were conducted using a vessel-mounted Acoustic Doppler Current Profiler (ADCP) 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 cutterhead 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.

1.1 Study Area and Dredge Operational Setup

The dredge contractor for this study was Great Lakes Dredge and Dock Company, LLC (GLDD), operating the cutterhead dredge *Illinois*, configured with a 1,785 hp cutterhead dredge with an 8.7-foot diameter rotating drill. During the first stage of the operations, the cutterhead dredge was employed within the S-KVK-1 contract area to break apart the underlying Serpentinite bedrock. Then the dredge's hydraulic suction pipeline was configured to move the broken rock from below the cutterhead to an adjacent area on the channel bottom through an installed downspout. Both of these operations began on 19 June 2009 and continued through the end of the far-field WQ/TSS survey. Beginning on June 23 2009, the cut rock was removed using the GLDD mechanical dredge *54*, which followed immediately behind the *Illinois*, and was configured with a 21 cubic yard bucket.

A far-field WQ/TSS survey was conducted between 15 June and 23 June 2009 in the vicinity of this dredging operation within Acceptance Area A of the S-KVK-1 Contract Area. For all surveys, the cutterhead dredge *Illinois* was situated within the Constable Hook Reach of the Kill Van Kull in the vicinity of the Green "#3" navigation buoy (Figure 1). This is a high volume vessel traffic area frequented by tugs and barges as well as large deep draft commercial vessels including container ships, car carriers, and is near the Staten Island Ferry St. George-Whitehall route.

2.0 METHODS

2.1 Hydrodynamic Survey

Hydrodynamic conditions within the Kill Van Kull 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 Kill Van Kull 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 the preliminary currents data collected by NOAA Station n03020 at The Narrows (NOAA 2012), where available, to place the survey within the context of the daily tidal cycle.

2.2 Survey Design of Mobile ADCP Transects

Suspended sediment plumes were also characterized using the 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 2.5 - ADCP Calibration* below). Similarly, navigation data (i.e. GPS positions) collected throughout the monitoring period by the cutterhead contractor were integrated during post-processing of the ADCP data to determine the distance each transect was from the source. To cover a range of tidal conditions, ADCP backscatter data were collected during various stages of ebb and flood tides during the survey periods.

Prior to initiating the mobile plume surveys, circular transects using the ADCP were conducted around the actively operating cutterhead to assess the location and acoustic signal of the plume. Subsequent ADCP transects were generally oriented in a direction perpendicular to the channel and extended 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 cutting 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.

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 two meter depth increments.

- **Three-dimensional 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 cutterhead activities.

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 erroneously 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.

2.3 Design of Fixed Station Turbidity Surveys

In addition to the mobile ADCP surveys, turbidity measurements were recorded at fixed locations and at various water depths using Campbell Scientific, Inc.'s (formerly D&A Instrument Company) OBS-3A turbidity sensors. Typically, these sensors would be tethered to a taut line and anchored at predetermined depths using a fixed anchor and buoy array. These arrays would be left in position for the duration of a tidal cycle while the research vessel conducted additional survey operations in the area. However, the high current and traffic conditions in this survey area prohibited the safe deployment of the anchored arrays. Instead, the Optical backscatter sensor (OBS) units were tethered to a weighted line and attached directly to the research vessel. The vessel was then held in a fixed position for a period of time during each tidal cycle.

OBS units project a beam of near-infrared light into the water, and measure the amount of light reflected back from suspended particles. The OBS units used in this survey were pre-calibrated by the manufacturer and programmed to measure turbidities in the 0-1,000 Nephelometric Turbidity Unit (NTU) range. The OBS units deployed during the fixed station survey were configured to output depth (meters), turbidity (NTU), temperature (°C), salinity (ppt), conductivity (µS/cm) and battery level (V). Readings were logged internally every 10 seconds at a rate of 25 samples per second for duration of 5 seconds. That is, every 10 seconds the OBS recorded 125 samples (25 samples/sec x 5 sec). All internally recorded data were retrieved from the units at the end of the survey.

2.4 Water Sample Collection

During the far-field surveys, water samples were collected to measure and calibrate TSS concentrations (mg/L) and turbidity (NTU) throughout the water column. The water samples were collected from the survey vessel using a Sea-Bird Electronics SBE32C Compact Carousel Water Sampler equipped with six 1.7L Nisken sample bottles. A Campbell Scientific, Inc. OBS-3A optical backscatter sensor was also mounted to the Carousel Sampler and hardwired directly to an onboard computer. The OBS unit provided depth, temperature, salinity, and turbidity values of the entire water profile. The Carousel Sampler was also hardwired to an onboard computer and featured a magnetically-actuated lanyard release system used to remotely “fire” the sample bottles. A custom application recorded the exact time that each bottle fired to the nearest second.

All the 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). The laboratory results were then used to provide a robust calibration data set to convert the raw ADCP backscatter measurements to estimates of TSS concentration using the Sediview methodology and software as further described below.

2.5 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.

Samples were collected at known locations within the water column, so that individual gravimetric samples could be directly compared with acoustic estimates of TSS concentration 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 is important to collect water samples frequently and it may be necessary to perform multiple calibrations specific to the time period where the ADCP data were collected. It is also important to collect enough samples to constitute a robust sample size as it is occasionally necessary for some outlier 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 Carousel Sampler (i.e. the Carousel 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 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. 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.

2.6 Sediment Sample Collection

To determine the sediment characteristics of the survey area, a sample was collected from the sediment bed in the vicinity of the planned cutterhead operation using a ponar grab. This sample was 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 Hydrodynamic Surveys

General hydrodynamic conditions within S-KVK-1 Contract Acceptance Area A and its immediate vicinity were assessed during both ebb and flood tides on 15 June 2009. Transects were conducted approximately perpendicular to the Kill Van Kull 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 3.3 below. The results of the general hydrodynamic surveys for the flood and ebb tides are presented in Figures 2 and 3, respectively.

For comparison purposes, the NOAA Preliminary Currents Data recorded from Station n03020 at The Narrows (NOAA 2012) for the respective survey day is also shown on Figures 2 and 3. The NOAA data show the Near Surface water speed (in cm/s; red line) and direction (in degrees from True North; green crosses) and is useful to place a particular survey within the context of the daily tide cycle.

3.1.1 15 June 2009 - Flood Tide

Figure 2 presents the results of the hydrodynamic survey conducted on 15 June 2009 during the beginning portion of a flood tide from approximately 10:25 to 12:59. During the survey depth-averaged current velocities within the area ranged from near 0 m/s to approximately 0.9 m/s. The survey area covered nearly the entire S-KVK-1 contract area in the Kill Van Kull channel, from near the large silos on the north bank of the Kill Van Kull west of the red "8" navigation buoy to near the "KV" navigation buoy in the Upper Bay. In general, current velocities were lower in the larger Upper Bay, and then steadily increased as the channel narrowed, with the highest current velocities (approximately 0.9 m/s) observed at the western end of the survey area. The lowest current velocities (approximately 0.3 m/s or less) were observed in the area of the Pierhead Channel and flats to the north of the main Kill Van Kull channel in the Upper Bay, and in the small areas of flats to the north of the channel in the Kill Van Kull. Current directions observed during this study varied somewhat depending on area. In the larger Upper Bay, current direction was generally towards the northwest. In the Kill Van Kull itself, current direction followed the direction of the channel, flowing to the west or southwest. Near what would be the location of the dredge *Illinois* during observed cutting operations, current direction was generally to the west-northwest.

3.1.2 15 June 2009 - Ebb Tide

Figure 3 presents the results of the hydrodynamic survey conducted on 15 June 2009 during the beginning portion of an ebb tide from approximately 15:22 to 16:56. During the survey depth-averaged current velocities within the area ranged between near 0 m/s and approximately 0.9 m/s. The area surveyed reached from near the large silos on the north bank of the Kill Van Kull west of the red “8” navigation buoy to a line extending from Robbins Reef to the St. George ferry terminal. In general, current velocities were higher within the channel, both in the Kill Van Kull proper, and in the extension of the Kill Van Kull channel into the larger Upper Bay. The highest velocities (approximately 0.8-0.9 m/s) were observed in a small area along the southern edge of the Kill Van Kull near the green “7” navigation buoy. Small areas of very high current velocity were present within the portion of the channel in the Upper Bay, however it is likely these are artifacts of heavy prop wash from passing tugs, barges and container ships, as noted in the field crew chief report for that day. The lowest current speeds (0-0.3 m/s) were observed in the Upper Bay in area to the north and south of the Kill Van Kull channel. Current directions in the Kill Van Kull itself were generally to the east or northeast, following the direction of the channel.

Results of the hydrodynamic surveys in the Kill Van Kull show a distinct bi-directional flow pattern similar to those seen in previous surveys in other large channels, such as the Main Channel of Newark Bay (USACE 2010). During both tides, current speeds in the Kill Van Kull proper and the extension of its channel into the Upper Bay were generally higher (greater than approximately 0.3 m/s) compared to current speeds in surrounding non-channel areas of the Upper Bay

3.2 Ambient conditions

It is important to consider that no single TSS measurement adequately represents ambient conditions; instead a range of samples, collected across multiple depth and tidal conditions, is a better representation of the dynamic nature of suspended sediment concentrations in a tidal estuary. A total of 35 ambient water samples were collected at various depths from 15-22 June 2009, and later analyzed in the laboratory for TSS and turbidity (Table 1). Ambient turbidity values ranged from 1.5 to 16.0 NTU, and the corresponding TSS values ranged between 7.0 to 46.3 mg/L.

However, for the purposes of delineating the margins of a sediment plume, it is necessary to determine a single critical TSS concentration, below which are ambient conditions and above which are plume conditions. Because of the naturally heterogeneous distribution of suspended sediment, ambient conditions are often associated with a large range of TSS concentrations and the distribution of these values is rarely symmetric. As a result, the average ambient TSS measured will often underestimate the ambient condition. A percentile approach was used to select ambient values in previous surveys, but because of variable and high ambient concentrations this approach also would have underestimated the ambient condition. The ambient conditions during this study were especially variable and were stratified within the water column. Ambient conditions often included a stratum in the bottom several meters of the water column with ADCP estimated TSS concentrations ranging from approximately 60-80 mg/L. Examples of this may be seen in the up-current ADCP transects presented in Figures 4q through 4t, among others. Considering these relatively high ambient TSS concentrations, a value of 50 mg/L was selected as the critical value. Thus, while most acoustically estimated TSS concentrations greater than 50 mg/L are attributable to the dredge-induced plume, some such signatures represent natural variability in background suspended sediment conditions, or are clearly attributable to air entrainment, vessel prop wash, or from other sources of resuspension such as tug and ship plumes, or from side-lobe interference (see ADCP calibration methods, Section 2.5, for further information).

3.3 Mobile ADCP Surveys

3.3.1 19 June 2009 - Flood Tide

A mobile ADCP plume characterization survey was conducted on 19 June 2009 during the beginning portion of a flood tide from approximately 12:59 to 14:39 (Figures 4a-t). The survey consisted of one circle transect (Figure 4a), four ambient transects (Figures 4q through 4t), and fifteen down-current transects (Figures 4b through 4p). 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 5a through 5h. For this survey, the dredge *Illinois* was located approximately 198 meters east-southeast of the charted position of the green “3” navigation buoy. Ambient transects were conducted southeast of the dredge and down-current transects were conducted northwest of the dredge. Ambient and down-current transects were oriented perpendicular to the channel, with the exception of one down current transect which was conducted parallel to the channel for the length of the entire plume, and shows it in a cross-section perpendicular to the rest of the down-current transects (Transect T15, Figure 4p). Figure 6 provides a three-dimensional depiction of average TSS values for selected representative transects.

Up-current conditions presented in Figures 4q through 4t show TSS concentrations between 0 and 50 mg/L throughout most of the water column, which is consistent with the gravimetric results of the ambient water samples collected. However, there was some natural variability in ambient conditions present, and a stratum of slightly higher ADCP estimated TSS concentrations (60-80 mg/L) were detected at the bottom of the water column, especially in Figures 4s and 4t. See the above discussion of ambient conditions (Section 3.2) for further details.

Plume signatures associated with the dredge operation were limited to within the first 985 meters down-current of the dredge (Transects T01 – T14). In the vertical profiles of these transects, a clearly defined plume was detected, remaining confined to the bottom one-third of the water column for its entire extent. Peak TSS concentrations within the plume reached approximately 600 mg/L close to the bottom and within 78 meters of the source (Transect T01). Similar TSS concentrations of up to 400 mg/L were recorded up to 370 meters away (T08), and small areas of TSS concentration of approximately 300 mg/L were recorded up to 820 meters away (T13). However, these concentrations were limited to a small area within the plume, and as noted above, the plume itself was strictly confined to the bottom one-third of the water column. Plume width varied from approximately 80 to over 200 meters at various locations, spreading laterally as distance from the source increased to reach a maximum width at approximately 313 meters from the source (T07). The plume then narrowed again as its distance from the dredge continued to increase. However, the plume remained within the Kill Van Kull channel for its entire extent. Because some transects extended into shallower water (less than 15 meters deep), sidelobe reflectivity can be observed on the slopes in these transects. Transect T15 (Figure 4p) was conducted in a direction perpendicular to all other plume and ambient transects, starting at the farthest down-current extent of the surveyed area and moving towards the dredge. The vertical profile of this transect shows the plume extending from 900-1000 meters down-current from the source, with concentrations up to 400 mg/L present within approximately 350 meters down-current. This transect also shows the plume decreasing in height within the water column as distance from the dredge increases.

Figure 7 presents the hydrodynamic conditions recorded during the 19 June 2009 mobile ADCP survey discussed above. During the survey, depth-averaged current velocities within the area ranged between approximately 0.2 m/s and 0.9 m/s. In the eastern end of the survey area, towards the Upper Bay current direction was to the northwest, but towards the Kill Van Kull proper currents shifted to due west. The highest current velocities observed (greater than approximately 0.7 m/s) were at the western end of the survey area in the Kill van Kull, and the lowest current velocities (less than 0.3 m/s) were observed in an area close to the position of the dredge *Illinois*. The current directions and high current velocities observed in the Kill Van Kull down current of the dredge position are consistent with the observations of the plume made in this survey.

3.3.2 22 June 2009 - Ebb Tide #1

Two separate mobile ADCP plume characterization surveys were conducted on 22 June 2009 during the beginning portion of an ebb tide. Each of these surveys consisted of a full set of ambient and down-current transects. The first survey (Figures 8a-k) was conducted from 10:18 to 11:07, and consisted of one circle transect (Figure 8a), three ambient transects (Figures 8i through 8k), and seven down-current transects (Figures 8b 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 9h. For this survey, the dredge *Illinois* was located approximately 44 meters Northeast of the charted position of the green "3" navigation buoy. Ambient transects were conducted northwest of the dredge and down-current transects were conducted southeast of the dredge. Ambient and down-current transects were oriented perpendicular to the channel. Figure 10 provides a three-dimensional depiction of average TSS values for selected representative transects.

Up-current conditions presented in Figures 8i and 8j show TSS concentrations between 0 and 50 mg/L throughout most of the water column, which is consistent with the gravimetric results of the ambient water samples collected. The area of very high ADCP backscatter near the surface in transect A03 (Figure 8j) represents prop wash from a passing tug boat.

Plume signatures associated with the dredge operation were limited to within the first 499 meters down-current of the dredge (Transects T01 – T07). In the vertical profiles of these transects, a clearly defined plume was detected. For much of its length, the plume appeared bifurcated, with two separate parts, one in the top half, and one in the bottom half of the water column. This bifurcation was likely the result of local site conditions and hydrodynamics in which varied current velocities within different depth strata work to separate the plume into distinct parts. At this phase in the dredging, no material was being mechanically lifted from the bottom. The bottom portion of the plume contained higher estimated TSS concentrations, however, the top portion persisted for a longer distance from the source. Peak TSS concentrations within the plume reached approximately 400 mg/L in the bottom third of the water column and within 168 meters of the source (Transect T01). Plume width varied from approximately 30 to 140 meters at various locations. The plume was at its widest at approximately 215 meters (T02) from the dredge where the upper and lower portions of the plume were just beginning to separate. The two portions of the plume both decreased in size and separated further as distance from the dredge increased. The lower portion was last observed at a distance of 413 meters (T06) from the dredge with a width of approximately 60 meters and TSS concentrations up to approximately 60 mg/L, while the upper portion of the plume persisted to as far as 499 meters (T07) from the dredge with a width of 30 meters and TSS concentrations of approximately 60-80 mg/L.

Figure 11 presents the hydrodynamic conditions recorded during the 22 June 2009 ebb tide mobile ADCP survey discussed above. During the survey, depth-averaged current velocities within the area ranged between 0 m/s and approximately 0.3 m/s. Observed current directions were generally to the southeast throughout the survey area. Current velocities were relatively low overall. The highest current velocities (greater than approximately 0.2 m/s) were seen in the northwestern corner of the survey area near the middle of the channel. Current velocities in the remainder of the survey extents were less than 0.2 m/s (with the exception of a few small areas). This may account for the fact that the plume was not carried as far down-current as was observed during the flood tide monitored on 19 June, where current velocities were higher.

3.3.3 22 June 2009 - Ebb Tide #2

A second mobile ADCP plume characterization survey was conducted on 22 June 2009 during the middle portion of an ebb tide, from 12:36 to 13:31 (Figures 12a-k). This survey consisted of one circle transect (Figure 12a), three ambient transects (Figures 12i through 12k), and seven down-current transects (Figures 12b through 12h). 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 13a through 13h. For this survey, the dredge *Illinois* was located approximately 44 meters Northeast of the charted position of the green “3” navigation buoy. Ambient transects were conducted northwest of the dredge and down-current transects were conducted southeast of the dredge. Ambient and down-current transects were oriented perpendicular to the channel. Figure 14 provides a three-dimensional depiction of average TSS values for selected representative transects.

Up-current conditions presented in Figures 12i through 12k show TSS concentrations between 0 and 50 mg/L throughout most of the water column, which is consistent with the gravimetric results of the ambient water samples collected. However, there was some natural variability in ambient conditions present, and small areas of slightly higher ADCP estimated TSS concentrations were detected at the bottom of the water column and can be seen in Figures 12i through 12k. See the above discussion of ambient conditions (Section 3.2) for further details. The large ADCP signature seen in Figure 12i represents wake from the passage of a container ship through the survey area, as noted in the field notes presented in Table 4.

Plume signatures associated with the dredge operation were limited to within the first 596 meters down-current of the dredge (Transects T01 – T07). In the vertical profiles of these transects, a clearly defined plume was detected. Peak TSS concentrations within the plume were generally below 250 mg/L except for a small (10 meter) signature near the bottom of the water column within 162 meters of the source (Transect T01). Within 162 meters the source the plume was detected throughout most of the water column, beginning at approximately 3 meters depth and extending to the bottom (Transect T01). Between approximately 232 and 428 meters down-current from the source, the plume persisted longer at the bottom of the water column (Transects T02 to T05). Plume width varied from approximately 50 to 250 meters at various locations. The plume spread out to its widest extent along the bottom closest to the source, and narrowed as the distance down-current increased. The plume remained confined to the Kill Van Kull channel and its side slopes for nearly its entire extent. Because some transects extended into shallower water (less than 15 meters deep), sidelobe reflectivity can sometimes be observed on the slopes.

Figure 15 presents the hydrodynamic conditions recorded during the second 22 June 2009 ebb tide mobile ADCP survey discussed above. During the survey, depth-averaged current velocities within the area ranged between 0 m/s and approximately 0.3 m/s. Observed current directions were generally to the southeast throughout the survey area, but more towards the south-southeast at the eastern end of the survey area. Current velocities were relatively low overall. The highest current velocities (approximately 0.2 m/s or greater) were seen in the southeastern corner of the survey area near the St. George Ferry Terminal. Current velocities in most of the rest of the survey area were less than 0.2 m/s. This may account for the fact that the plume was not carried as far down-current as was observed during the flood tide monitored on 19 June, where current velocities were higher.

3.3.4 22 June 2009 - Flood Tide

A mobile ADCP plume characterization survey was conducted on 22 June 2009 during the beginning portion of a flood tide from approximately 15:59 to 16:55 (Figures 16a-p). The survey consisted of one circle transect (Figure 16a), three ambient transects (Figures 16n through 16p), and twelve down-current transects (Figures 16b through 16m). 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 17a through 17h. For this survey, the dredge *Illinois* was located approximately 36 meters north of the charted position of the green "3" navigation buoy. Ambient transects were conducted southeast of the dredge and down-current transects were conducted northwest of the dredge. Ambient and down-current transects were oriented perpendicular to the channel. Figure 18 provides a three-dimensional depiction of average TSS values for selected representative transects.

Up-current conditions presented in Figures 16n through 16p show TSS concentrations between 0 and 50 mg/L throughout most of the water column, which is consistent with the gravimetric results of the ambient water samples collected. However, there was some natural variability in ambient conditions present, and slightly higher ADCP estimated TSS concentrations were detected in small areas at the bottom of the water column. See the above discussion of ambient conditions (Section 3.2) for further details.

Plume signatures associated with the dredge operation were limited to within the first 646 meters down-current of the dredge (Transects T01 – T09). In the vertical profiles of these transects, a clearly defined plume was detected in the bottom third of the water column. Peak TSS concentrations within the plume reached approximately 400 mg/L within 111-

122 meters of the source (Transect T01-T02). As distance from the dredge increased, the clearly defined plume with TSS concentrations up to 400 mg/L began to dissipate, however, a stratum of higher ADCP estimated TSS concentrations persisted in all down-current transects. This stratum had TSS concentrations of up to approximately 250 mg/L from approximately 646 to 871 meters from the dredge and concentrations of up to 150 mg/L within 944 meters from the dredge. This acoustic signature may represent a natural, ambient stratification of TSS values within the water column, caused by high current velocities re-suspending bottom sediments. It is also possible that this signature represents portions of the cutterhead-generated plume spreading out along the channel bottom, or a combination of this plume with naturally re-suspended sediments. Plume width varied from approximately 80 to 100 meters at various locations, excluding any portion of the plume which may have spread out along the bottom across the entire width of the survey area. The plume was at its widest 122 meters down-current from the dredge (T02). The plume then narrowed and moved toward the bottom as its distance from the dredge continued to increase. An acoustic signature can also be seen in the upper half of the water column in the vertical profiles of down-current transects T03-T12. This signature had a lower estimated TSS concentration than the plume near the bottom, peaking at 100 mg/L within 365 meters of the dredge (T06). This signature can be seen to follow the edge of the channel slope for the length of much of the survey area at depths of 0-8 meters (Figures 17a-d). This suggests that it may represent a natural re-suspension of sediments caused by the interaction of currents with the edge of the channel slope, rather than a cutterhead related plume. Because some transects extended into shallower water (less than 15 meters deep), sidelobe reflectivity can be observed on the slopes in these transects. Prop wake from passing tug boats was also detected near the surface in some transects in this survey.

Figure 19 presents the hydrodynamic conditions recorded during the 22 June 2009 flood tide mobile ADCP survey discussed above. During the survey, depth-averaged current velocities within the area ranged between approximately 0.2 m/s and 1.1 m/s. Observed current directions were generally to the west throughout the survey area, tending more towards the northwest at the eastern end of the survey area. The highest current velocities (approximately 0.7 m/s or greater) were seen in the western portion of the survey area, in the Kill Van Kull proper. In general, current velocities decreased moving further east. The lowest current velocities (less than approximately 0.3 m/s) were observed along the southeastern part of the Kill Van Kull channel near the location of the dredge *Illinois*. The current directions and high current velocities in the Kill Van Kull are consistent with the observations of the plume made in this survey, namely that the plume was predominantly carried west within the Kill Van Kull channel, as was observed during the flood tide mobile ADCP survey on 19 June.

3.4 Fixed Station Turbidity Surveys

Two fixed station turbidity surveys were conducted on 23 June 2009, one each during an ebb and a flood tide. The procedures followed for these surveys differed from those used in previous far-field TSS surveys due to high vessel traffic and current conditions in the survey area. Typically, OBS units would be tethered to a taut line and anchored at predetermined depths using a fixed anchor and buoy array. Several of these arrays would be left in position up- and down-current of the dredge for the duration of a tidal cycle while the research vessel conducted additional survey operations in the area. An attempt was made to deploy such arrays, however, it was observed that due to current speeds of ~0.87 m/s, the arrays were being carried towards the active navigation channel and/or the shoreline. These arrays were retrieved soon after deployment, and instead, fixed station turbidity surveys were conducted by tethering OBS units to a weighted line, and attaching this array directly to the research vessel, which was held in position under power against the current. The same array was deployed sequentially up-current and down-current from the active cutterhead operation for approximately 30 minutes at a time. This array consisted of one OBS unit tethered at mid-depth, and one tethered at near-bottom depth, based on water depth of the deployment locations.

3.4.1 23 June 2009 – Ebb Tide

A fixed station turbidity survey was conducted on 23 June 2009 during an ebb tide. As discussed above, an OBS array was deployed directly from the research vessel. The array was first deployed 194 meters down-current (east) of the cutterhead from 11:11 to 11:46. The array was then deployed 137 meters up-current (west) of the cutterhead from 11:53 to 12:23, and then again down-current, 117 meters east of the cutterhead, from 12:41 to 13:11. Figure 20 shows the location of each deployment with respect to the cutterhead position. Figure 21 plots the recorded turbidity values (NTU) from the mid-depth (blue line), and bottom (purple line) OBS units for the up-current deployment, and the mid-depth (red line) and bottom (black line) OBS units from both down-current deployments.

Mid-water and bottom turbidity readings from the ambient, up-current OBS deployment remained constant throughout the deployment, ranging only between 6.7 and 13.6 NTU across both depths. During both down-current array deployments, turbidity readings from the mid-depth OBS unit fell within a similar range (between 5.4 and 8.8 NTU for the first deployment and 9.6 and 12.4 NTU for the second). However, the near-bottom OBS unit showed more variability in turbidity readings, and higher NTU values, during both down-current deployments. During the first deployment, near bottom turbidity readings ranged between 7.3 and 27.6 NTU and averaged 20.9 NTU. During the second deployment, near bottom turbidity readings ranged between 8.8 and 70.0 NTU and averaged 28.3 NTU.

The difference between mid-depth to bottom OBS turbidity readings is consistent with the characteristics of the cutterhead-generated plume observed during mobile ADCP surveys. Namely, the plume was found to be confined to the bottom half to one-third of the water column within the channel, so it is possible that the near-bottom OBS unit was within the plume while the mid-depth unit was outside of it.

The near-bottom turbidity readings also varied considerably during the deployments. This is especially true for the second deployment, when turbidity readings spiked multiple times to high values and then returned to ambient levels. This is likely due to the OBS array moving into and out of the plume (or vice-versa).

3.4.2 23 June 2009 – Flood Tide

A fixed station turbidity survey was conducted on 23 June 2009 during a flood tide. As discussed above, an OBS array was deployed directly from the research vessel. When this survey was conducted, mechanical dredging of spoils from the cutterhead operation had begun. The mechanical bucket-arm dredge *54* was situated to the east (up-current during a flood tide) of the dredge *Illinois,* and a plume generated by the mechanical dredge was detected by the ADCP in this area. Because of this, both arrays were deployed down-current of the *Illinois.* The ambient array was first deployed 117 meters down-current (west) of the cutterhead from 16:10 to 16:41, but outside of the known location of the cutterhead-generated plume. The array was then deployed within the known location of the plume, 184 meters down-current (west) of the cutterhead from 16:57 to 17:30. Figure 22 shows the location of each deployment with respect to the cutterhead position. Figure 23 plots the recorded turbidity values (NTU) from the mid-depth (blue line), and bottom (purple line) OBS units for the up-current deployment, and the mid-depth (red line) and bottom (black line) OBS units from the down-current deployment.

Mid-water and bottom turbidity readings from the ambient OBS deployment remained constant throughout the deployment, ranging between 2.7 and 15.4 NTU across both depths.

During the in-plume deployment, turbidity readings from the mid-depth OBS unit also remained fairly constant, ranging between 8.8 and 26.2 NTU. However, turbidity readings from the in-plume, near-bottom OBS unit varied to a much higher degree across the deployment, and reached higher values, ranging from 6.6 to 115.8 NTU. As was discussed for the 23 June 2009 ebb tide OBS survey, the difference between mid-depth and bottom down current turbidity readings may be due to the observed stratification of the sediment plume, and the spikes between ambient and high values in bottom turbidity are likely due to the vessel-deployed OBS array moving into and out of the plume and/or the natural heterogeneity of plume concentrations.

3.5 Laboratory Analysis of Water Samples

A total of 88 water samples were collected in the project area from 15 June to 22 June 2009. The laboratory results of the optical turbidity and the gravimetric analysis of TSS concentration of those 88 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.

In this study, the TSS concentrations of the 88 water samples ranged from 7.0 to 564.0 mg/L and turbidity concentrations ranged from 1.5 to 296.0 NTU. Figure 24a plots the paired gravimetric measurements and ADCP acoustic estimates of TSS arranged in concentration versus time order for the 71 water samples used in the Sediview calibration. Note that some of the 88 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 2.5). Overall, there was a strong agreement (R^2 = 0.93) between the acoustic estimates of TSS concentration and the gravimetric measurements (Figure 24b).

3.6 Sediment Sample

A sediment sample was collected from the cutterhead operation area on 15 June 2009 by means of a ponar grab. The laboratory results of this sample for grain size distribution, density, and Atterberg Limits are presented in Table 6. This sample was classified generally by the lab as saturated, dark brown silty gravel with sand. According to the grain size distribution results, the sample was comprised of 46.4% gravel, 39.9% sand, and 13.7% silt and clay. The Atterberg Limits analysis determined the sample to be non-plastic. The bulk density of the sample was determined to be 78.7 lb/ft^3 (1.26 g/cc), and the dry density was 22.3 lb/ft^3 (0.36 g/cc).

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 forces, 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, a far-field WQ/TSS survey was conducted between 19 June 2009 and 23 June 2009 within the S-KVK-1 contract area in the Constable Hook Reach of the Kill Van Kull in Upper Bay, New York (Figure 1). The objective of the far-field survey was to assess the spatial extent and temporal dynamics of suspended sediment plumes associated with cutterhead dredge operations. The methodologies employed for this survey were similar to those used previously and subsequently 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 2013). Similar methodologies were also used subsequently to survey cutterhead dredge operations in the Kill Van Kull (USACE 2012). However, direct comparisons between studies are inexact due to the varying hydrodynamic conditions and sediment types within the different study areas.

The cutterhead dredge features rotating blades designed to direct loosen material efficiently to assist in the mechanical excavation of consolidated material (in this study, Serpentinite bedrock from the Kill Van Kull). Previous studies have shown that the mechanical mixing by the rotating cutterhead can be a factor in sediment resuspension at the point of dredging for this type of dredge, but that sediment resuspension can be minimized through proper dredge design and operation (Havis 1988). During typical cutterhead operations, a hydraulic suction pipeline is used to directly remove the loosened material from the area of excavation. In this study, hydraulic suction was not used to remove material; instead, the cut rock was temporally relocated to an adjacent area on the channel bottom through an installed downspout before final removal using a mechanical excavator dredge.

Havis (1988) reported that sediment resuspension from cutterhead dredges is chiefly in the lower portion of the water column and that plume TSS concentrations measured during field studies of a cutterhead dredge operating in Calumet Harbor, Illinois did not exceed 200 mg/L. The results of this survey in the Kill Van Kull were similar with regard to the distribution of the plume in the water column, but differed in the maximum TSS concentrations observed.

Peak estimates of TSS concentrations directly attributable to the cutterhead dredging operation in the Kill Van Kull reached 600 mg/L in a small area during one flood tide TSS survey, and peak concentrations of 200-400 mg/L were typical across other surveys. These peak concentrations were for the most part higher than those observed in other surveys monitoring cutterhead dredge operations (approximately 200 mg/L), including a subsequent survey in the same S-KVK-1 contract area (Havis 1988, USACE 2012). Although the target of the excavation for this survey was the underlying Serpentinite bedrock, sampling locations in the survey area may have been overlain with a thin layer of finer grained black silt/clay. The results of the grain size analysis conducted on the sediment sample collected during this survey from the cutterhead field of operation showed the sample to contain 13.7% silt/clay. These finer grained sediments may have remained longer in suspension and accounted for the higher estimated TSS concentrations.

In general the plume was confined to the lower third of the water column, and because the prevailing currents within the Kill Van Kull are strongly oriented along the channel, the plume did not extend beyond the channel bottom or into adjacent shallow water areas. In this respect, the results of this cutterhead monitoring survey were similar to previous, and on-going, USACE-NYD efforts to monitor mechanical clamshell bucket dredging of fine grain sediments within the HDP which has clearly documented that re-suspended sediments typically remain within channel boundaries. In instances where a portion of the plume was seen in the upper water column in this survey, this portion of the plume contained relatively low TSS concentrations (approximately 100 mg/L or less), with higher concentrations confined to the bottom of the water column.

With one exception, the sediment plume dissipated to essentially background conditions by 500-600 meters down current. This is similar to the extent of the plume that was observed during the second monitoring survey of cutterhead operations in the Kill Van Kull (USACE 2012). In one flood tide TSS survey, plume signatures were observed further down current from the dredge, returning to near ambient conditions by 985 meters down current (Figures 4f-4t). This may have been due to the possible excavation of finer grained sediments, and greater current velocities (close to 1.0 m/s), during this survey.

In general, during these surveys, the plume generated by cutterhead operations extended further down-current from the source during a flood tide than an ebb tide. On average plume signatures dissipated to ambient conditions within approximately 500 meters during an ebb tide, but reached ambient levels within approximately 800 meters down current during a flood tide. Higher TSS concentrations also persisted a greater distance down-current from the dredge during a flood tide than during an ebb tide. Suspended sediment concentrations dissipated to near 100 mg/L or below within an average of approximately 300 meters during an ebb tide, but during flood tides, concentrations of approximately 250-300 mg/L were seen up to approximately 600-800 meters from the cutterhead. This may be due to differences in current speed across the S-KVK-1 contract area. Throughout the survey and across both tide cycles, current velocities were observed to be much faster within the narrower channel of the Kill Van Kull than in the portion of the channel which extended into the Upper Bay. The dredge *Illinois* was positioned near the transition between these two areas, and thus current velocities to the west of the dredge were likely higher than to the east during both tide cycles. Thus during a flood tide, the velocities would have been stronger in the down-current direction, which may account for the greater down-current extent of the plume during a flood tide in this area.

5.0 LITERATURE CITED

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Table 1. Laboratory Results of Water Samples - S-KVK-1 Far Field TSS Survey (15-22 June 2009)

Sample	Sample Date	Sample Time	Location	Total Suspended Solids (mg/L)	Turbidity (NTU)
1	6/15/2009	9:58:13 AM	Ambient	17.8	2.9
2	6/15/2009	9:58:20 AM	Ambient	23.8	2.3
3	6/15/2009	9:58:24 AM	Ambient	19.5	2.4
4	6/15/2009	9:58:29 AM	Ambient	22.0	2.4
5	6/15/2009	9:58:35 AM	Ambient	18.5	2.3
6	6/15/2009	9:58:41 AM	Ambient	12.8	2.3
7	6/15/2009	1:17:20 PM	Ambient	7.0	2.3
8	6/15/2009	1:17:25 PM	Ambient	16.8	3.2
9	6/15/2009	1:17:29 PM	Ambient	18.3	1.8
10	6/15/2009	1:17:32 PM	Ambient	13.2	2.5
11	6/15/2009	1:17:35 PM	Ambient	10.0	2.2
12	6/15/2009	1:17:37 PM	Ambient	11.0	2.9
13	6/15/2009	1:37:44 PM	Ambient	18.2	2.2
14	6/15/2009	1:37:51 PM	Ambient	19.2	1.9
15	6/15/2009	1:37:57 PM	Ambient	18.5	3.2
16	6/15/2009	1:38:01 PM	Ambient	16.5	2.5
17	6/15/2009	1:38:05 PM	Ambient	14.5	3.2
18	6/15/2009	1:38:10 PM	Ambient	8.2	2.4
19	6/15/2009	3:05:23 PM	Ambient	13.3	1.5
20	6/15/2009	3:05:28 PM	Ambient	18.5	1.5
21	6/15/2009	3:05:33 PM	Ambient	14.2	1.6
22	6/15/2009	3:05:37 PM	Ambient	18.2	2.0
23	6/15/2009	3:05:40 PM	Ambient	13.3	2.3
24	6/15/2009	3:05:43 PM	Ambient	20.3	2.3
25	6/19/2009	9:27:27 AM	Ambient	24.0	10.1
26	6/19/2009	9:27:28 AM	Ambient	46.3	16.0
27	6/19/2009	9:27:39 AM	Ambient	32.0	7.2
28	6/19/2009	9:27:40 AM	Ambient	24.0	4.4
29	6/19/2009	9:27:49 AM	Ambient	22.0	5.9
30	6/19/2009	12:49:24 PM	Ambient	26.7	5.6
31	6/19/2009	12:49:28 PM	Ambient	17.7	2.3
32	6/19/2009	12:49:31 PM	Ambient	11.5	2.6
33	6/19/2009	12:49:35 PM	Ambient	15.5	2.4
34	6/19/2009	12:49:38 PM	Ambient	11.0	2.4
35	6/19/2009	12:49:43 PM	Ambient	11.7	2.6

Table 1. Laboratory Results of Water Samples - S-KVK-1 Far Field TSS Survey (15-22 June 2009)

Sample	Sample Date	Sample Time	Location	Total Suspended Solids (mg/L)	Turbidity (NTU)
36	6/19/2009	1:58:32 PM	Plume	341.0	142.0
37	6/19/2009	1:58:35 PM	Plume	184.0	73.4
38	6/19/2009	1:58:39 PM	Plume	20.7	4.7
39	6/19/2009	1:58:40 PM	Plume	18.7	4.7
40	6/19/2009	1:58:43 PM	Plume	13.7	5.2
41	6/19/2009	1:58:46 PM	Plume	14.3	5.5
42	6/19/2009	2:08:05 PM	Plume	564.0	296.0
43	6/19/2009	2:08:06 PM	Plume	524.0	268.0
44	6/19/2009	2:08:08 PM	Plume	474.0	224.0
45	6/19/2009	2:08:54 PM	Plume	338.0	155.0
46	6/19/2009	2:09:12 PM	Plume	27.7	11.3
47	6/19/2009	2:24:32 PM	Plume	76.0	28.0
48	6/19/2009	2:24:34 PM	Plume	130.0	26.9
49	6/19/2009	2:24:52 PM	Plume	31.7	10.4
50	6/19/2009	2:24:54 PM	Plume	37.0	14.2
51	6/19/2009	2:25:11 PM	Plume	20.7	5.1
52	6/19/2009	2:25:14 PM	Plume	17.0	4.9
53	6/22/2009	10:11:47 AM	Plume	95.0	88.0
54	6/22/2009	10:11:50 AM	Plume	108.0	62.4
55	6/22/2009	10:11:51 AM	Plume	94.0	39.8
56	6/22/2009	10:11:54 AM	Plume	148.0	39.6
57	6/22/2009	10:11:57 AM	Plume	37.3	13.4
58	6/22/2009	10:12:03 AM	Plume	33.8	5.8
59	6/22/2009	11:14:12 AM	Plume	58.0	26.9
60	6/22/2009	11:14:14 AM	Plume	71.0	31.5
61	6/22/2009	11:14:19 AM	Plume	78.5	38.4
62	6/22/2009	11:14:21 AM	Plume	58.5	26.9
63	6/22/2009	11:14:24 AM	Plume	47.5	20.7
64	6/22/2009	11:14:28 AM	Plume	40.5	13.2
65	6/22/2009	11:41:20 AM	Plume	86.5	28.8
66	6/22/2009	11:41:23 AM	Plume	99.0	48.6
67	6/22/2009	11:41:44 AM	Plume	54.0	24.8
68	6/22/2009	11:41:45 AM	Plume	57.5	29.3
69	6/22/2009	11:41:47 AM	Plume	78.5	36.3
70	6/22/2009	11:42:00 AM	Plume	31.0	13.6

Table 1. Laboratory Results of Water Samples - S-KVK-1 Far Field TSS Survey (15-22 June 2009)

Sample	Sample Date	Sample Time	Location	Total Suspended Solids (mg/L)	Turbidity (NTU)
71	6/22/2009	11:56:49 AM	Plume	26.0	11.5
72	6/22/2009	11:56:51 AM	Plume	32.2	14.4
73	6/22/2009	11:56:54 AM	Plume	37.0	15.8
74	6/22/2009	11:56:55 AM	Plume	57.3	23.4
75	6/22/2009	11:56:57 AM	Plume	55.7	21.8
76	6/22/2009	11:56:59 AM	Plume	61.5	22.9
77	6/22/2009	3:26:26 PM	Plume	537.0	274.0
78	6/22/2009	3:26:27 PM	Plume	512.0	276.0
79	6/22/2009	3:26:39 PM	Plume	539.0	296.0
80	6/22/2009	3:26:40 PM	Plume	525.0	270.0
81	6/22/2009	3:26:56 PM	Plume	19.3	9.9
82	6/22/2009	3:26:58 PM	Plume	24.5	11.1
83	6/22/2009	5:04:09 PM	Plume	131.0	34.1
84	6/22/2009	5:04:12 PM	Plume	143.0	35.2
85	6/22/2009	5:04:21 PM	Plume	166.0	61.8
86	6/22/2009	5:04:22 PM	Plume	210.0	69.0
87	6/22/2009	5:04:24 PM	Plume	222.0	79.0
88	6/22/2009	5:04:26 PM	Plume	184.0	65.8

Table 2. 19 June 2009 - Far Field Flood Tide Survey - Transect Summary Table

Transect Number	Figure Number	Time	Transect Length (m)	Distance From Dredge (m)	Plume Description	Additional Field Remarks
C01	4a	12:59:17	857		Circle transect to locate plume; plume is along edge of bank	
T01	4b	13:07:05	191	78	Heavy plume in bottom 1/3 of water column, concentrations up to 600 mg/L	
T02	4c	13:09:13	244	123	Plume persists, widens, but remains confined to bottom 1/3 of water column and within channel; concentrations up to 400 mg/L	Tug prop wash at end
T03	4d	13:12:08	234	152		Tug prop wash at beginning
T04	4e	13:14:33	203	180		
T05	4f	13:17:02	226	247		
T06	4g	13:20:28	164	311		
T07	4h	13:22:44	203	313		
T08	4i	13:25:05	130	370		
T09	4j	13:26:50	203	463	Plume gradually narrows and dissipates, remains confined to bottom 1/3 of water column; concentrations up to 300 mg/L; some sidelobe present	Prop wash from self (Parker)
T10	4k	13:29:35	142	543		
T11	4l	13:33:39	211	637		
T12	4m	13:35:51	141	735		
T13	4n	13:38:01	248	820		Prop wash
T14	4o	13:40:36	186	985	Weak possible plume still visible along bottom, concentrations up to 150 mg/L	Large wake
T15	4p	13:44:10	988	77 to 928	Cross section along length of plume; concentrations up to 400 mg/L; plume decreases in height further from dredge	Recorded parallel to plume, moving towards dredge
A01	4q	14:32:07	147	125	Ambient stratification along bottom, concentrations up to 60 mg/L; some sidelobe present	
A02	4r	14:34:02	211	161		
A03	4s	14:36:32	200	203	Ambient stratification along bottom, concentrations up to 80 mg/L; surface propwash; some sidelobe present	Prop wash from launch boat
A04	4t	14:39:04	238	274		

Table 3. 22 June 2009 Far Field Ebb Tide Survey #1 - Transect Summary Table

Transect Number	Figure Number	Time	Transect Length (m)	Distance From Dredge (m)	Plume Description	Additional Field Remarks
C01	8a	10:18:50	772		Circle transect to locate plume	
T01	8b	10:30:25	396	168	Plume has two parts: in bottom half concentrations up to 400 mg/L, in top half up to 100 mg/L.	
T02	8c	10:34:01	185	215	Both parts of plume widen, bottom weakens somewhat, top remains at ~100 mg/L	
T03	8d	10:36:25	256	267	Both parts of plume gradually weaken	
T04	8e	10:39:29	245	315		
T05	8f	10:42:11	250	370		
T06	8g	10:45:17	279	413	Only top half of plume remains, concentrations 60-80 mg/L	
T07	8h	10:48:20	267	499		
A01	8i	10:56:09	264	93	Up-current ambient transects	
A02	8j	10:59:16	264	126		
A03	8k	11:07:25	246	162		Prop wash at end - tug Marjorie McAllister

Table 4. 22 June 2009 Far Field Ebb Tide Survey #2 - Transect Summary Table

Transect Number	Figure Number	Time	Transect Length (m)	Distance From Dredge (m)	Plume Description	Additional Field Remarks
C01	12a	12:46:26	733		Circle transect to locate plume	Ens. 7600 prop wash from tug Brangus
A01	12b	13:27:28	179	104	Up-current ambient transect, some small areas of higher ambeint TSS; large propwash at surface	Propwash from cont. ship Cosco Osaka
A02	12c	13:29:35	176	144	Up-current ambient transects, some small areas of higher ambient TSS	
A03	12d	13:31:34	199	195		
T01	12e	12:53:34	305	162	Plume spreading out from edge of bank, concentrations up to 200 mg/L	
T02	12d	12:56:42	276	232	Plume spreads out into channel and weakens	
T03	12g	13:00:02	222	281		
T04	12h	13:03:26	264	348		
T05	12i	13:06:37	437	428	Plume narrows	Prop wash Moran tug
T06	12j	13:11:11	419	517	Very weak plume remains at bottom of water column (concentrations up to 60 mg/L)	
T07	12k	13:15:22	364	596		

Table 5. 22 June 2009 Far Field Flood Tide Survey - Transect Summary Table

Transect Number	Figure Number	Time	Transect Length (m)	Distance From Dredge (m)	Plume Description	Additional Field Remarks
C01	16a	15:59:56	724		Circle transect to locate plume	
A01	16b	16:50:20	180	143	Up-current ambient transects; include some small areas of higher ambient TSS	
A02	16c	16:52:43	204	182		
A03	16d	16:55:41	157	232		
T01	16e	16:09:44	247	111	Heavy plume in bottom half of water column, concentrations up to 400 mg/L; heavy sidelobe signals.	
T02	16f	16:12:09	134	122		
T03	16g	16:13:49	183	176		
T04	16h	16:15:47	205	224		
T05	16i	16:18:13	224	289		
T06	16j	16:20:36	224	365		
T07	16k	16:23:25	223	456	Plume begins to dissipate	
T08	16l	16:26:07	224	538		Tug prop wash at end
T09	16m	16:28:57	284	646	Plume spreads out to stratum of higher TSS in bottom 2-3 meters of water column; concentrations up to 250 mg/L	Tug prop wash 16:29:30
T10	16n	16:32:33	226	739		
T11	16o	16:36:14	258	871		16:37:20 prop wash
T12	16p	16:38:56	95	944	Stratum of higher TSS in bottom 2-3 meters of water column, concentrations up to 150 mg/L	Cut short, tug

Table 6. Sediment Collection and Analyses Summary Table
S-KVK-1 Survey - 15 June 2009

			Grain Size Distribution[1]			Density[2]			Atterberg Limits[3]			
Sample Location	Date Sampled	Time Sampled	Gravel	Sand	Silt/Clay	Bulk Density	Moisture Content[4]	Dry Density	Liquid Limit	Plastic Limit	Liquidity Index	Plasticity Index
			(%)	(%)	(%)	(lb/ft^3)	(%)	(lb/ft^3)	--	--	--	--
Dredge Field	6/15/2009	9:54	46.4	39.9	13.7	78.7	252	22.3	n/a*	n/a*	n/a*	n/a*

*Sample was determined to be Non-Plastic

[1]ASTM D-422-63 Method

[2]ASTM D-2937 Method

[3]ASTM D-4318-05 Method

[4]ASTM D-2216 Method

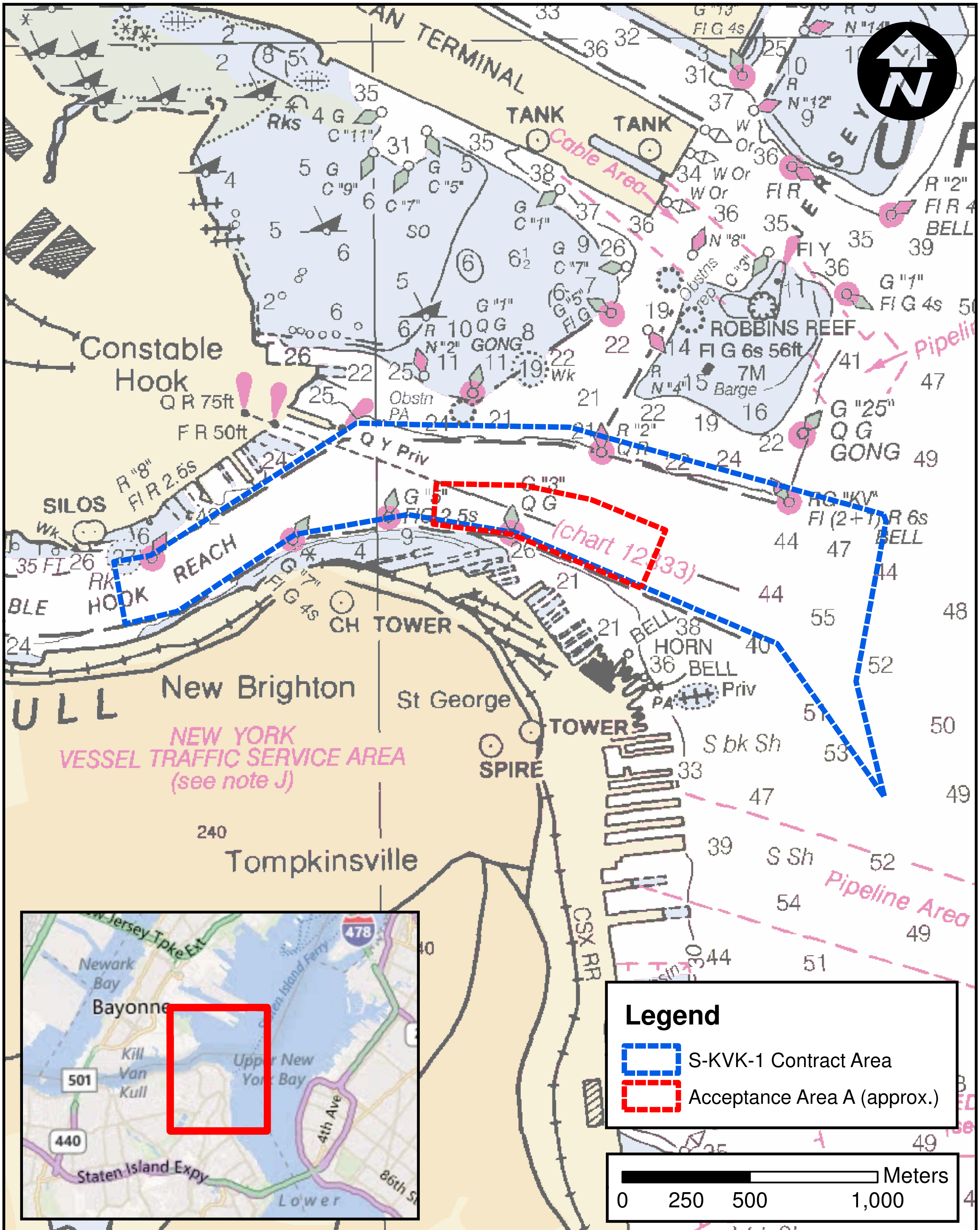


Figure	USACE Harborwide TSS Far Field Survey KVK Cutterhead	Upper Bay - Kill Van Kull Channel S-KVK-1 Cutterhead Far Field Study Area	Tide
1			N/A

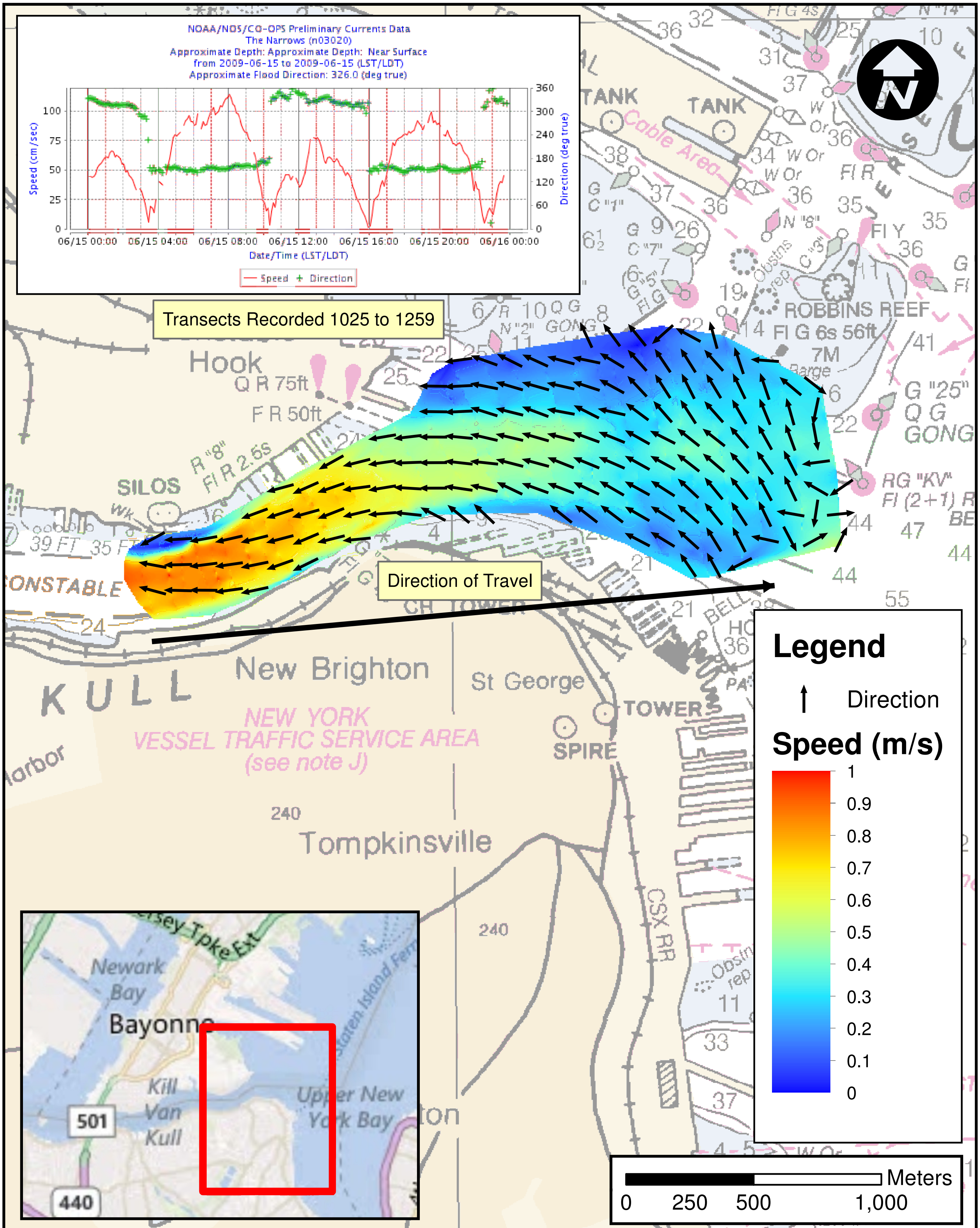


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-KVK-1	Depth Averaged Velocities 15 June 2009 - Flood Tide Hydrodynamic Survey	Tide
2			Flood

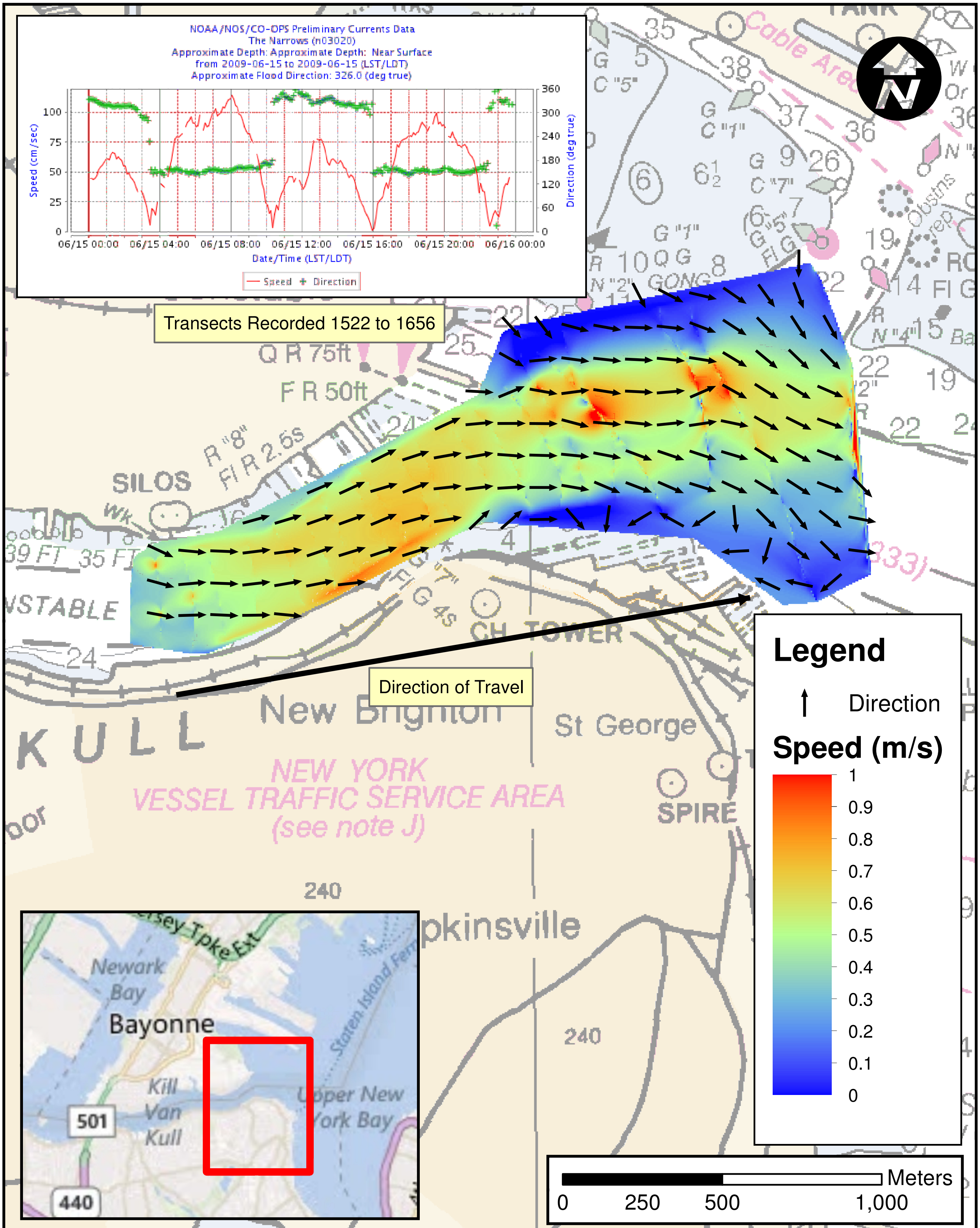
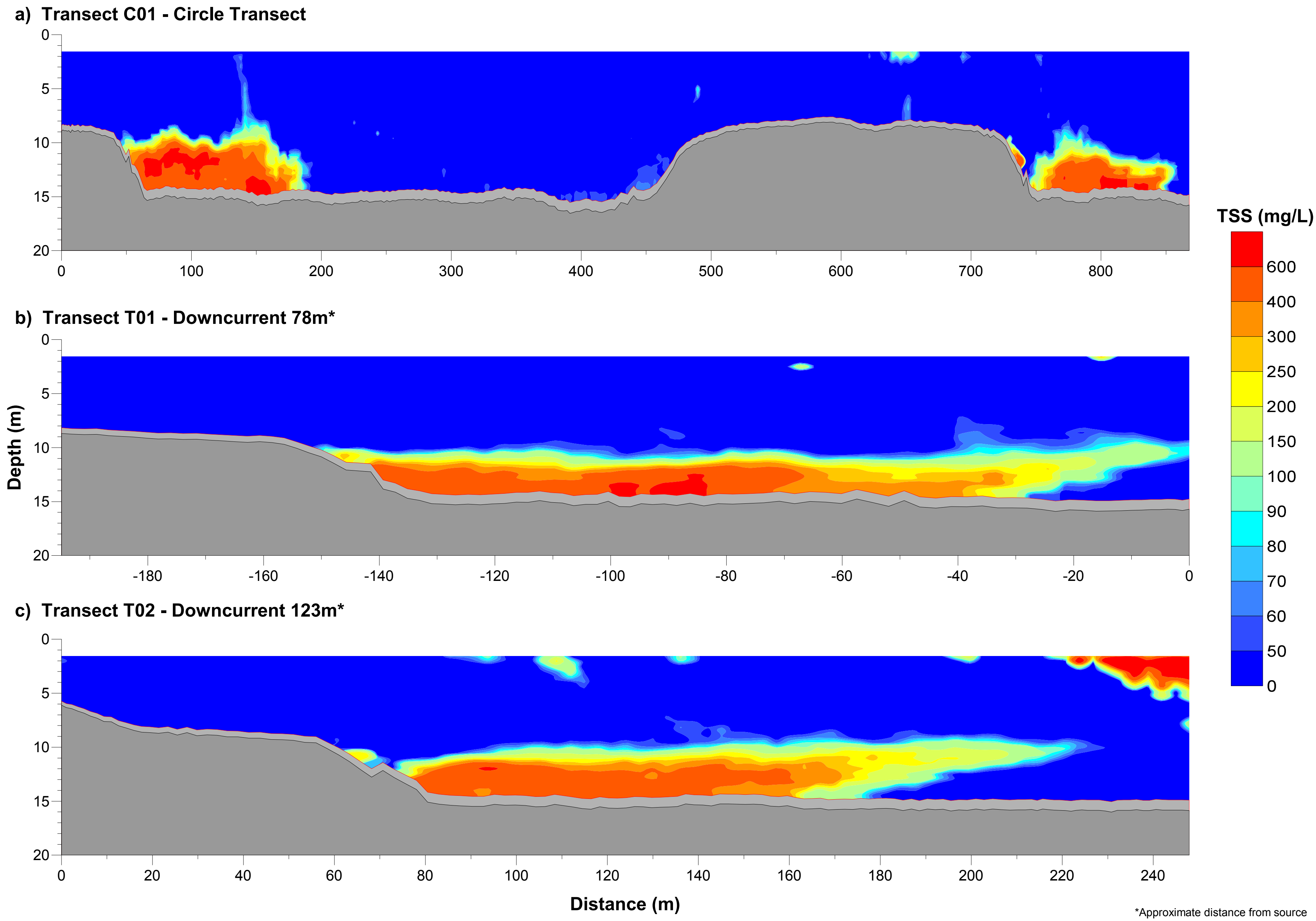
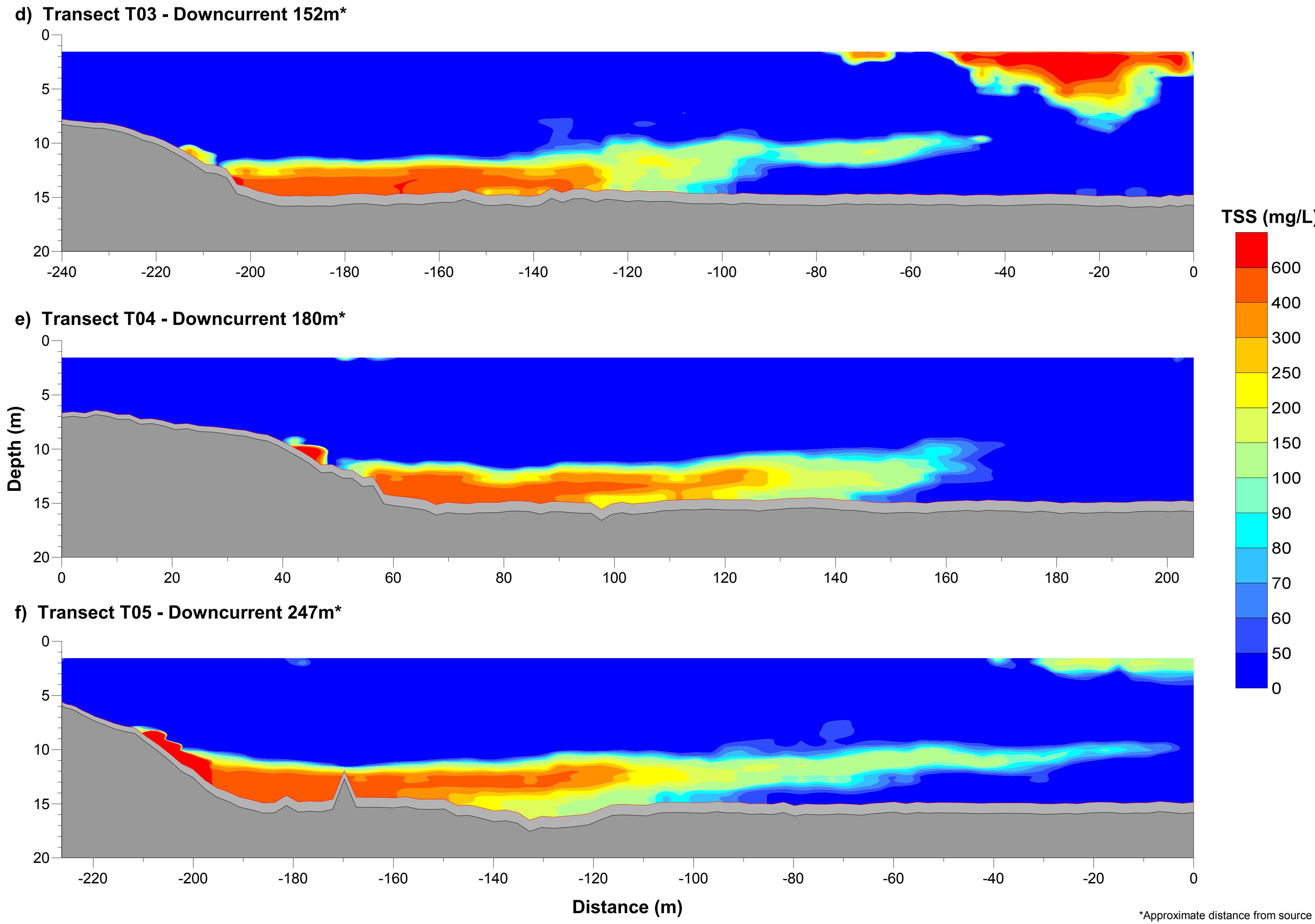


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-KVK-1	Depth Averaged Velocities 15 June 2009 - Ebb Tide Hydrodynamic Survey	Tide
3			Ebb



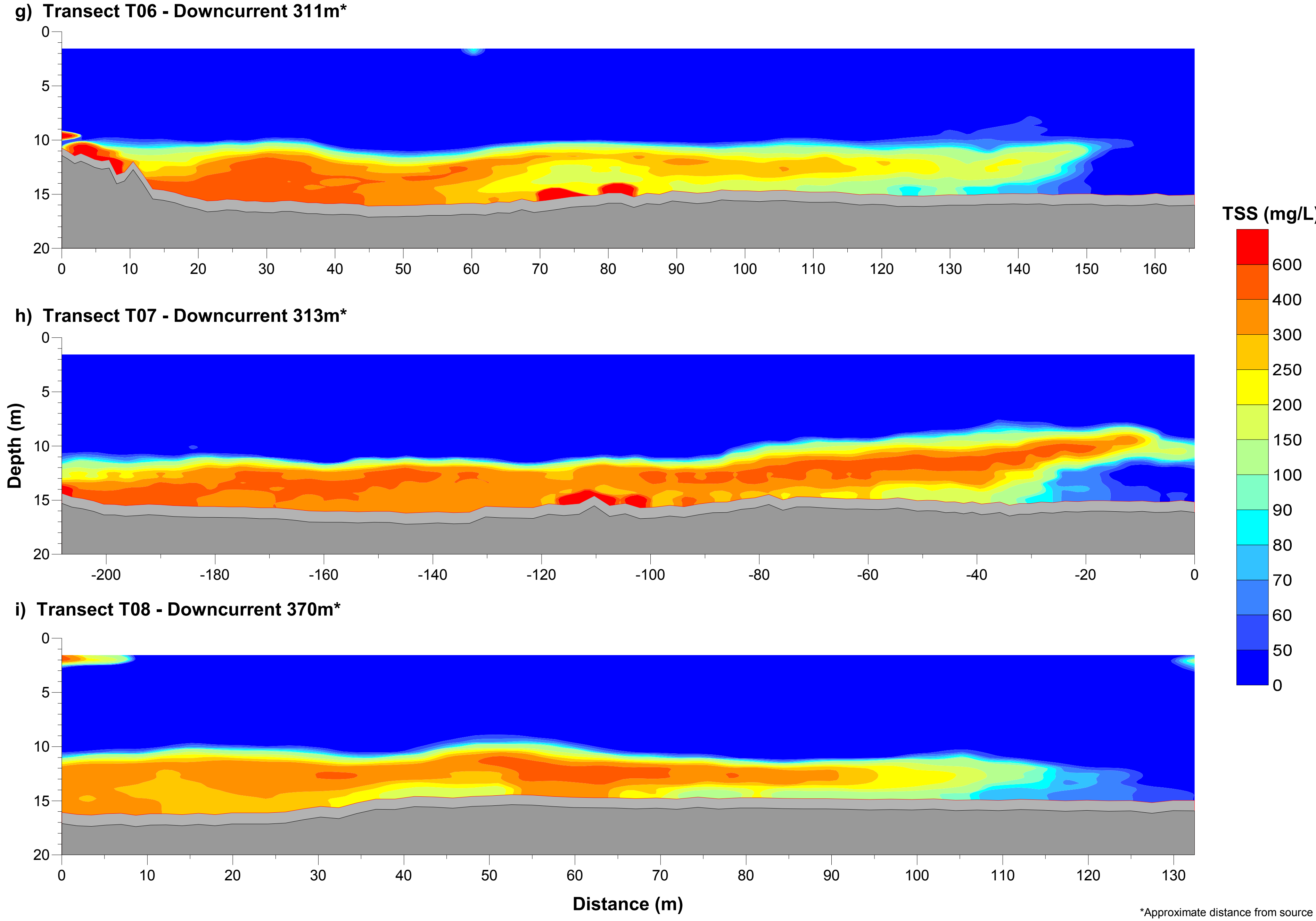
*Approximate distance from source

FIGURE	*USACE Harborwide TSS* *Far Field Survey* *S-KVK-1*	**Vertical Profiles of ADCP Average TSS** **19 June 2009 - Flood Tide**	TIDE
4a-c			**Flood**



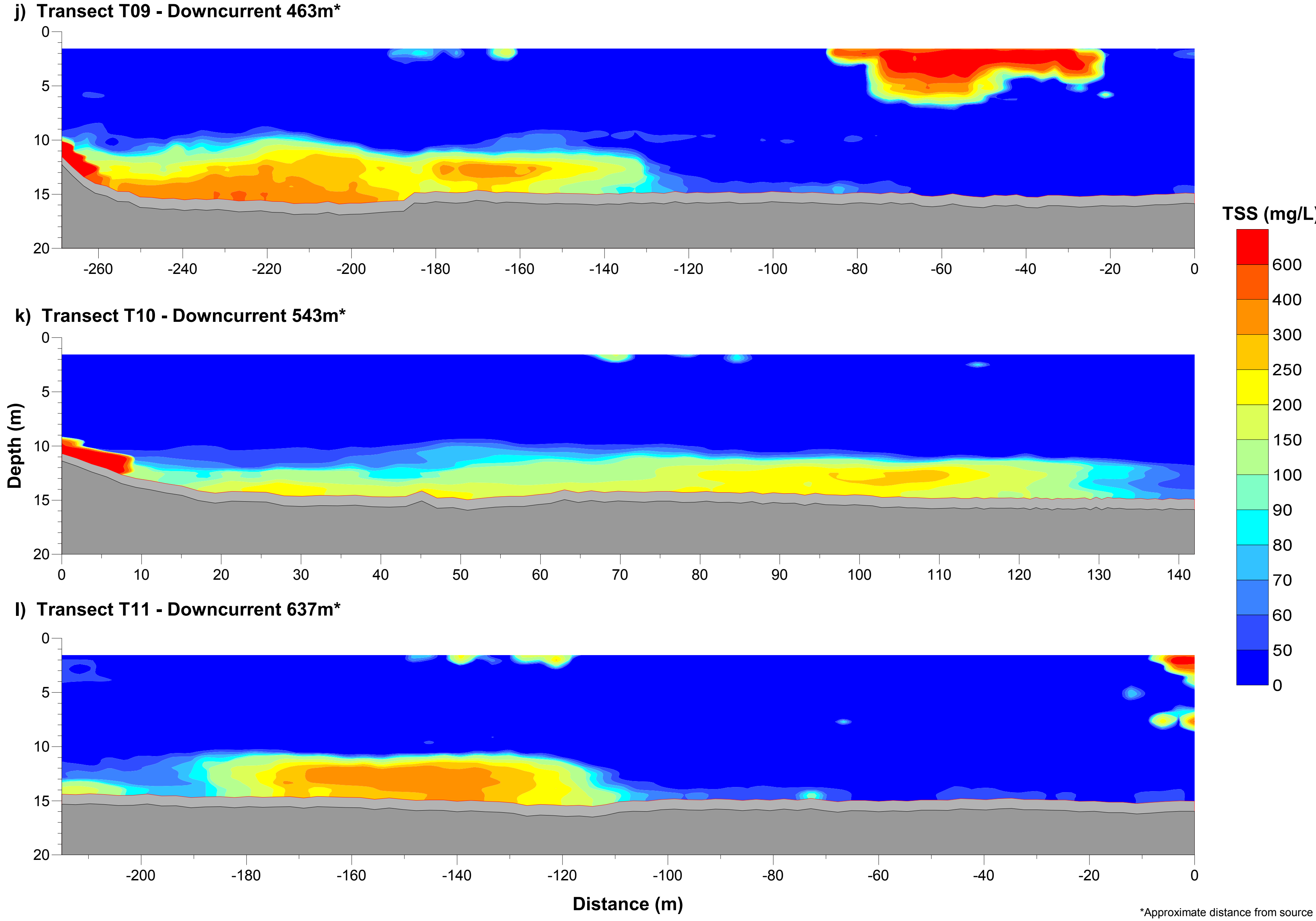
*Approximate distance from source

FIGURE	*USACE Harborwide TSS Far Field Survey S-KVK-1*	**Vertical Profiles of ADCP Average TSS 19 June 2009 - Flood Tide**	TIDE
4d-f			Flood



*Approximate distance from source

FIGURE	USACE Harborwide TSS Far Field Survey S-KVK-1	Vertical Profiles of ADCP Average TSS 19 June 2009 - Flood Tide	TIDE
4g-i			Flood



*Approximate distance from source

FIGURE	USACE Harborwide TSS Far Field Survey S-KVK-1	Vertical Profiles of ADCP Average TSS 19 June 2009 - Flood Tide	TIDE
4j-l			Flood

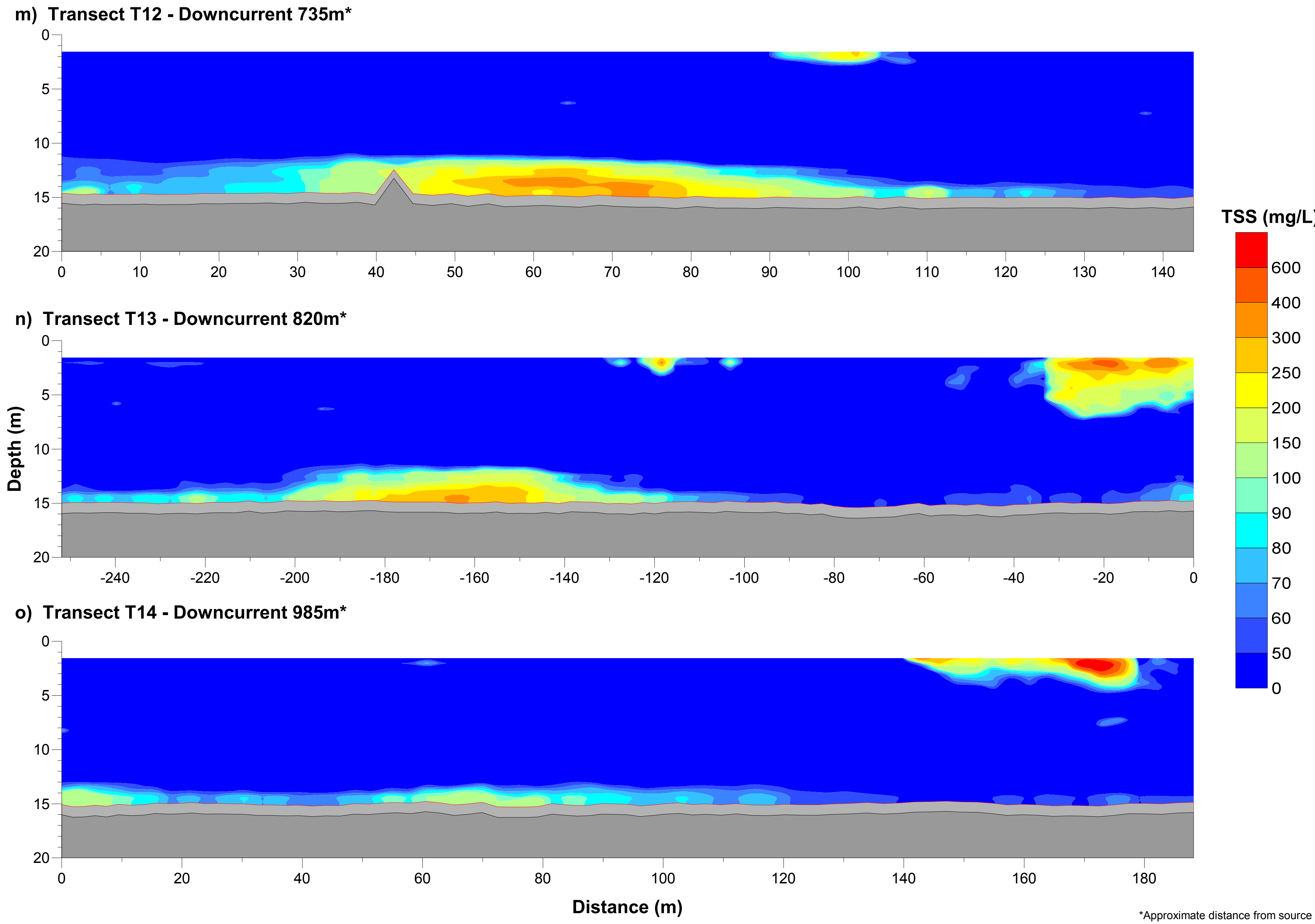
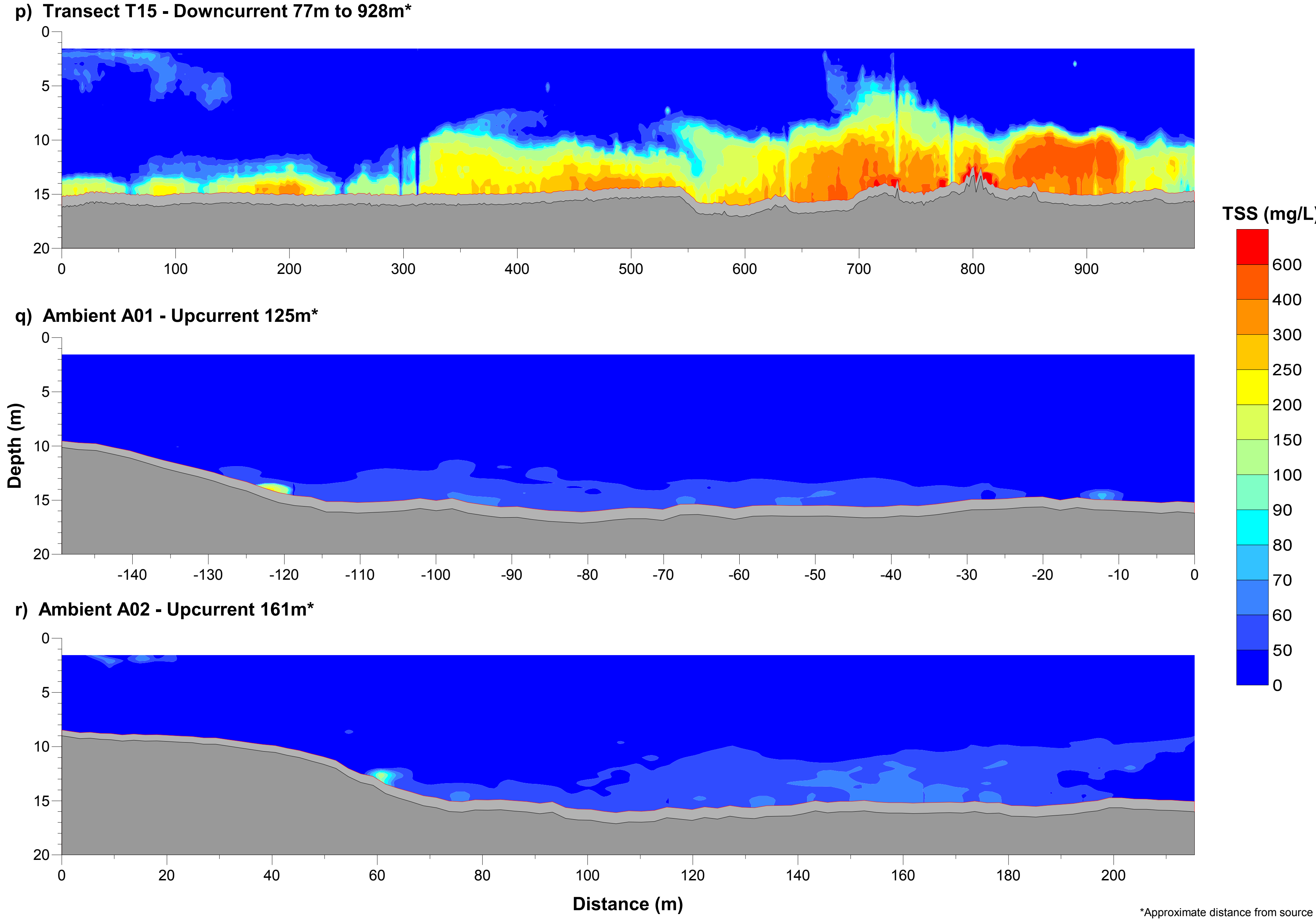
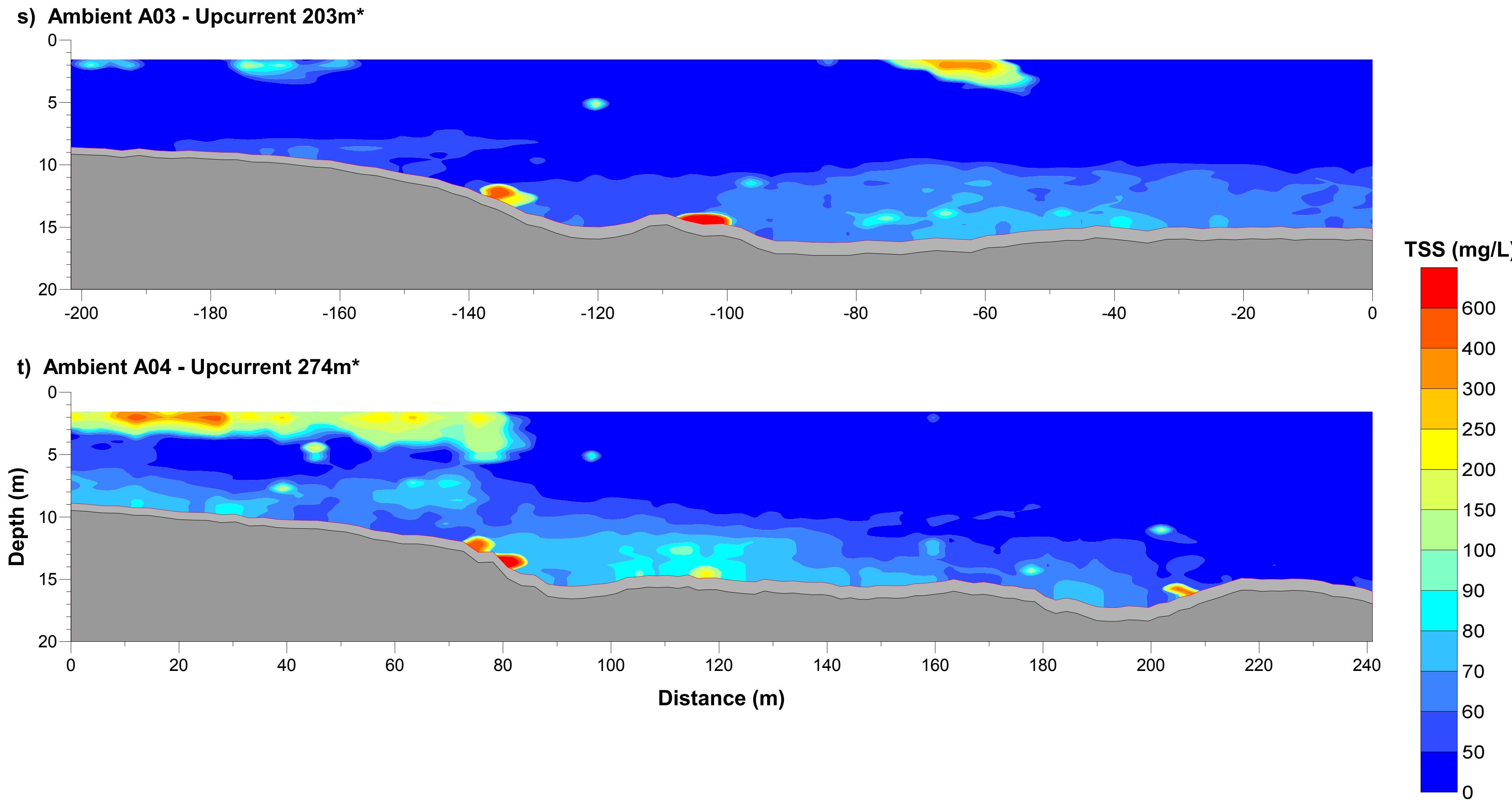


FIGURE	USACE Harborwide TSS Far Field Survey S-KVK-1	Vertical Profiles of ADCP Average TSS 19 June 2009 - Flood Tide	TIDE
4m-o			Flood



*Approximate distance from source

FIGURE	USACE Harborwide TSS Far Field Survey S-KVK-1	Vertical Profiles of ADCP Average TSS 19 June 2009 - Flood Tide	TIDE
4p-r			Flood



*Approximate distance from source

FIGURE	*USACE Harborwide TSS Far Field Survey S-KVK-1*	Vertical Profiles of ADCP Average TSS 19 June 2009 - Flood Tide	TIDE
4s-t			Flood

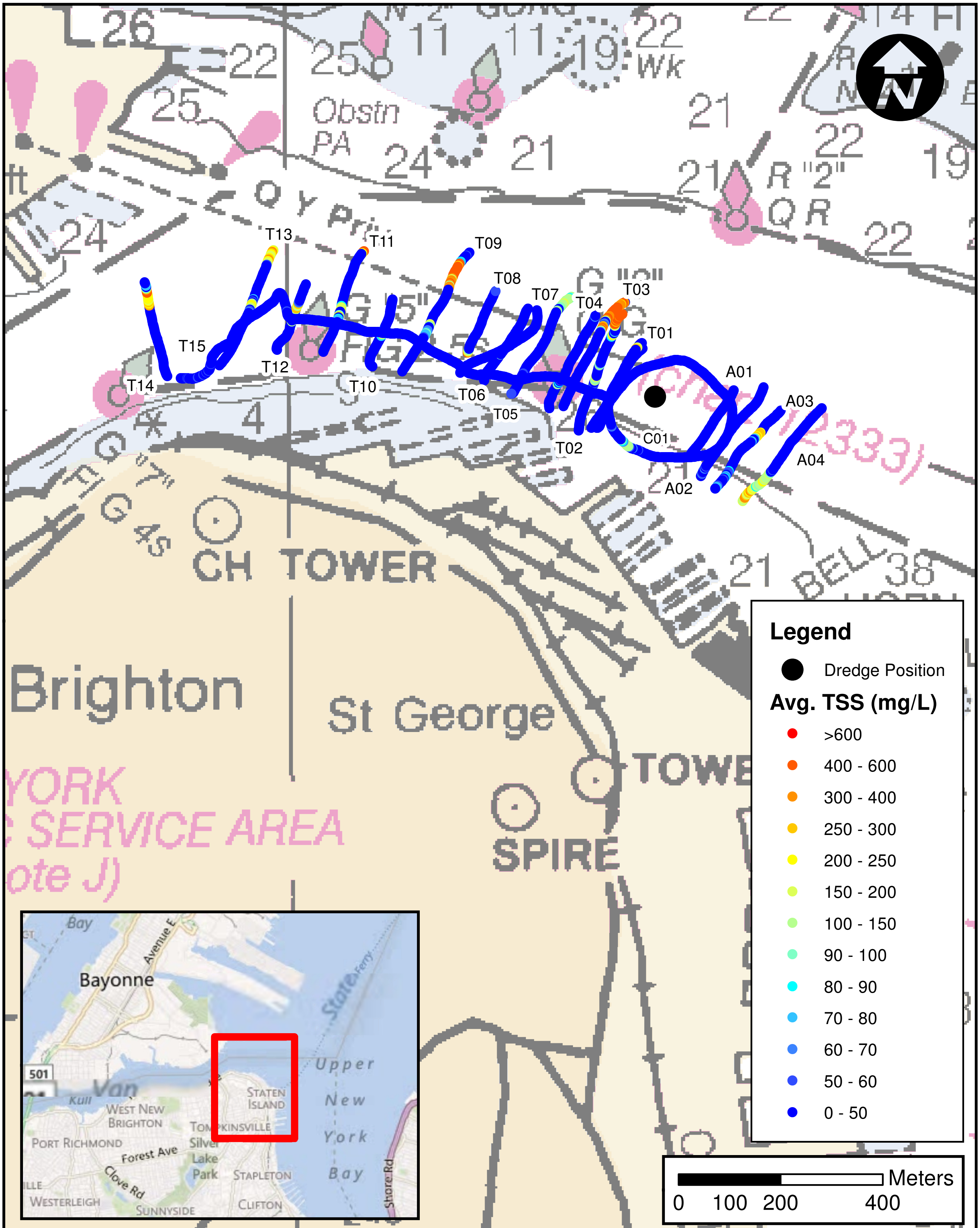


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-KVK-1	ADCP Average TSS - 19 June 2009 0-2 Meter Depth Interval	Tide
5a			Flood

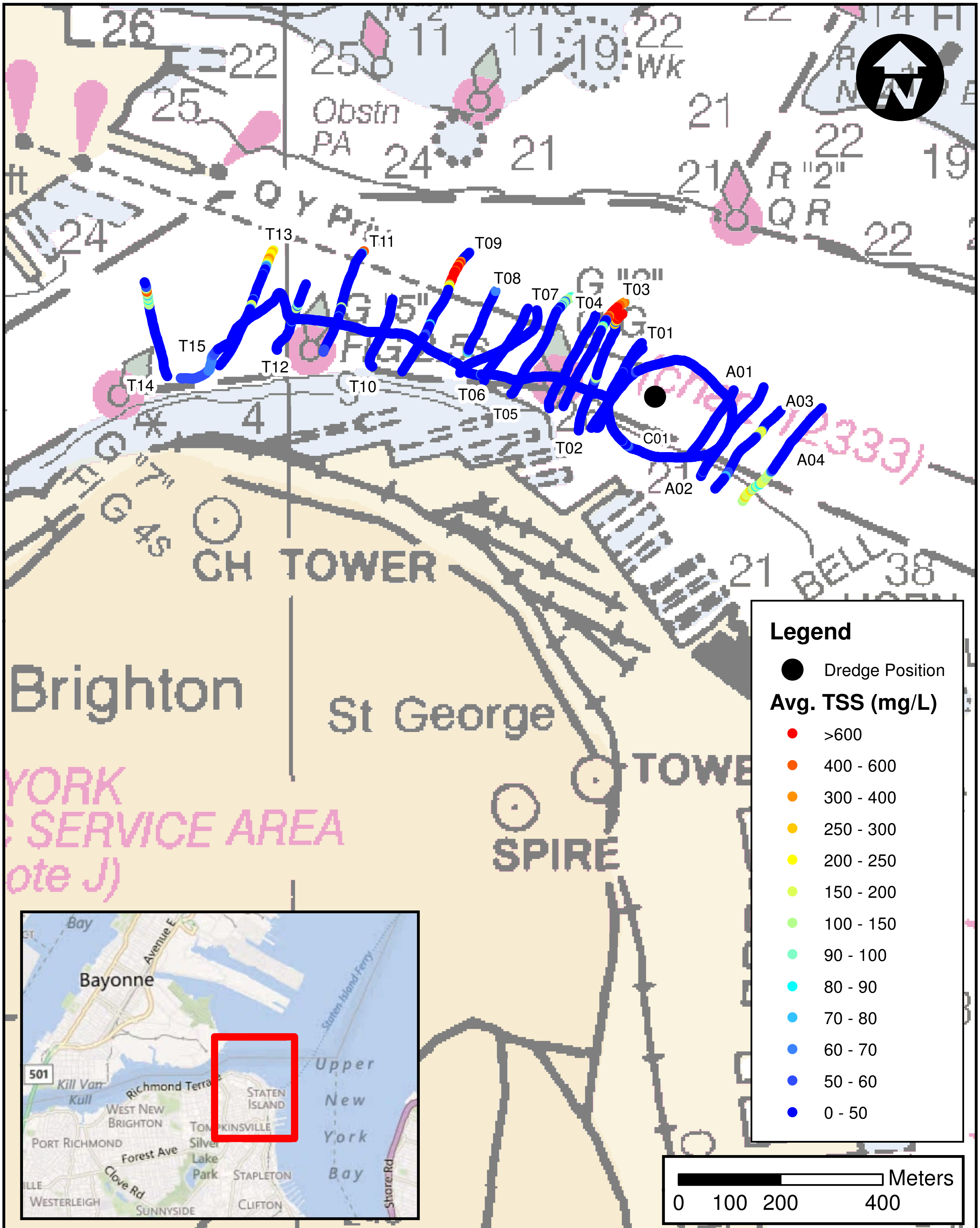


Figure	*USACE Harborwide TSS Far Field Survey HDP Contract Area: S-KVK-1*	**ADCP Average TSS - 19 June 2009 2-4 Meter Depth Interval**	Tide
5b			Flood

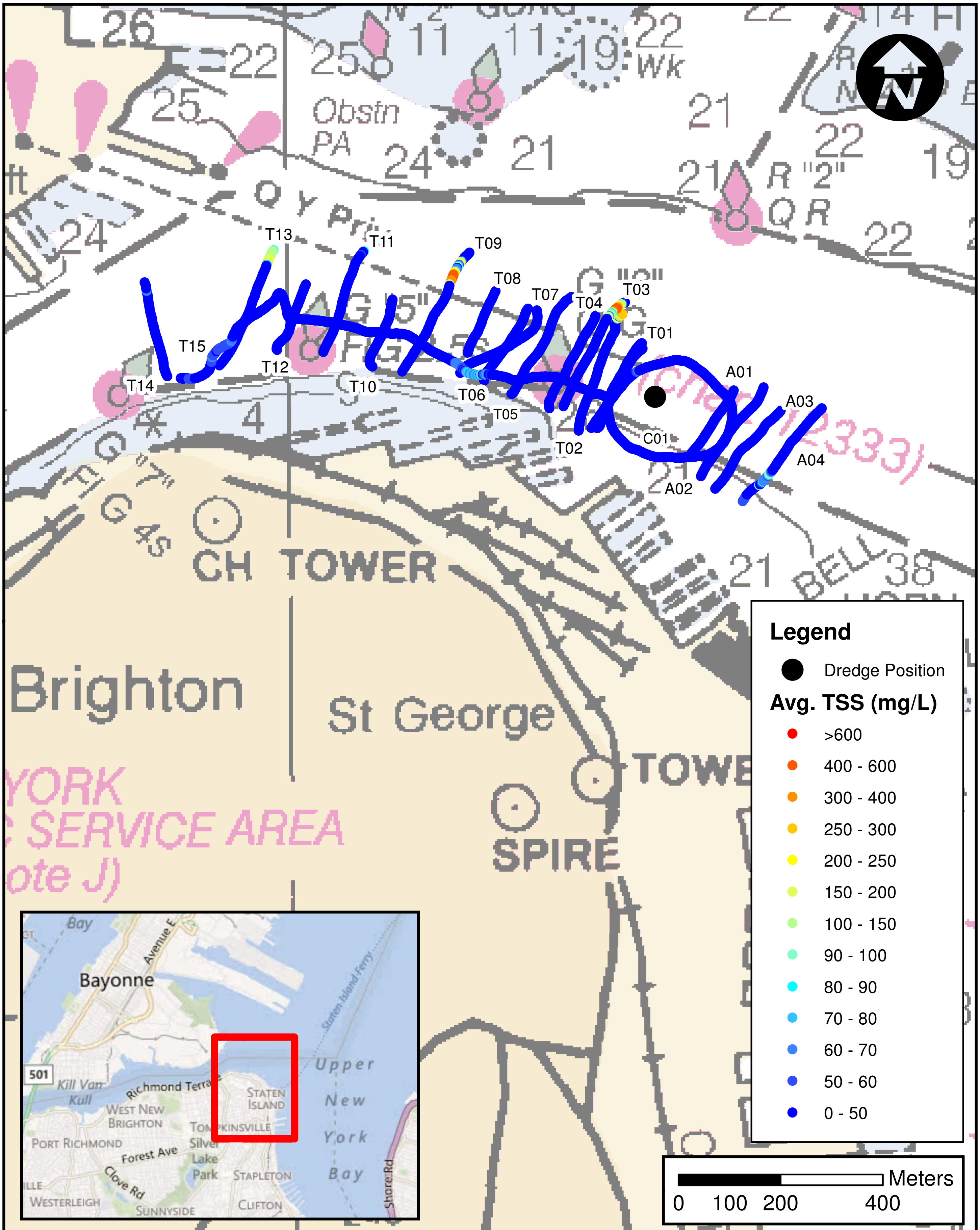


Figure	*USACE Harborwide TSS Far Field Survey HDP Contract Area: S-KVK-1*	**ADCP Average TSS - 19 June 2009 4-6 Meter Depth Interval**	Tide
5c			**Flood**

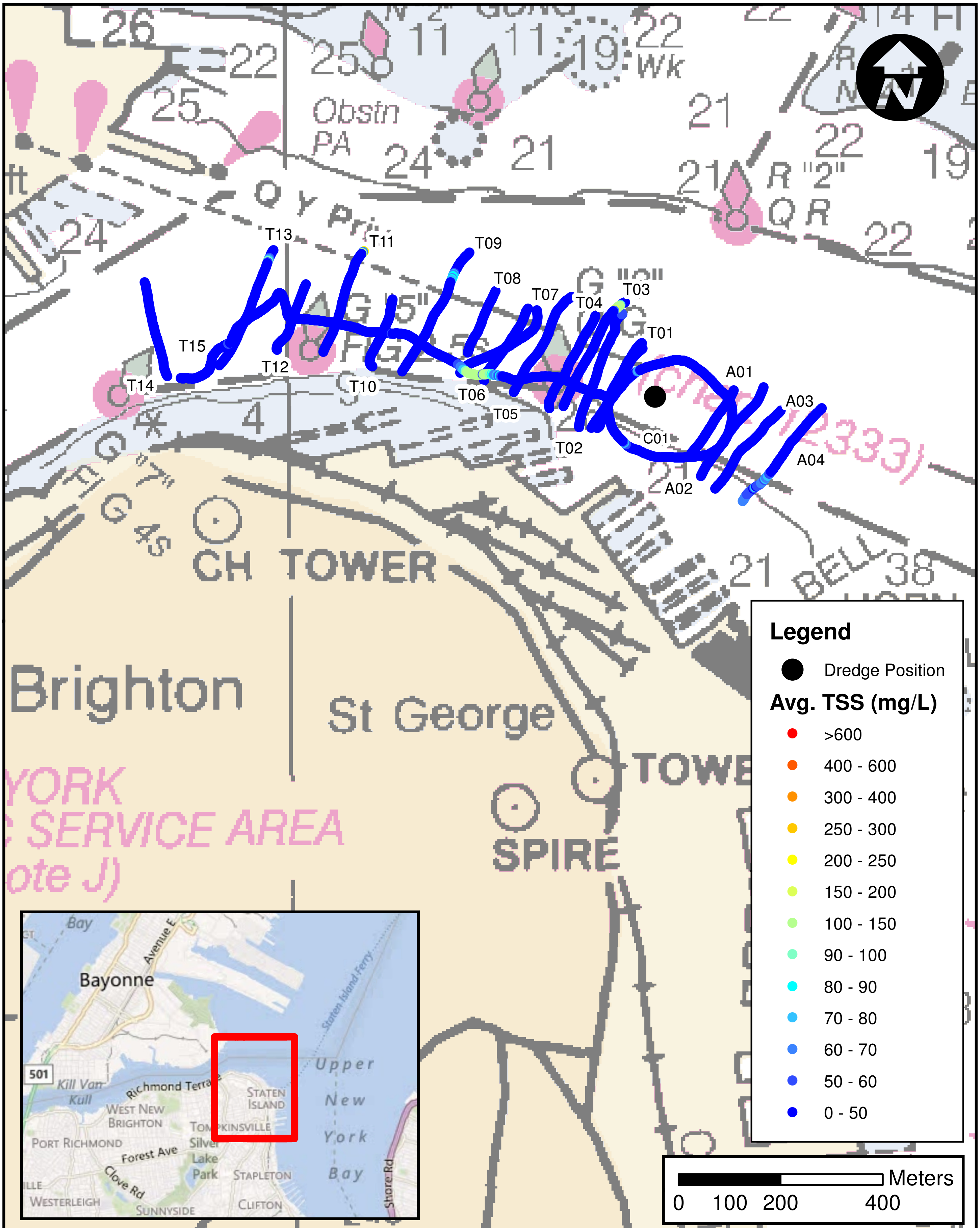


Figure	*USACE Harborwide TSS Far Field Survey HDP Contract Area: S-KVK-1*	ADCP Average TSS - 19 June 2009 6-8 Meter Depth Interval	Tide
5d			Flood

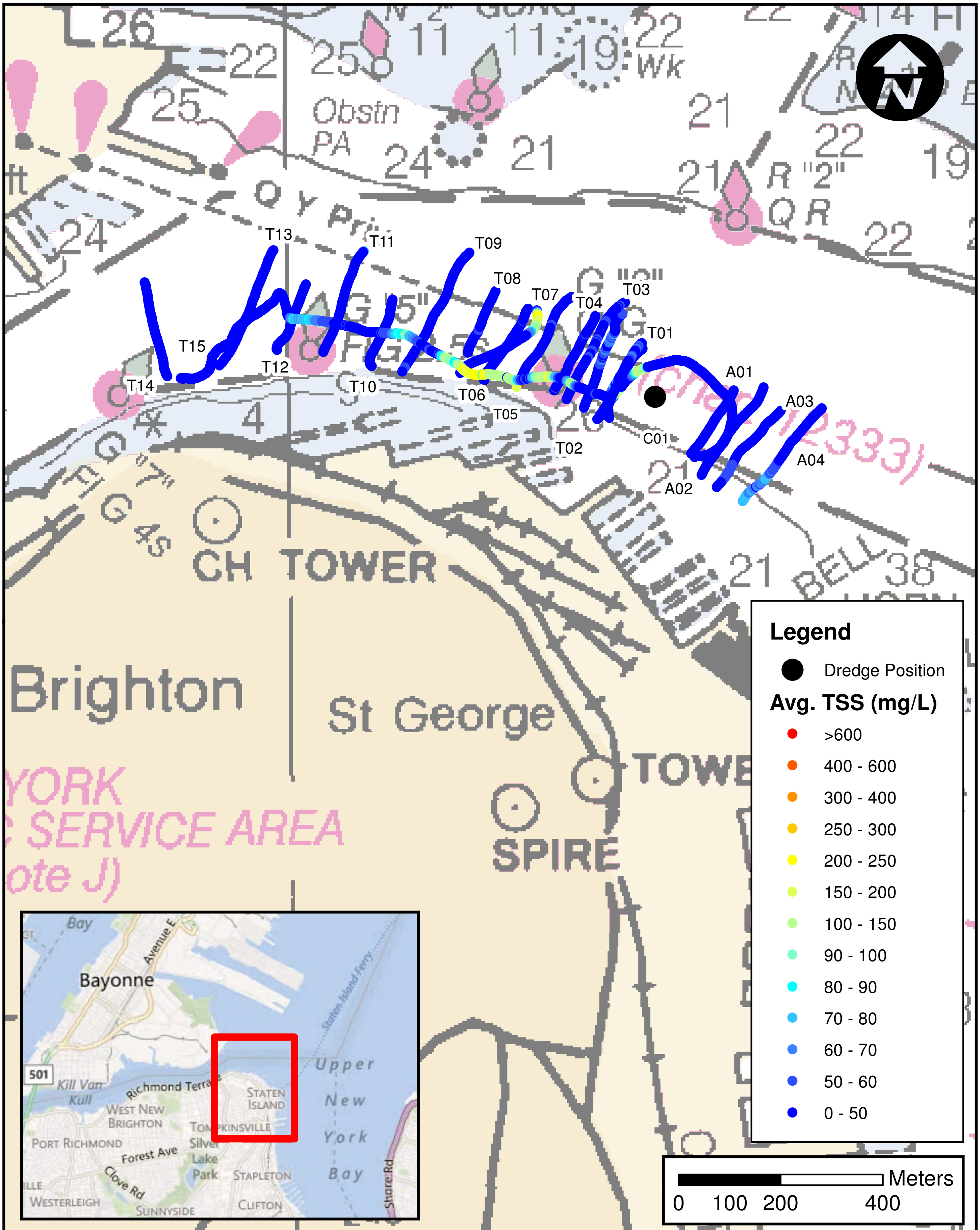


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-KVK-1	ADCP Average TSS - 19 June 2009 8-10 Meter Depth Interval	Tide
5e			Flood

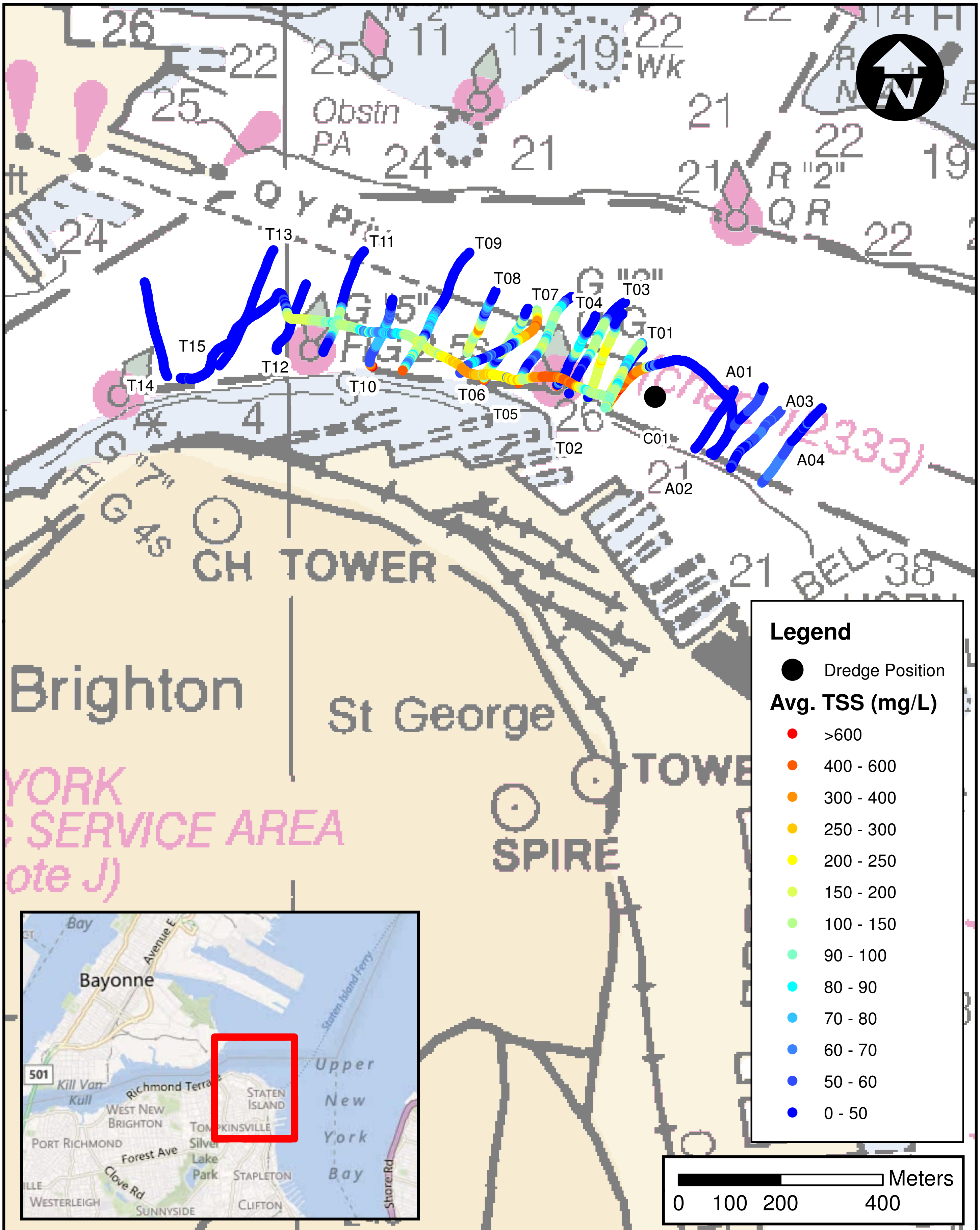


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-KVK-1	ADCP Average TSS - 19 June 2009 10-12 Meter Depth Interval	Tide
5f			Flood

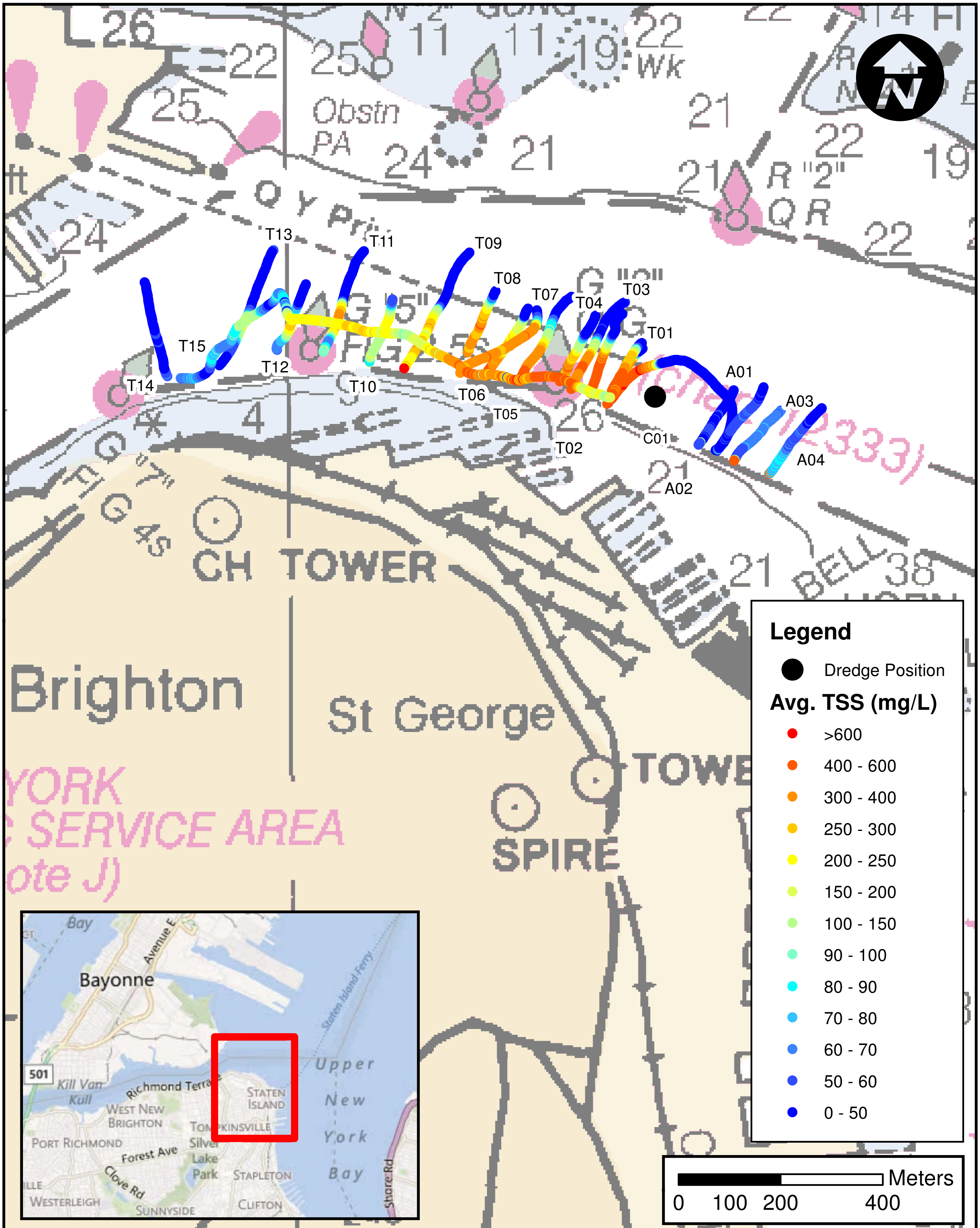


Figure	*USACE Harborwide TSS* *Far Field Survey* *HDP Contract Area: S-KVK-1*	**ADCP Average TSS - 19 June 2009** **12-14 Meter Depth Interval**	Tide
5g			Flood

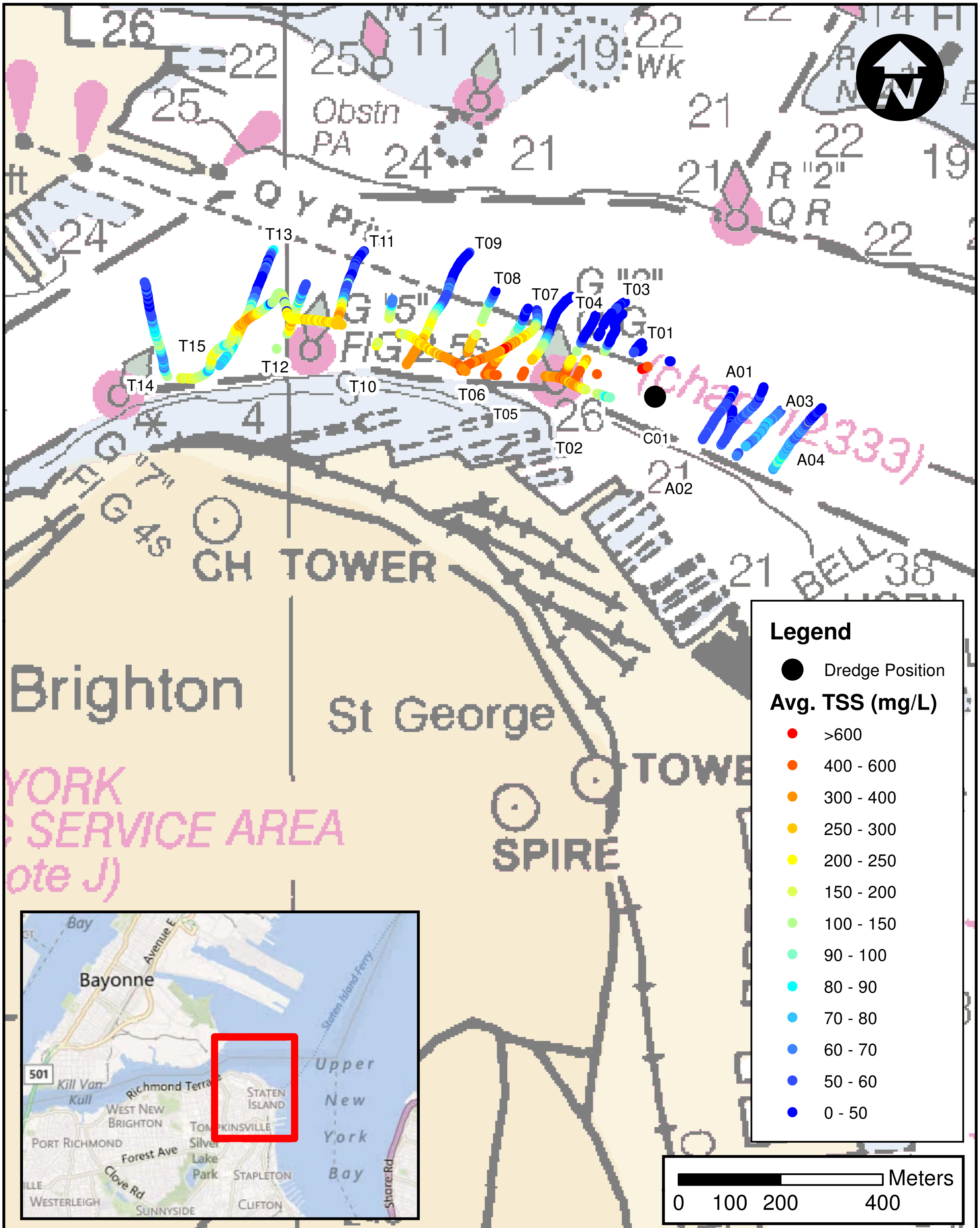
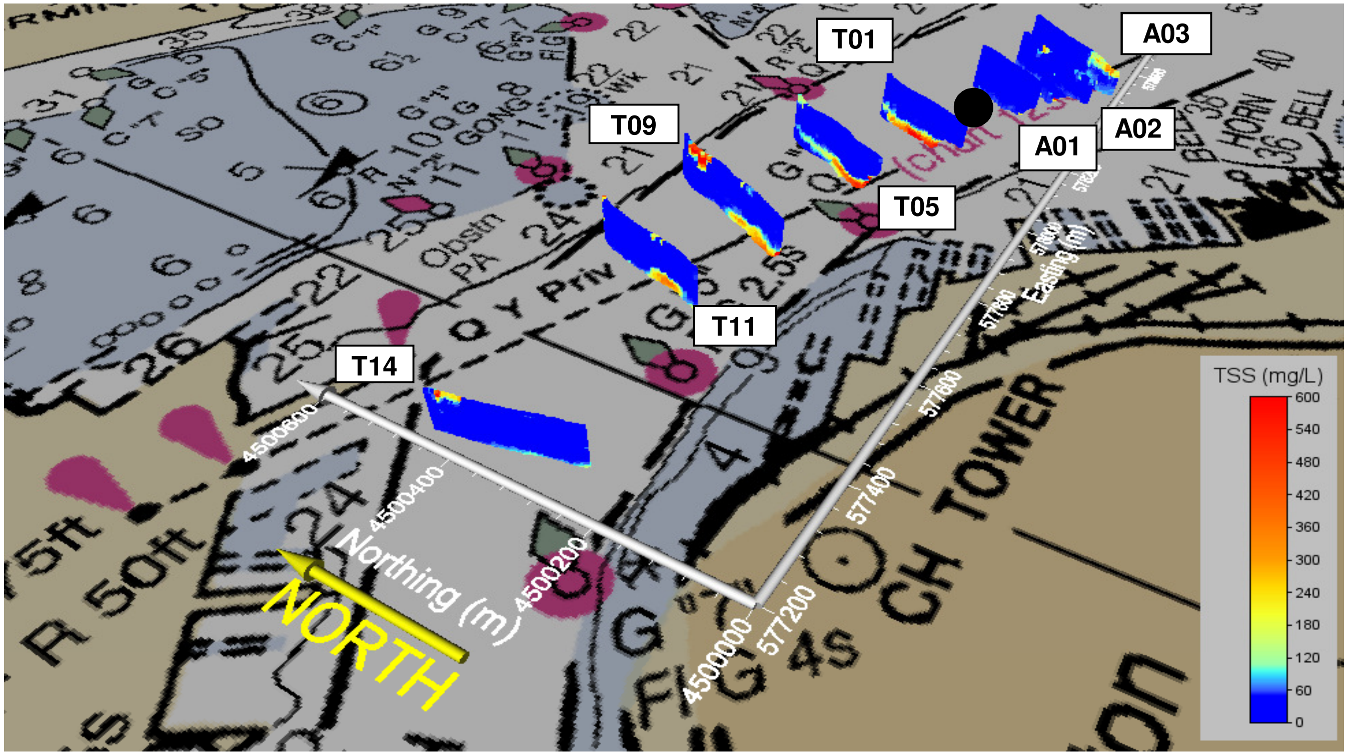


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-KVK-1	ADCP Average TSS - 19 June 2009 14-16 Meter Depth Interval	Tide
5h			Flood



⬤ = Dredge Location

Z scale exaggerated 6X

Figure	*USACE Harborwide TSS Far Field Survey HDP Contract Area S-KVK-1*	ADCP Average TSS Values, 3D View of Selected Transects 19 June 2009 - Flood Tide	Tide
6			Flood

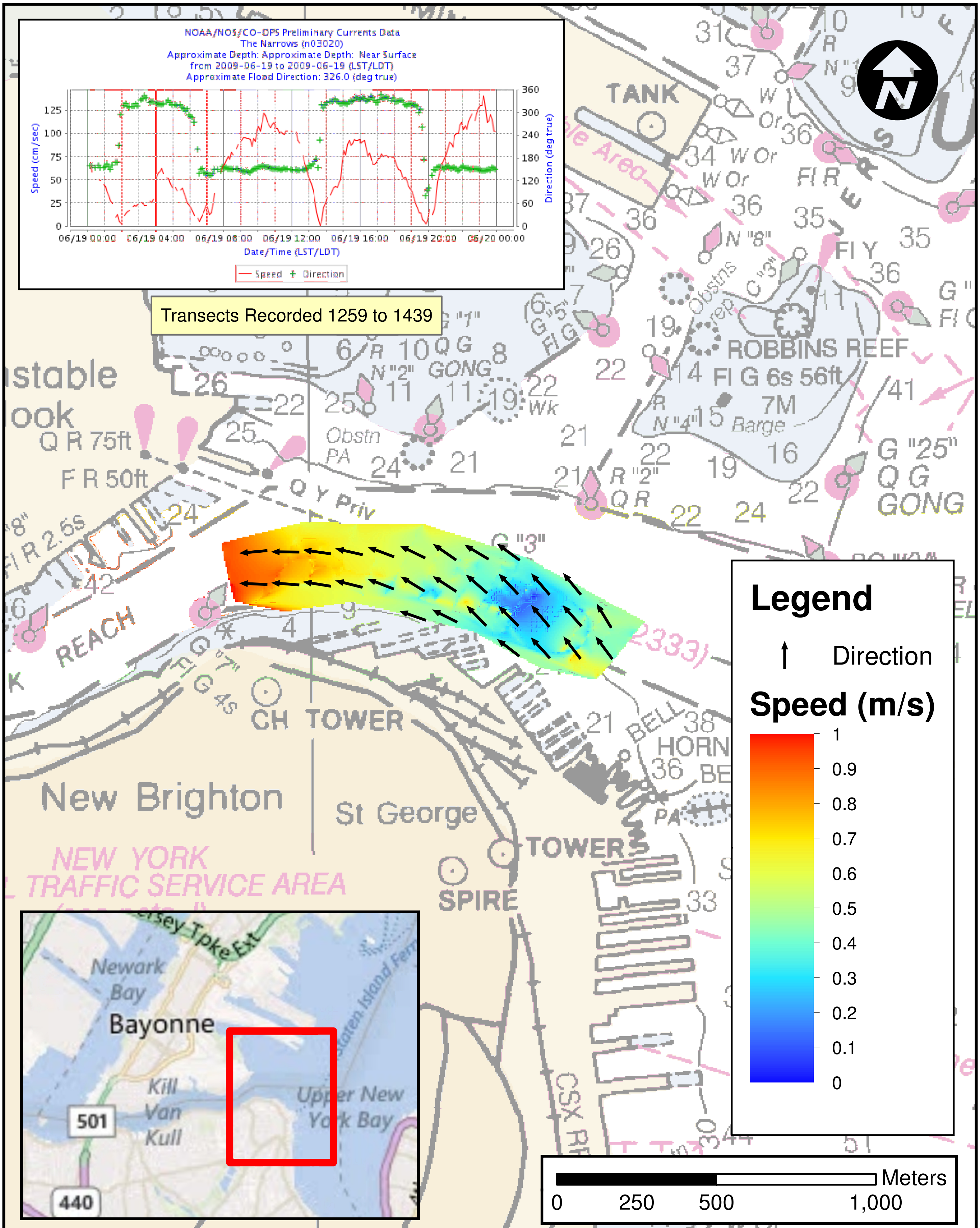


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-KVK-1	Depth Averaged Velocities 19 June 2009 - Flood Tide TSS Survey	Tide
7			Flood

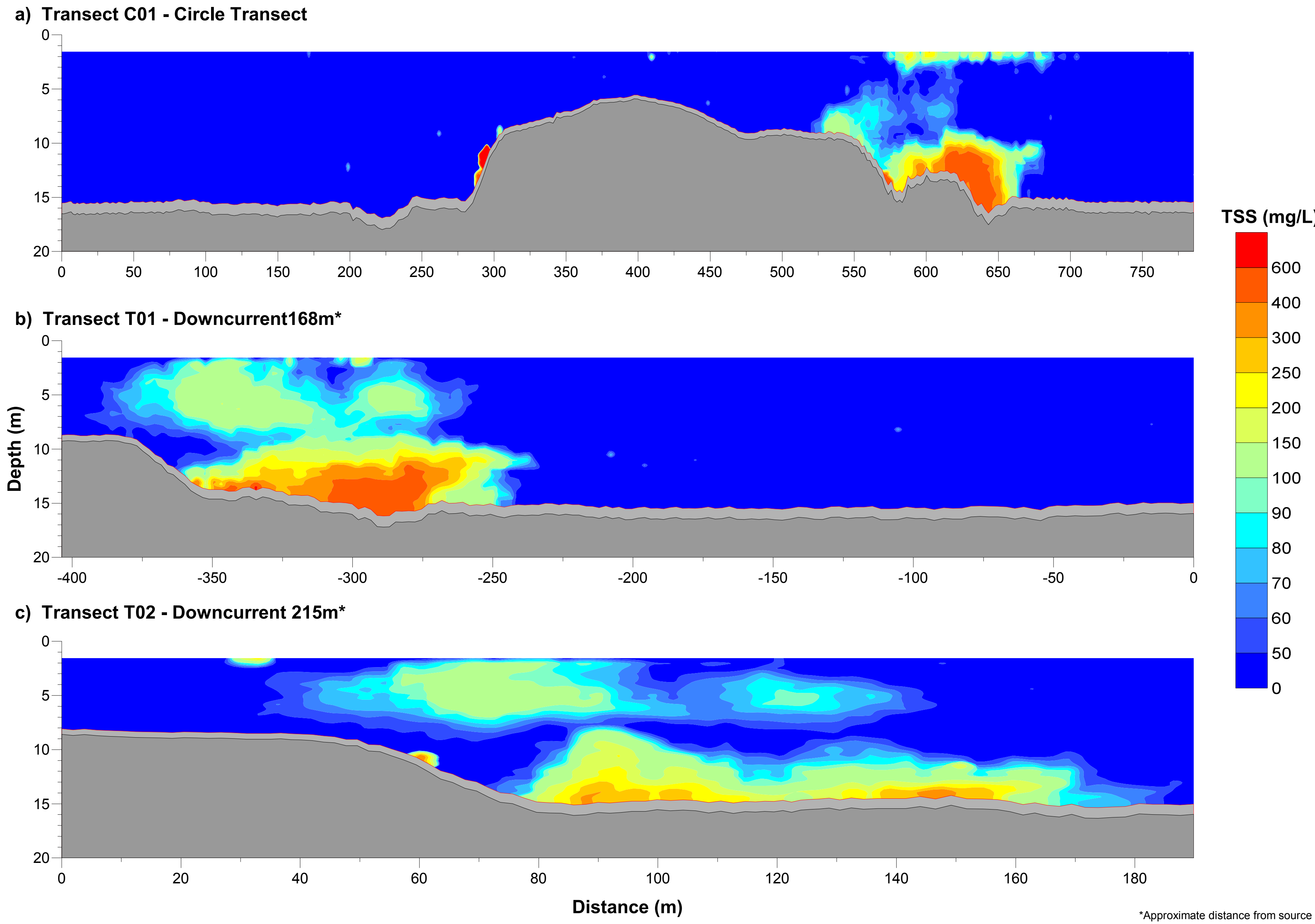
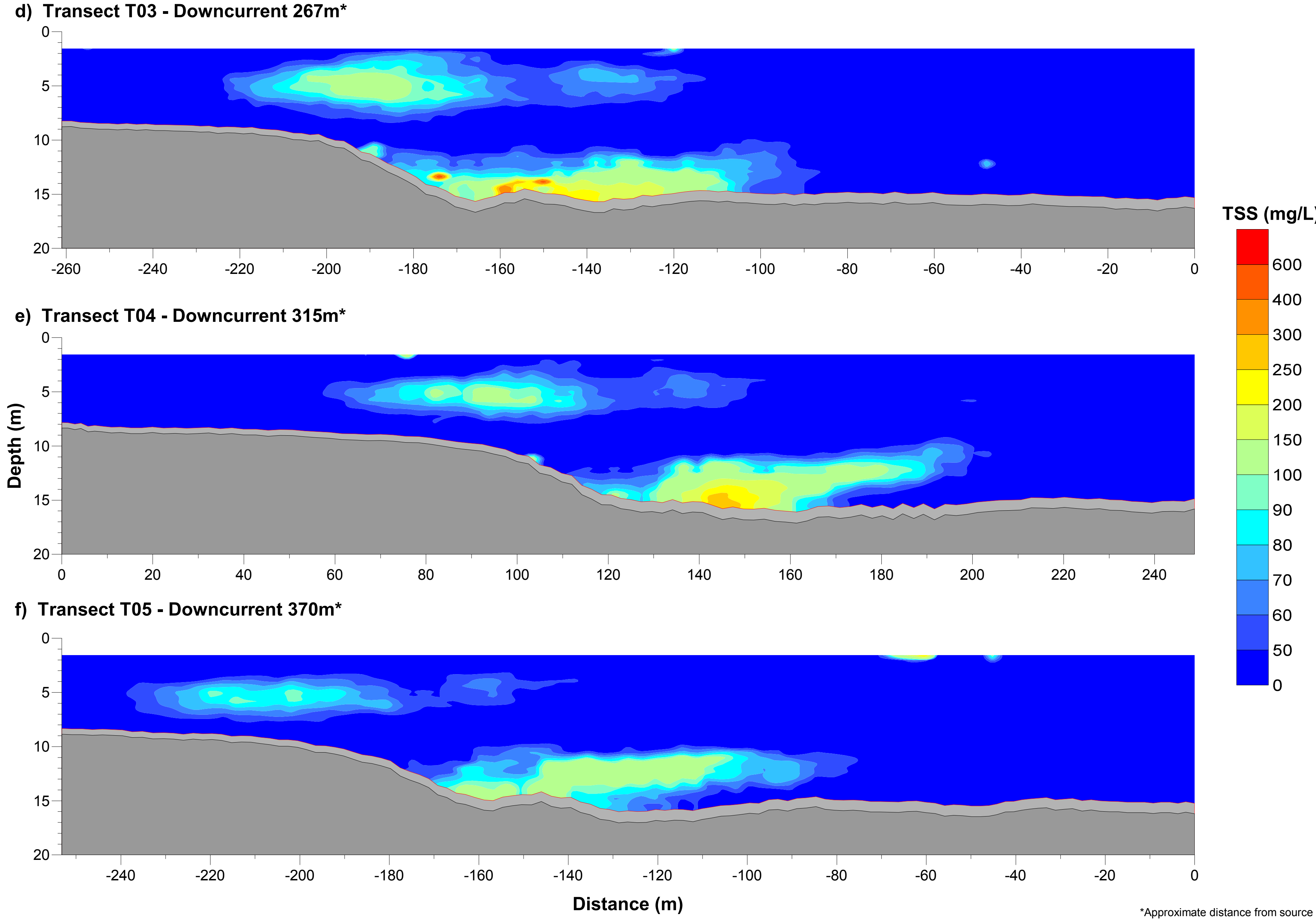


FIGURE	*USACE Harborwide TSS Far Field Survey S-KVK-1*	Vertical Profiles of ADCP Average TSS 22 June 2009 - Ebb Tide #1	TIDE
8a-c			Ebb



*Approximate distance from source

FIGURE	USACE Harborwide TSS Far Field Survey S-KVK-1	Vertical Profiles of ADCP Average TSS 22 June 2009 - Ebb Tide #1	TIDE
8d-f			Ebb

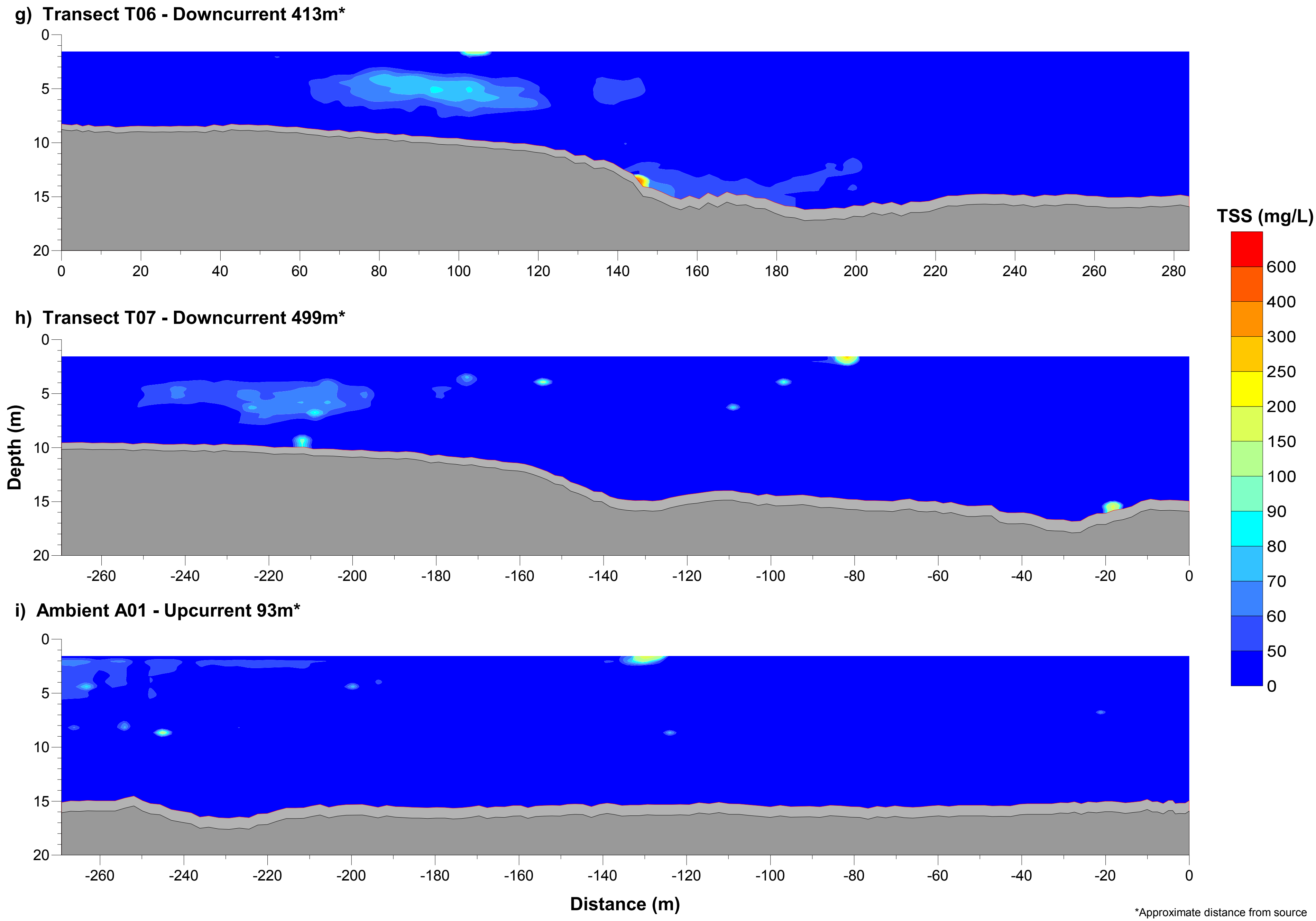
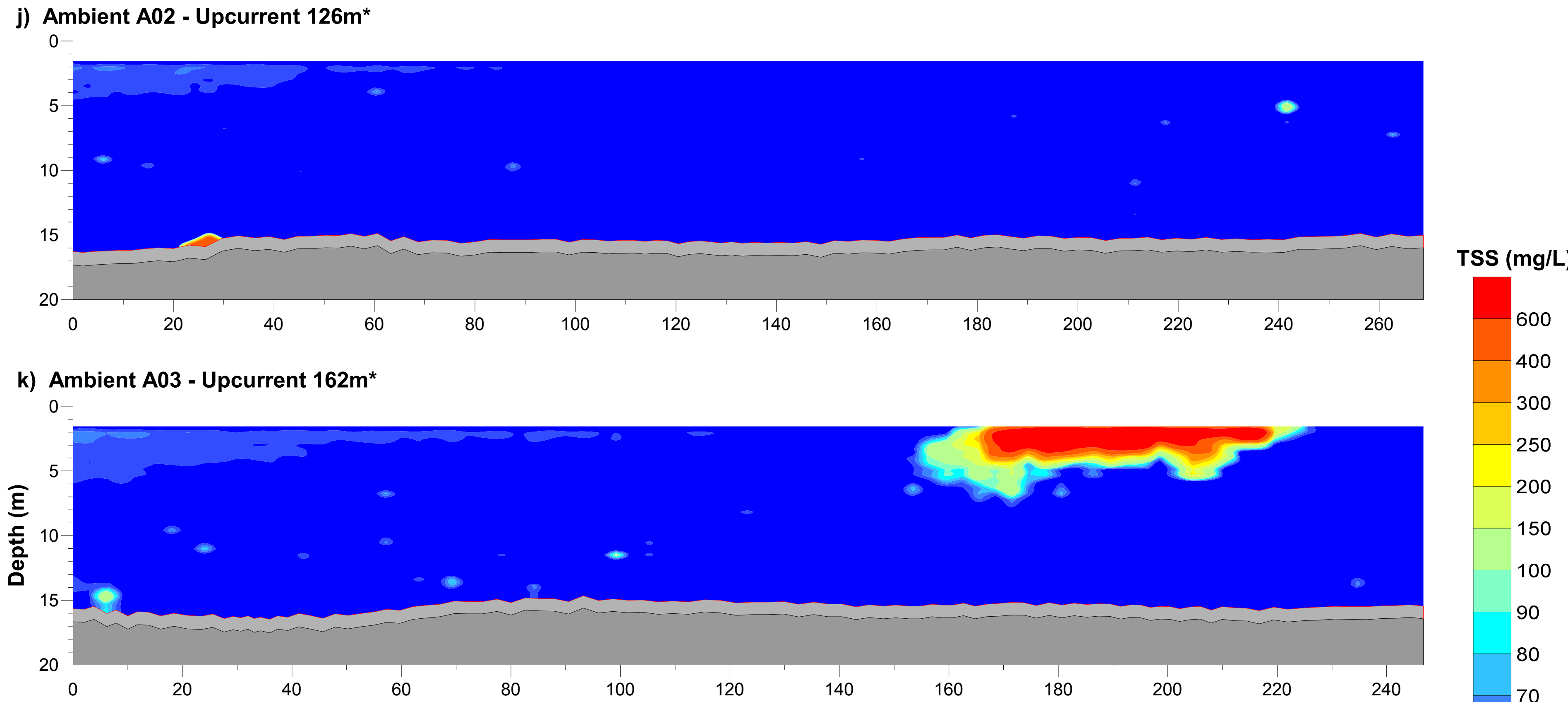


FIGURE	USACE Harborwide TSS Far Field Survey S-KVK-1	Vertical Profiles of ADCP Average TSS 22 June 2009 - Ebb Tide #1	TIDE
8g-i			Ebb



*Approximate distance from source

FIGURE	USACE Harborwide TSS Far Field Survey S-KVK-1	Vertical Profiles of ADCP Average TSS 22 June 2009 - Ebb Tide #1	TIDE
8j-k			Ebb

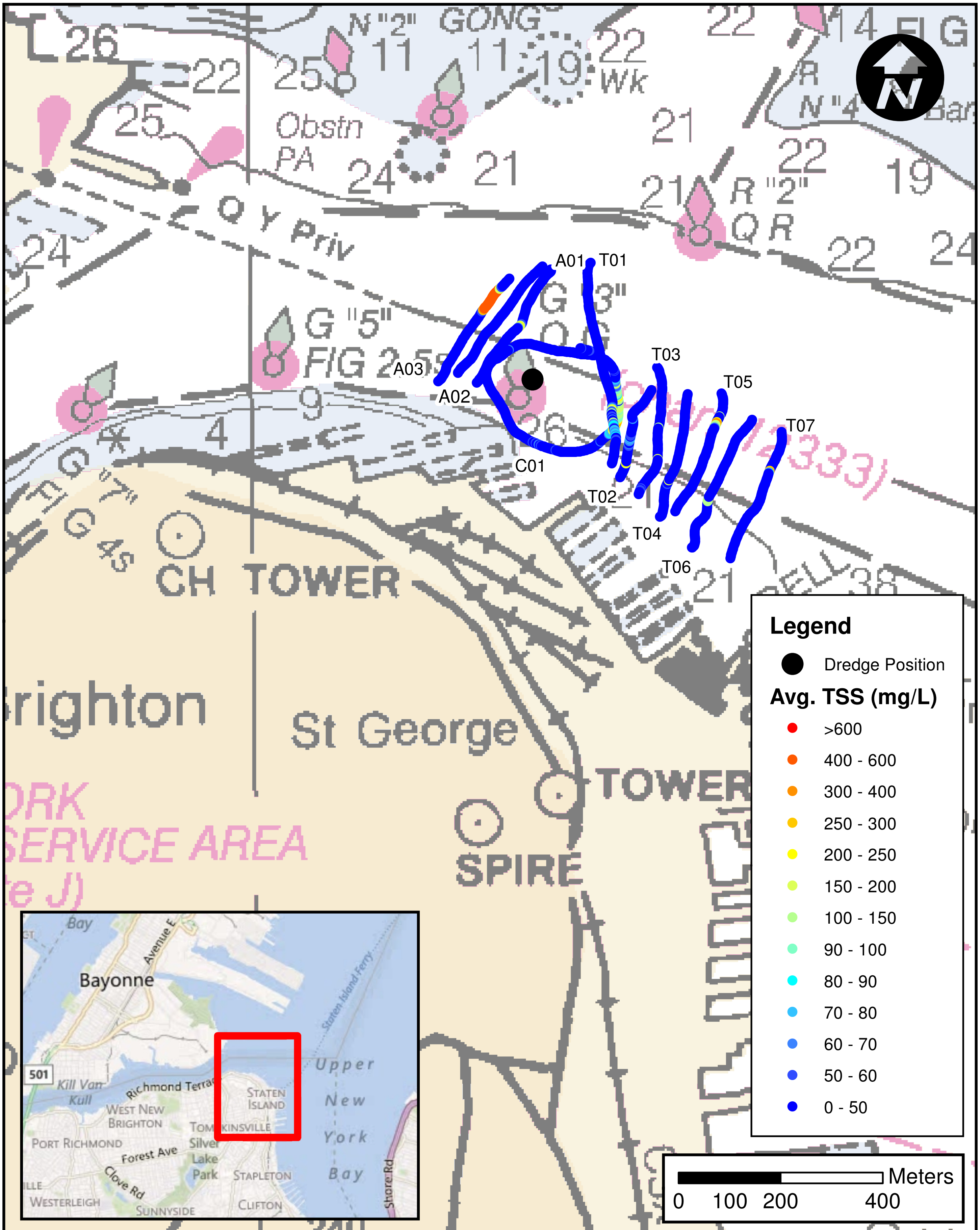


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-KVK-1	ADCP Average TSS - 22 June 2009 0-2 Meter Depth Interval - Set 1	Tide
9a			Ebb

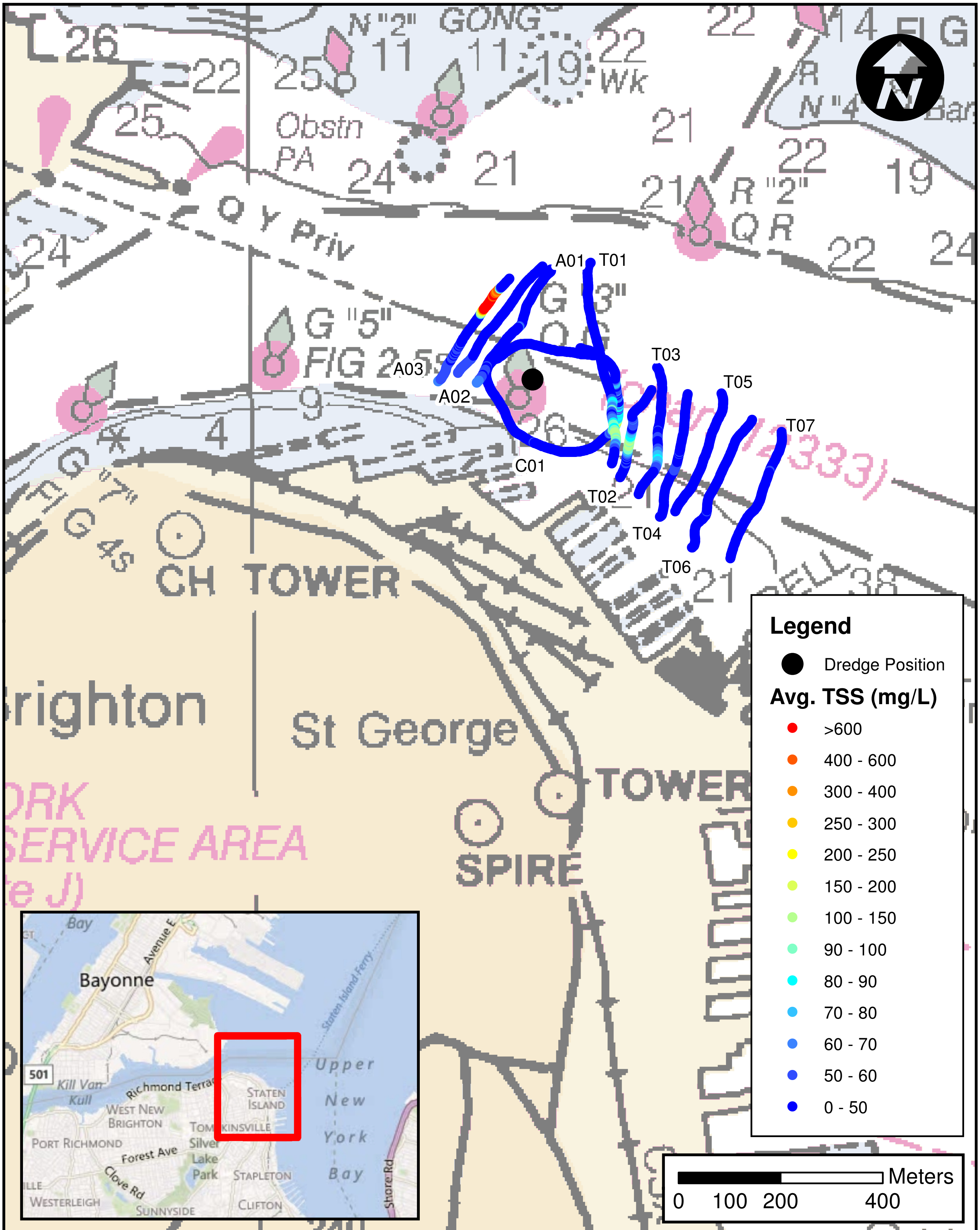


Figure	*USACE Harborwide TSS Far Field Survey HDP Contract Area: S-KVK-1*	ADCP Average TSS - 22 June 2009 2-4 Meter Depth Interval - Set 1	Tide
9b			Ebb

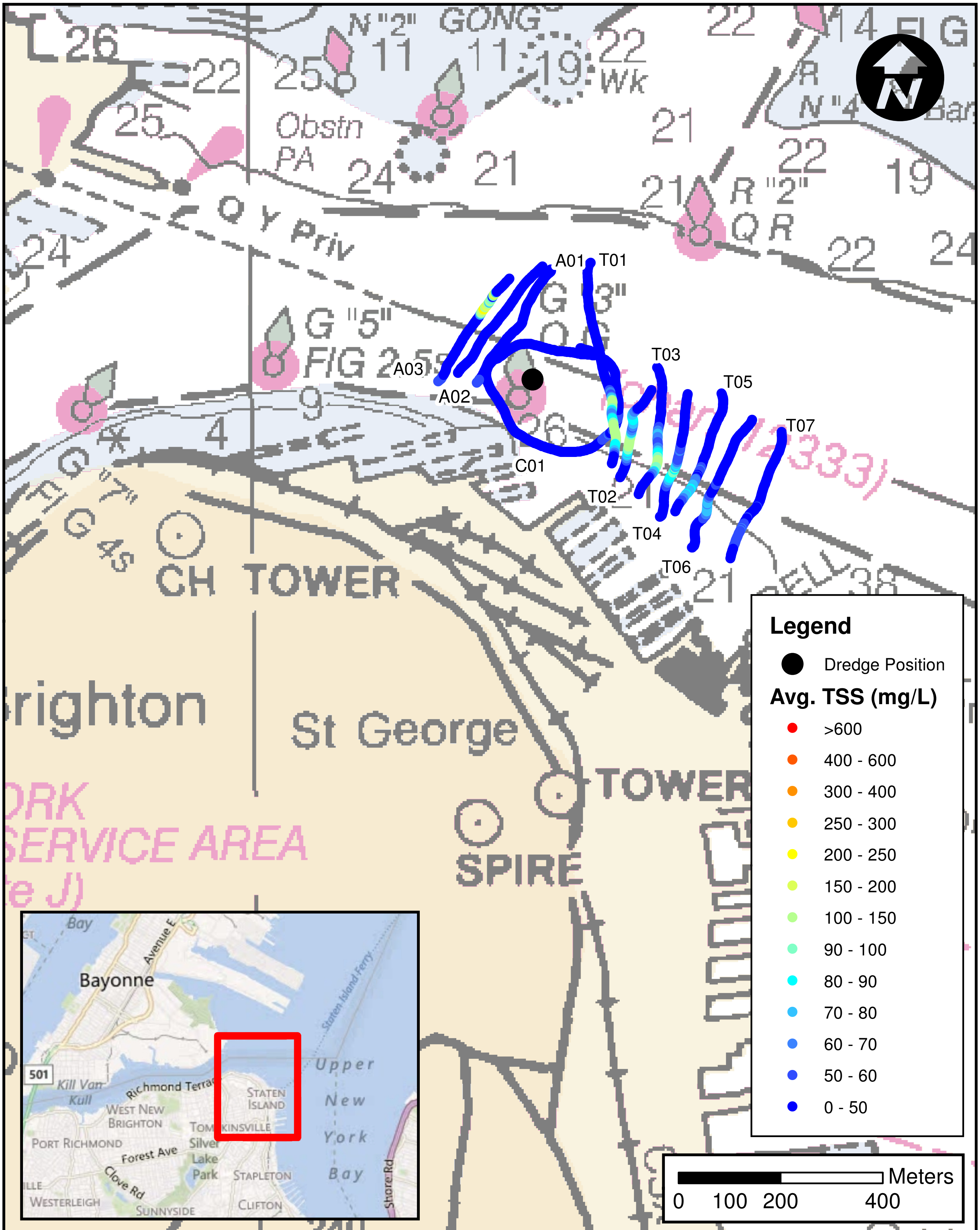


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-KVK-1	ADCP Average TSS - 22 June 2009 4-6 Meter Depth Interval - Set 1	Tide
9c			Ebb

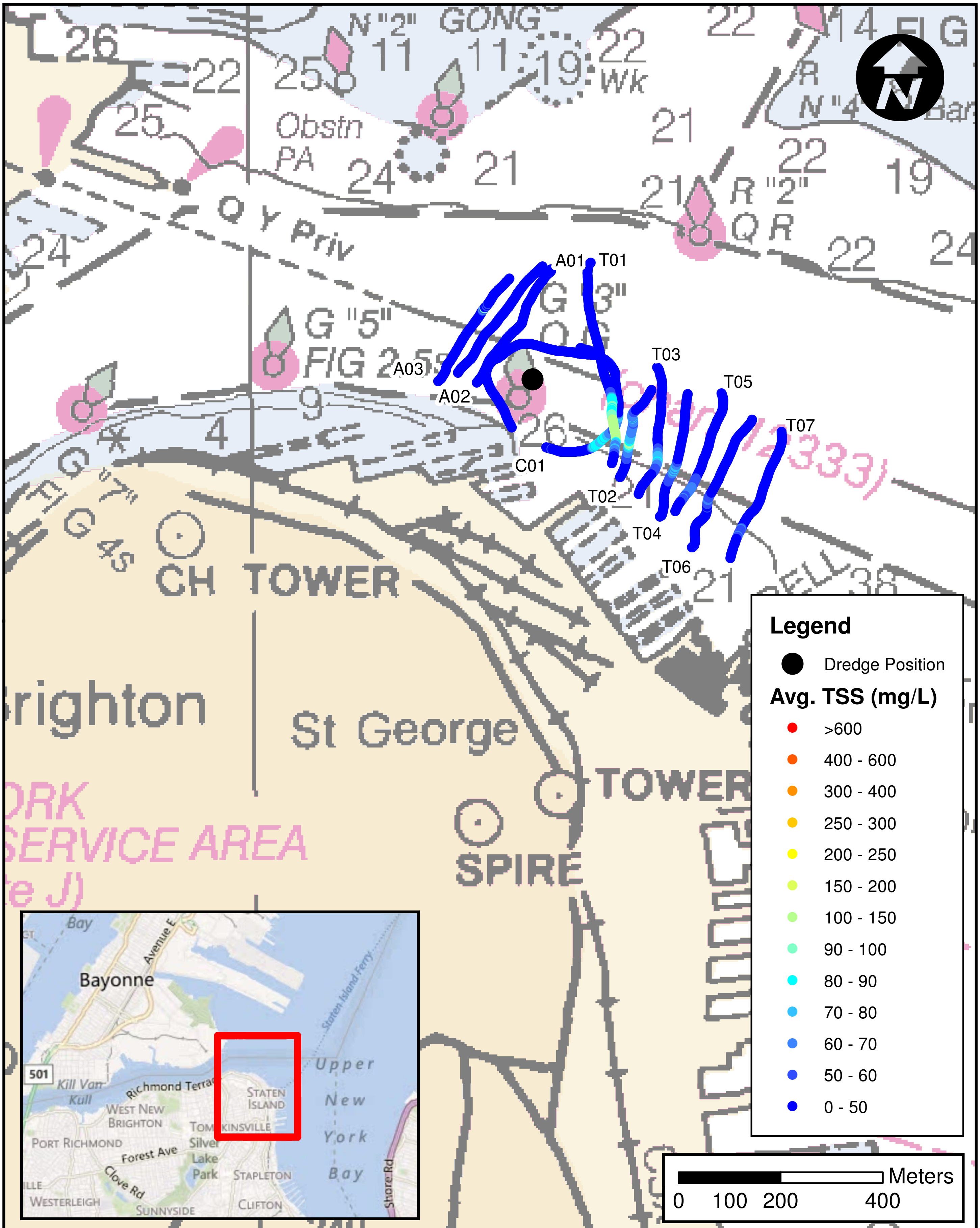


Figure	*USACE Harborwide TSS Far Field Survey HDP Contract Area: S-KVK-1*	ADCP Average TSS - 22 June 2009 6-8 Meter Depth Interval - Set 1	Tide
9d			Ebb

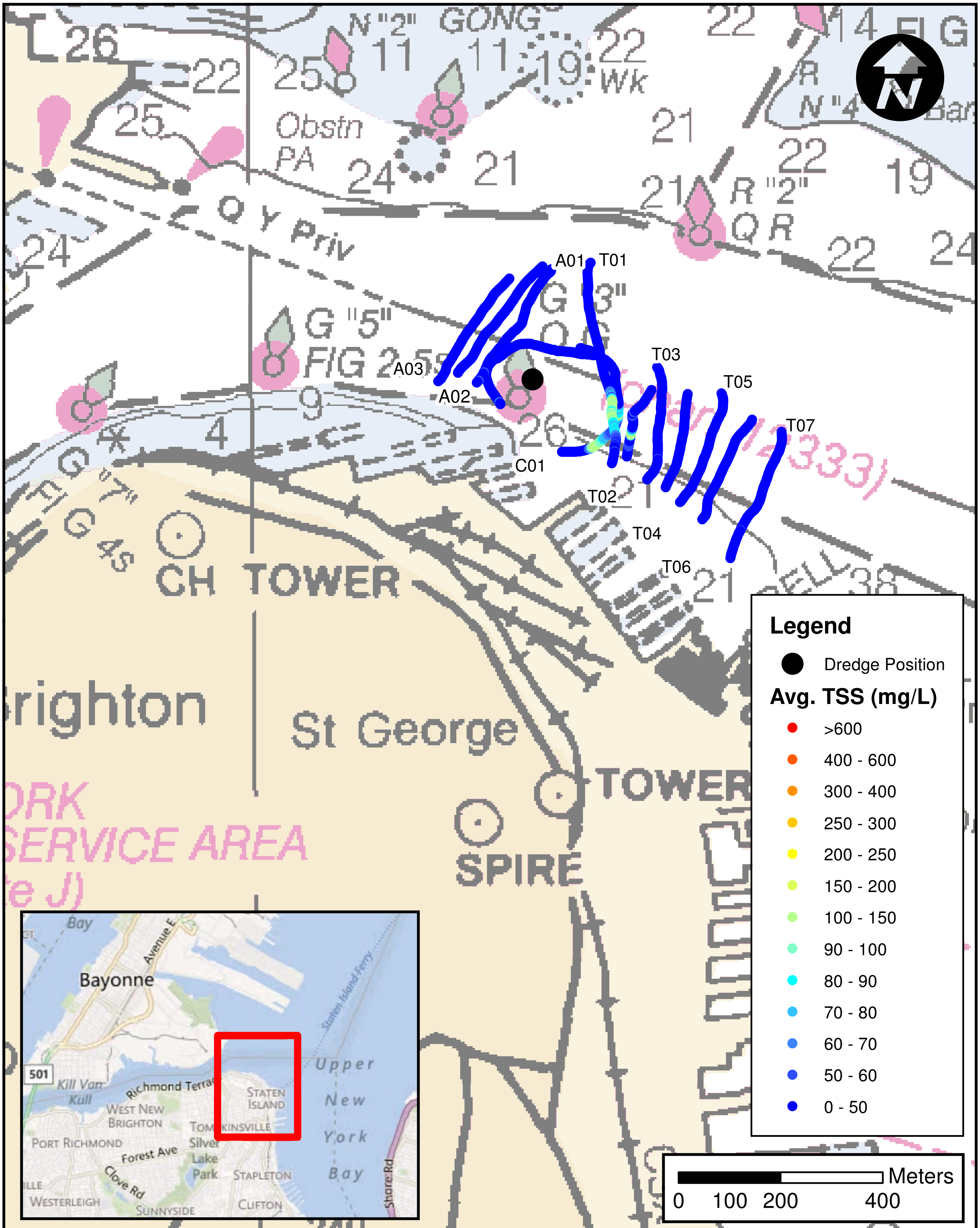


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-KVK-1	ADCP Average TSS - 22 June 2009 8-10 Meter Depth Interval - Set 1	Tide
9e			Ebb

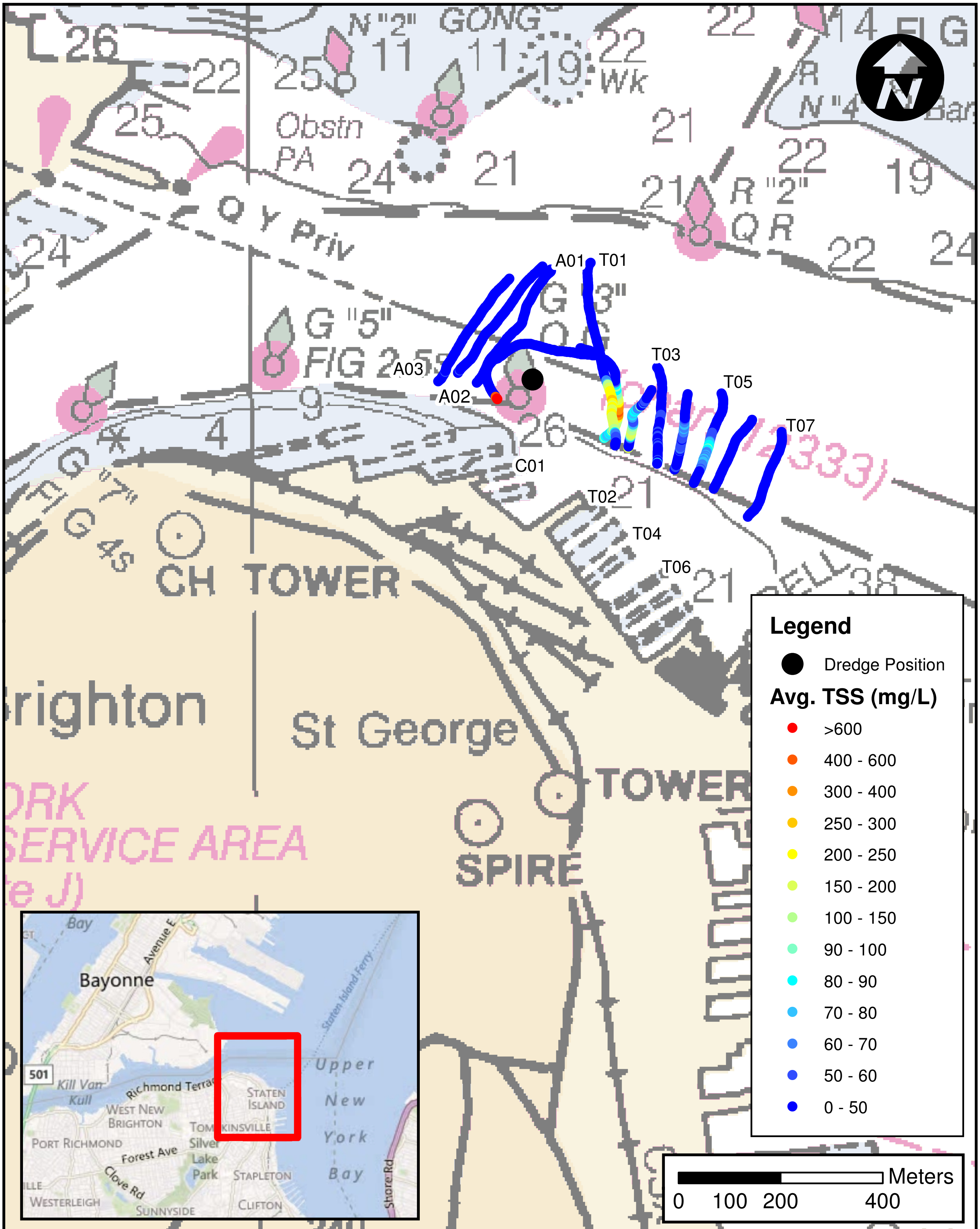


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-KVK-1	ADCP Average TSS - 22 June 2009 10-12 Meter Depth Interval - Set 1	Tide
9f			Ebb

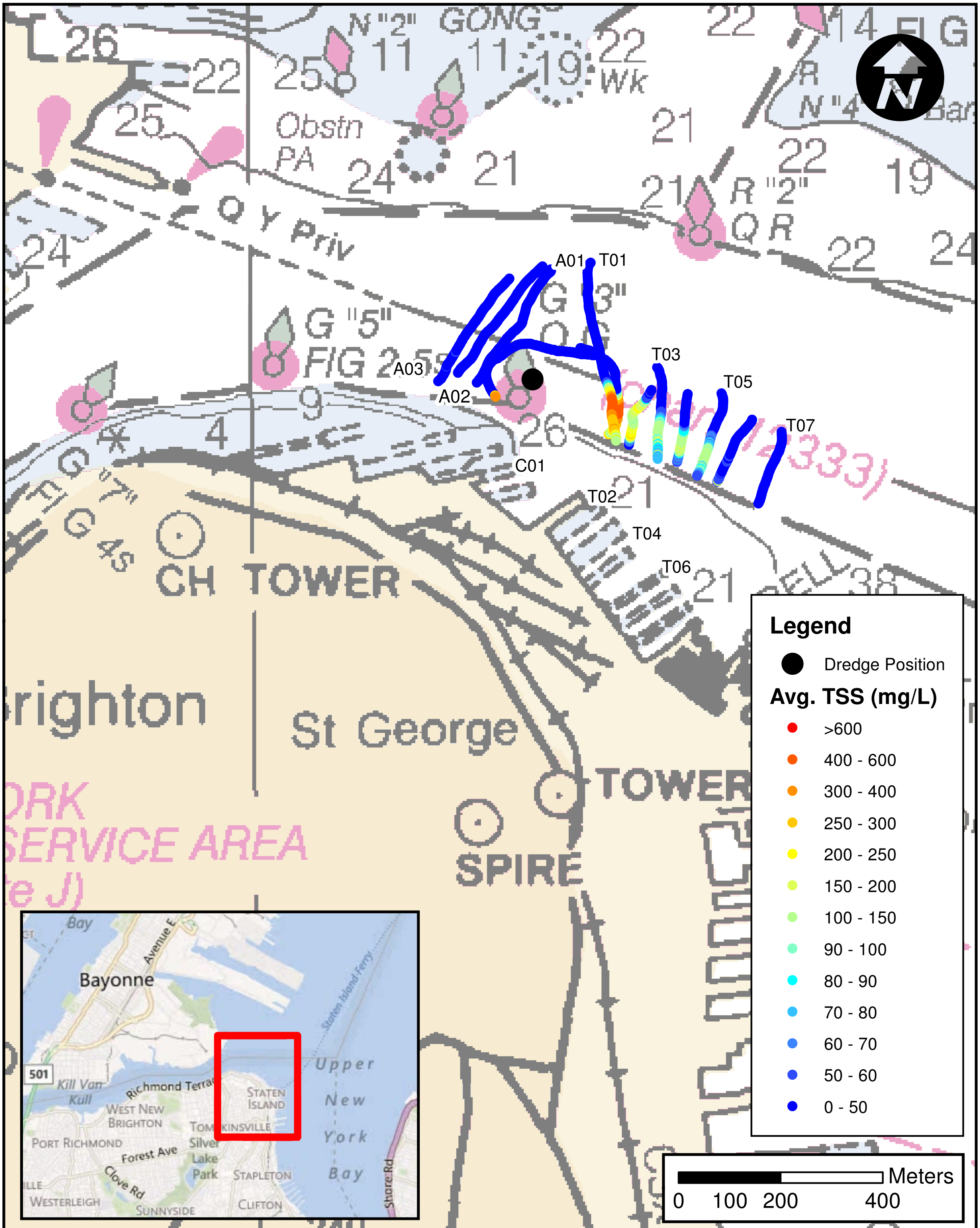


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-KVK-1	ADCP Average TSS - 22 June 2009 12-14 Meter Depth Interval - Set 1	Tide
9g			Ebb

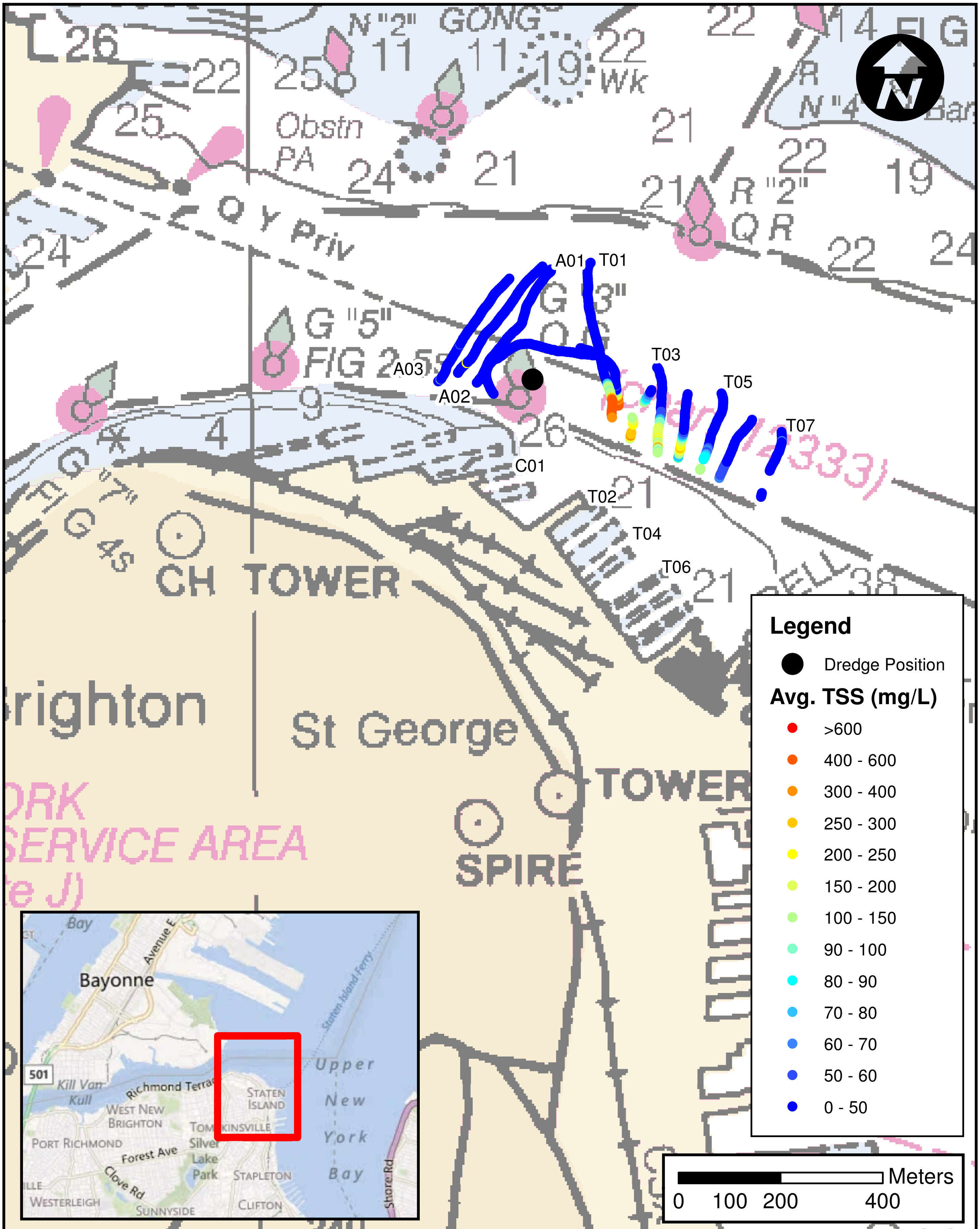
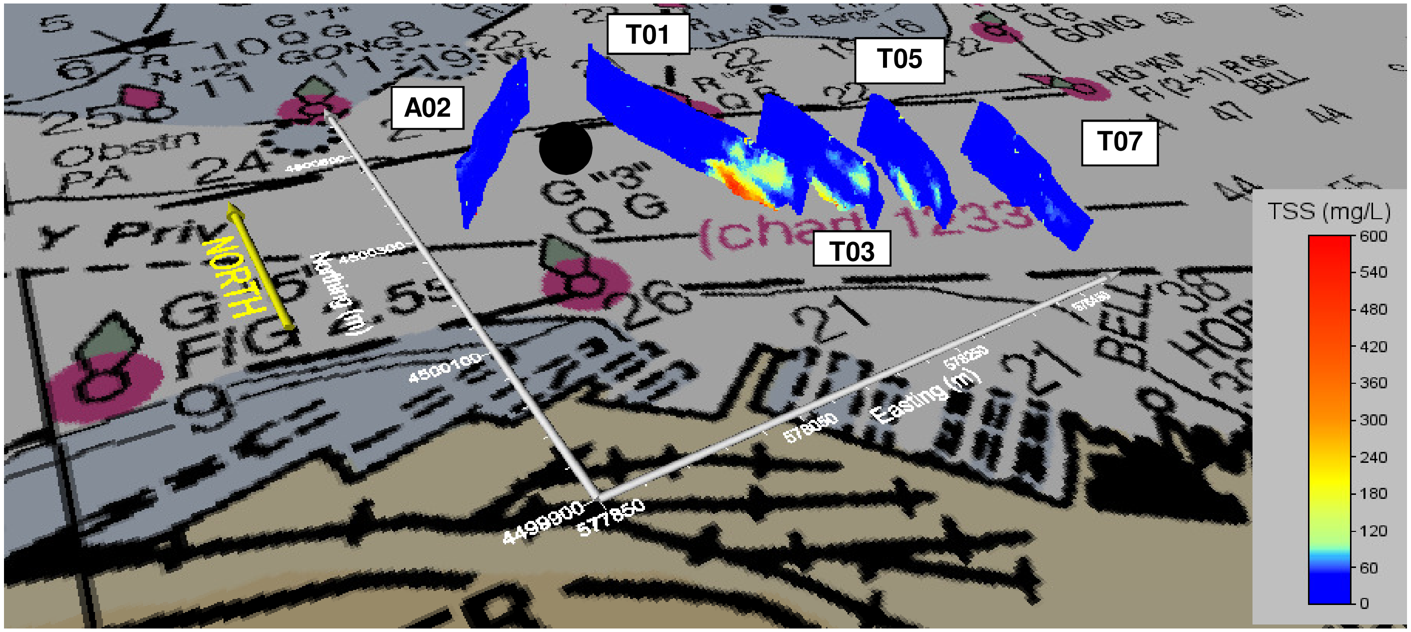


Figure	*USACE Harborwide TSS Far Field Survey HDP Contract Area: S-KVK-1*	ADCP Average TSS - 22 June 2009 14-16 Meter Depth Interval - Set 1	Tide
9h			Ebb



● = Dredge Location

Z scale exaggerated 6X

Figure	*USACE Harborwide TSS Far Field Survey HDP Contract Area S-KVK-1*	ADCP Average TSS Values, 3D View of Selected Transects 22 June 2009 – Ebb Tide #1	Tide
10			Ebb

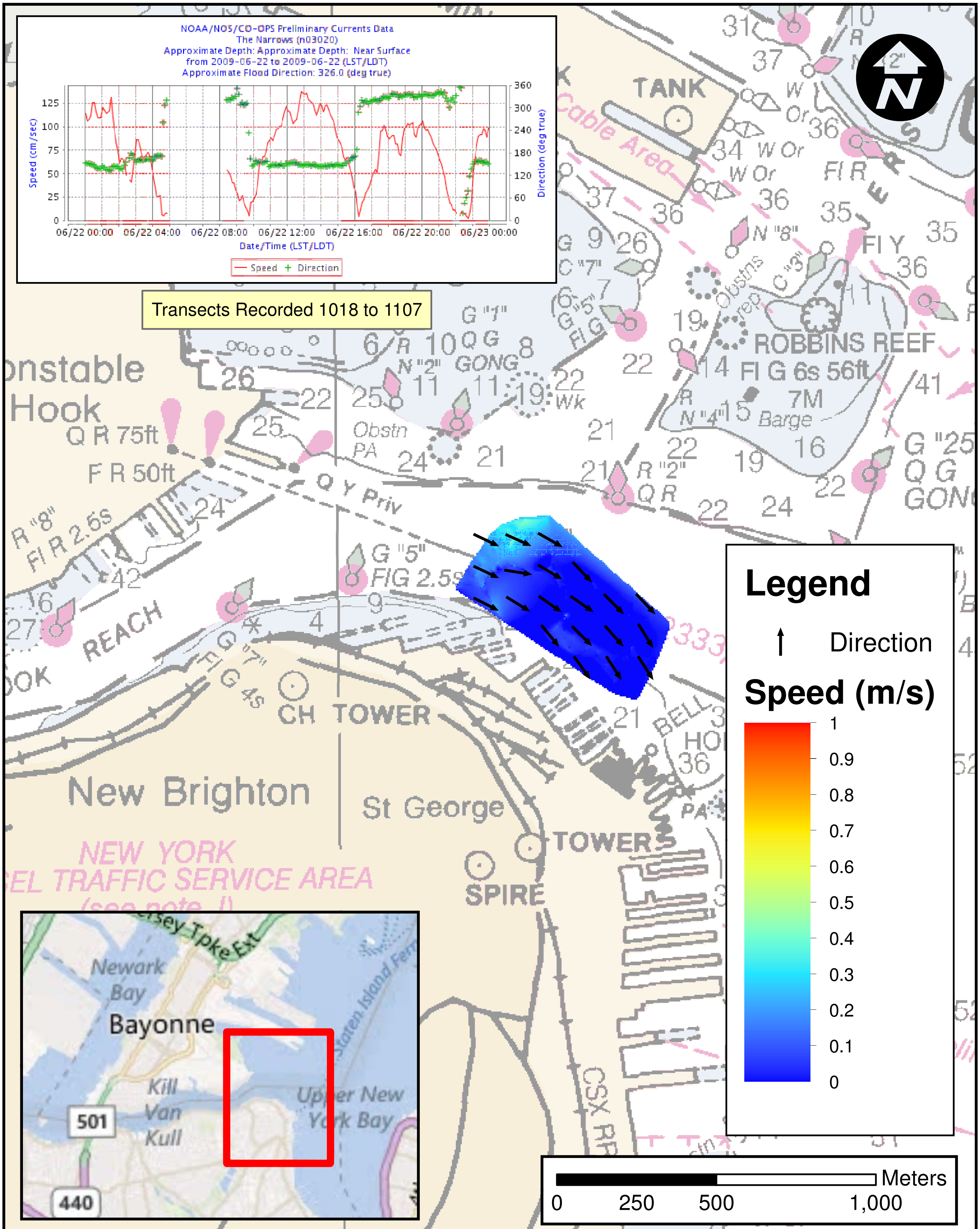


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-KVK-1	Depth Averaged Velocities 22 June 2009 - Ebb Tide Hydrodynamic Survey	Tide
11			Ebb

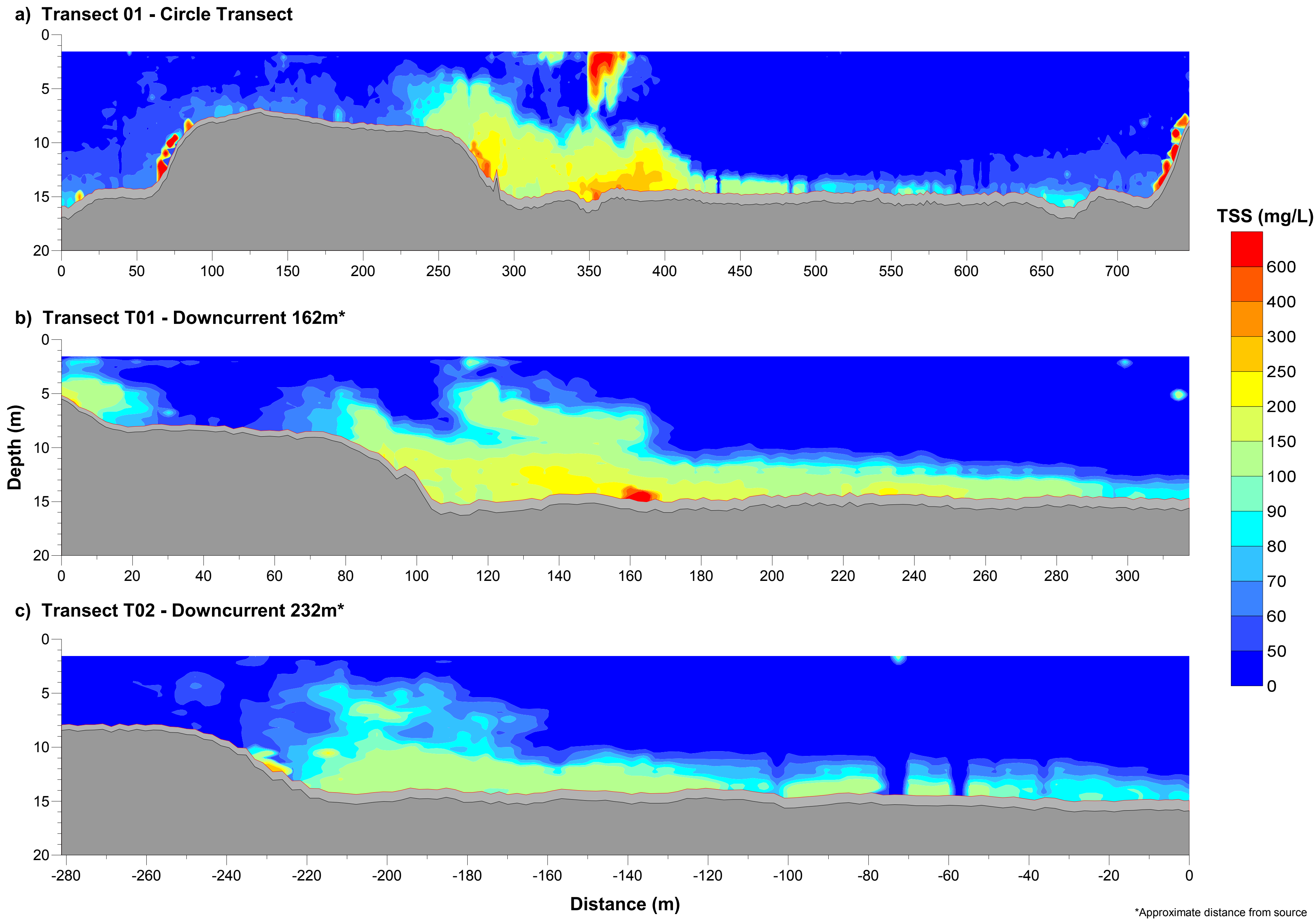


FIGURE	*USACE Harborwide TSS Far Field Survey S-KVK-1*	Vertical Profiles of ADCP Average TSS 22 June 2009 - Ebb Tide #2	TIDE
12a-c			Ebb

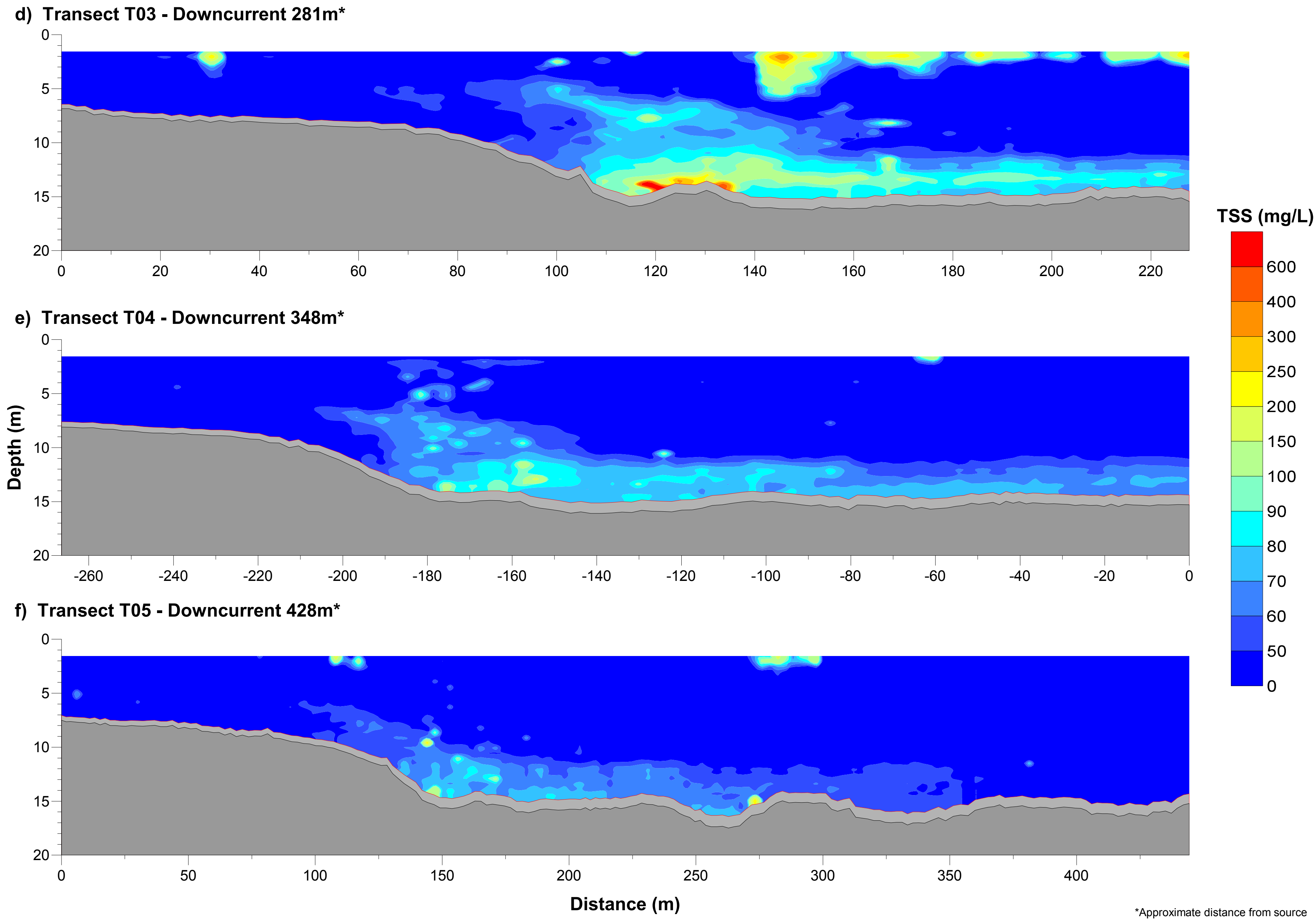
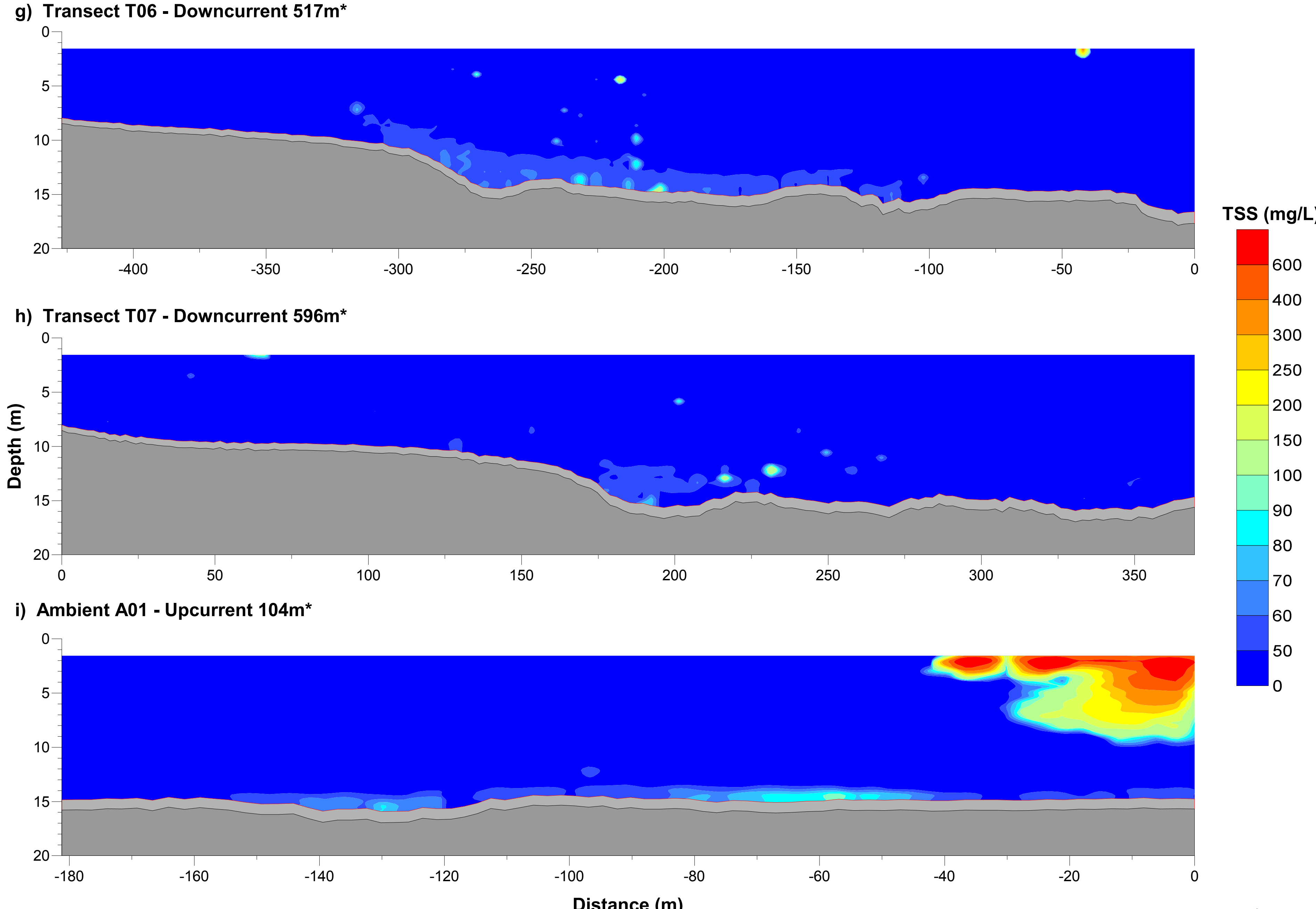
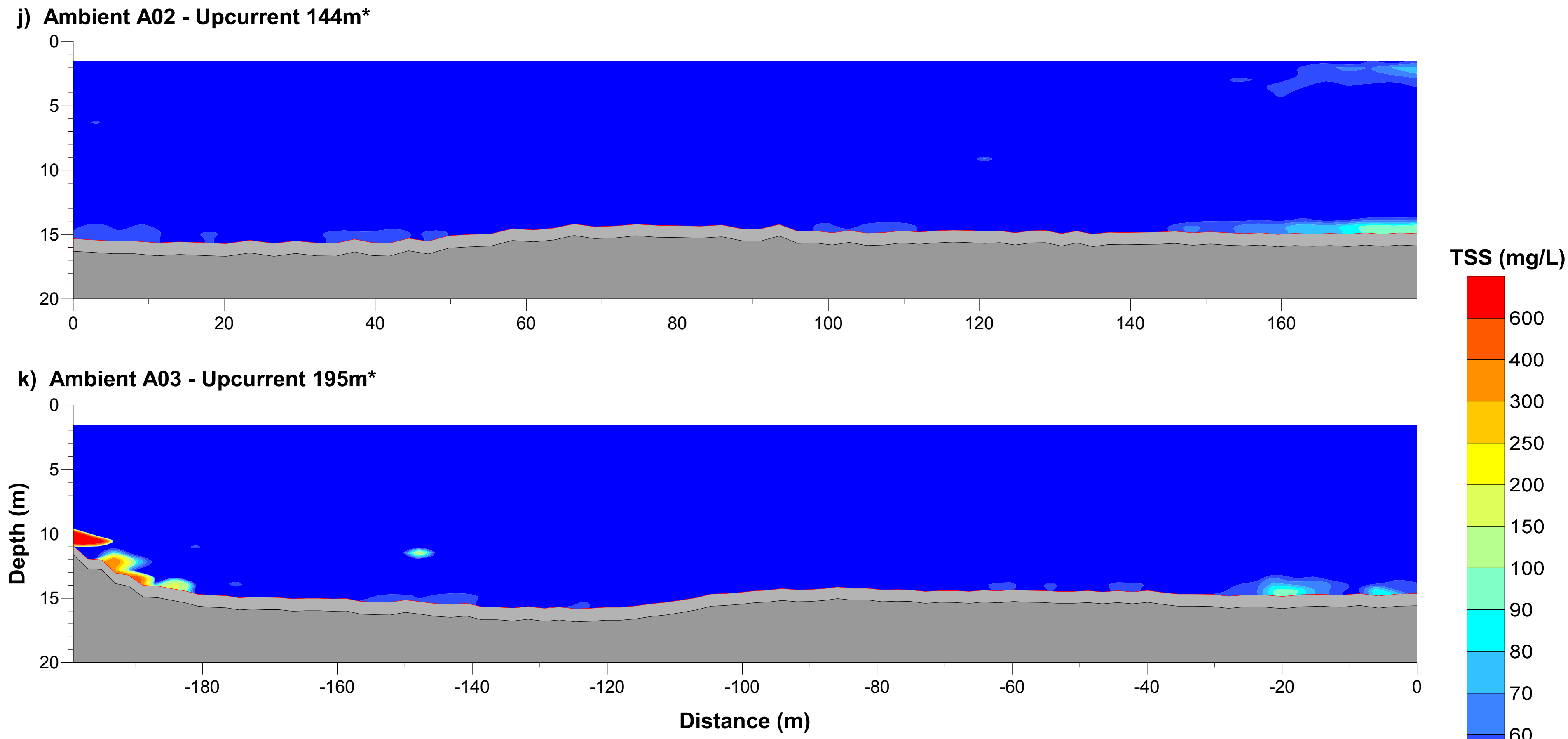


FIGURE	USACE Harborwide TSS Far Field Survey S-KVK-1	Vertical Profiles of ADCP Average TSS 22 June 2009 - Ebb Tide #2	TIDE
12d-f			Ebb



*Approximate distance from source

FIGURE	USACE Harborwide TSS Far Field Survey S-KVK-1	Vertical Profiles of ADCP Average TSS 22 June 2009 - Ebb Tide #2	TIDE
12g-i			Ebb



*Approximate distance from source

FIGURE	USACE Harborwide TSS Far Field Survey S-KVK-1	Vertical Profiles of ADCP Average TSS 22 June 2009 - Ebb Tide #2	TIDE
12j-k			Ebb

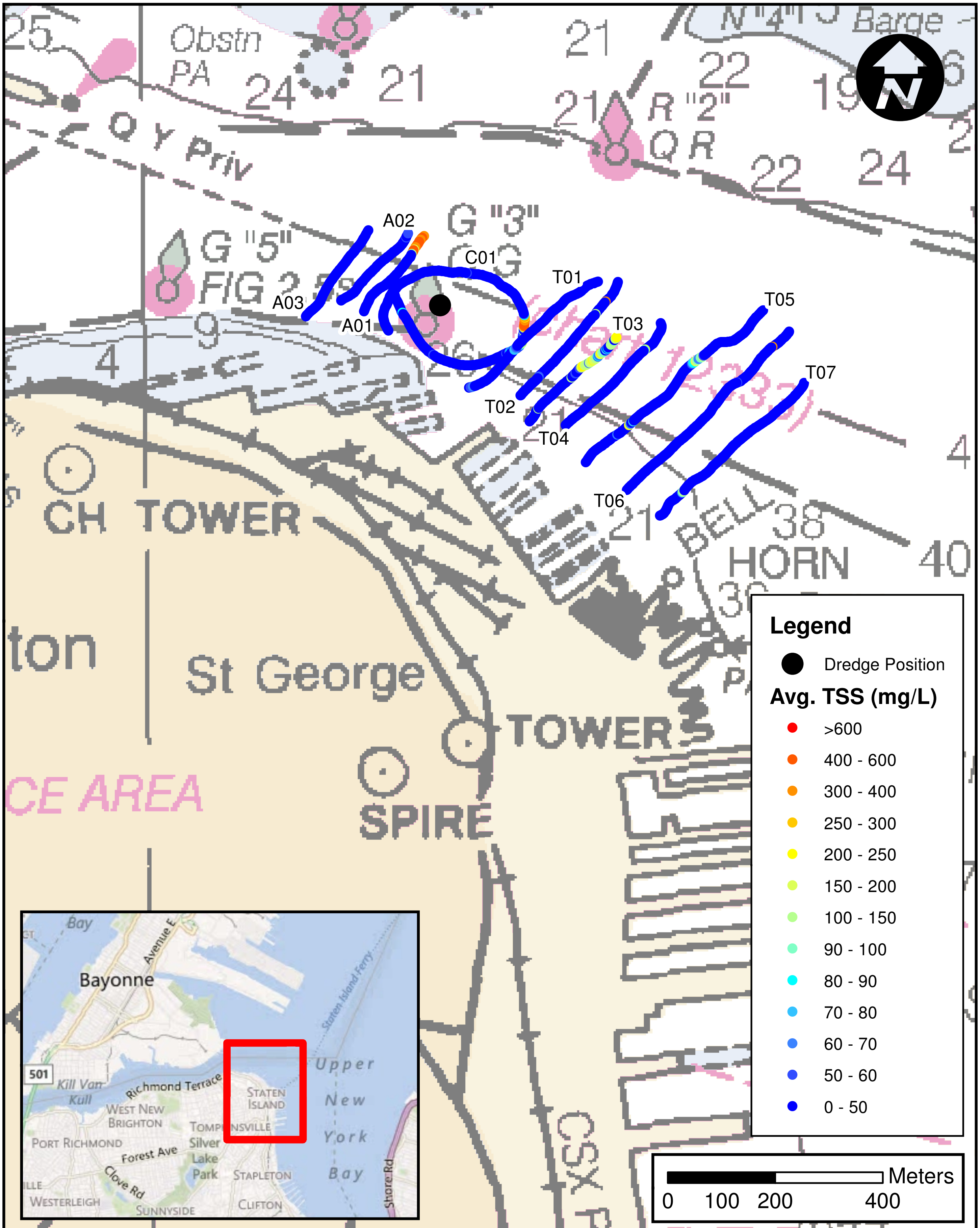


Figure	*USACE Harborwide TSS Far Field Survey HDP Contract Area: S-KVK-1*	**ADCP Average TSS - 22 June 2009 0-2 Meter Depth Interval - Set 2**	Tide
13a			Ebb

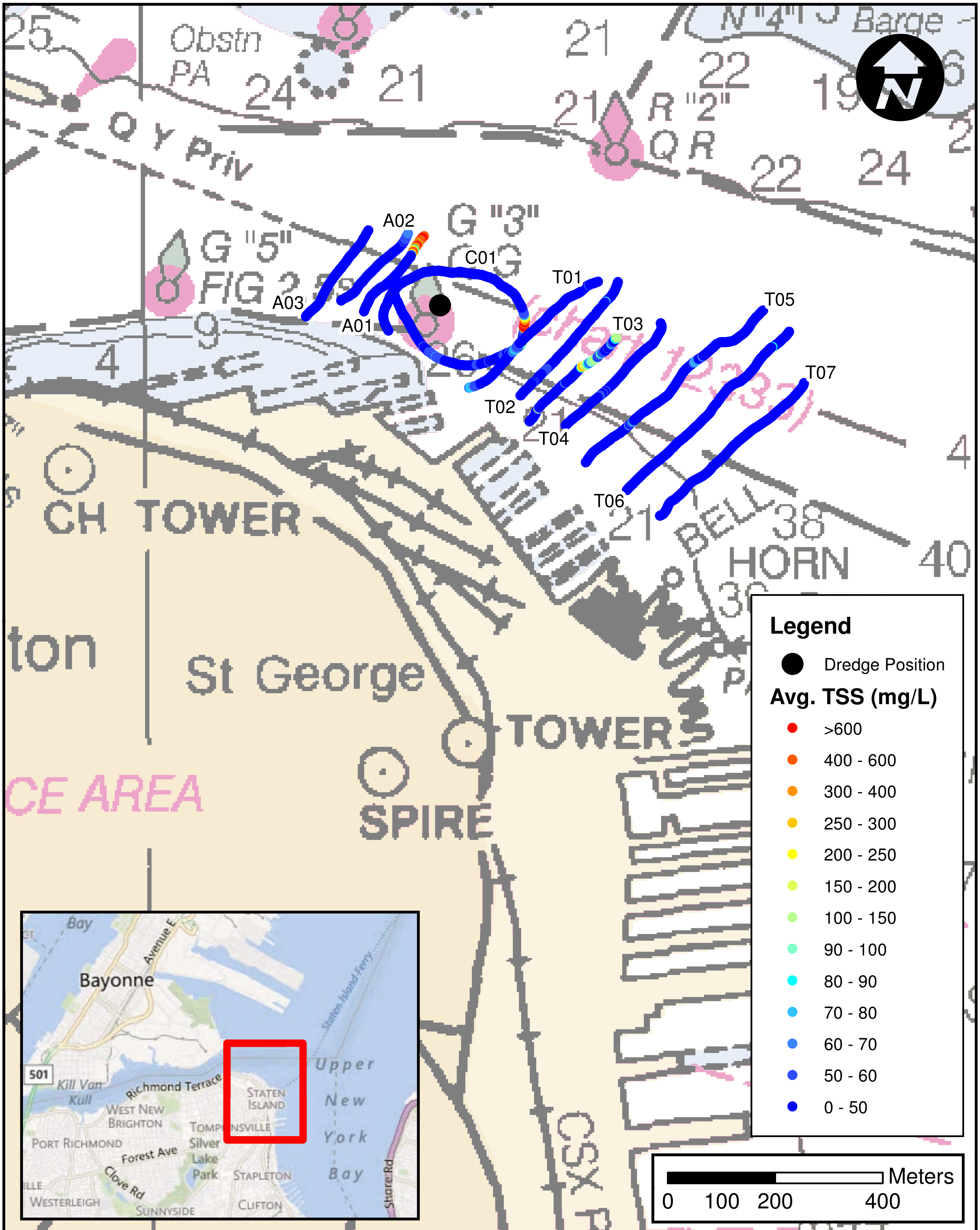


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-KVK-1	ADCP Average TSS - 22 June 2009 2-4 Meter Depth Interval - Set 2	Tide
13b			Ebb

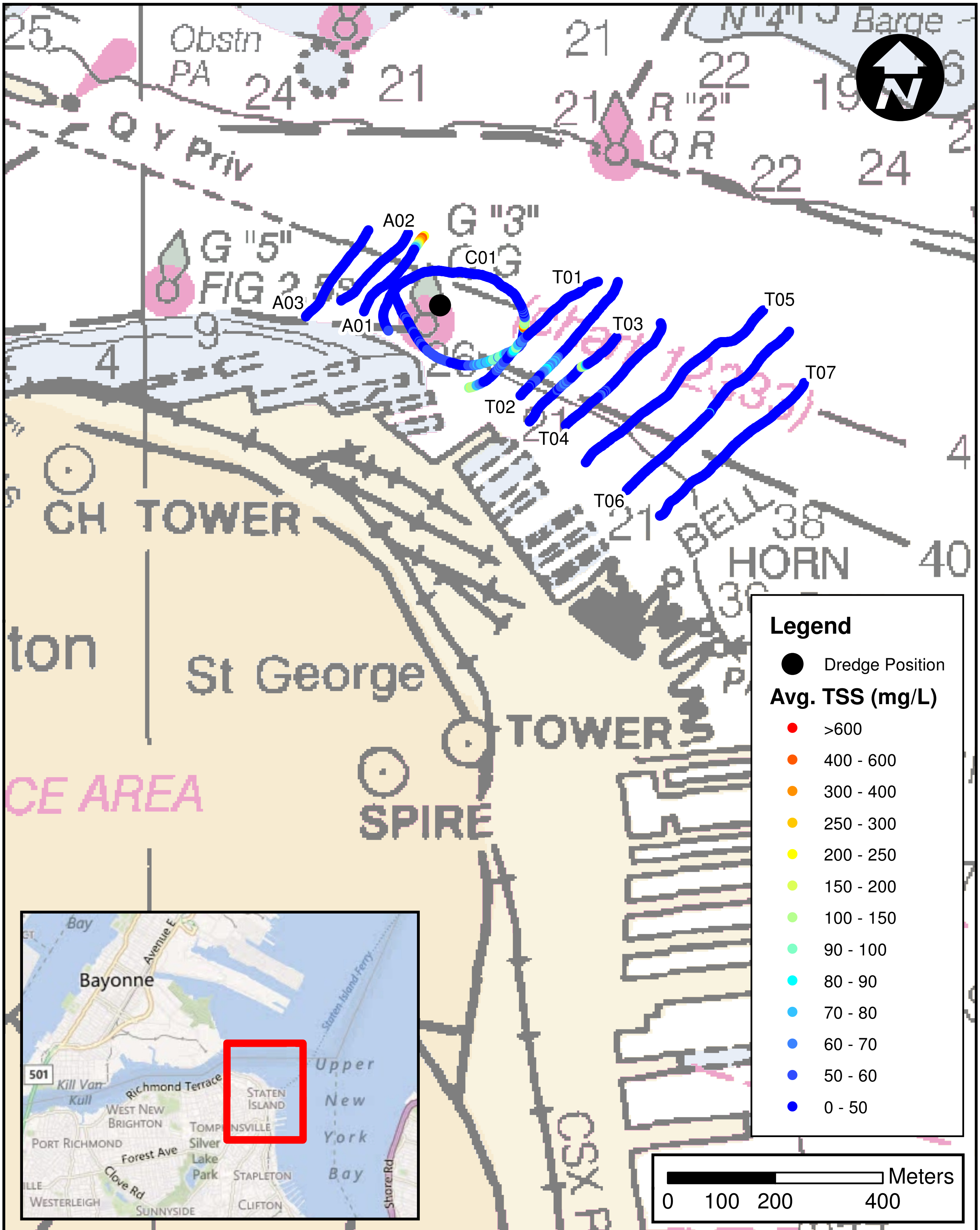


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-KVK-1	ADCP Average TSS - 22 June 2009 4-6 Meter Depth Interval - Set 2	Tide
13c			Ebb

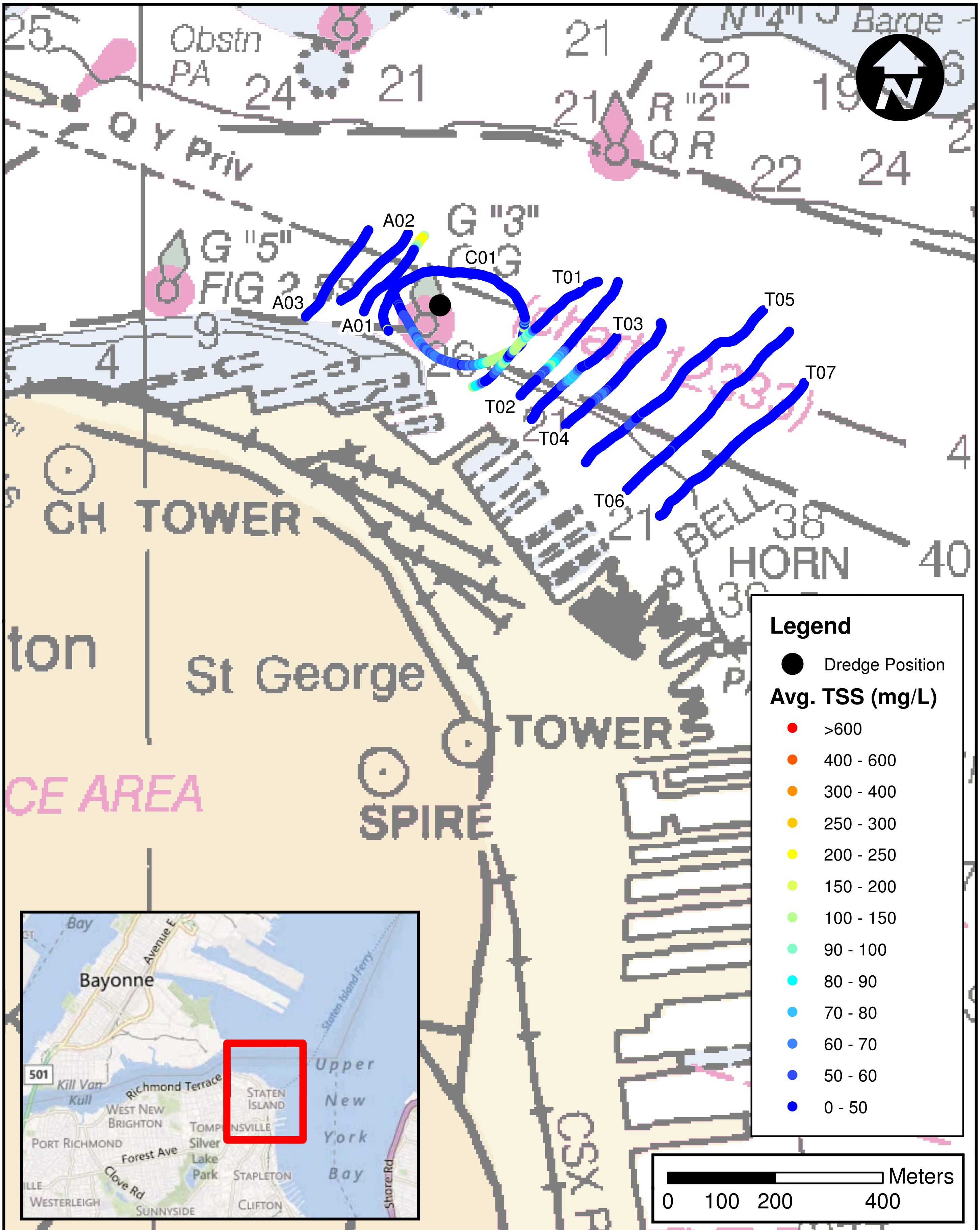


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-KVK-1	ADCP Average TSS - 22 June 2009 6-8 Meter Depth Interval - Set 2	Tide
13d			Ebb

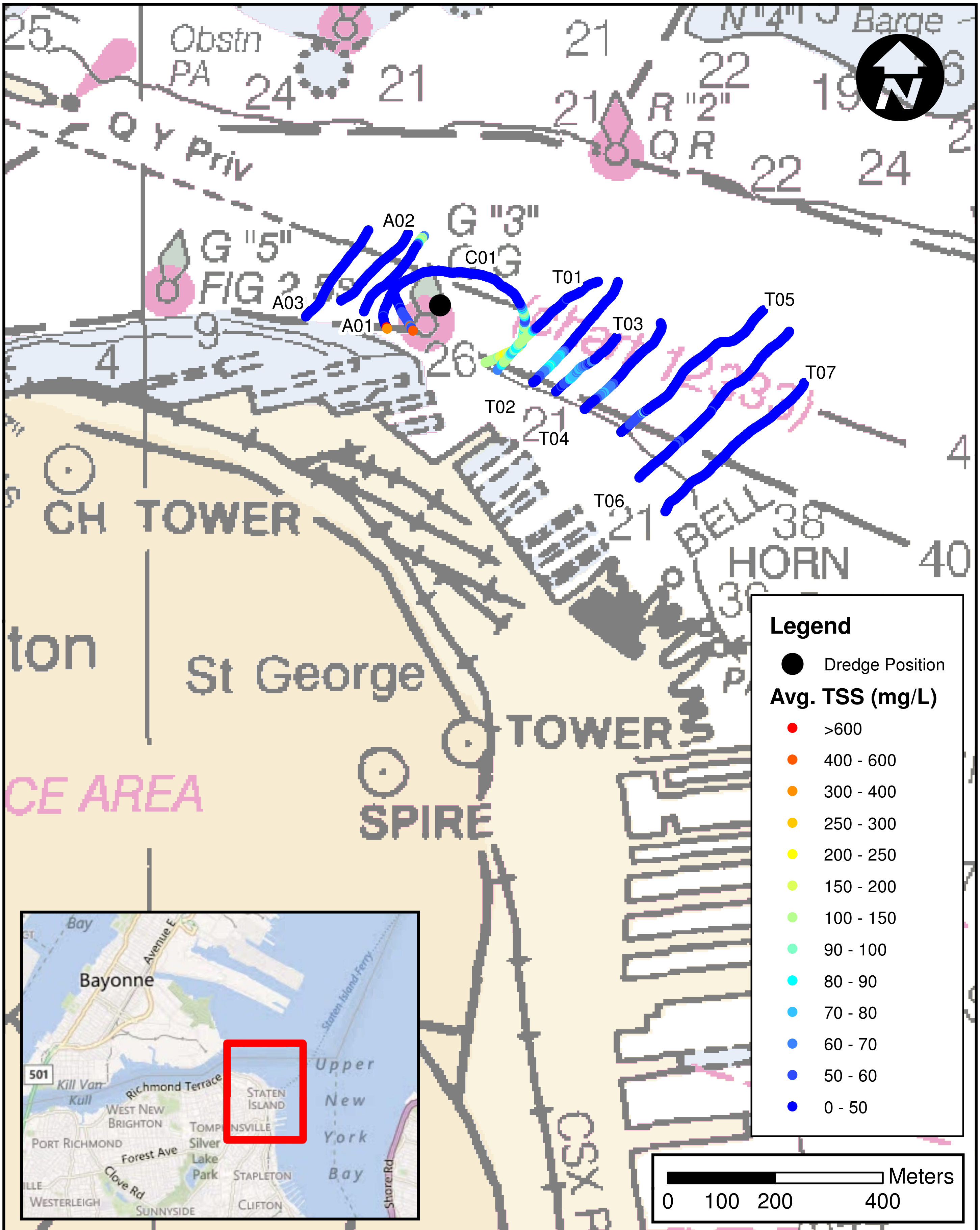


Figure	*USACE Harborwide TSS Far Field Survey HDP Contract Area: S-KVK-1*	**ADCP Average TSS - 22 June 2009** **8-10 Meter Depth Interval - Set 2**	Tide
13e			Ebb

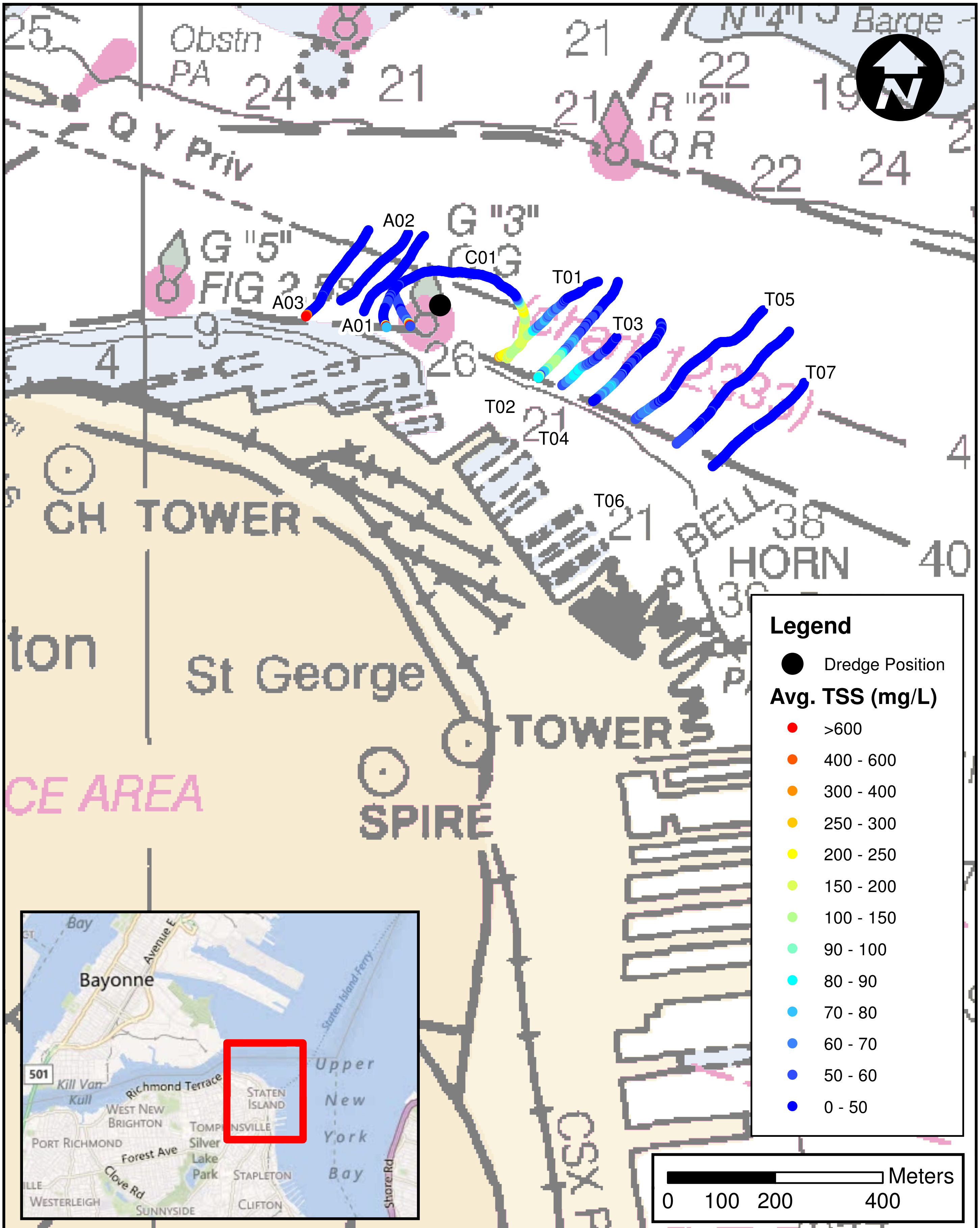


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-KVK-1	ADCP Average TSS - 22 June 2009 10-12 Meter Depth Interval - Set 2	Tide
13f			Ebb

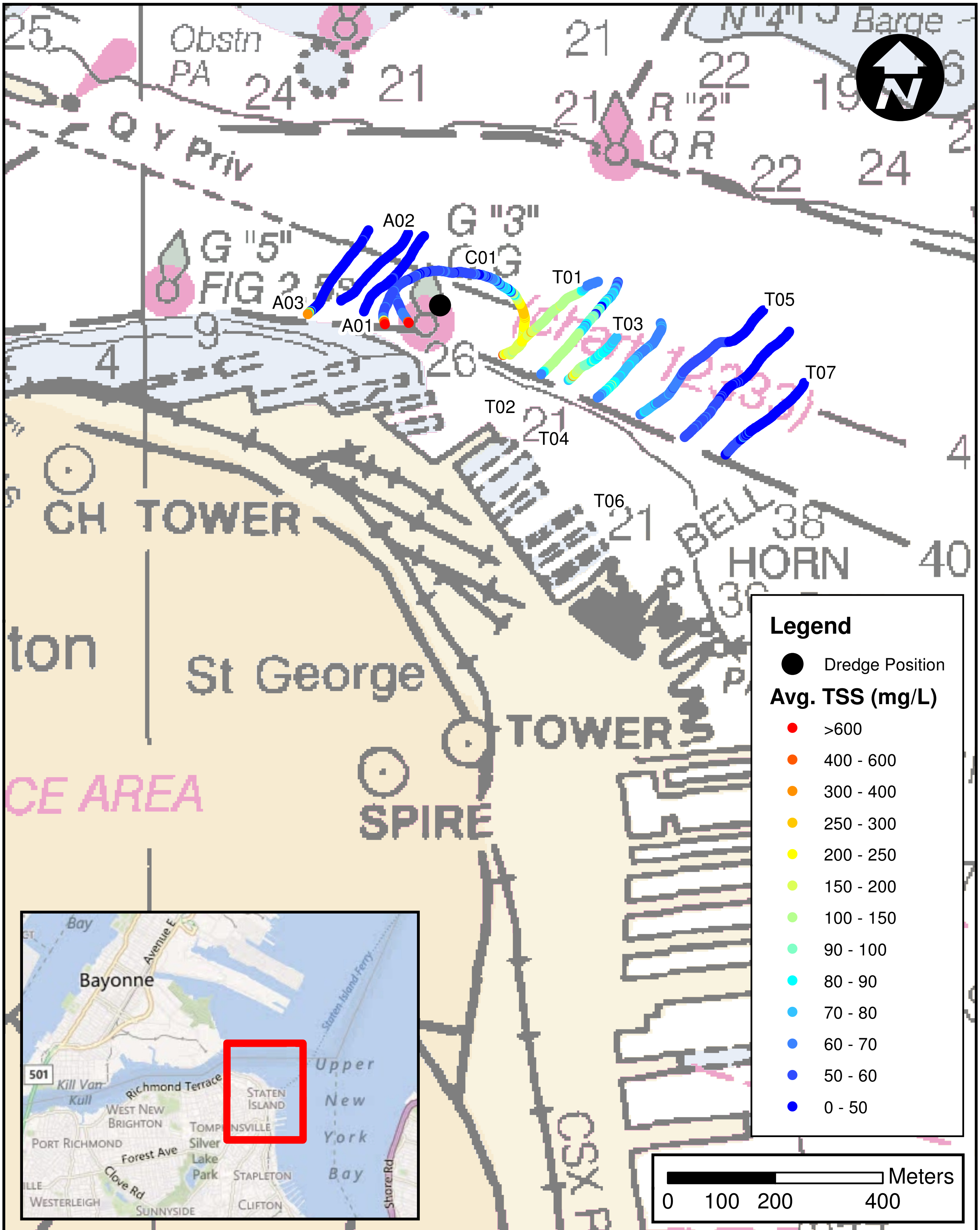


Figure	*USACE Harborwide TSS Far Field Survey HDP Contract Area: S-KVK-1*	**ADCP Average TSS - 22 June 2009 12-14 Meter Depth Interval - Set 2**	Tide
13g			Ebb

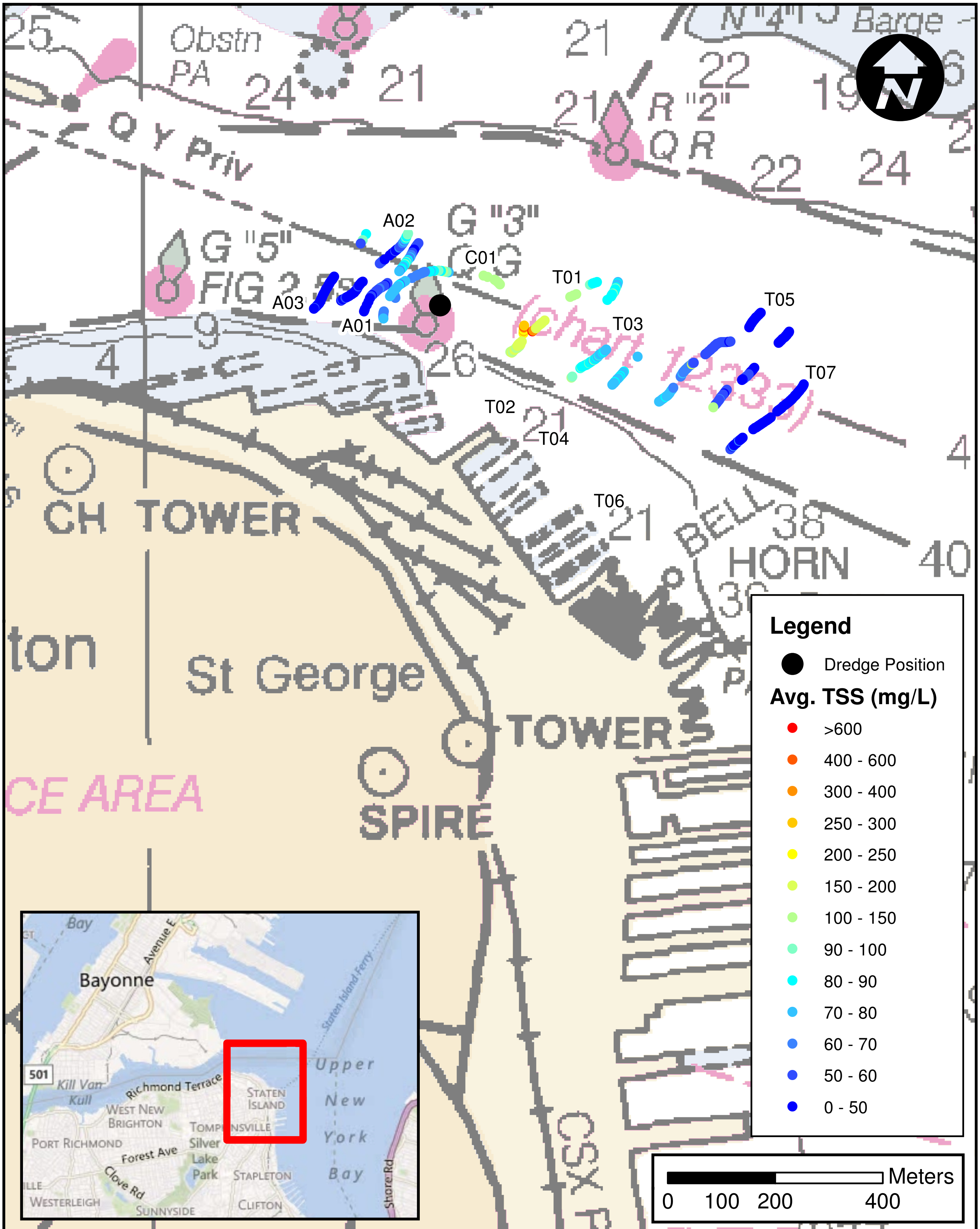
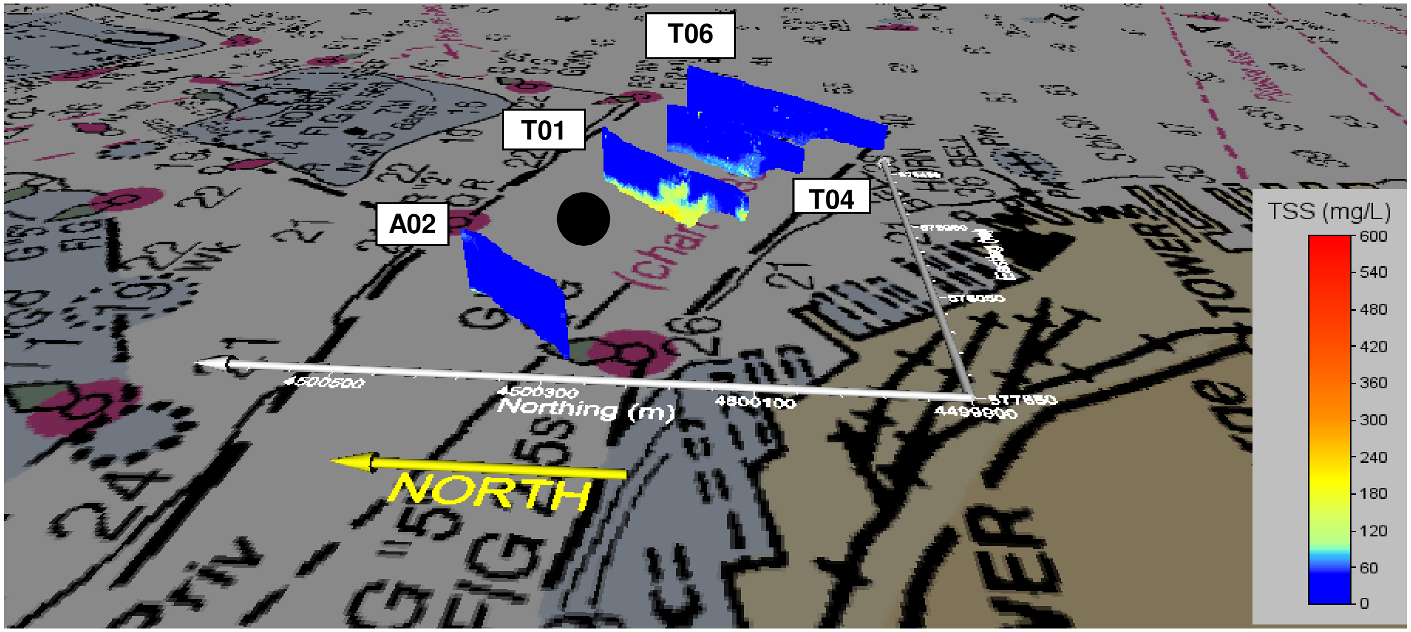


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-KVK-1	ADCP Average TSS - 22 June 2009 14-16 Meter Depth Interval - Set 2	Tide
13h			Ebb



● = Dredge Location

Z scale exaggerated 6X

Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area S-KVK-1	ADCP Average TSS Values, 3D View of Selected Transects 22 June 2009 – Ebb Tide #2	Tide
14			Ebb

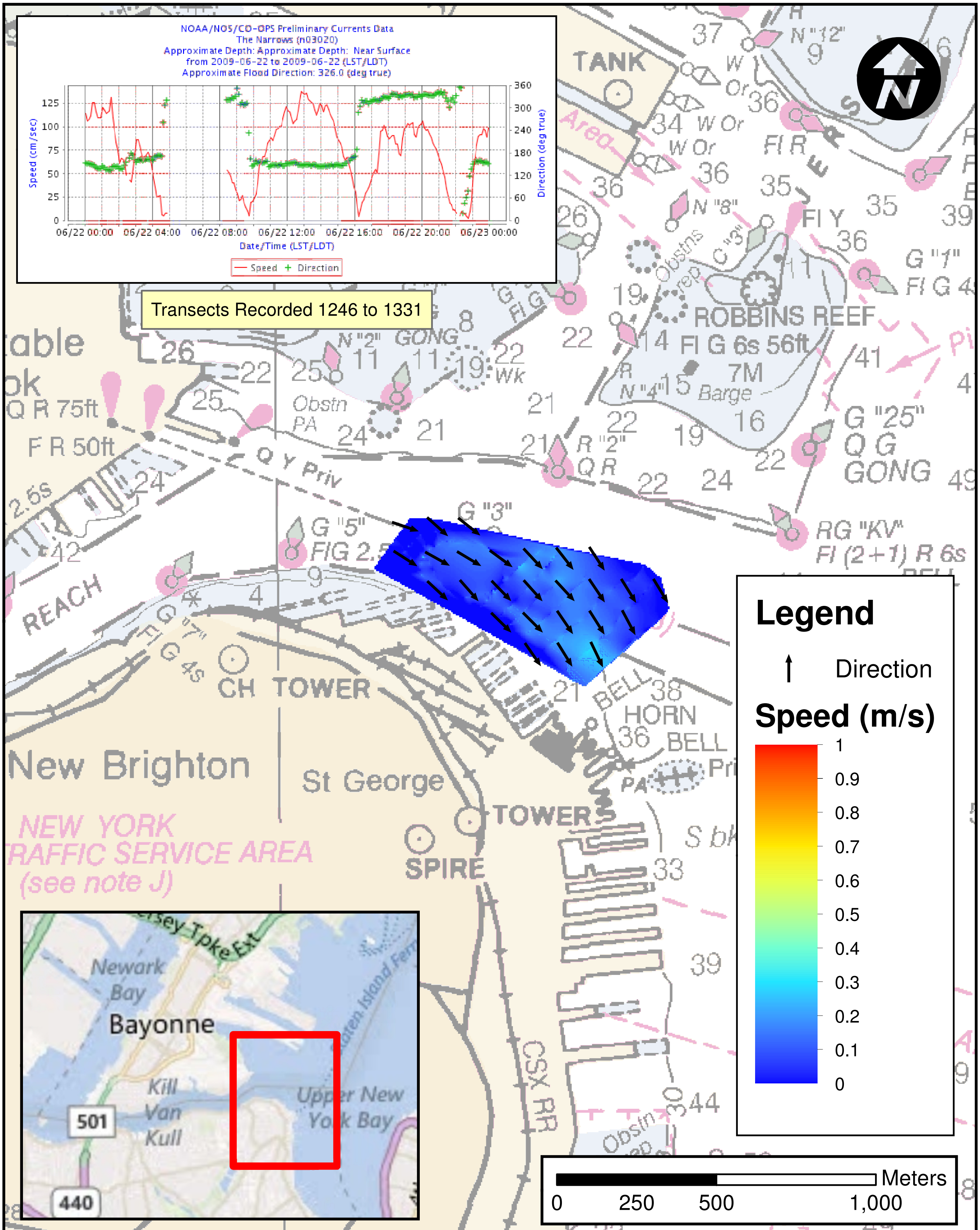


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-KVK-1	Depth Averaged Velocities 22 June 2009 - Ebb Tide Hydrodynamic Survey	Tide
15			Ebb

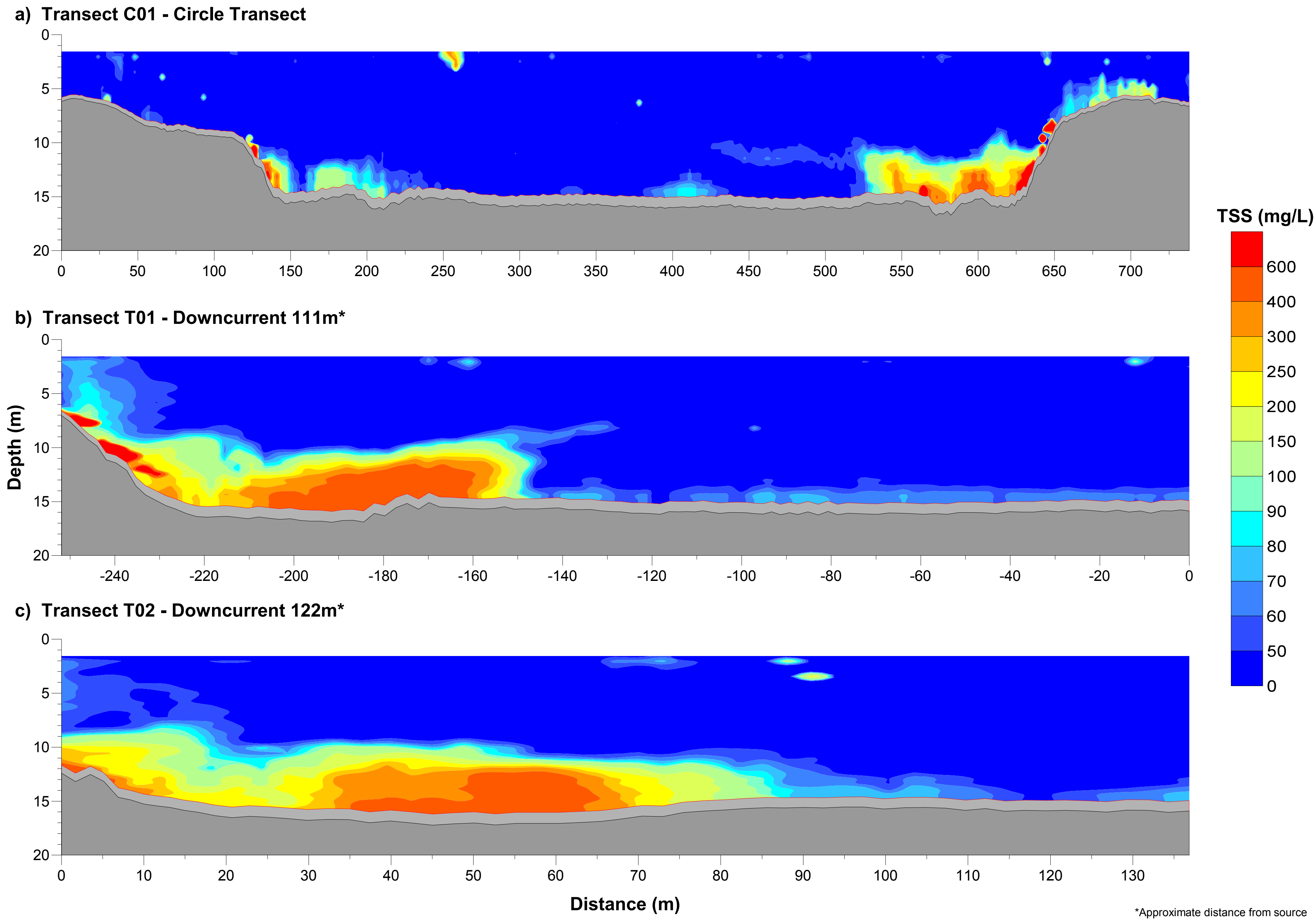


FIGURE	USACE Harborwide TSS Far Field Survey S-KVK-1	Vertical Profiles of ADCP Average TSS 22 June 2009 - Flood Tide	TIDE
16a-c			Flood

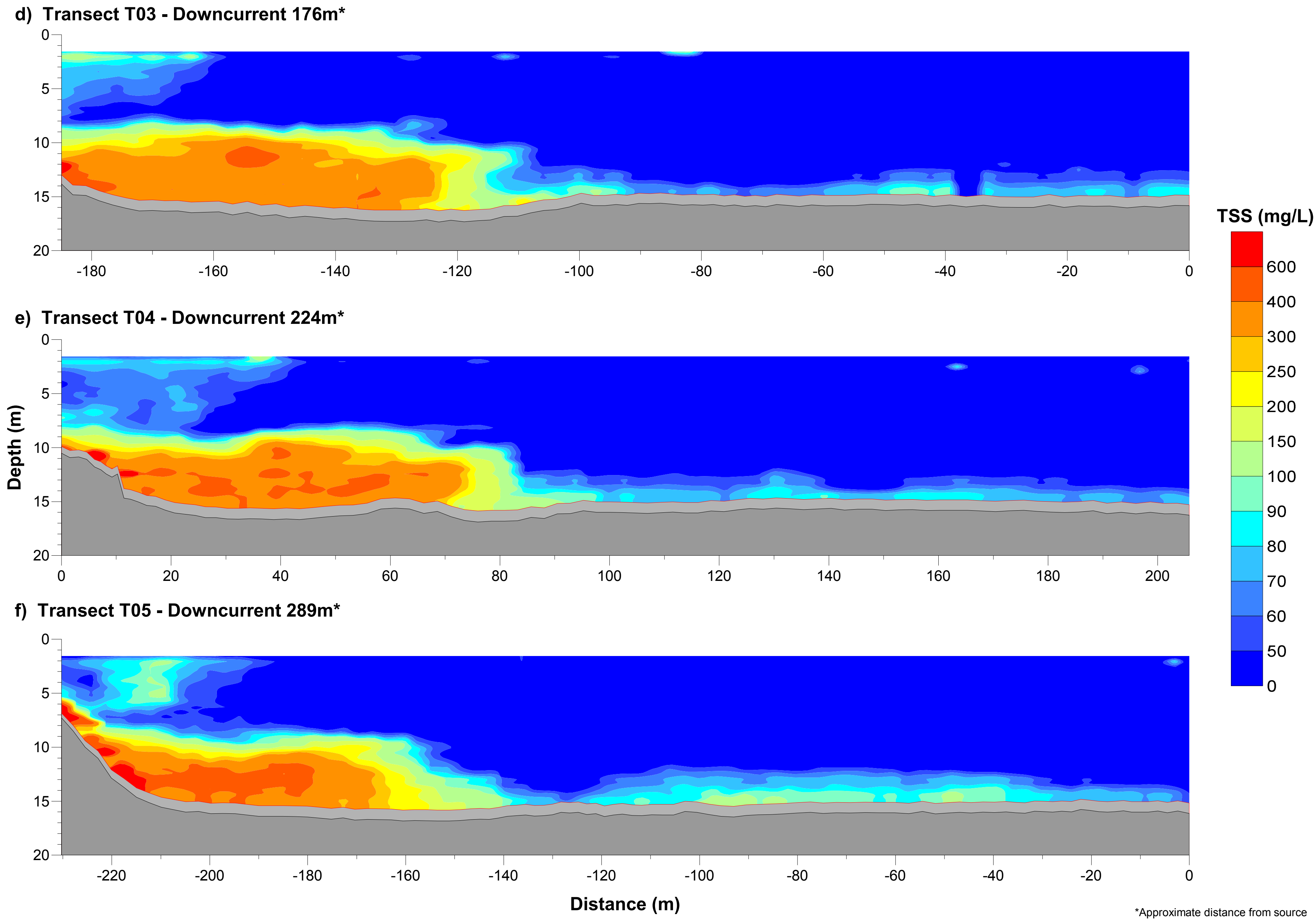
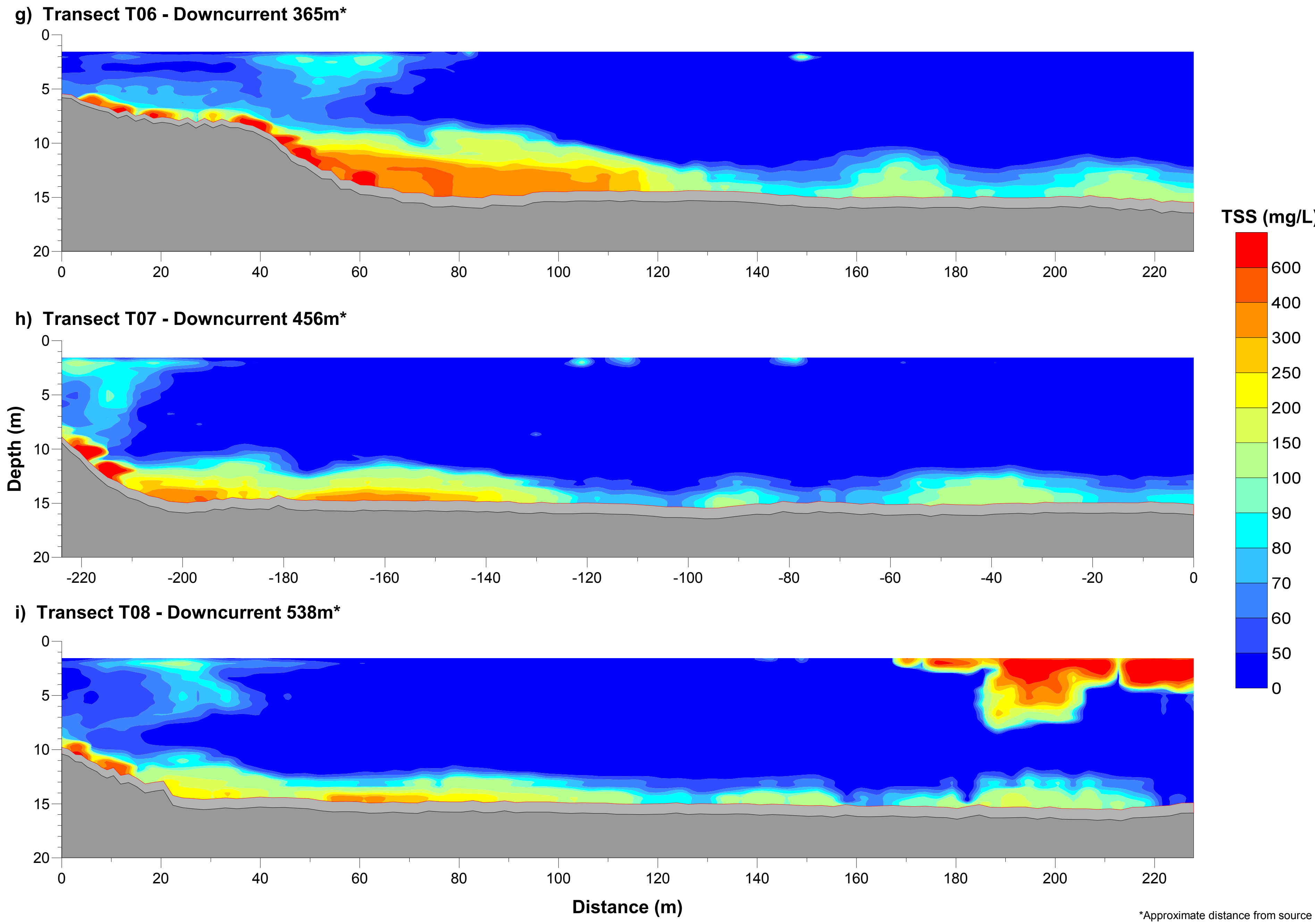
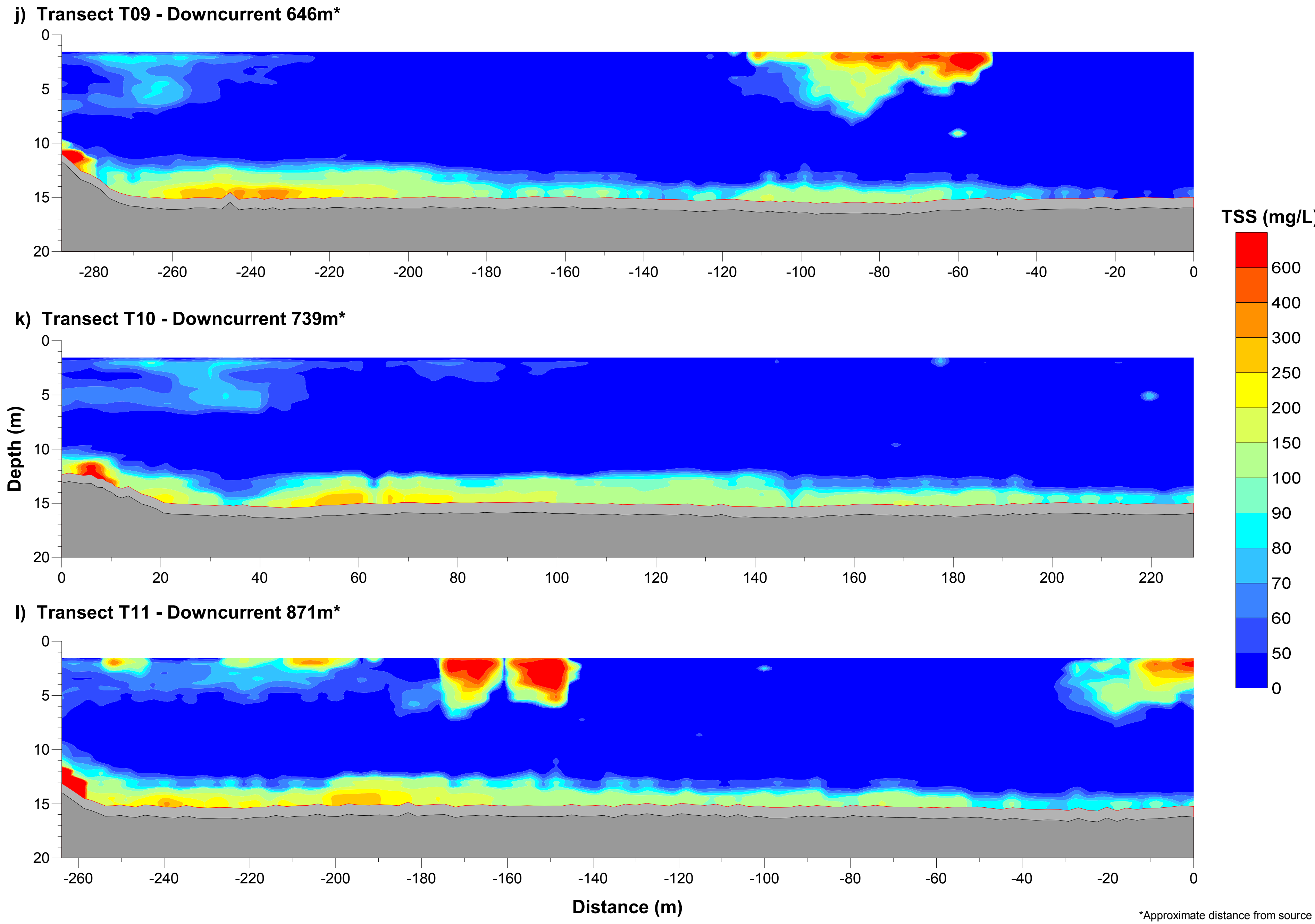


FIGURE	USACE Harborwide TSS Far Field Survey S-KVK-1	Vertical Profiles of ADCP Average TSS 22 June 2009 - Flood Tide	TIDE
16d-f			Flood



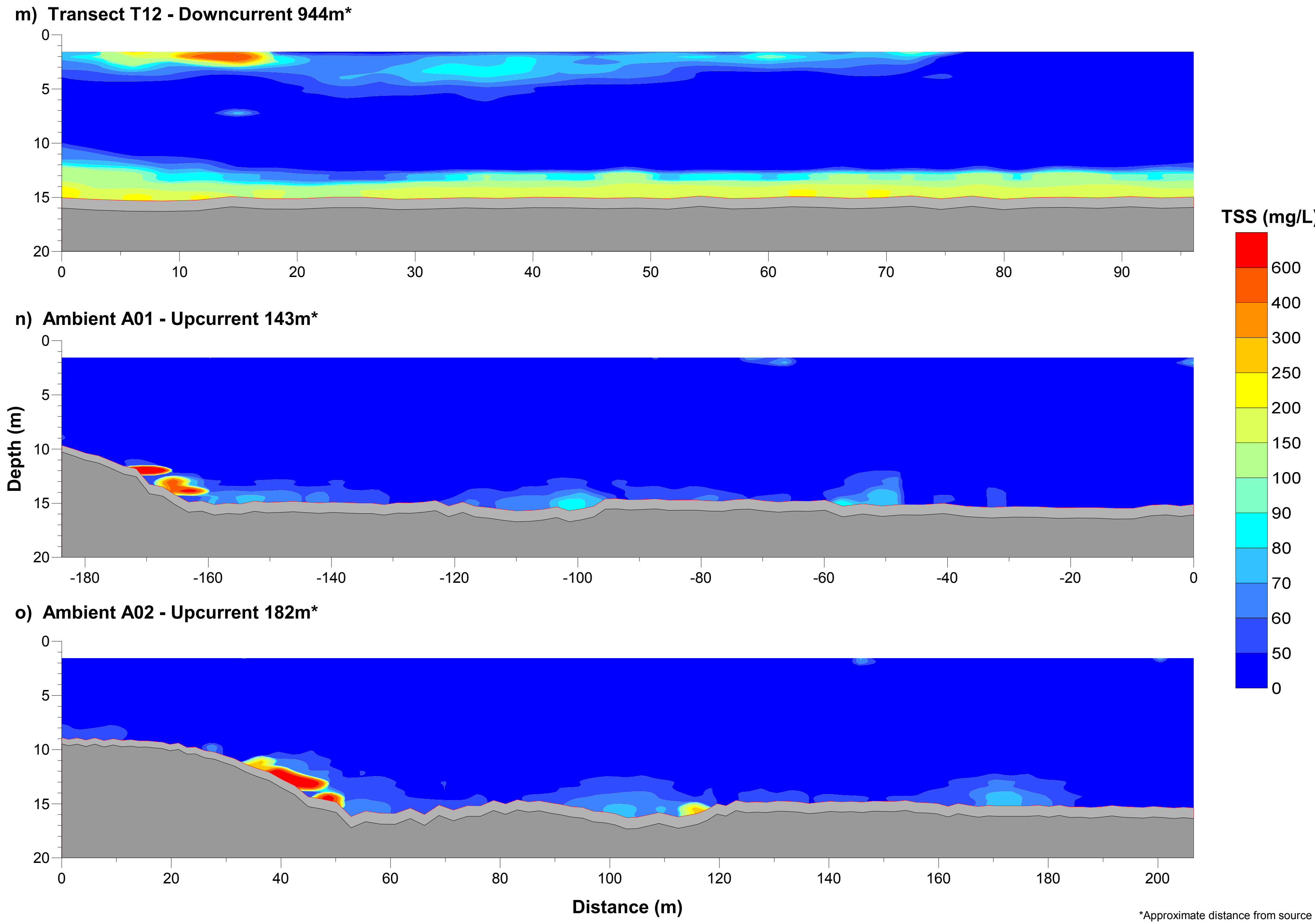
*Approximate distance from source

FIGURE	*USACE Harborwide TSS Far Field Survey S-KVK-1*	Vertical Profiles of ADCP Average TSS 22 June 2009 - Flood Tide	TIDE
16g-i			Flood



*Approximate distance from source

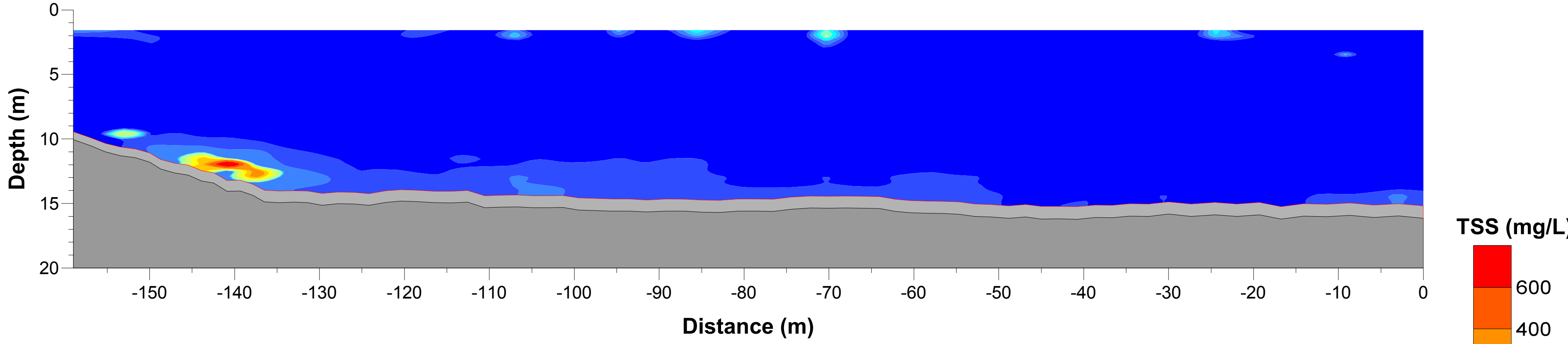
FIGURE	*USACE Harborwide TSS* *Far Field Survey* *S-KVK-1*	**Vertical Profiles of ADCP Average TSS** **22 June 2009 - Flood Tide**	TIDE
16j-l			Flood



*Approximate distance from source

FIGURE	*USACE Harborwide TSS* *Far Field Survey* *S-KVK-1*	**Vertical Profiles of ADCP Average TSS** **22 June 2009 - Flood Tide**	TIDE
16m-o			**Flood**

p) Ambient A03 - Upcurrent 232m*



*Approximate distance from source

FIGURE	USACE Harborwide TSS Far Field Survey S-KVK-1	Vertical Profiles of ADCP Average TSS 22 June 2009 - Flood Tide	TIDE
16p			Flood

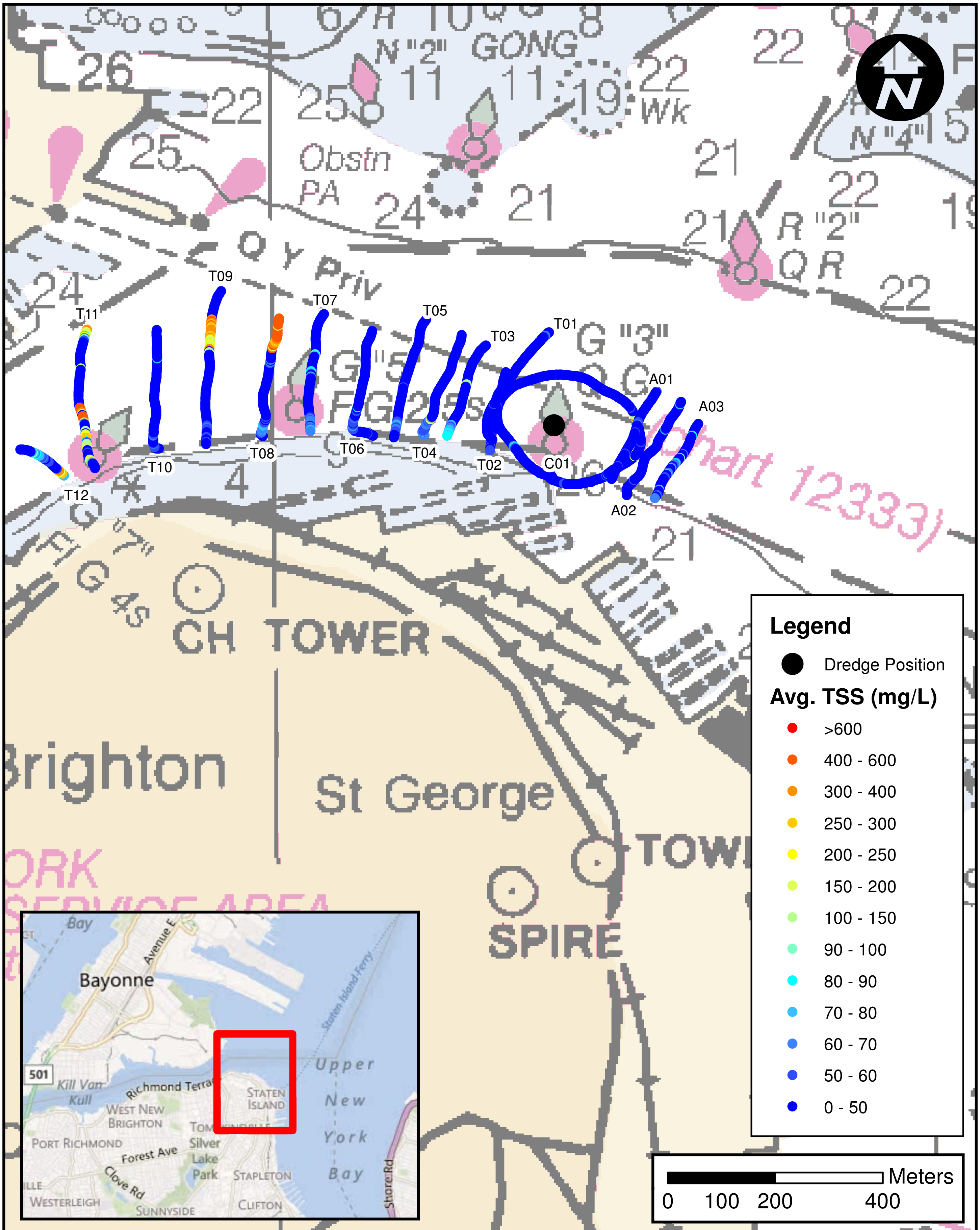


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-KVK-1	ADCP Average TSS - 22 June 2009 0-2 Meter Depth Interval	Tide
17a			Flood

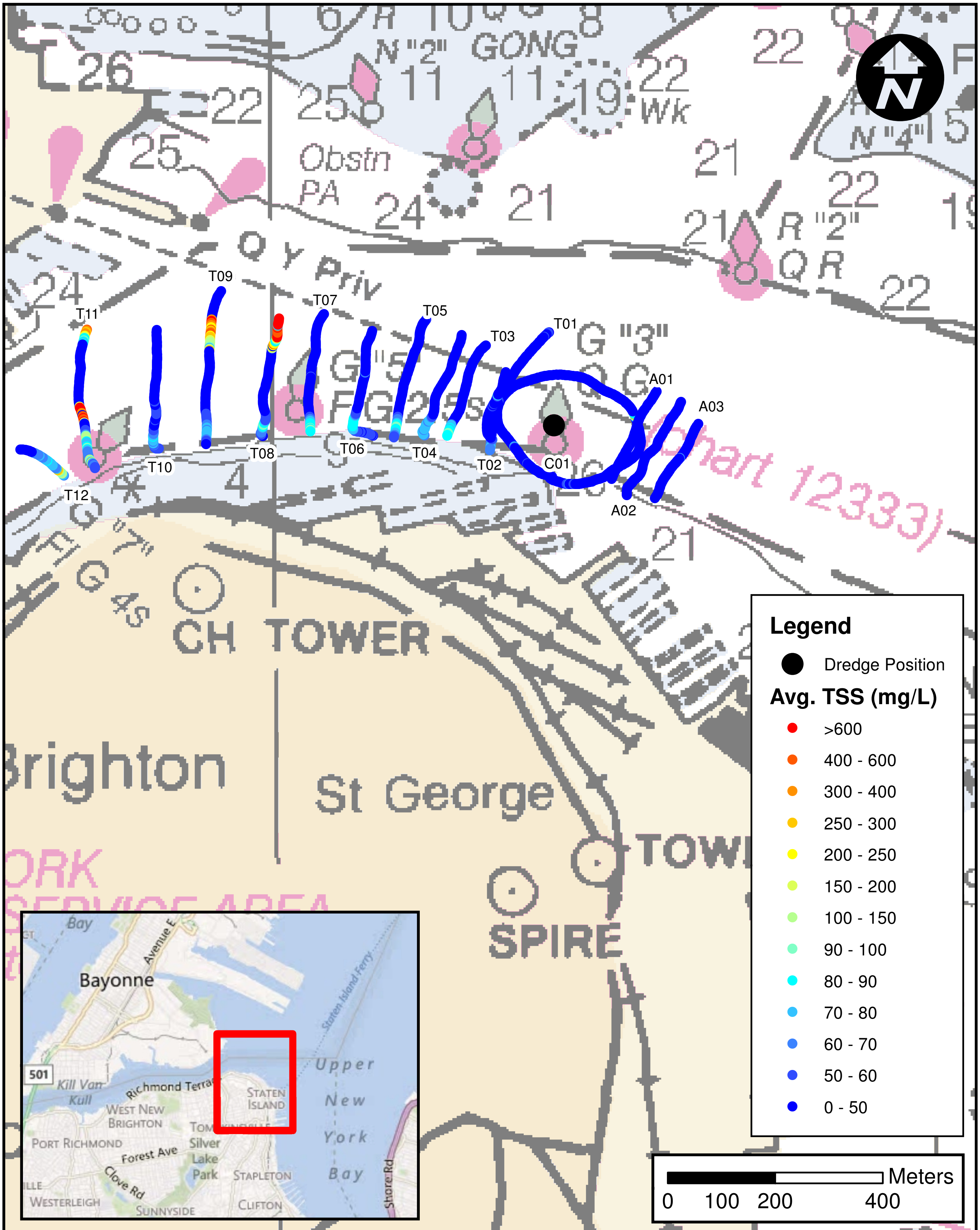


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-KVK-1	ADCP Average TSS - 22 June 2009 2-4 Meter Depth Interval	Tide
17b			Flood

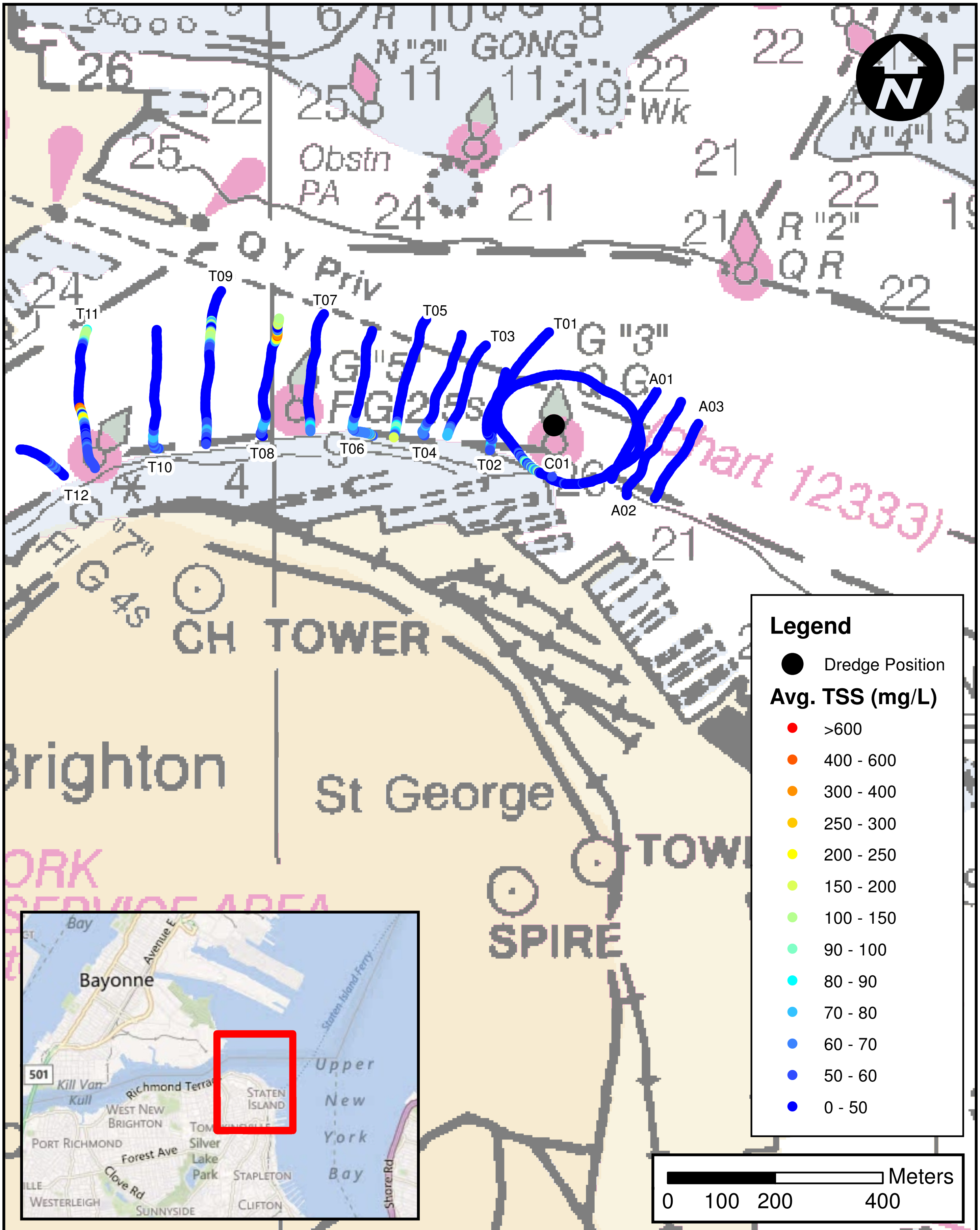


Figure	*USACE Harborwide TSS Far Field Survey HDP Contract Area: S-KVK-1*	**ADCP Average TSS - 22 June 2009 4-6 Meter Depth Interval**	Tide
17c			Flood

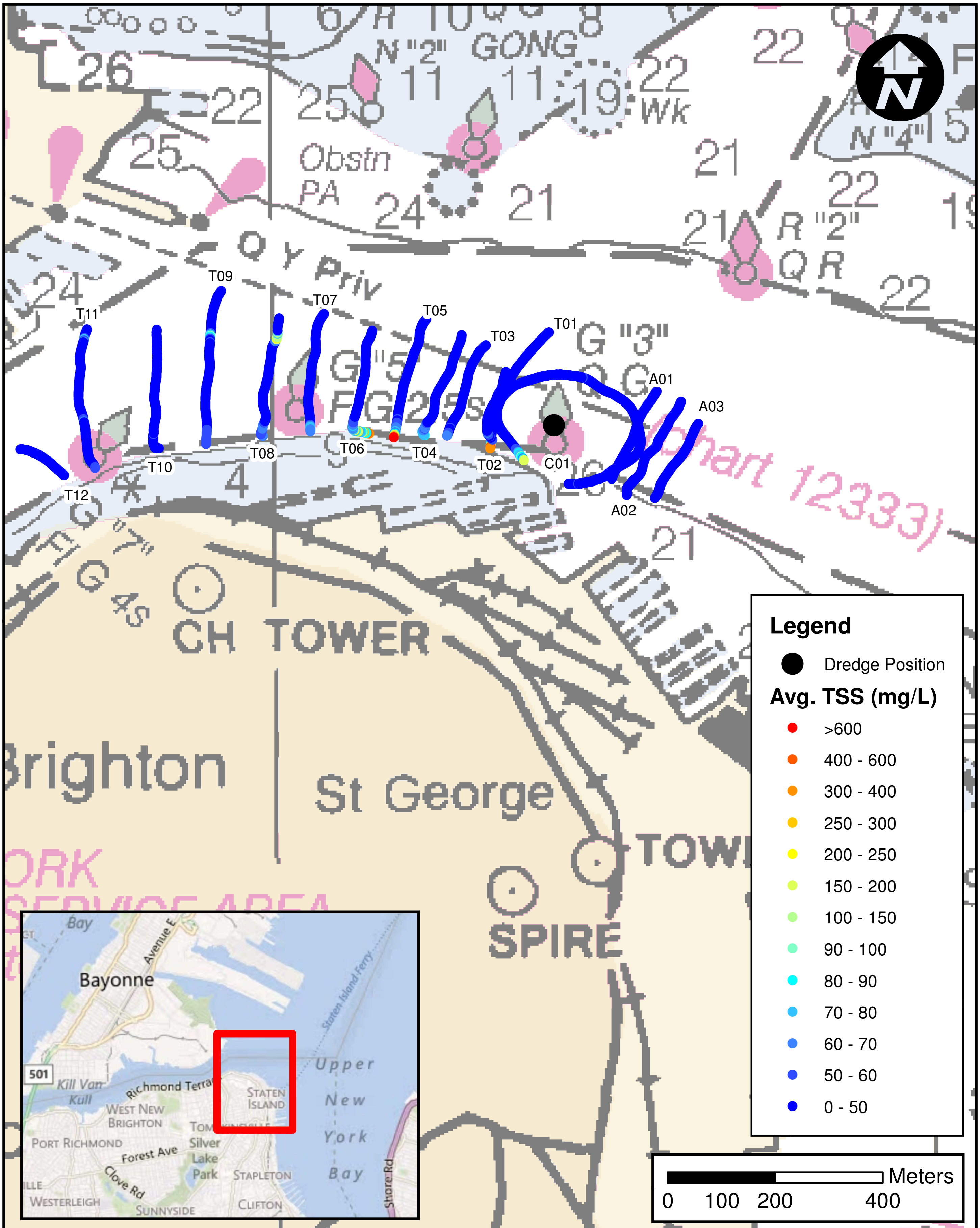


Figure	*USACE Harborwide TSS Far Field Survey HDP Contract Area: S-KVK-1*	**ADCP Average TSS - 22 June 2009 6-8 Meter Depth Interval**	Tide
17d			Flood

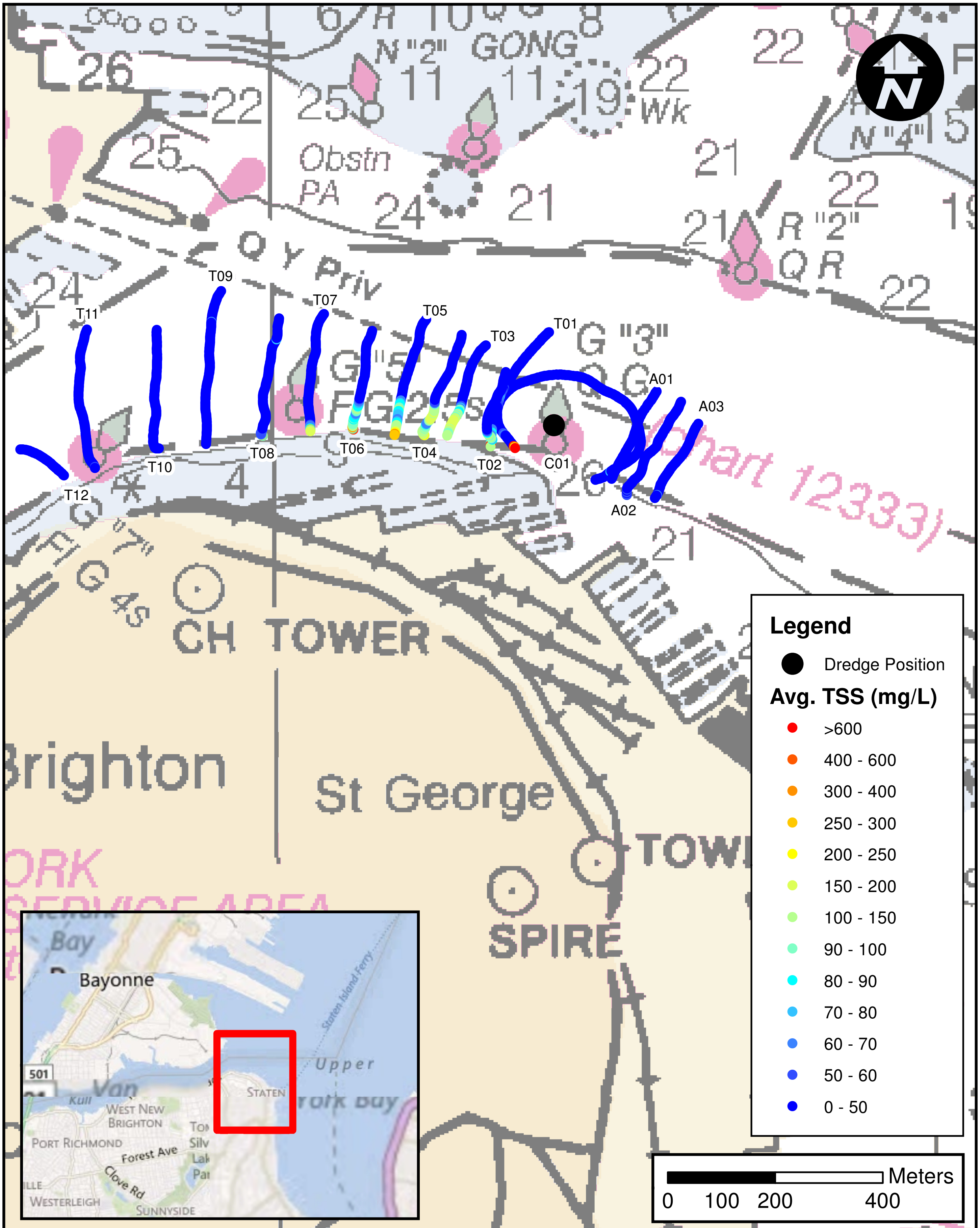


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-KVK-1	ADCP Average TSS - 22 June 2009 8-10 Meter Depth Interval	Tide
17e			Flood

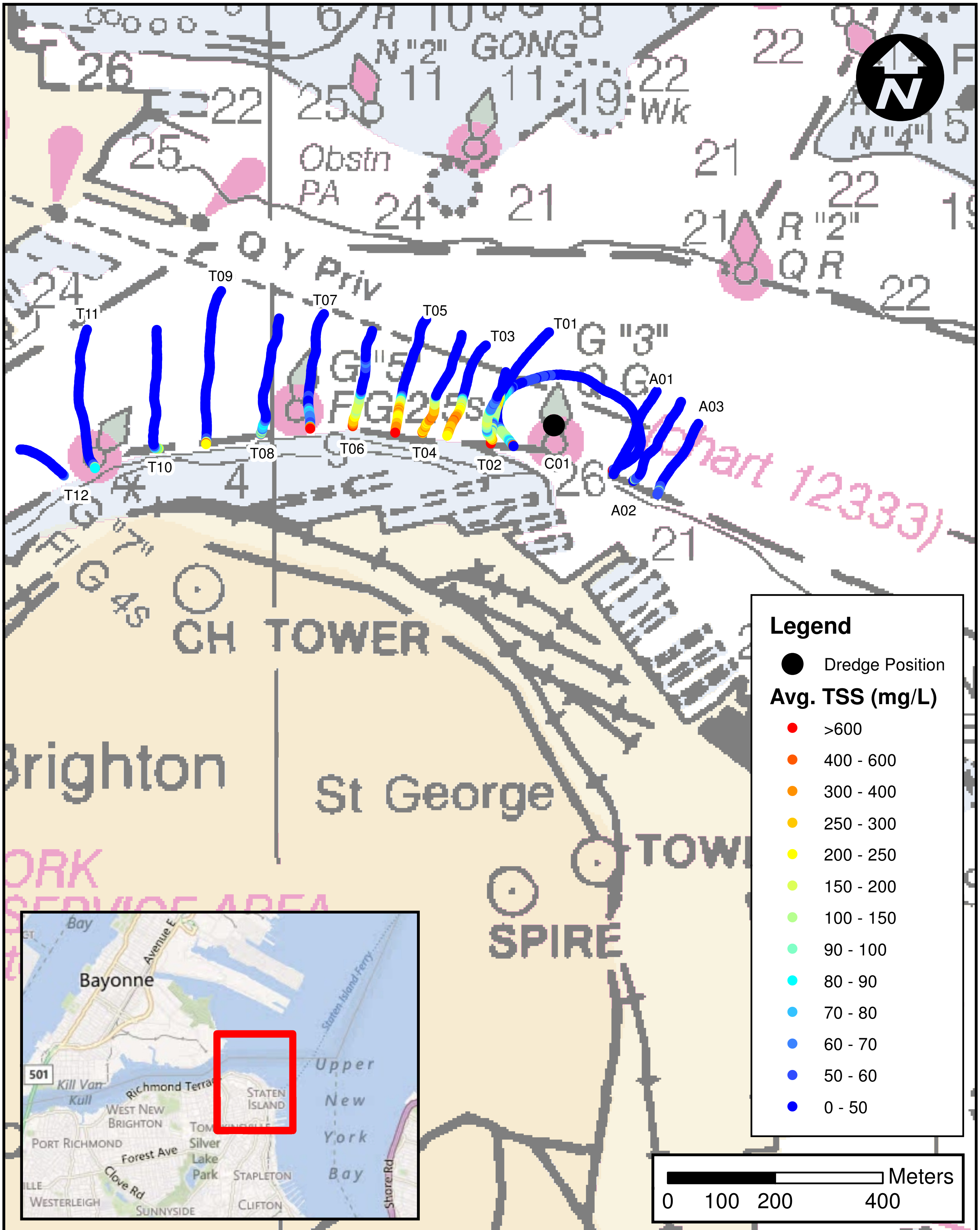


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-KVK-1	ADCP Average TSS - 22 June 2009 10-12 Meter Depth Interval	Tide
17f			Flood

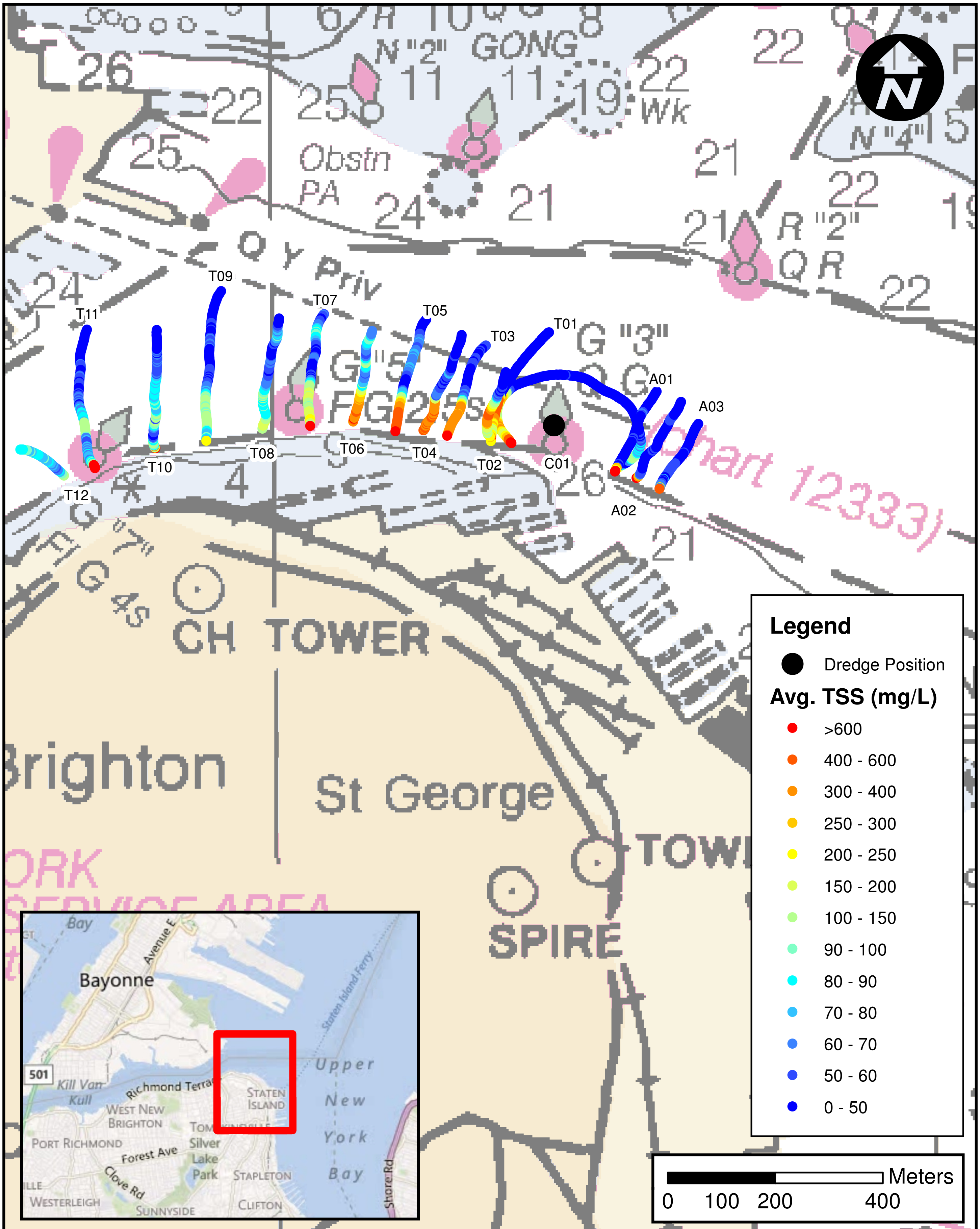


Figure	*USACE Harborwide TSS Far Field Survey HDP Contract Area: S-KVK-1*	**ADCP Average TSS - 22 June 2009**	**Tide**
17g		**12-14 Meter Depth Interval**	**Flood**

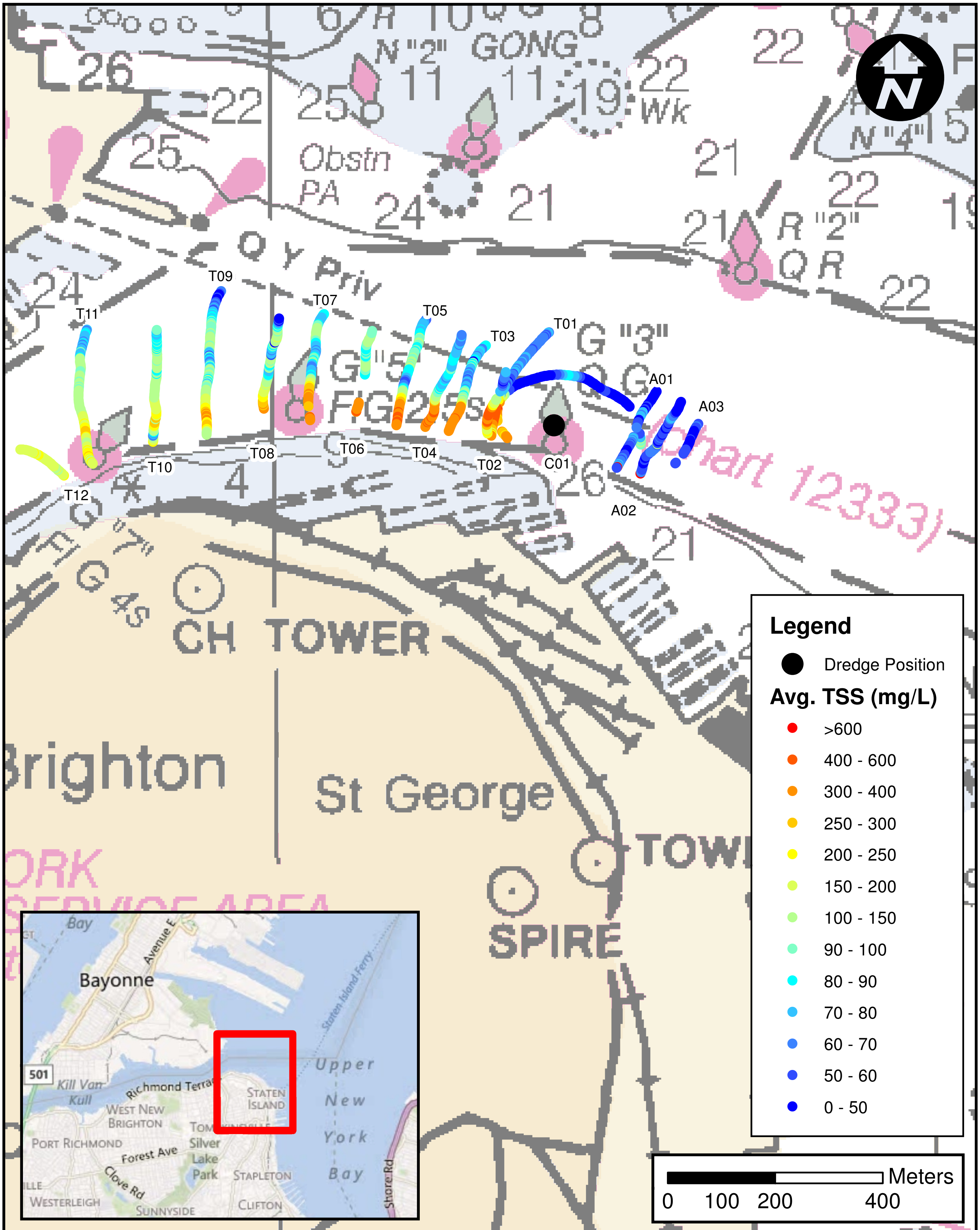
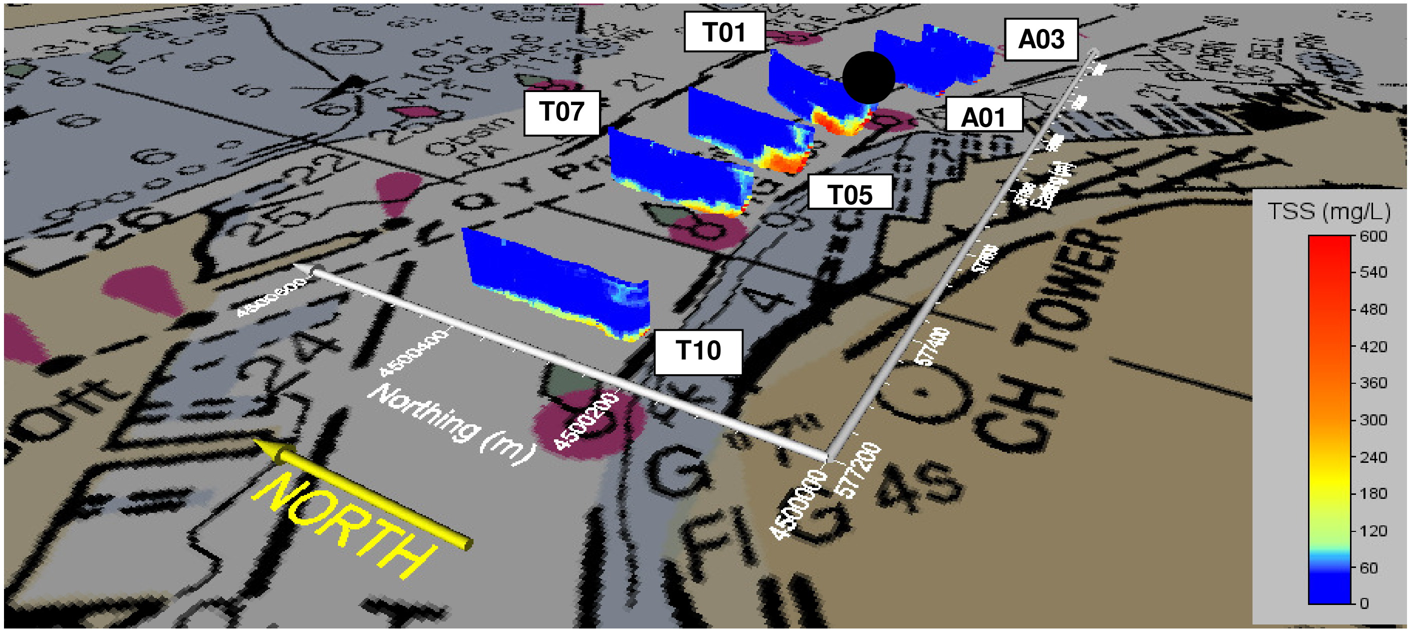


Figure	*USACE Harborwide TSS Far Field Survey HDP Contract Area: S-KVK-1*	ADCP Average TSS - 22 June 2009 14-16 Meter Depth Interval	Tide
17h			Flood



= Dredge Location

Z scale exaggerated 6X

Figure	*USACE Harborwide TSS Far Field Survey HDP Contract Area S-KVK-1*	ADCP Average TSS Values, 3D View of Selected Transects 22 June 2009 – Flood Tide	Tide
18			Flood

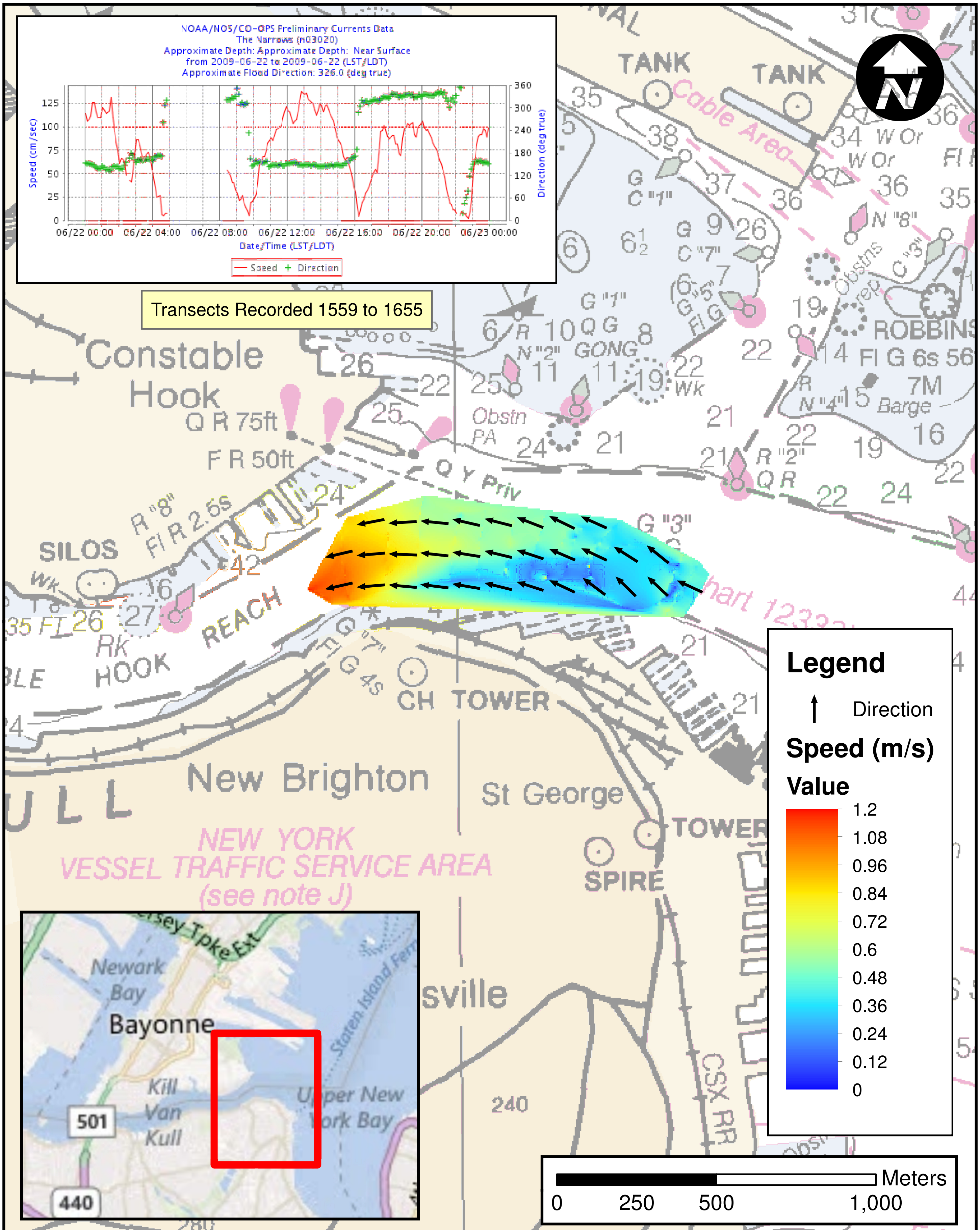


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-KVK-1	Depth Averaged Velocities 22 June 2009 - Flood Tide TSS Survey	Tide
19			Flood

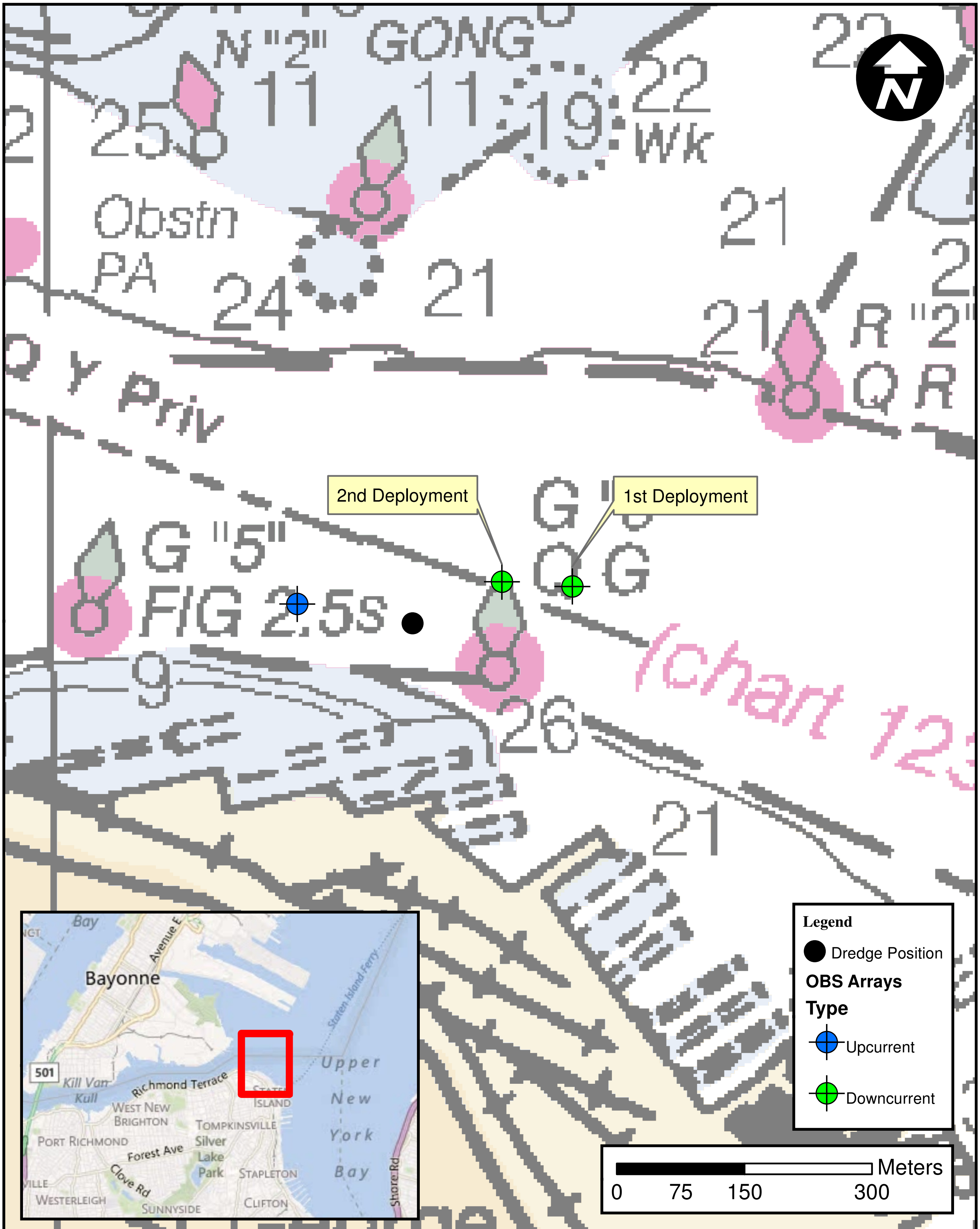
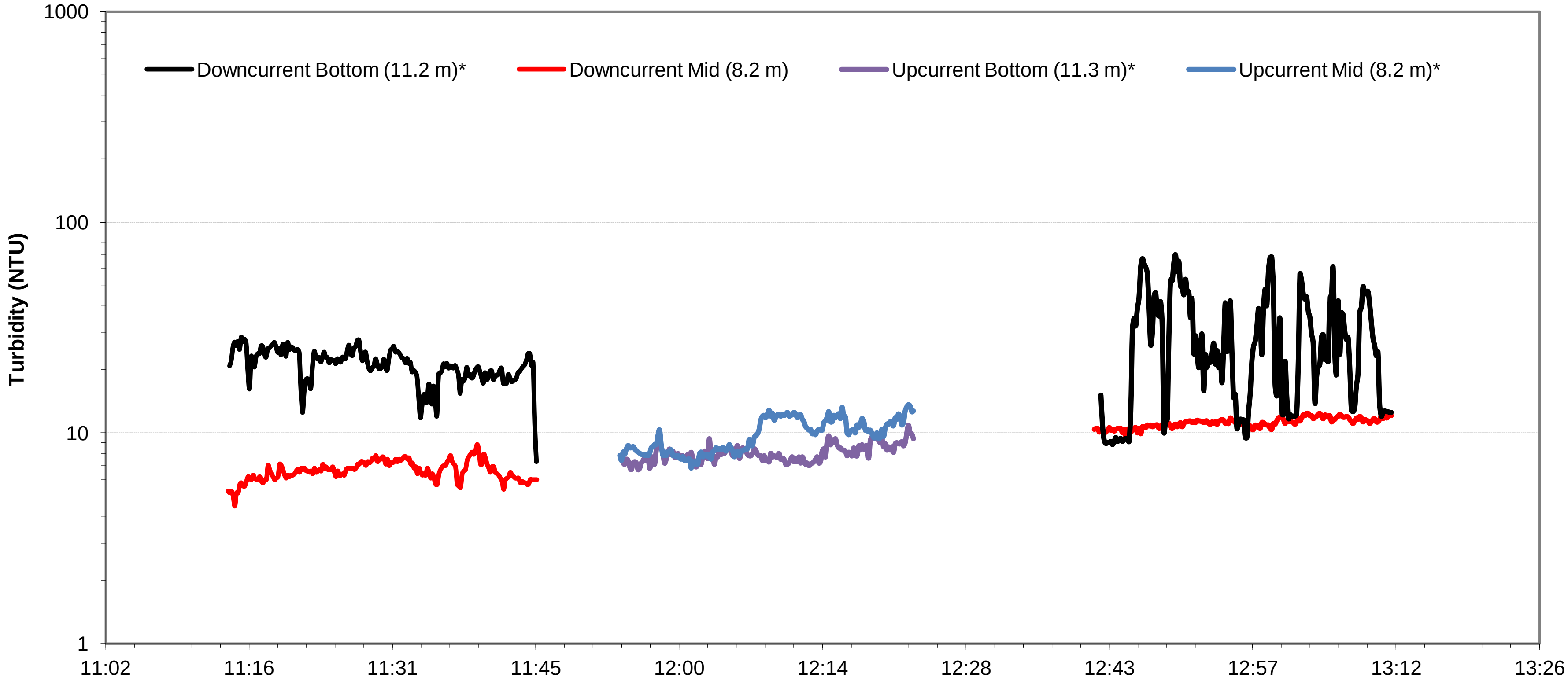


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-KVK-1	Location of OBS Vertical Arrays and Dredge Position 23 June 2011	Tide
20			Ebb

194 meters (1st Deployment) & 117 meters (2nd Deployment) Downcurrent; 137 meters Upcurrent from Dredge



*Number in parentheses is average depth of instrument over period recorded

Figure	*USACE Harborwide TSS Far Field Survey S-KVK-1*	**Mid-depth and Bottom OBS Turbidities at 137 m Upcurrent and 194 m & 117 m Downcurrent of Dredge - 23 June 2009**	Tide
21			Ebb

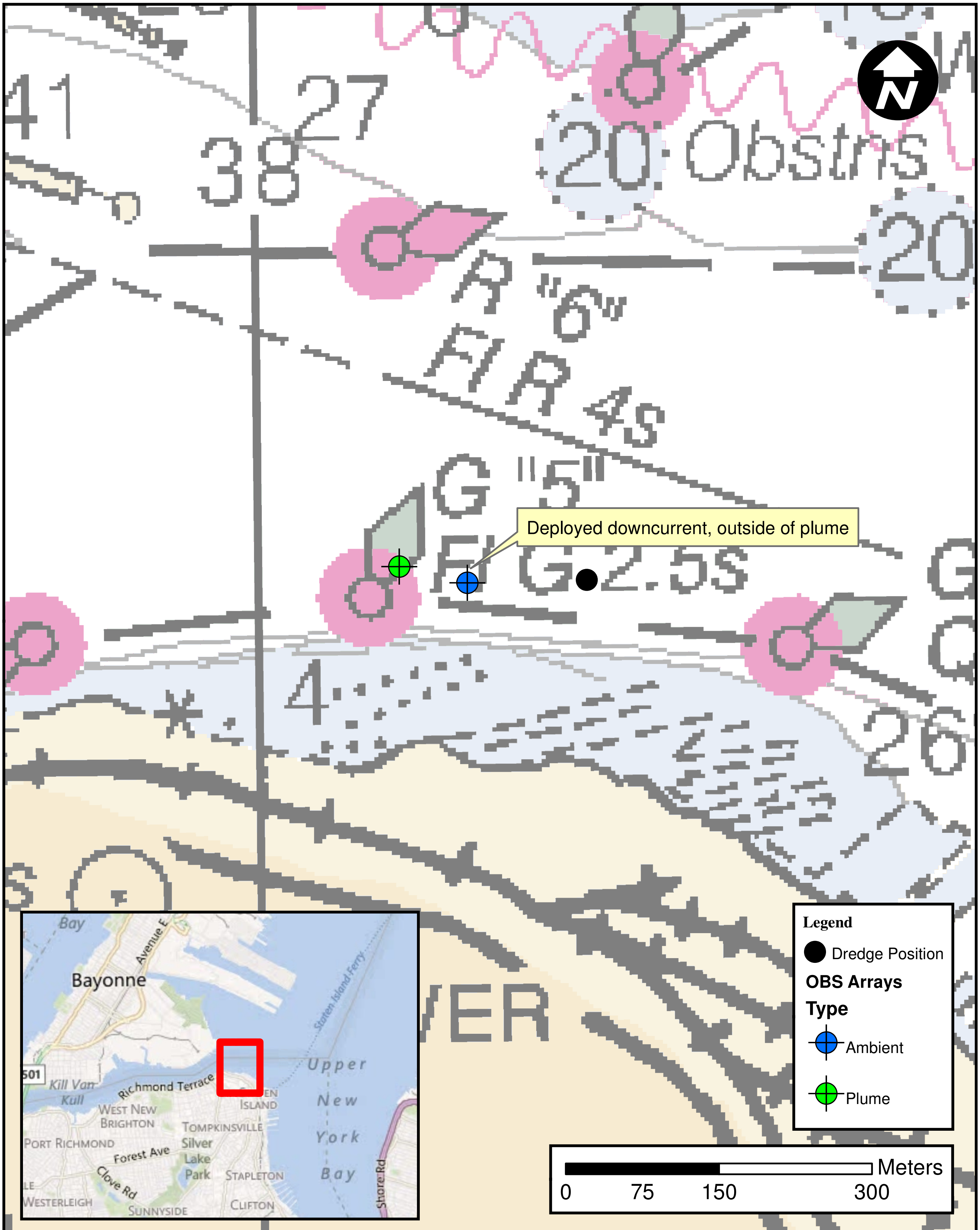
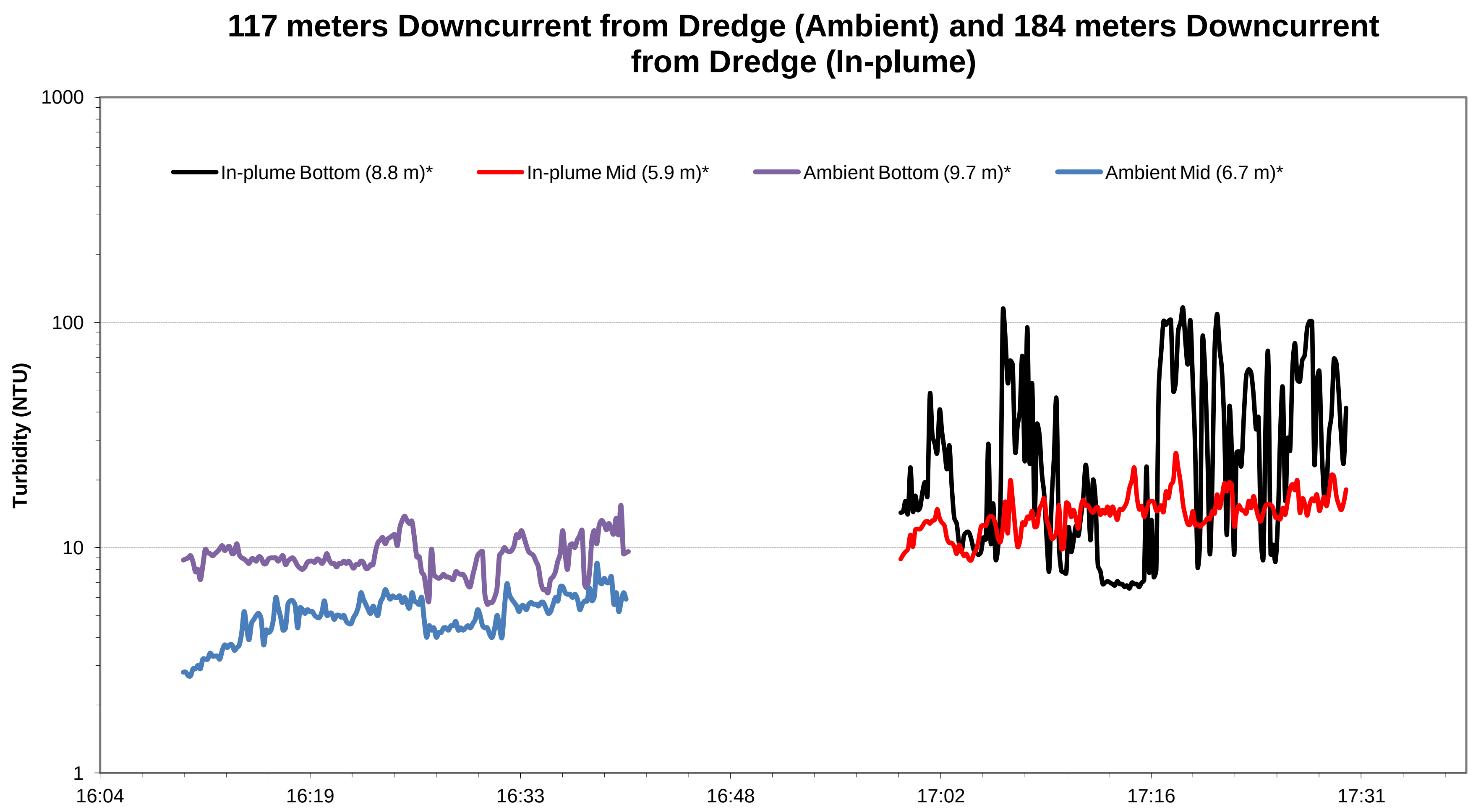


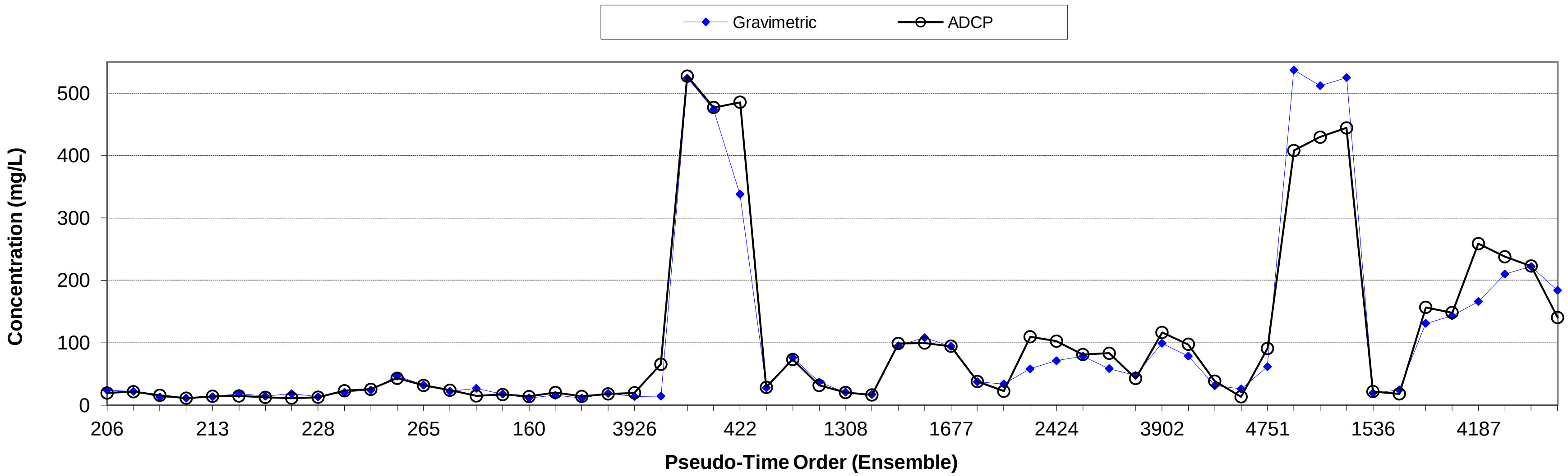
Figure	*USACE Harborwide TSS* *Far Field Survey* *HDP Contract Area: S-KVK-1*	**Location of OBS Vertical Arrays and Dredge Position** **23 June 2011**	**Tide**
22			**Flood**



*Number in parentheses is average depth of instrument over period recorded

Figure	*USACE Harborwide TSS Far Field Survey S-KVK-1*	**Surface and Bottom OBS Turbidities at 117 m (Ambient) and 184 m (In-plume) Downcurrent of Dredge 23 June 2009**	Tide
23			Flood

a)



b)

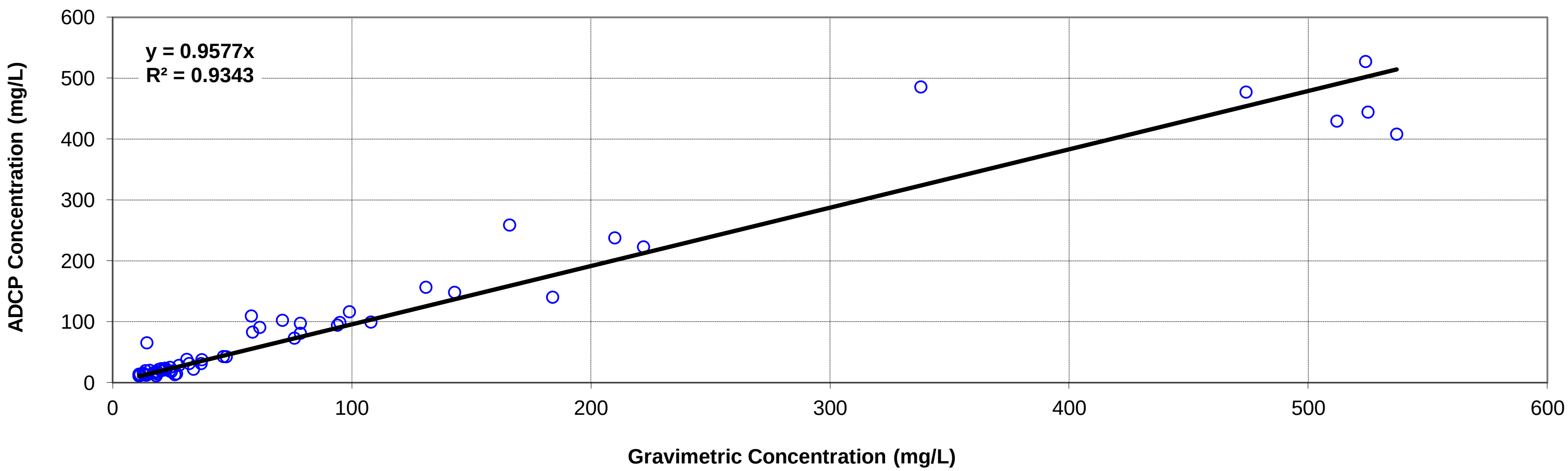


Figure	USACE Harborwide TSS Far Field Survey S-KVK-1	Comparison of Gravimetric and ADCP Estimates of TSS Concentration a) Concentration vs. Time b) ADCP Concentration vs. Gravimetric Concentration 15 June - 23 June 2009 TSS Survey
24		