TECHNICAL MEMO:

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

S-AN-2 Contract Area

(Anchorage Channel)

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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 scope, 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 03 January 2011 and 07 January 2011 within the S-AN-2 contract area of the Anchorage Channel near its junction with 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 mechanical dredging. The methodologies employed for this survey were similar to those used previously to survey environmental or "closed" (i.e. with seals and flaps, as per contract specifications) clamshell bucket dredging of fine-grained sediment within the Arthur Kill (USACE 2007a), Newark Bay (USACE 2008 and USACE 2009) and Port Elizabeth Channel (USACE 2010). However, fixed optical backscatter sensor (OBS) arrays were not deployed this survey due to the high vessel traffic including the Staten Island Ferry and navigational safety concerns.

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 dredge 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 Plant

Far-field WQ/TSS surveys were conducted in the vicinity of an active dredge operating within the S-AN-2 Contract Area of the Harbor Deepening Project (HDP) between 03 January 2011 and 07 January 2011. For all surveys, the dredge plant was situated in Upper Bay within the Anchorage Channel between the Jersey Flats and the Bay Ridge Flats (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 the Staten Island Ferry (St. George-Whitehall route).

Anchorage Channel is approximately 2,000 meters wide with the Bay Ridge Flats on the eastern side and the Jersey Flats and Robbins Reef on the western side. Anchorage Channel adjoins to the Bay Ridge Channel to the east and the Kill Van Kull immediately west of the Study Area. Prevailing depths within the study area, according to NOAA soundings, were between 10-15 meters (33 – 49 feet) at Mean Lower Low Water (Figure 1).

The dredge contractor for this study was Donjon Marine Company, Inc. (Donjon), operating the Dredge Michigan configured with an eight (8) cubic-yard capacity "environmental" bucket (with seals and flaps). During the survey, mechanical dredging operations occurred within the S-AN-2 contract area as shown in Figure 1 which consisted primarily of Holocene age course-grained sandy material suitable for disposal at the Historic Area Remediation Site (HARS).

2.0 METHODS

2.1 Hydrodynamic Survey

Hydrodynamic conditions within Anchorage 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 Anchorage Channel.

ADCP data provided a characterization of prevailing hydrodynamic conditions within the Anchorage Channel. 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. The observed hydrodynamic conditions were then cross referenced against the preliminary currents data collected by NOAA at the Narrows 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 real-time display of plume acoustic signatures and data recording. The ADCP operates by emitting acoustic pulses into the water column at set time intervals. Each group of pulses, referred to as an "ensemble," is vertically stratified into discrete, fixed-depth increments, or "bins." The number of bins and size of each bin is a configurable operation parameter of the instrument. In this study, 40 bins of 0.5-meter depth were used, for a maximum profile range of 20 meters. After the instrument emits a pulse, the ADCP then "listens" for the return of any sound (i.e. backscatter) that has been reflected from particles in the water column (in this case, a "particle" is any acoustic reflector, including sediment, plankton, fish, air bubbles etc.). Once the instrument receives the reflected signals, the WinRiver software can calculate the three-dimensional movement of particles in the water column and thus determine water velocity in each bin. When water samples are collected concurrently, suspended sediment concentration can be determined using additional software and analyses (see *Section 2.4 - ADCP Calibration* below). Dredge navigation data were collected concurrently by the dredge contractor and integrated during post-processing of the ADCP data. To cover a range of tidal conditions, ADCP backscatter data were collected during various stages of ebb and flood tides during the survey period.

Prior to initiating the mobile plume surveys, circular transects using the ADCP were conducted around the actively operating dredge to assess the location and acoustic strength 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 dredging area. Individual transect length was generally determined by bathymetry at the site, but always with the objective of extending beyond the detectable boundaries of the plume. The number, and consequently 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 then the Z extents). Channel bathymetry was generated using NOAA sounding data collected in Anchorage Channel.

For all figures, unless otherwise noted, estimates of TSS concentrations above ambient concentration are assumed to be associated with dredging 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 minimum blanking distance is approximately 0.5 meters.

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 Water Sample Collection

During the far-field survey, water samples were collected to directly measure 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 laptop. The OBS unit provided real-time depth, temperature, salinity and turbidity values of the entire water profile. The Carousel Sampler was also hardwired to an onboard laptop 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.

2.4 ADCP Calibration

Following the field data collection effort, the raw acoustic backscatter measurements collected by the ADCP were converted to estimates of suspended sediment concentration using Sediview Software provided by Dredging Research, Ltd. The Sediview Method (Land and Bray 2000) derives estimates of suspended solids concentration in each ADCP data bin by converting relative backscatter intensity to TSS concentration. This process requires collecting a calibration data set consisting of discrete water samples and concurrently recorded ADCP acoustic backscatter data. The degree of confidence that can be placed in the estimates of TSS is proportional to the strength 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 is often 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 samples to be excluded. For example, samples may exhibit excessively high TSS based on the disturbance of bottom sediments by the Carousel Sampler (i.e. the Carousel apparatus impacts the sea floor) or if the ADCP backscatter exhibited signs of air bubble contamination (e.g. air bubbles will show as extremely high backscatter/TSS estimates but the corresponding water sample for that time/position is relatively low) or interference (e.g. the ADCP beam(s) reflect off the carousel sampler apparatus itself, causing an erroneously high reading).

Because air is injected into the water column as the 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. During the present study, current flows were relatively consistent with flows observed in a similar survey in the Providence River where a closed bucket was monitored during maintenance dredging operations (Reine *et al*. 2006). Experiments during the Providence River monitoring, in which the bucket was intentionally plunged through the air-water interface without removing sediment from the bottom, 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 therefore be accurate.

2.5 Sediment Sample Collection

Sediment samples were collected once per day from the dredge scow and the sediment bed. Dredge scow samples were collected by the dredge operators and *in situ* sediment samples from the dredge field were collected using a ponar grab. These samples were analyzed in the laboratory 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).

2.6 Dredge Operations – Videography

Video footage of the active dredge was recorded on 07 January 2011 for approximately 30 minutes spanning multiple dredge cycles (i.e. Descent, Grab, Ascent, Slew Over, Release, Slew Back). From this recording, a time budget and analysis of the bucket cycle can be used in interpretation of the ADCP data. The video record was also examined for evidence of spillage and leakage of sediment from the bucket, frequency of occurrence of large debris, and other factors that influence the production rate of the dredging operation.

3.0 RESULTS

3.1 Hydrodynamic Survey

Hydrodynamic conditions within Anchorage Channel and its immediate vicinity were assessed during both ebb (04 January and 06 January) and flood tides (04 January, 05 January, and 06 January). The surveys were conducted concurrently with far-field data collection within Anchorage Channel. The transects were conducted with an alternating northwest to southeast orientation, approximately perpendicular to Anchorage Channel. The results of the hydrodynamic surveys are presented on Figures 2a-e.

For comparison purposes, the NOAA Preliminary Currents Data recorded at The Narrows for the respective survey day is also shown on Figures 2a-e. 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 interpret where in the tide cycle a particular survey event occurred.

3.1.1 Flood Tide (04 January 2011)

Figure 2a presents the results of the hydrodynamic survey conducted on 04 January 2011 during the second half of a flood tide from approximately 09:23 to 10:16. During the survey, depth averaged current velocities within the area ranged between 0 cm/s and up to approximately 40 cm/s (Figure 2a). Within the majority of the Anchorage Channel, currents were minimal and generally flowed in a north-northeast direction; however towards the end of the survey (south end in Figure 2a) the tide was beginning to turn to the ebb tide as evidenced by the lower velocities and the changing flow direction.

3.1.2 Ebb Tide (04 January 2011)

Figure 2b presents the results of the hydrodynamic survey conducted on 04 January 2011 during the peak of an ebb tide from approximately 11:46 to 12:58. During the survey, depth averaged current velocities within the area ranged between 30 cm/s and up to approximately 90 cm/s (Figure 2b). Current direction was uniformly parallel to Anchorage Channel flowing south-southwest. There was no evidence of any stratified flows, tidal eddies, or other patterns that could influence plume dispersion.

3.1.3 Flood Tide (05 January 2011)

Figure 2c presents the results of the hydrodynamic survey conducted on 05 January 2011 during the peak of a flood tide from approximately 08:33 to 09:44. This survey was conducted closer to the peak flood than the previous day's survey therefore the observed velocities were higher. Depth averaged current velocities within the area ranged between 30 cm/s and 70 cm/s (Figures 2c). Current direction was uniformly parallel to Anchorage Channel flowing in a north-northeast direction.

3.1.4 Flood Tide (06 January 2011)

Figure 2d presents the results of the hydrodynamic survey conducted on 06 January 2011 during the middle portion of a flood tide from approximately 09:19 to 10:00. Depth averaged current velocities within the area ranged between 40 cm/s and up to approximately 90 cm/s (Figure 2d). Currents were strong and flowed uniformly parallel to Anchorage Channel in a north-northeast direction.

3.1.5 Ebb Tide (06 January 2011)

Figure 2e presents the results of the hydrodynamic survey conducted on 06 January 2011 during the early stages of an ebb tide from approximately 12:19 to 13:03. During the survey, depth averaged current velocities within the area ranged between 0 cm/s and up to approximately 40 cm/s (Figure 2e). Currents were minimal and flowed uniformly parallel to Anchorage Channel in a south-southwest direction.

3.2 Ambient conditions

It is important to consider that no single TSS measurement adequately represents ambient conditions; instead a range of samples variable with regard to depth and tidal conditions is a better representation of the dynamic nature of suspended sediment concentrations in a tidal estuary. On 4 January 2011, a total of 27 ambient water samples were collected at various depths and later analyzed in the laboratory for TSS and turbidity (Table 1). Ambient turbidity values ranged from 3.1 to 7.1 NTU, however corresponding TSS values ranging between 58 and 134 mg/L. The average gravimetric estimate of TSS concentration based on the 27 ambient water samples was 91.6 mg/L. When compared to the available water data collected by the New York City Department of Environmental Protection (NYCDEP) for the Inner Harbor area from 1991 to 2009 (NYCDEP 2010), the ambient TSS concentration for this survey is atypically high. These high TSS concentrations could have been due to ship traffic, tug traffic and potentially due to higher discharge from tributaries (see Section 4.0 below). Ambient TSS concentrations for the NYCDEP study ranged between 8 and 52 mg/L and averaged 22 mg/L with a standard deviation of 10 mg/L for the time period between 1991 and 2009. Because an ambient TSS concentration of 91.6 mg/L would artificially mask any plume signatures, for graphical purposes in this study, all acoustically estimated TSS concentrations greater than 30 mg/L are herein considered above background and attributable to the dredging-induced plume unless otherwise noted, e.g., clearly attributable to air entrainment from the bucket, vessel prop wash, or from other sources of resuspension such as tug and ship plumes (see ADCP calibration methods, Section 2.4, for further information).

3.3 Mobile ADCP Surveys

3.3.1 Ebb Tide (04 January 2011)

The 04 January 2011 mobile ADCP plume characterization was completed during the peak of an ebb tide from approximately 11:46 to 12:58 (Figure 2b). The survey consisted of three ambient transects (Figures 3a through 3c) and one set of down-current transects (Figures 3d through 3t). 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, similar to the above are given in Figures 4a through 4h. For this survey, the dredge was located approximately 500 meters of the red “26” navigation buoy. Ambient transects were conducted north of the dredge platform while down-current transects were south of the dredge and oriented perpendicular to the channel. Figure 5 provides a three-dimensional depiction of average TSS values for selected representative transects superimposed on existing channel bathymetry. Bathymetry was computed from soundings reported on NOAA nautical charts.

Up-current conditions presented in Figures 3a through 3c showed TSS concentrations between 100 and 150 mg/L throughout most of the water column which is consistent with the results of the gravimetric water samples collected this day. Estimated TSS concentration signatures above ambient (30 mg/L) associated with the dredging operation was primarily limited to within the first 1,000 meters down-current of the dredge. Peak estimated TSS concentrations were above 500 mg/L throughout the water column up to approximately 250 meters down-current (Figure 3d). Down-current of transect T06 (509 meters from the dredge), the plume began to sink from the surface and estimated TSS concentrations fell within 100-200 mg/L. The plume in transects T01 through T04 appeared to range between approximately 25 and 100 meters wide (Figures 4a through 4h).

3.3.2 Flood Tide (05 January 2011)

A mobile ADCP plume characterization survey was conducted during the peak of a flood tide on 05 January 2011 from approximately 08:33 to 09:44 (Figure 2c). The survey consisted of three ambient transects (Figures 6a through 6c) and ten down-current transects (Figures 6d through 6m). These down-current transects were conducted perpendicular to Anchorage Channel between the Red “26” and Red “28” navigational buoys. A summary of each of the graphically represented transects is presented in Table 3.

The up-current transects recorded higher than ambient conditions along the bottom of transects A01 and A03, and throughout most of the water column in transect A02 (Figures 6a-6c). Even though at the time of the survey, the currents were flooding strongly (Figure 2c), there are elevated TSS concentration present up-current of the dredge. However, these above-ambient conditions were likely the result of tug boat traffic in the area during the time of the survey and/or from the tugs and barges that accompany the dredge platform (tug traffic was noted in the field logs for this survey). As noted in the field observations, the plume quickly began dissipating within approximately five minutes and within completing the third up-current transect approximately 190 meters from the dredge (Figure 6c).

The down-current plume as depicted in the vertical profiles (Figures 6d through 6m) was restricted primarily in the bottom half of the water column. The highest estimates of TSS were less than 150 mg/L and were confined to the lower half of the water column within approximately 389 meters down current of the dredge (Figures 6d through 6i). Down-current of T09 (655 meters from the dredge) only a trace signature of the plume was detected with concentrations slightly above ambient conditions in the lower third of the water column (Figure 6l).

The spatial extent of the plume is best displayed in a series of plan-view layouts of the ADCP transects depicting estimates of TSS concentrations in two meter depth-averaged intervals (Figures 7a through 7h). Figure 8 provides a three-dimensional depiction of average TSS values for selected representative transects superimposed on existing channel bathymetry.

3.3.3 Flood Tide (06 January 2011)

A mobile ADCP survey occurred on 06 January 2011 during a flood tide. The survey lasted from approximately 09:19 to 10:00 and extended throughout the mid-portion of the flood tide (Figure 2d). The survey included three ambient transects (Figures 9a through 9c), and eleven down-current transects (Figures 9c through 9n). A summary of each of the graphically represented transects is presented in Table 4.

Figures 10a through 10h display the plan-view profiles of this survey in two meter depth-averaged increments, while Figure 11 provides a three-dimensional depiction of average TSS values for selected representative transects superimposed on existing channel bathymetry. During this survey, the dredge was positioned approximately 325 meters northwest of the Red “26” navigational buoy in Anchorage Channel. The down-current transects were conducted northeast of the dredge and perpendicular to Anchorage Channel.

The up-current transects showed a uniform ambient TSS concentration of less than 40 mg/L (Figures 9a through 9c), with some very small elevated concentrations at some points along the bottom. This concentration is more similar to typical ambient concentrations observed on previous surveys in New York/New Jersey Harbor. Peak concentrations within the plume signature were recorded during transect T01 and T02 at approximately 35 and 70 meters from the source and measured between 80 and 90 mg/L near the bottom of the water column and extended no wider than 60 meters (Figures 9d and 9e). Transects T03 through T08 at 119 to 400 meters, respectively, showed faint signatures of the plume and was primarily confined to the lower water column just above the bottom. Peak concentrations in these transects were less than 70 mg/L (Figures 9f through 9k). From transect T09 (462 meters) through T11 (596 meters) the plume is essentially dissipated with only a faint bottom layer of elevated TSS concentrations less than 50 mg/L (Figures 9l through 9n). The surface wake interference from prop wash from the survey vessel can be seen at the ends of transects T05, T06, and T11.

3.3.4 Ebb Tide (06 January 2011)

The final mobile ADCP survey for the week occurred on 06 January 2011 during the early stages of an ebb tide from approximately 12:19 to 13:03 (Figure 2e). The survey included three ambient transects (Figures 12a through 12c) and eleven down-current transects (Figures 12d through 12n). A summary of each of the graphically represented transects is presented in Table 5.

Figures 13a through 13h display the plan-view profiles of this survey in two meter depth-averaged increments, while Figure 14 provides a three-dimensional depiction of average TSS values for selected representative transects superimposed on existing channel bathymetry. During this survey, the dredge was positioned approximately 350 meters northwest of the Red “26” navigational buoy in Anchorage Channel. The down-current transects were conducted southwest of the dredge and perpendicular to Anchorage Channel.

The up-current transects showed a uniform ambient TSS concentration of less than 40 mg/L (Figures 12a through 12c). Peak concentrations within the plume signature were recorded during transect T01 and T02 at approximately 109 and 126 meters from the source and measured between 100 and 150 mg/L near the bottom of the water column and extended no wider than 60 meters (Figures 12d and 12e). Transects T03 through T05 at 160 to 214 meters, respectively, showed the plume focused primarily in the lower third of the water column with peak concentrations generally less than 100 mg/L (Figures 12f through 12h). From transect T06 through T11 the plume quickly dissipates and is only faintly detected at 517 meters down-current of the dredge (T11) with maximum estimates of TSS less than 50 mg/L near the bottom (Figure 12n). The surface wake interference from a passing ship can be seen in Transects T06 and T07. Prop wash from the survey vessel can also been seen at the surface at the start of Transect T01.

3.4 Laboratory Analysis of Water Samples

A total of 100 water samples were collected in the project area during the week of 03 January 2011. The laboratory results of the optical turbidity and the gravimetric analysis of TSS concentration of those 100 samples are presented in Table 1. To accommodate the requirement 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 100 water samples ranged from 45 to 164 mg/L and turbidity concentrations ranged from 3.1 to 19.5 NTU. Figure 15a plots the paired gravimetric measurements and ADCP acoustic estimates of TSS arranged in concentration versus time order for the 58 water samples used in the Sediview calibration. Note that some of the 100 water samples collected were excluded if they exhibited clear signs of air bubble contamination, interference with the water sampler apparatus, or contact with the sea bottom (see ADCP calibration methods described in section 2.4). Overall, there was a strong agreement (R^2 = 0.73) between the acoustic estimates of TSS concentration and the gravimetric measurements (Figure 15b).

3.5 Sediment Samples

A total of six sediment samples were collected (three from dredge scow and three from dredge area) during the week of 03 January 2011. The laboratory results of these sediment collections for grain size distribution, density and Atterberg Limits are presented in Table 7. Sediment samples collected during the S-AN-2 far-field survey were comprised mostly of fine sand and silt with fine sand comprising between 29% and 68% of each sample collected. Each of the samples collected also consisted of 17% to 57% silt with only 4% or less medium sand and coarser material. The in-place density of the sediment samples ranged between 0.93 and 1.22 g/cc (Table 7).

3.6 Dredging Operations — Bucket Cycles

To examine the bucket cycle sequence, a video record was obtained of 19 complete cycles during a flood tide. The video was then analyzed for time increments for each component of the cycle (Figure 16). The average total elapsed time per cycle was 67.7

seconds. A certain degree of variability in cycle component elapsed times can be seen across the 19 cycles in Figure 16. The shortest cycle was 60 seconds, whereas the longest cycle was 78 seconds.

4.0 DISCUSSION

During the course of normal dredging operations, some sediment is resuspended into the water column. In many cases, this suspended sediment is evident as a visible 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 during the week of 03 January 2011 within the S-AN-2 contract area of the Anchorage Channel in Upper Bay, New York. The objective of the far-field survey was to assess the spatial extent and temporal dynamics of suspended sediment plumes associated with mechanical dredging. The methodologies employed for this survey were similar to those used previously to survey environmental or "closed" (i.e. with seals and flaps, as per contract specifications) clamshell bucket dredging of fine-grained sediment within the Arthur Kill (USACE 2007a), Newark Bay (USACE 2008 and USACE 2009) and Port Elizabeth Channel (USACE 2010). However, direct comparisons between studies are inexact due to the varying hydrodynamic conditions, sediment types within the different study areas and different dredge bucket types.

Sediment conditions in the S-AN-2 contract area were predominantly sand and silt (Table 7). Because sandy sediments fall out of suspension faster than finer grained sediments (i.e. silt), it is difficult to collect water samples with high sand concentrations (as that would require the water sampling apparatus to be within the safety exclusion zone of the operating dredge). As can be seen on the Sediview Calibration results (Figure 15a-b), the data set used for calibration consisted of relatively low concentrations (less than 200 mg/L). Therefore, when interpreting the ADCP TSS results from this survey, care must be taken when concentrations are reported that are over 200 mg/L as these essentially are Sediview extrapolations from the data.

Moreover, the acoustic backscatter patterns and dimensions observed during the far-field surveys conducted within the S-AN-2 contract area were variable depending on the tide and the location of the dredge operating within Anchorage Channel. Prevailing currents in the Anchorage Channel are very strongly oriented along the channel and therefore confined the plume to within the navigation channel (and therefore no resuspended sediment entered the surrounding shallow water areas).

In general, the suspended sediment plume was confined to the lower half of the water column and did not extend outside of the navigation channel. Suspended sediment concentrations were typically 200 mg/L or less within 500 meters of the dredge platform and dissipated to background conditions within 1,000 meters of the dredge.

Ambient conditions during the 04 January surveys showed an atypically high TSS concentration which could be due to ship traffic, tug traffic and potentially due to higher discharge from tributaries (in the week previous to these surveys there were some snowfall events followed by several consecutive days of above-freezing temperatures. These conditions could have produced additional discharges into the estuary which in turn could have created elevated turbidity levels). In order to delineate the sediment plumes more clearly, a conservative ambient TSS concentration of 30 mg/L was used in order to show the plume. This value is based on available water data collected in the area between 1991 and 2009 by the NYC Department of Environmental Protection (NYCDEP 2010). Peak TSS concentrations in excess of 500 mg/L were recorded during the 04 January ebb tide survey and extended the length of the water column to approximately 200 meters down current of the dredge before dissipating to the lower half of the water column at concentrations of less than 150 mg/L at approximately 1,000 meters from the dredge.

Surveys conducted on 05 January 2011 during a flood tide showed some plume dispersion in the up-current side of the dredge. This may have resulted from high vessel traffic around the dredge (tug traffic in the dredge vicinity was noted in the field logs at the time of this survey) or some other transient event such as the passage of a deep-draft container ship. Anchorage Channel is a high volume vessel traffic area and acoustic backscatter created by prop wash, and perhaps by the sediment resuspension created by the passage of deep-draft container ships, their attending tugs and the Staten Island Ferry may have been recorded during some of the ambient ADCP transects. Previous WQ/TSS surveys in Newark Bay have been conducted to quantify the spatial and temporal extent of sediment resuspension attributable to deep-draft ships (USACE 2007b), although in the field it is often hard to simultaneously distinguish between the plume created by a passing ship from that created by an active dredge operating within the same channel at the same time. Results of the ship-induced suspended sediment plumes study showed that TSS concentrations peaked during vessel maneuvering and dissipated back to background conditions within approximately 25-30 minutes after the ship passage. Further, the plumes associated with ship passage were contained within the navigation channel and did not enter onto the flats or surrounding shallow water areas (USACE 2007b).

Mobile ADCP plume surveys conducted during both an ebb and flood tide on 06 January 2011 showed ambient conditions that were more typical of those expected in the Upper Bay based on the NYCDEP data. Down current transects during these surveys showed plumes that were highly localized to the channel (i.e. did not extend onto the adjacent flats) and did not extend more than 200 meters from the dredge at concentrations above 80 mg/L.

5.0 LITERATURE CITED:

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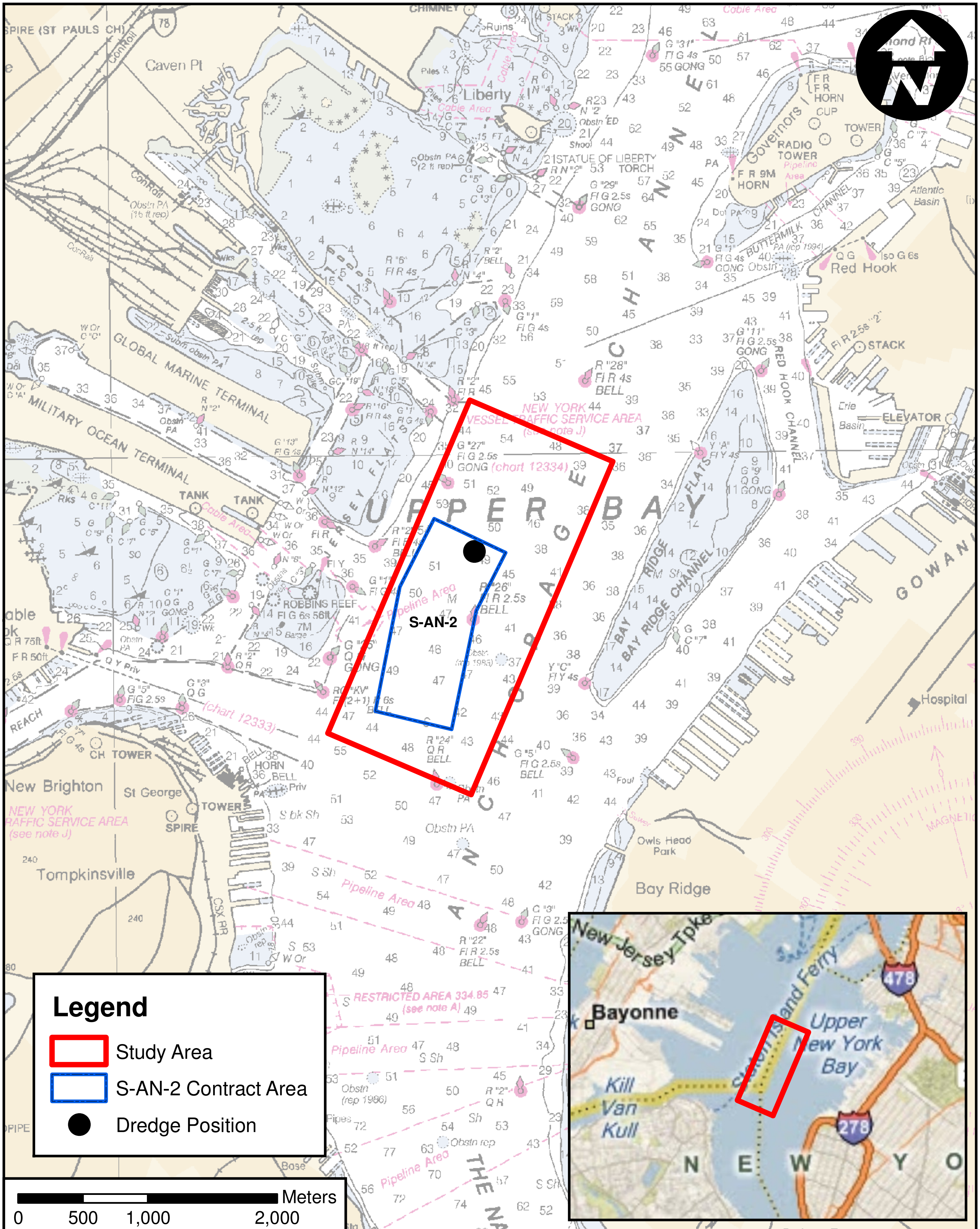


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	Upper Bay - Anchorage Channel S-AN-2 Far-Field Study Area	Tide
1			N/A

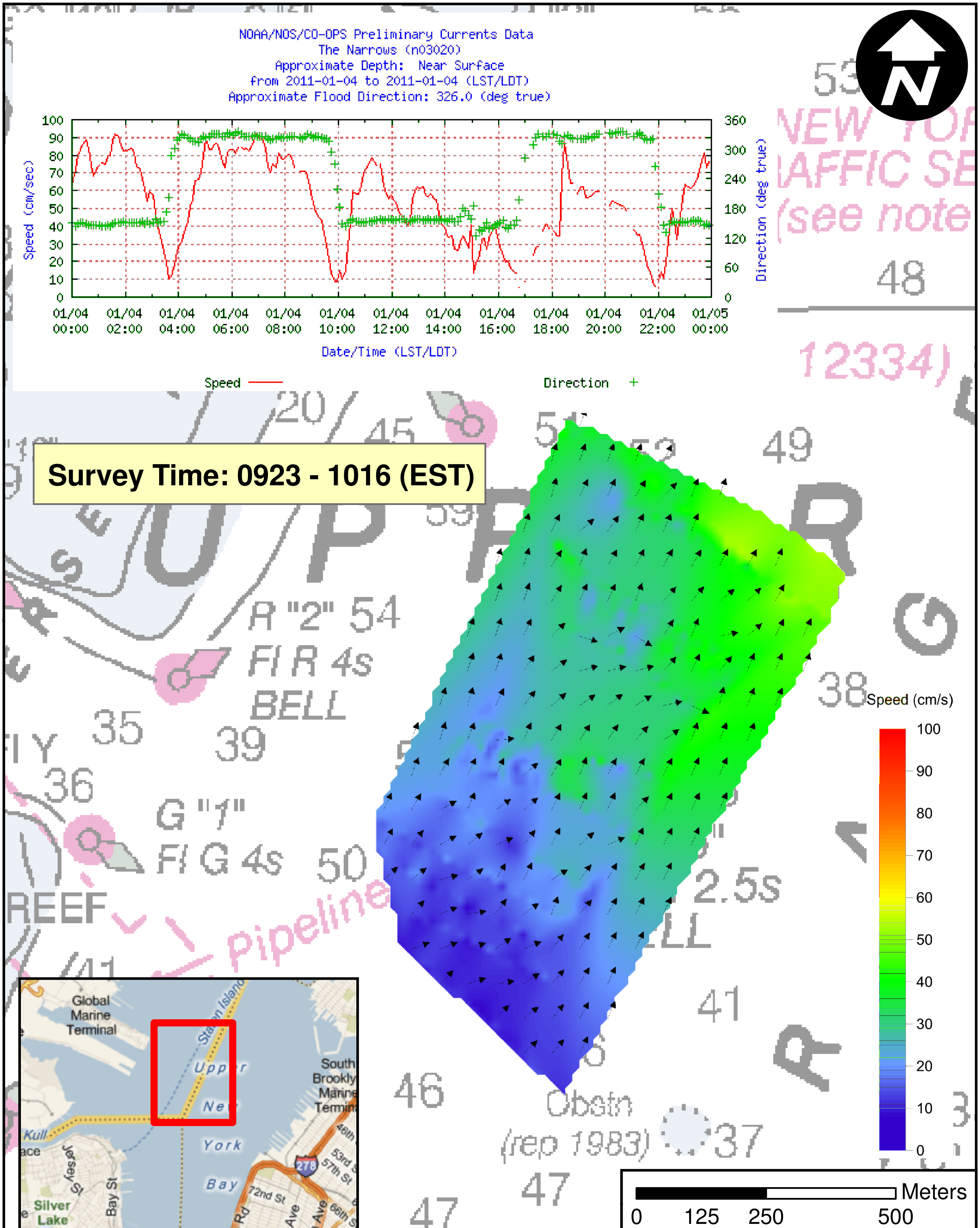


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	Depth Averaged Velocities 04 January 2011	Tide
2a			Flood

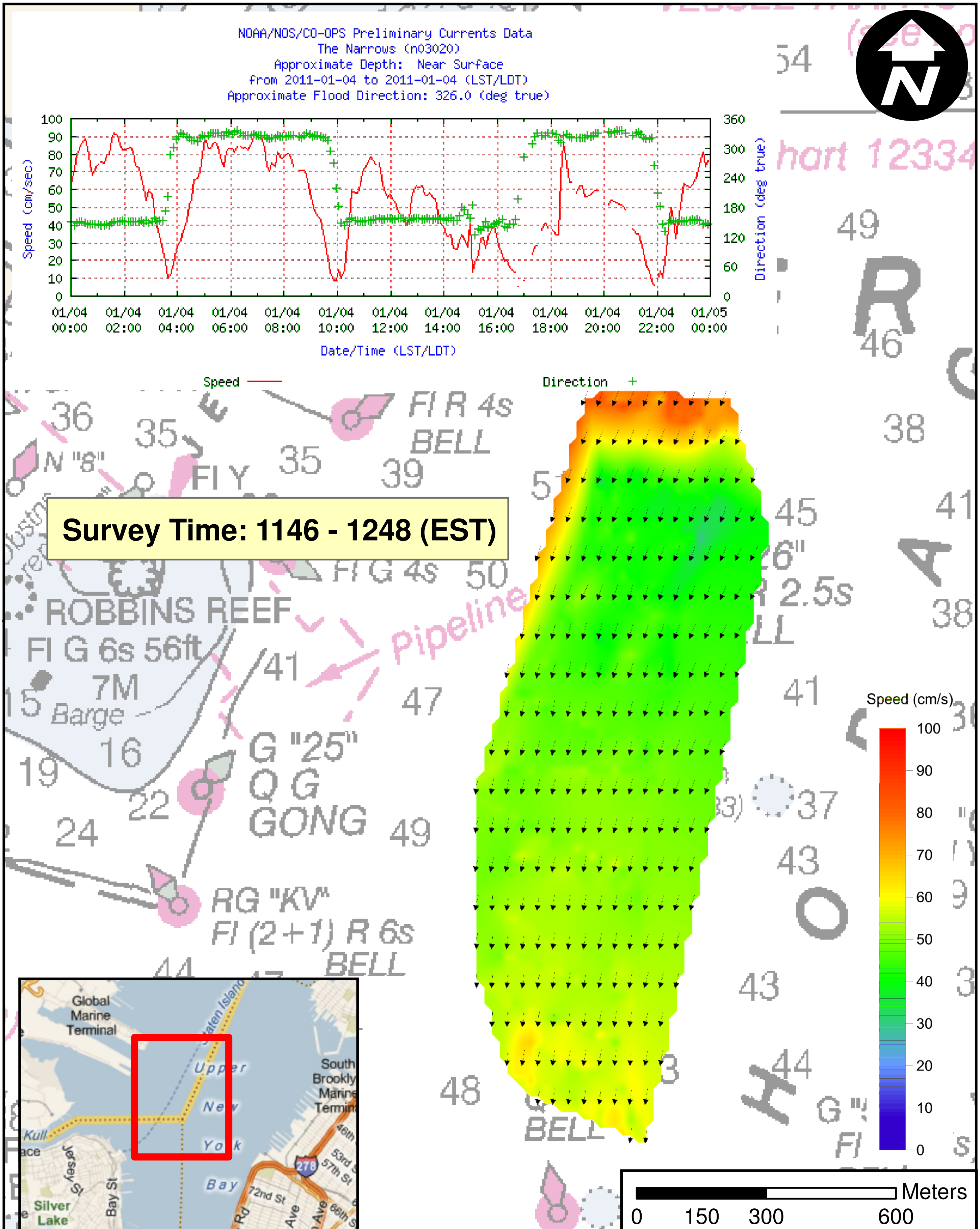


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	Depth Averaged Velocities 04 January 2011	Tide
2b			Ebb

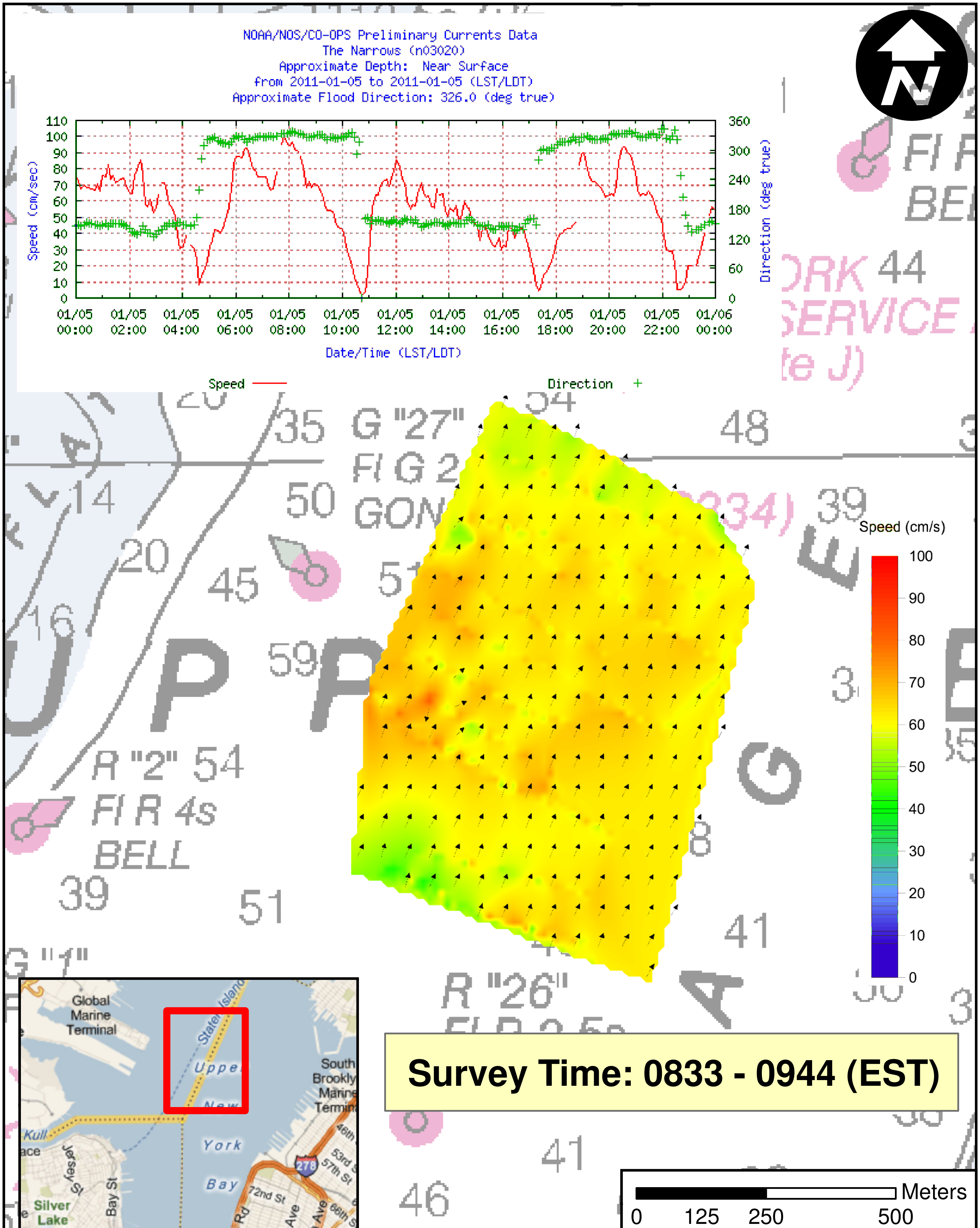


Figure	*USACE Harborwide TSS* *Far Field Survey* *HDP Contract Area: S-AN-2*	Depth Averaged Velocities 05 January 2011	Tide
2c			Flood

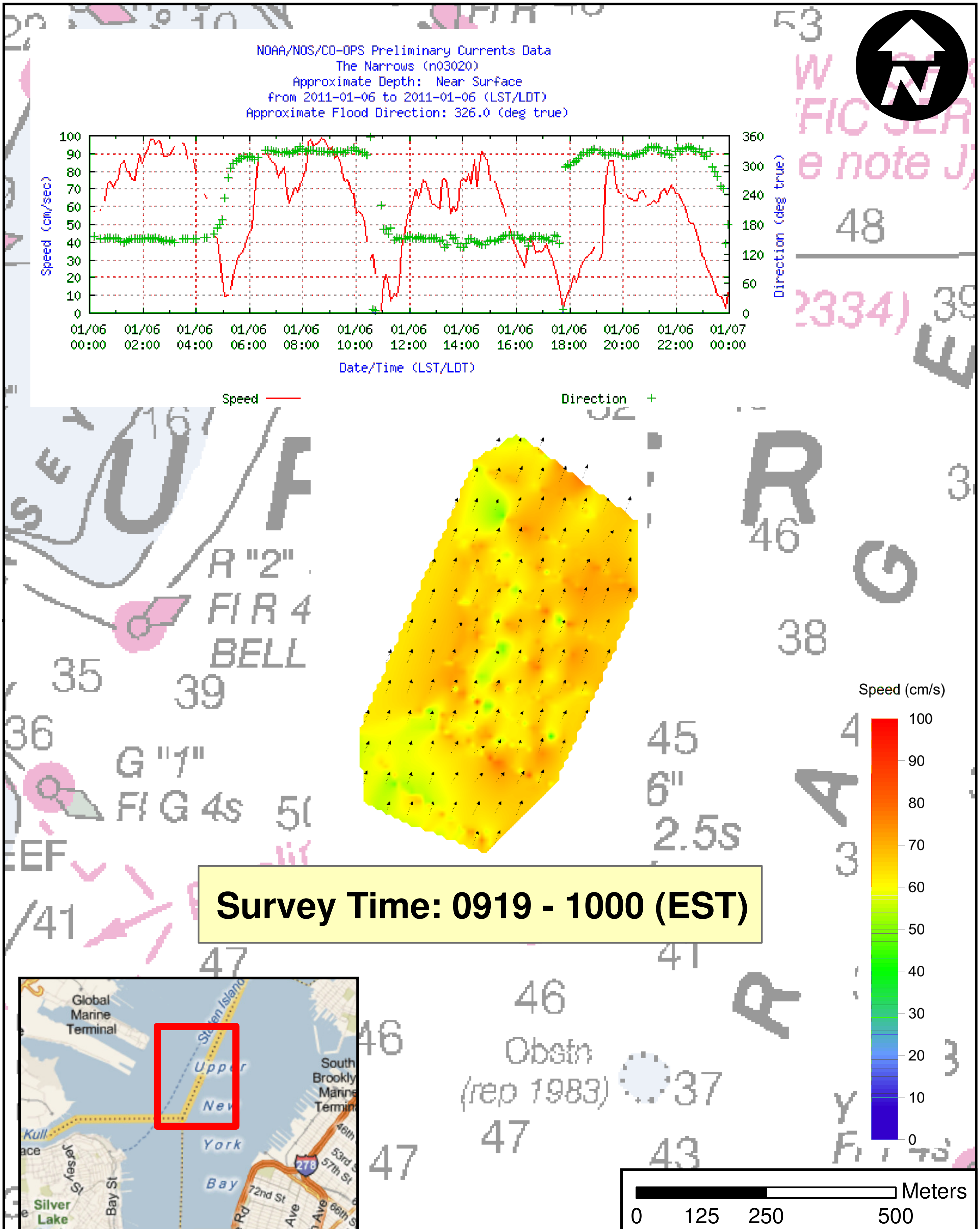


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	Depth Averaged Velocities 06 January 2011	Tide
2d			Flood

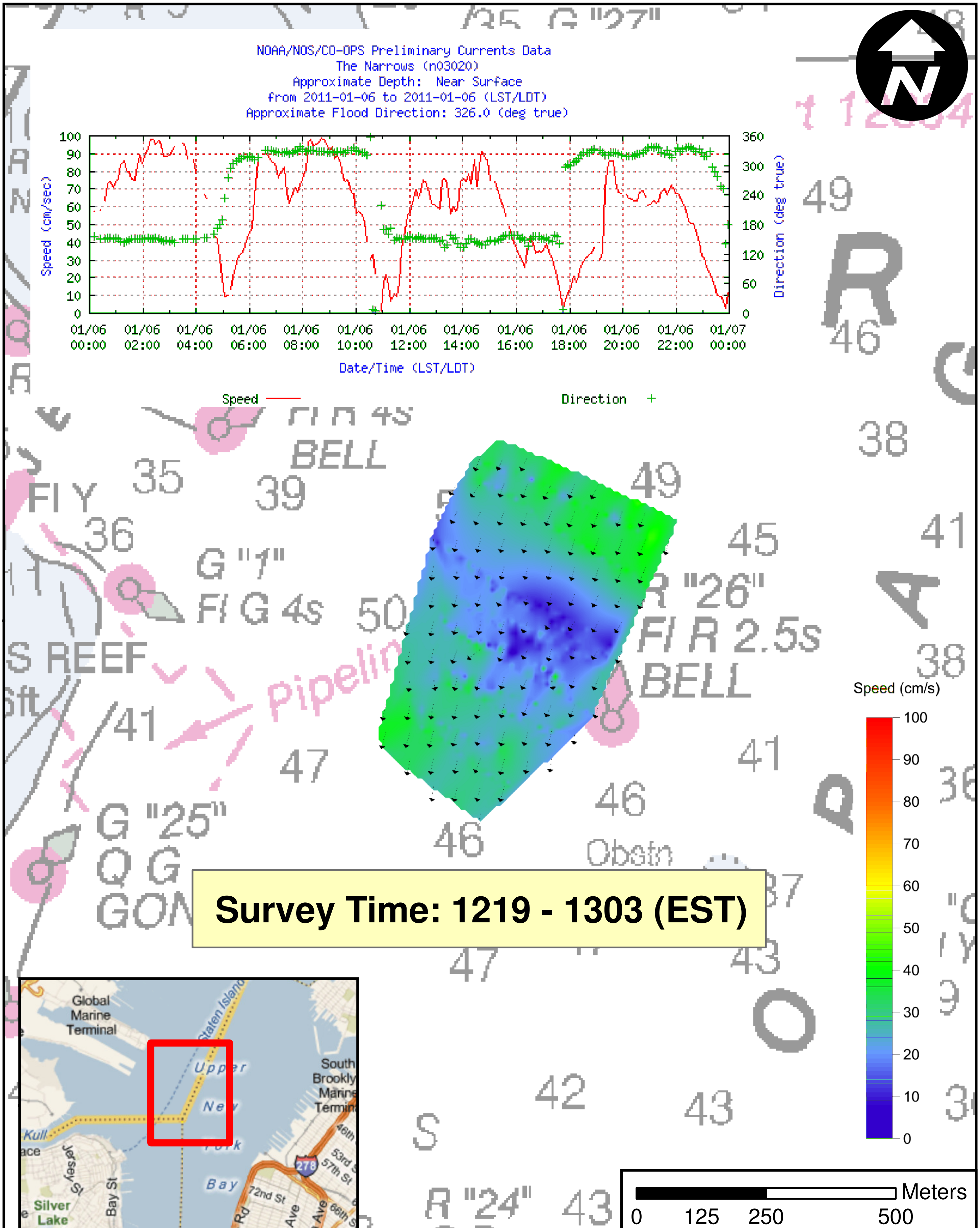
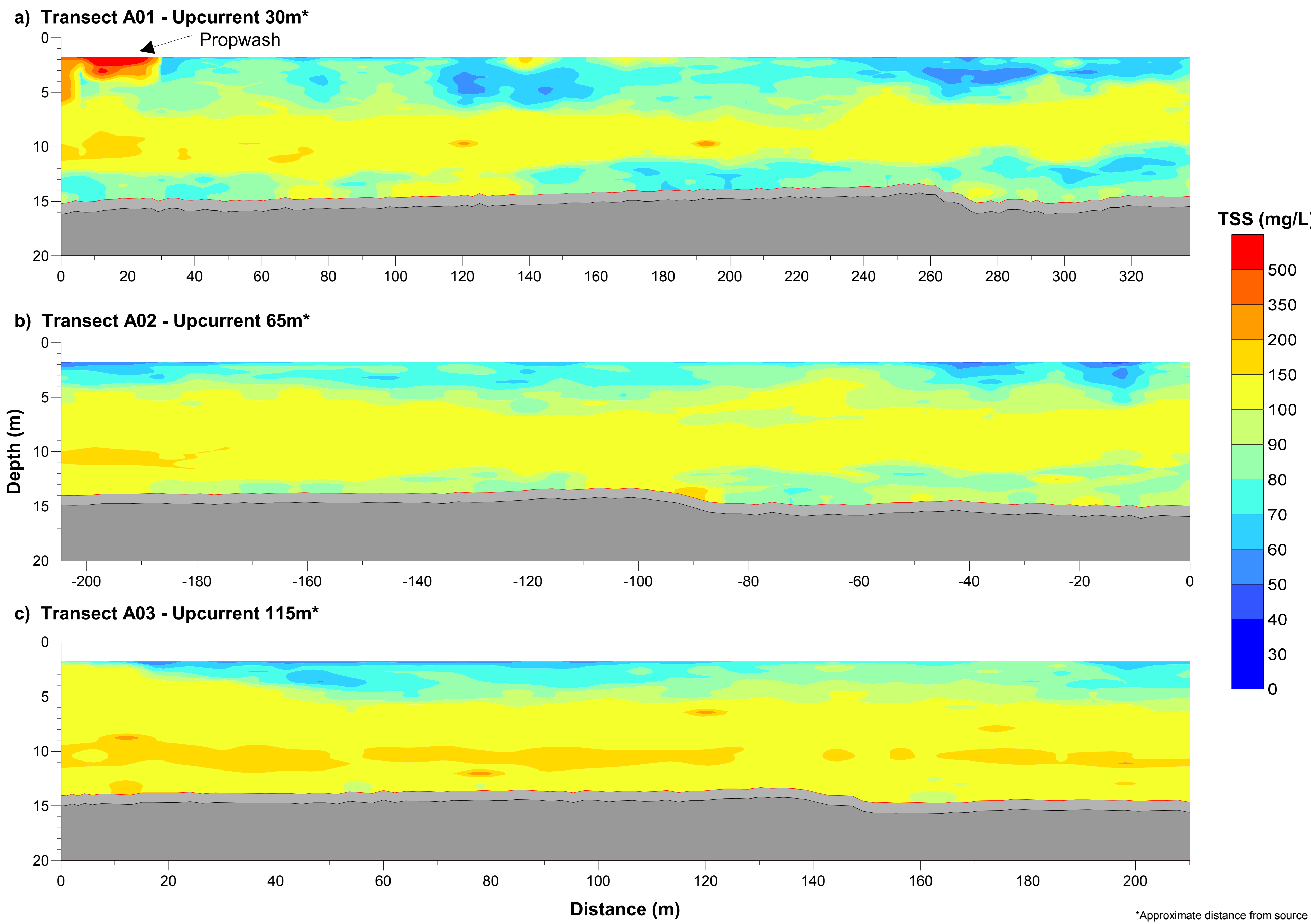


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	Depth Averaged Velocities 06 January 2011	Tide
2e			Ebb



*Approximate distance from source

FIGURE	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	Vertical Profiles of ADCP Average TSS 04 January 2011	TIDE
3a-c			Ebb

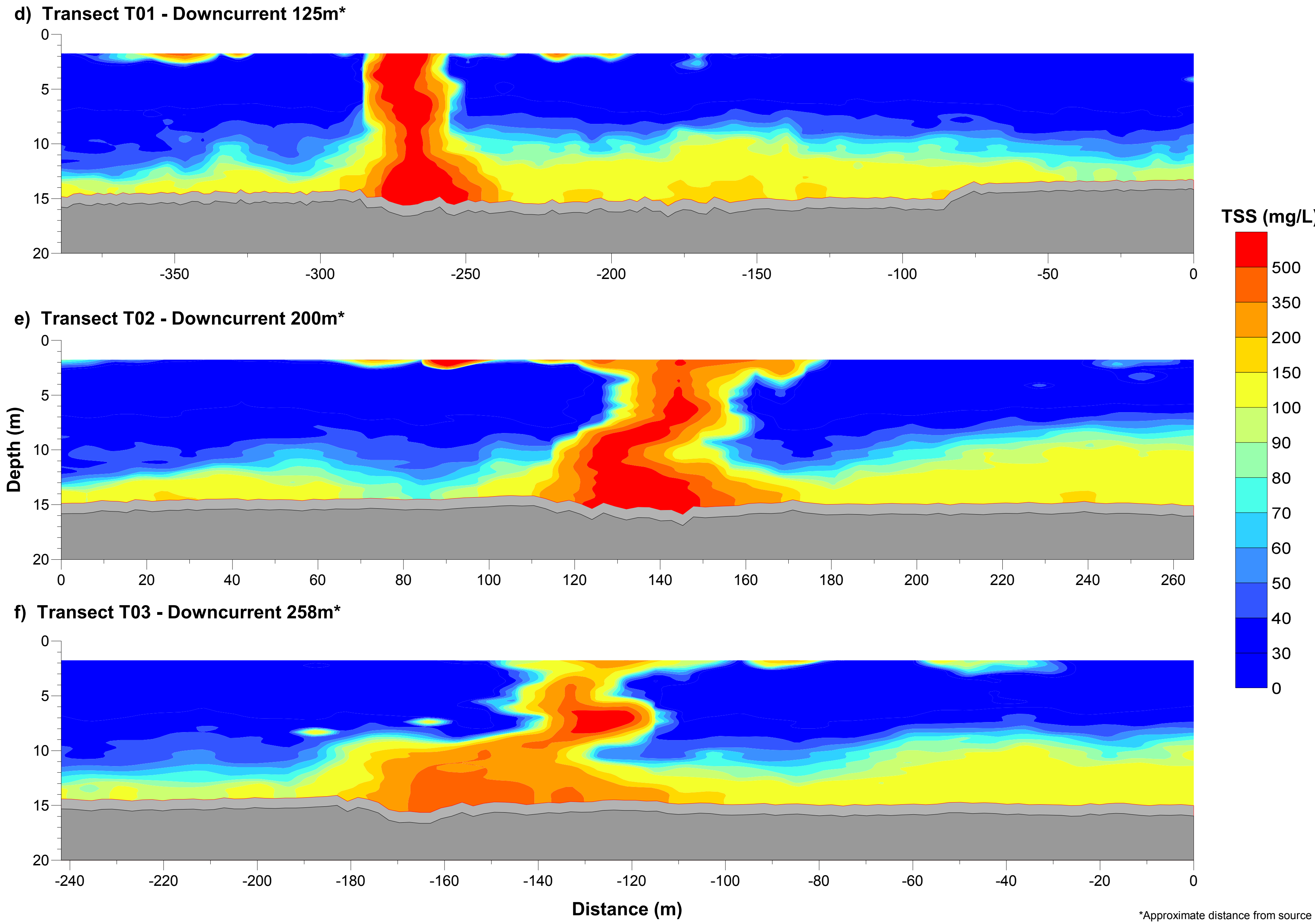
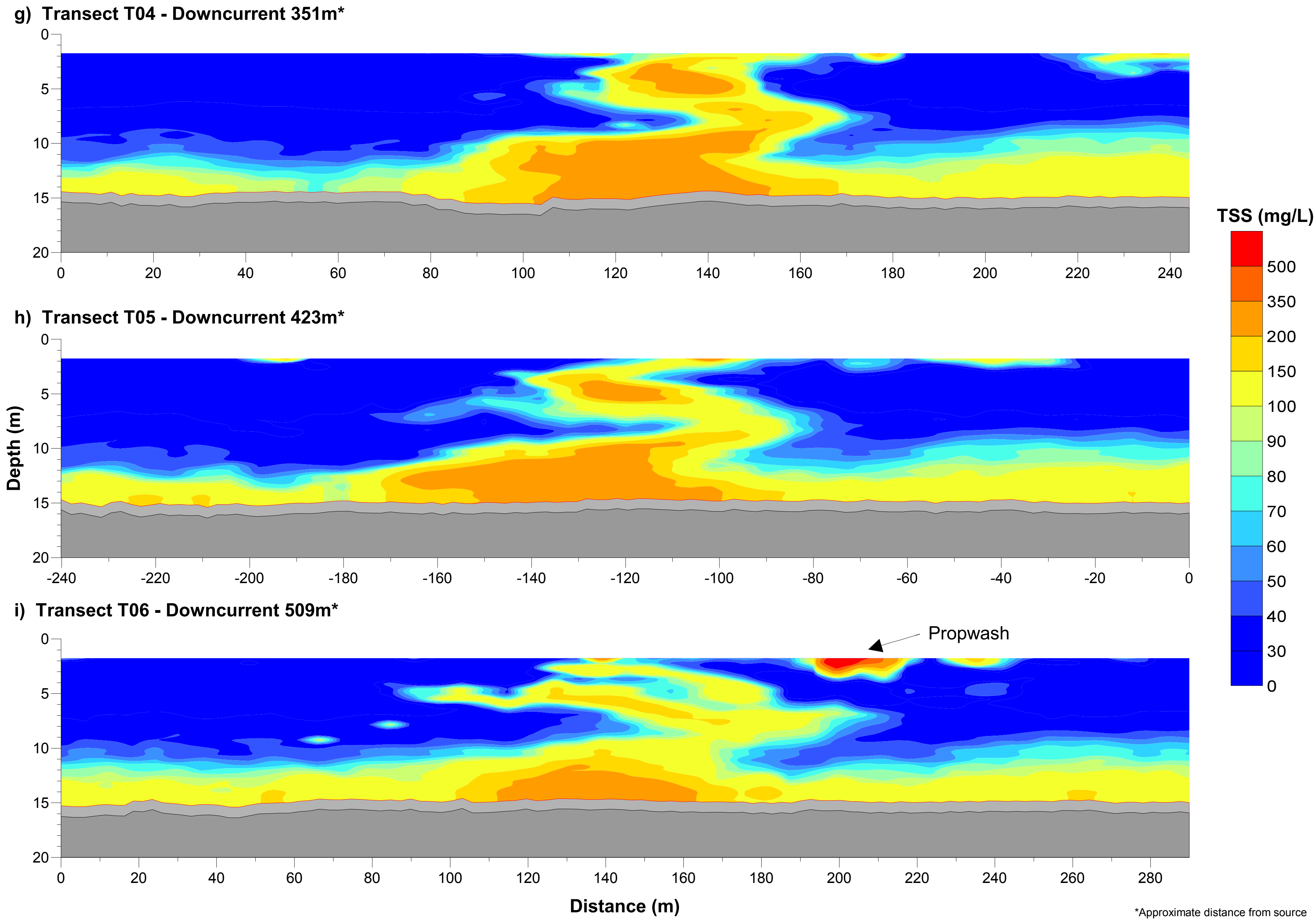
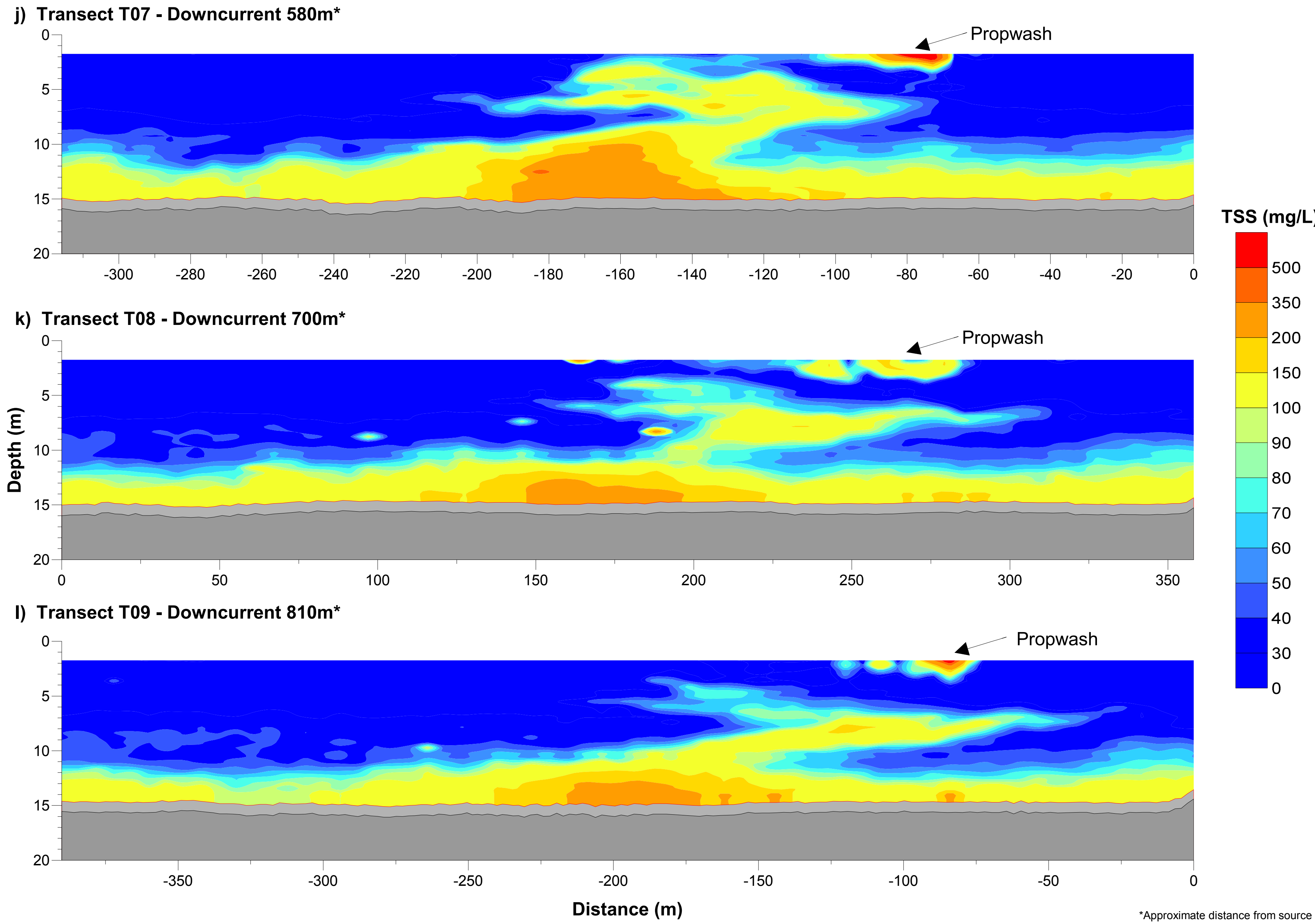


FIGURE	*USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2*	**Vertical Profiles of ADCP Average TSS 04 January 2011**	TIDE
3d-f			**Ebb**



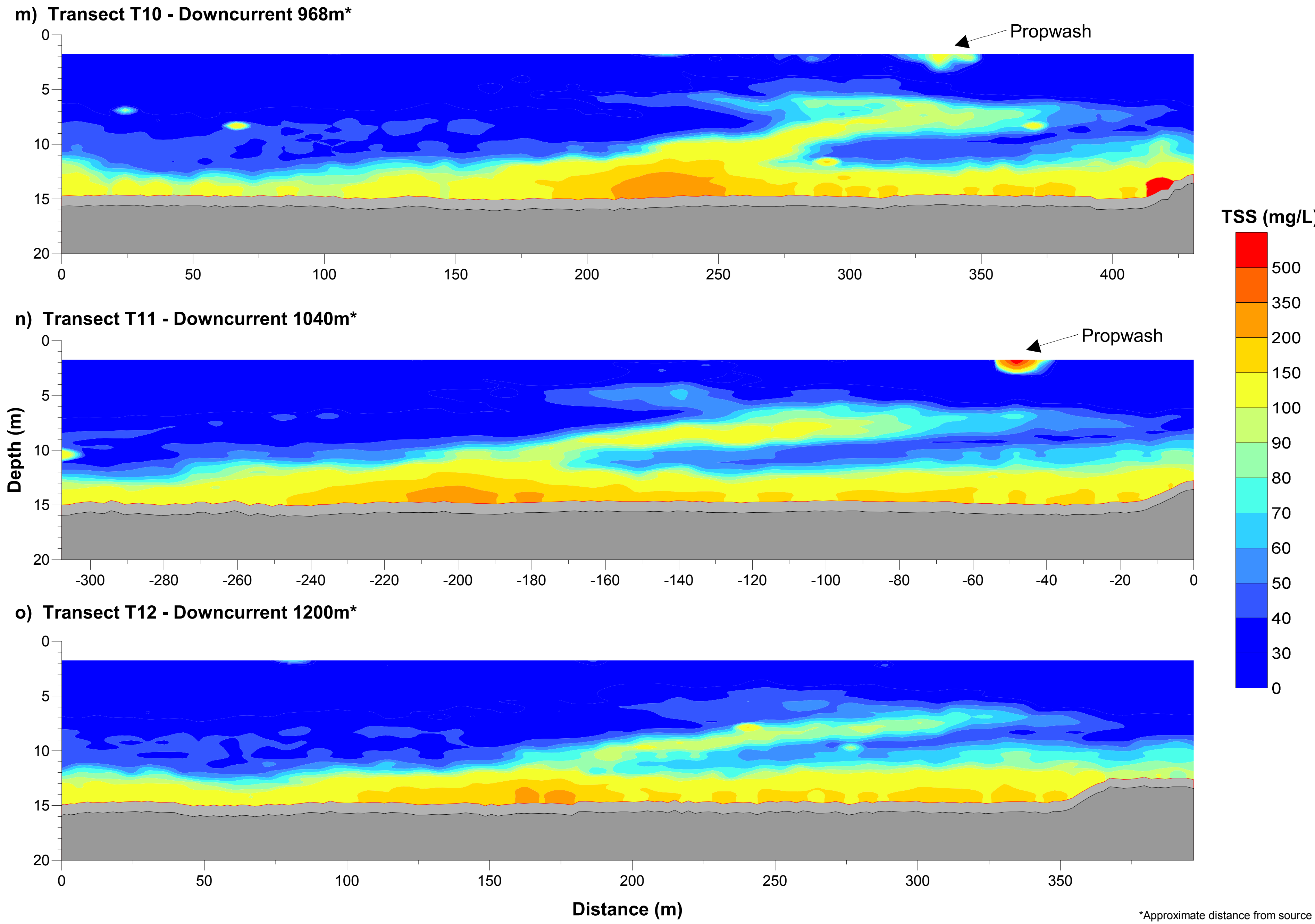
*Approximate distance from source

FIGURE	*USACE Harborwide TSS* *Far Field Survey* *HDP Contract Area: S-AN-2*	**Vertical Profiles of ADCP Average TSS** **04 January 2011**	TIDE
3g-i			Ebb



*Approximate distance from source

FIGURE	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	Vertical Profiles of ADCP Average TSS 04 January 2011	TIDE
3j-l			Ebb



*Approximate distance from source

FIGURE	*USACE Harborwide TSS* *Far Field Survey* *HDP Contract Area: S-AN-2*	**Vertical Profiles of ADCP Average TSS** **04 January 2011**	TIDE
3m-o			**Ebb**

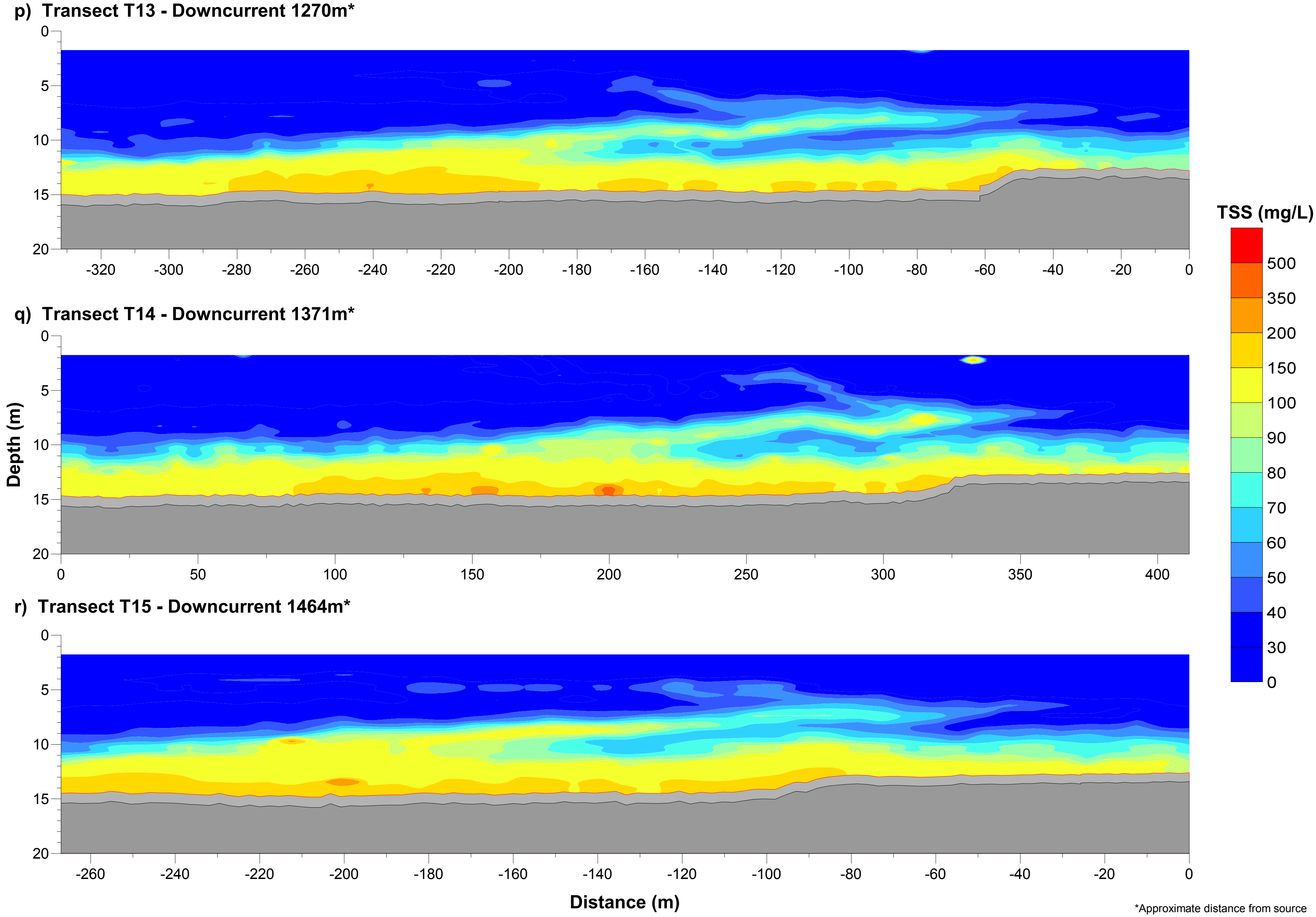
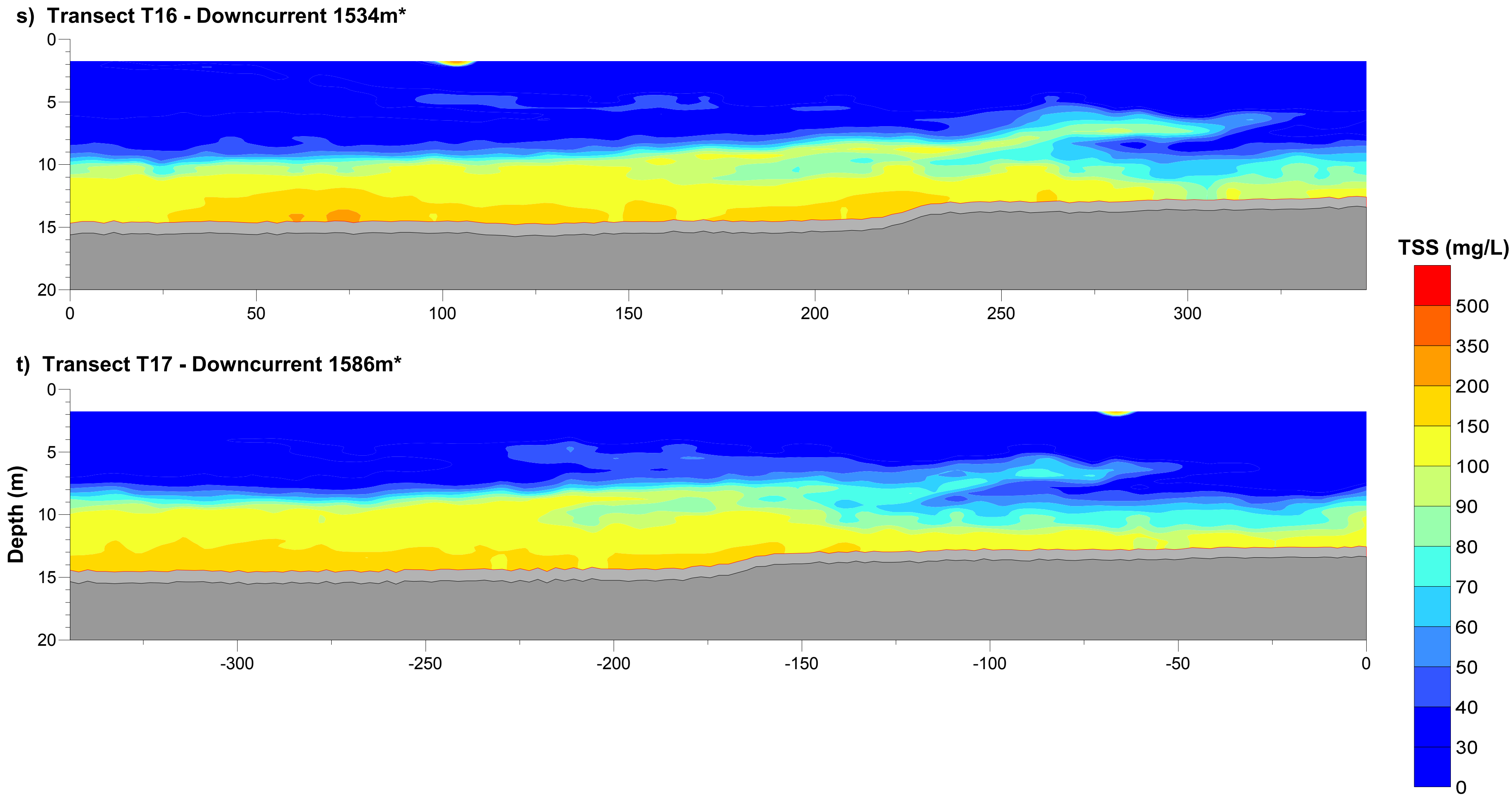


FIGURE	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	Vertical Profiles of ADCP Average TSS 04 January 2011	TIDE
3p-r			Ebb



*Approximate distance from source

FIGURE	USACE Harborwide TSS *Far Field Survey* *HDP Contract Area: S-AN-2*	Vertical Profiles of ADCP Average TSS 04 January 2011	TIDE
3s-t			Ebb

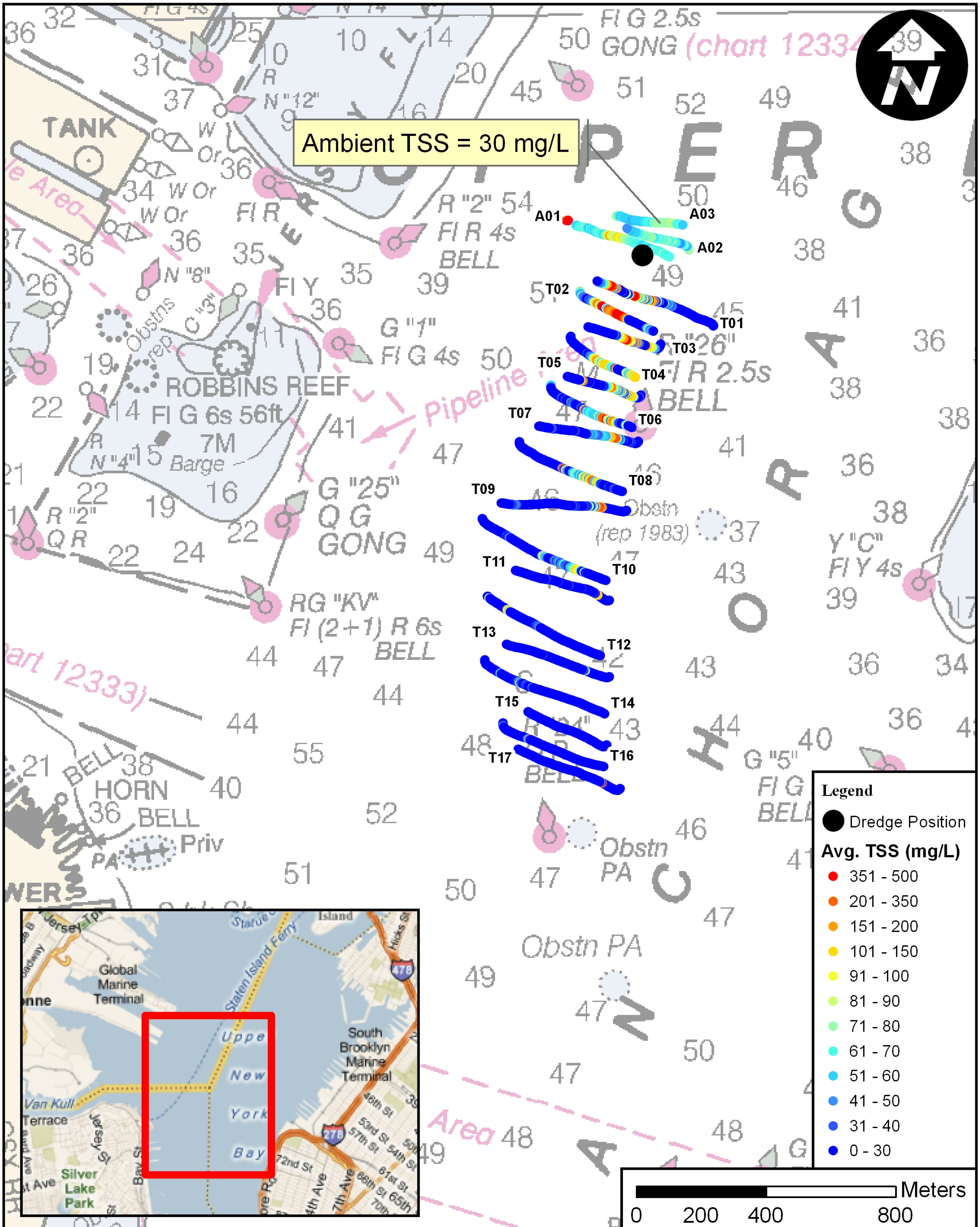


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	ADCP Average TSS - 04 January 2011 0-2 Meter Depth Interval	Tide
4a			Ebb

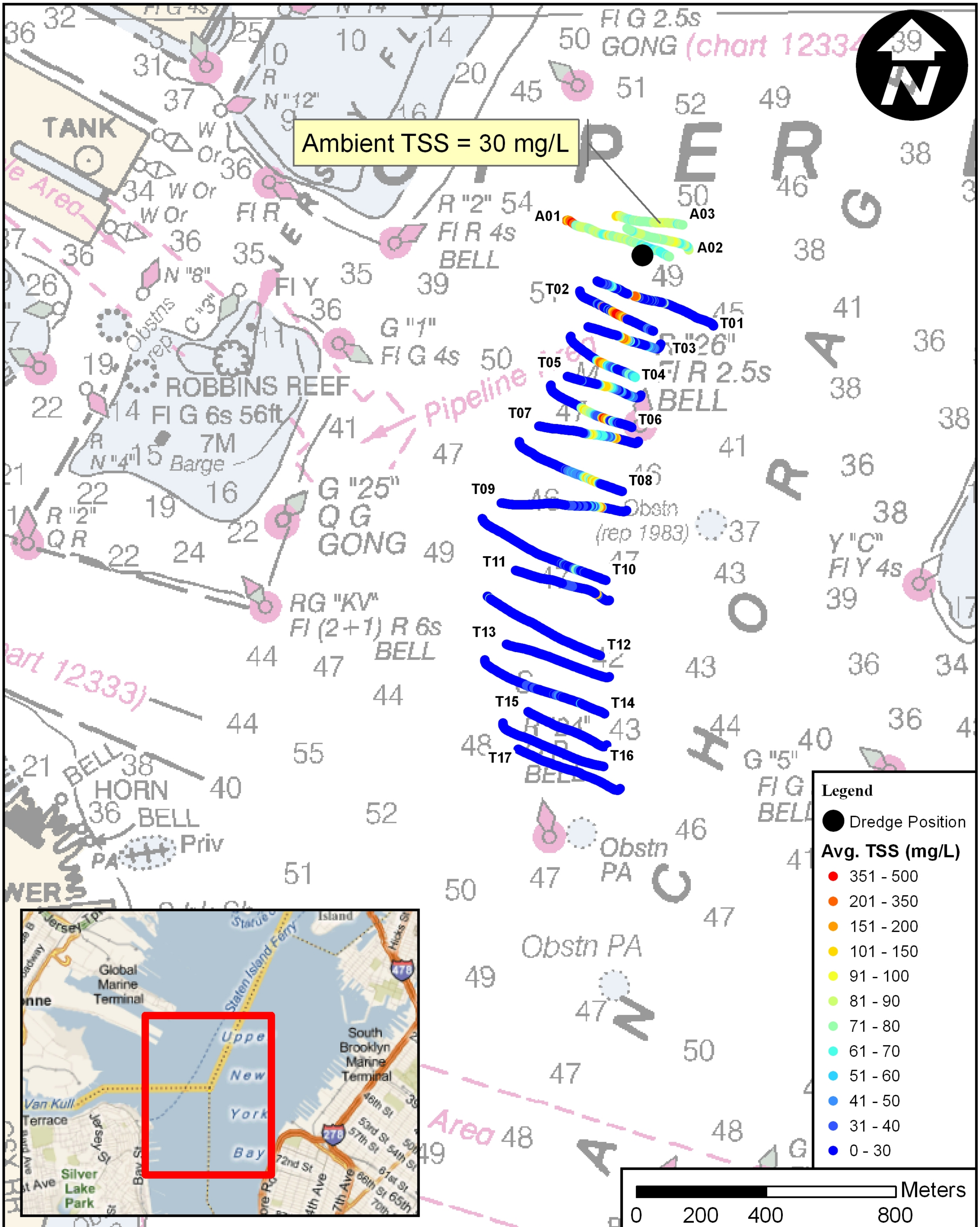


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	ADCP Average TSS - 04 January 2011 2-4 Meter Depth Interval	Tide
4b			Ebb

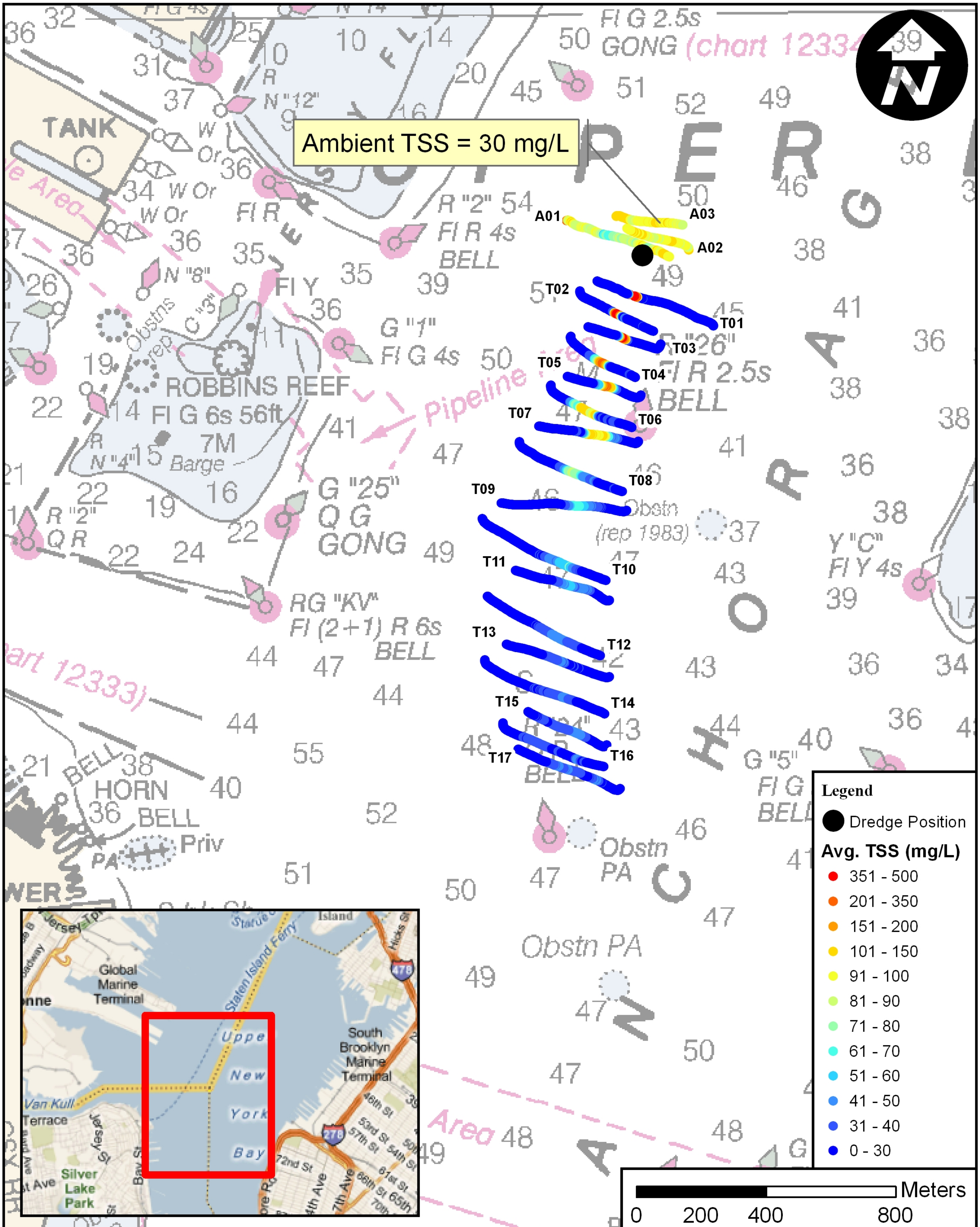


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	ADCP Average TSS - 04 January 2011 4-6 Meter Depth Interval	Tide
4c			Ebb

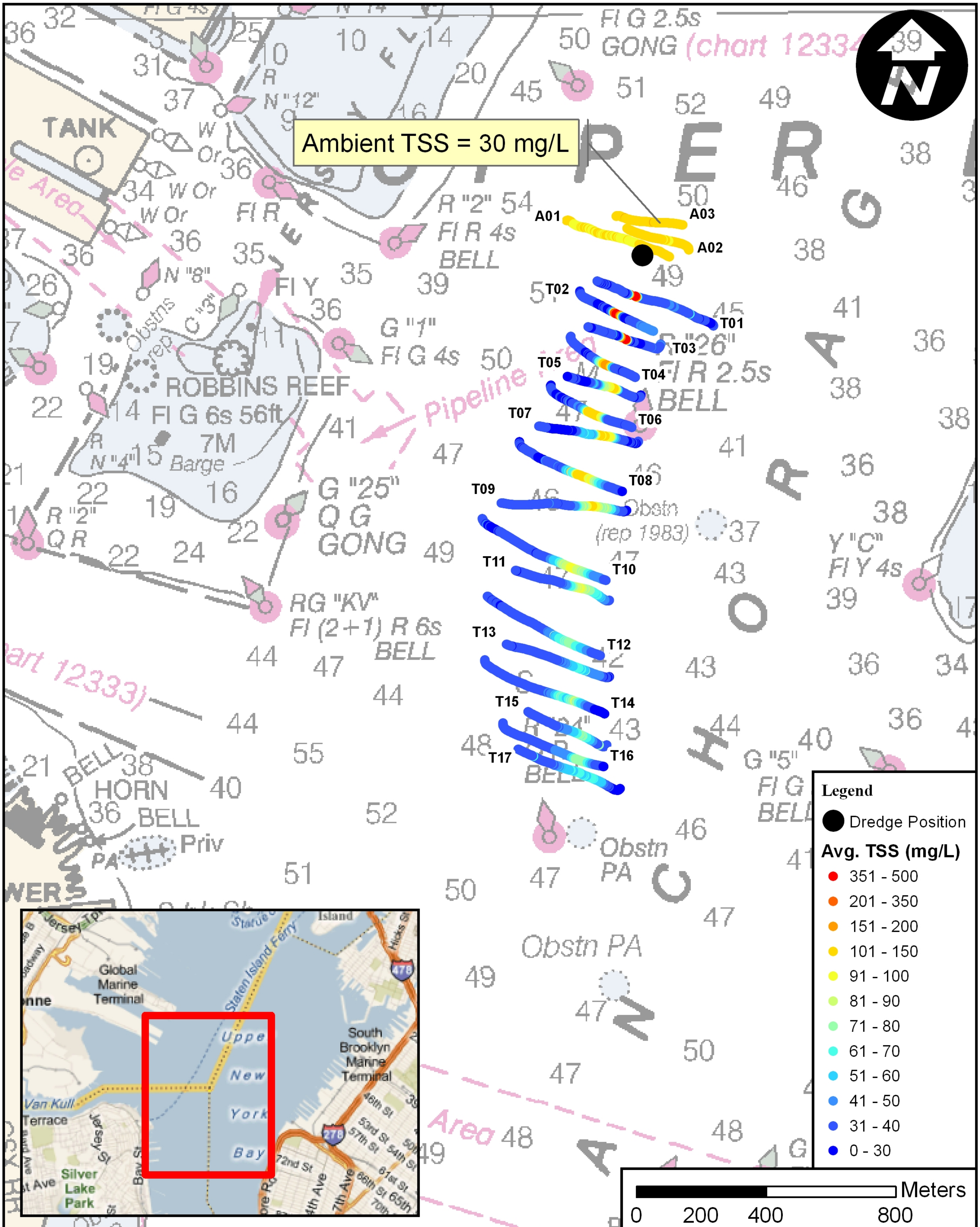
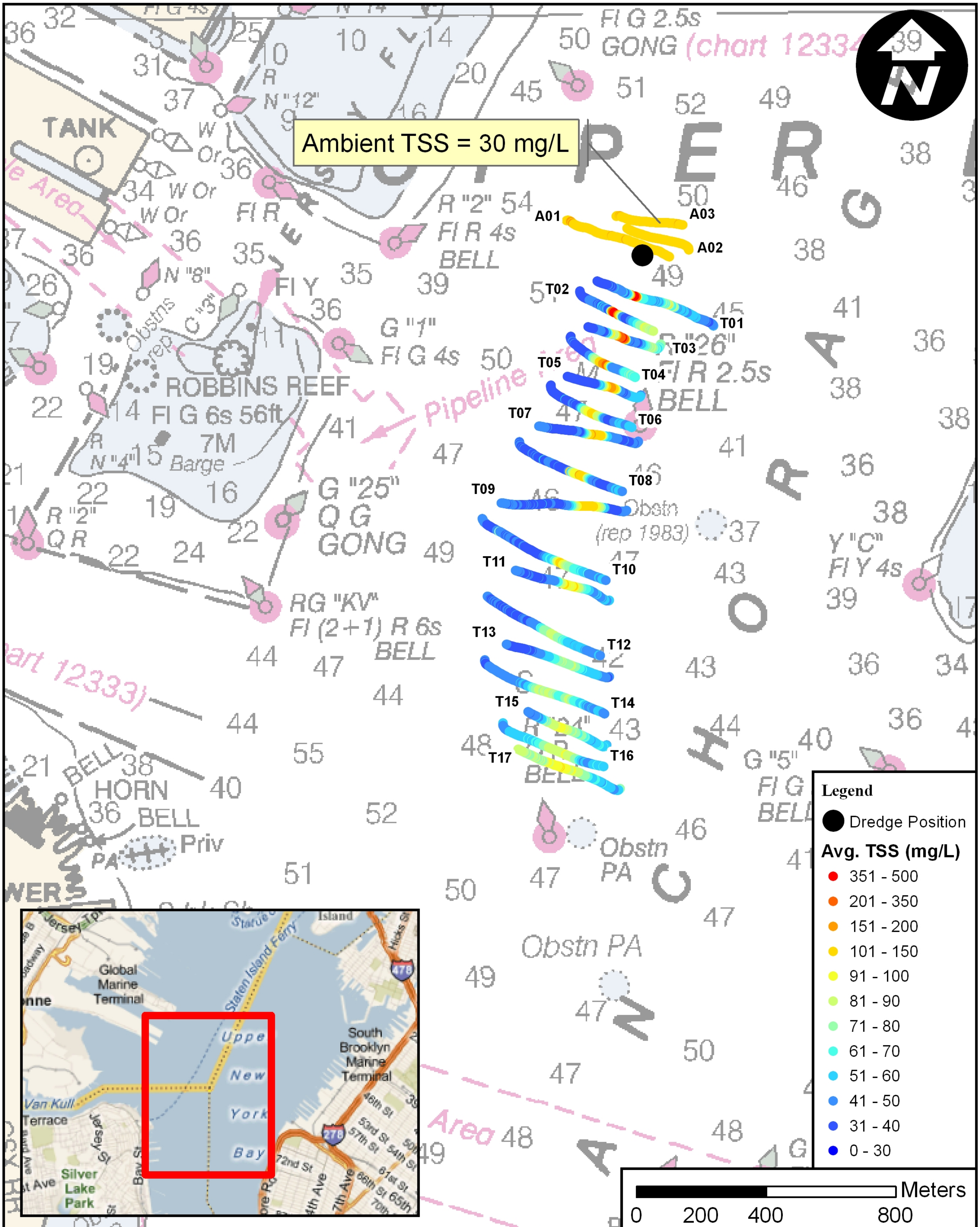


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	ADCP Average TSS - 04 January 2011 6-8 Meter Depth Interval	Tide
4d			Ebb



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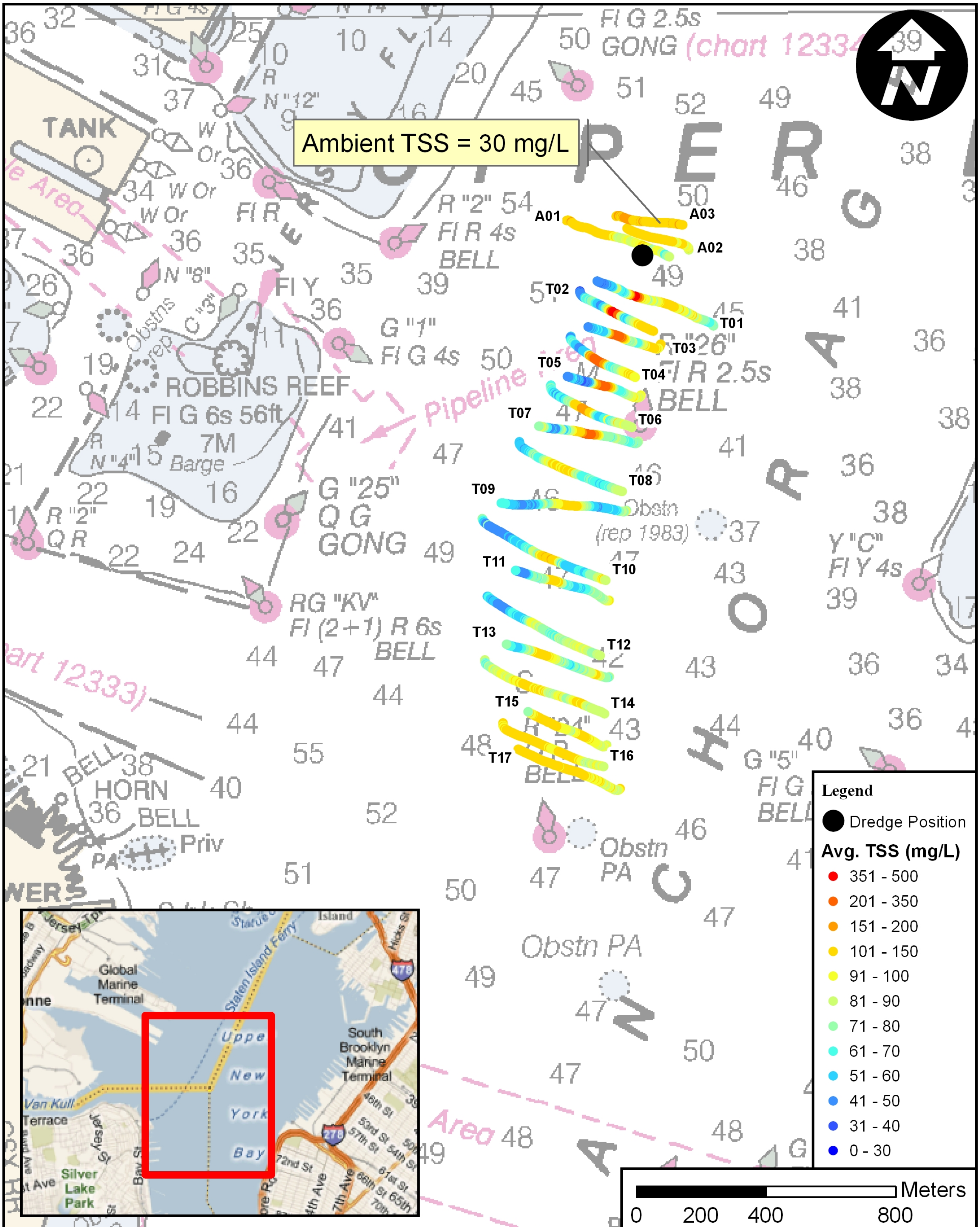
4e			Ebb



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4f			Ebb

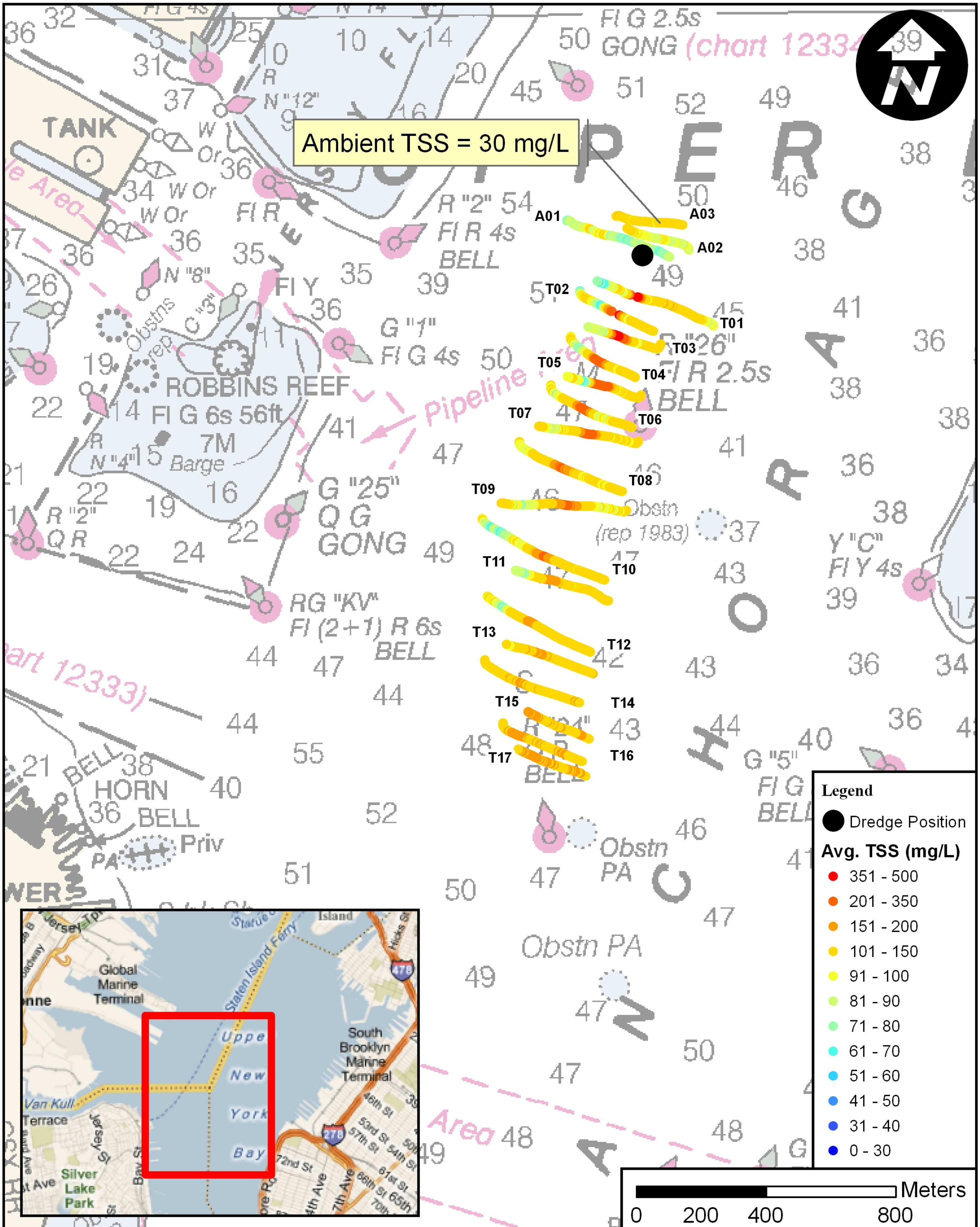


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	ADCP Average TSS - 04 January 2011 12-14 Meter Depth Interval	Tide
4g			Ebb

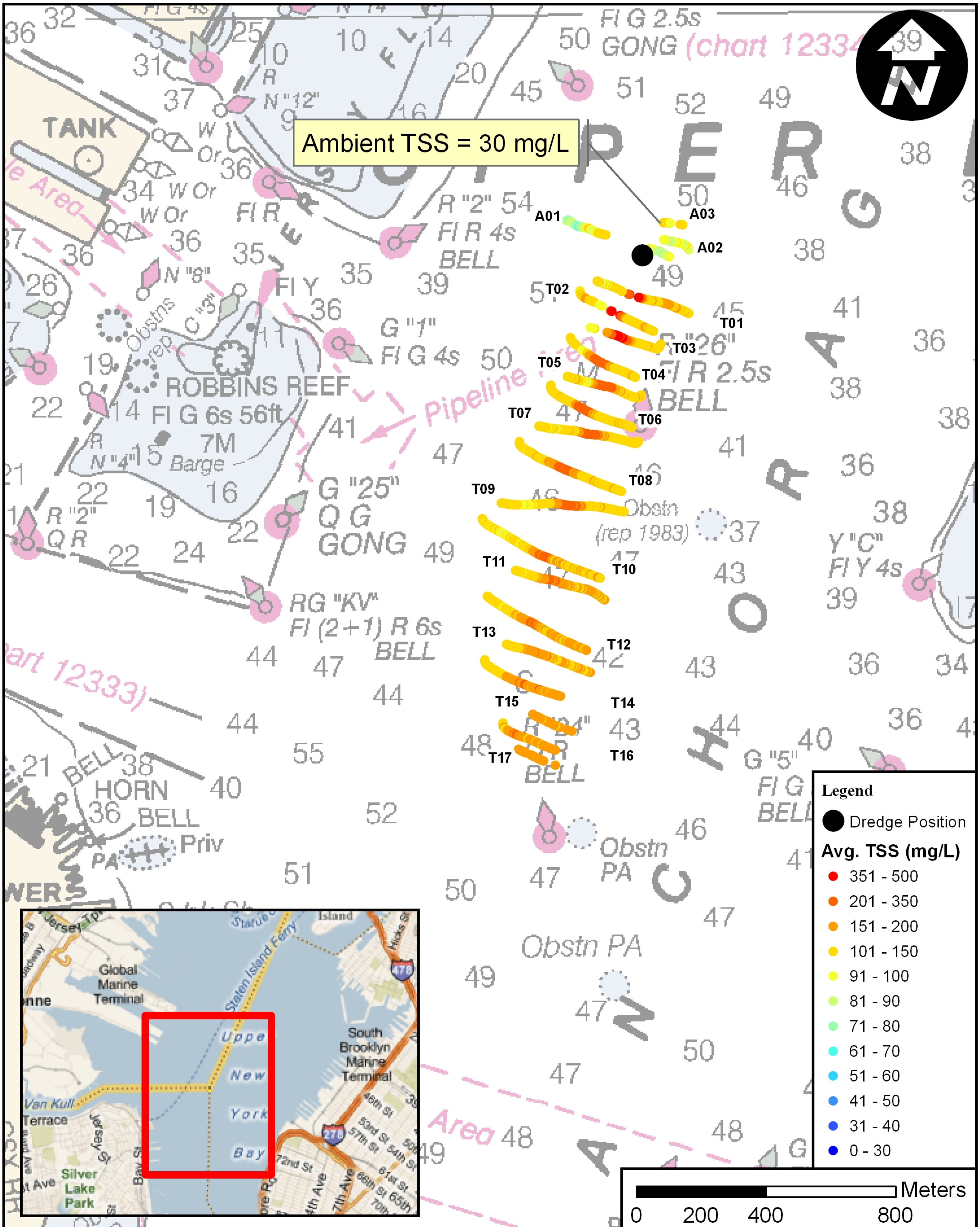
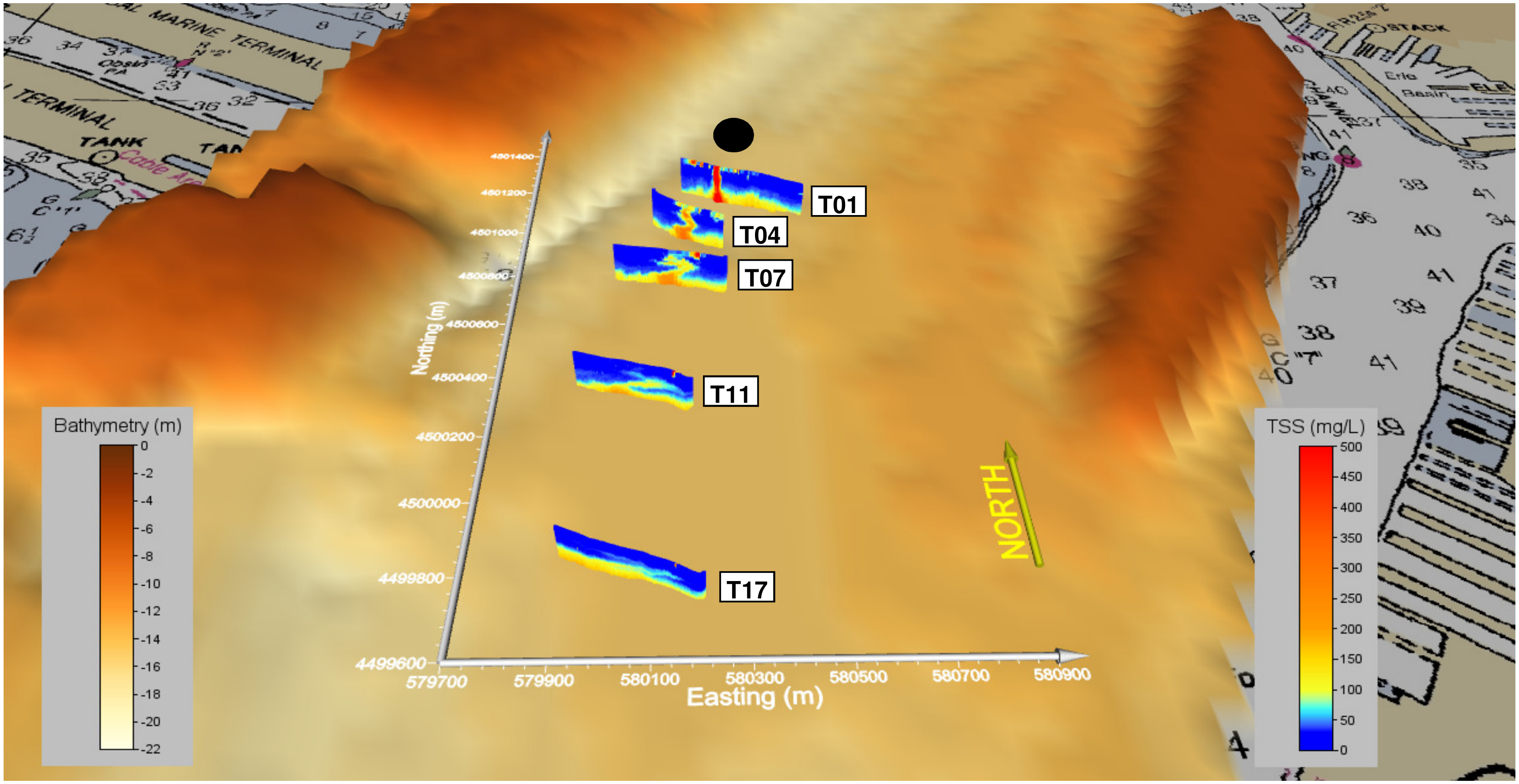


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	ADCP Average TSS - 04 January 2011 14-16 Meter Depth Interval	Tide
4h			Ebb



Bathymetry produced by NOAA soundings ● = Dredge Location Z scale exaggerated 6X

Figure	*USACE Harborwide TSS Far Field Survey HDP Contract Area S-AN-2*	ADCP Average TSS Values, 3D View of Selected Transects Superimposed on Channel Bathymetry 04 January 2011	Tide
5			Ebb

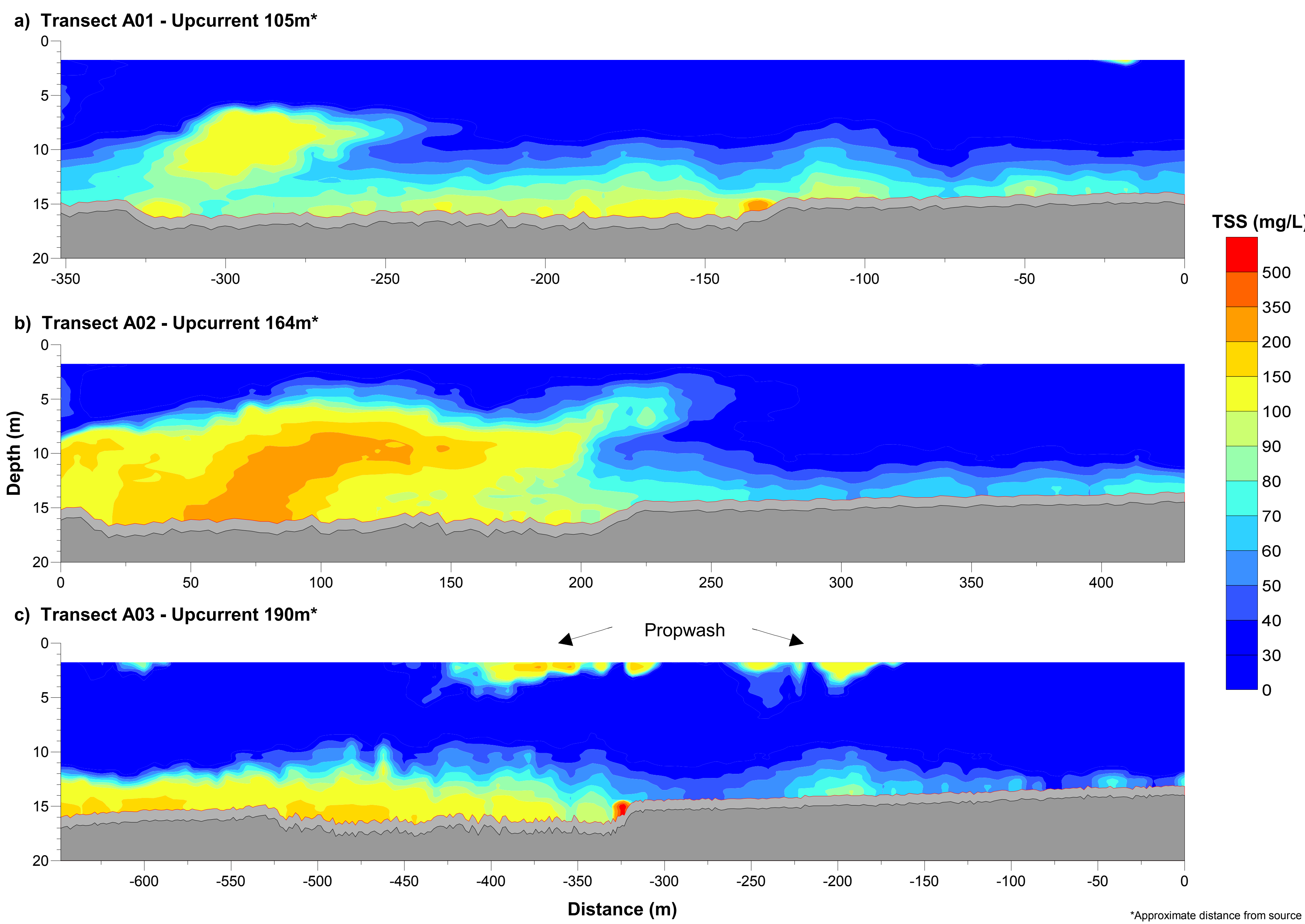


FIGURE	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	Vertical Profiles of ADCP Average TSS 05 January 2011	TIDE
6a-c			Flood

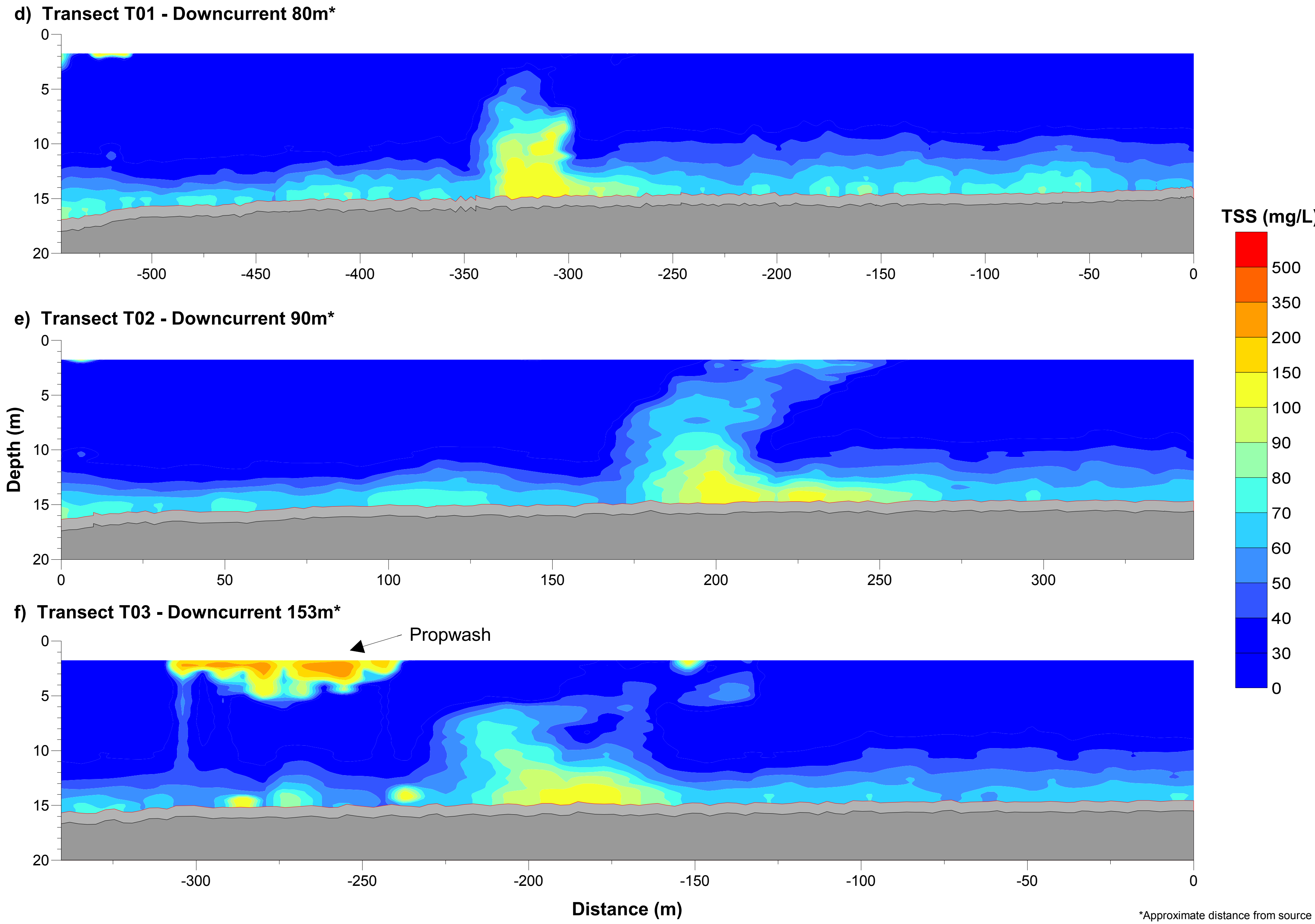


FIGURE	*USACE Harborwide TSS* *Far Field Survey* *HDP Contract Area: S-AN-2*	**Vertical Profiles of ADCP Average TSS** **05 January 2011**	TIDE
6d-f			**Flood**

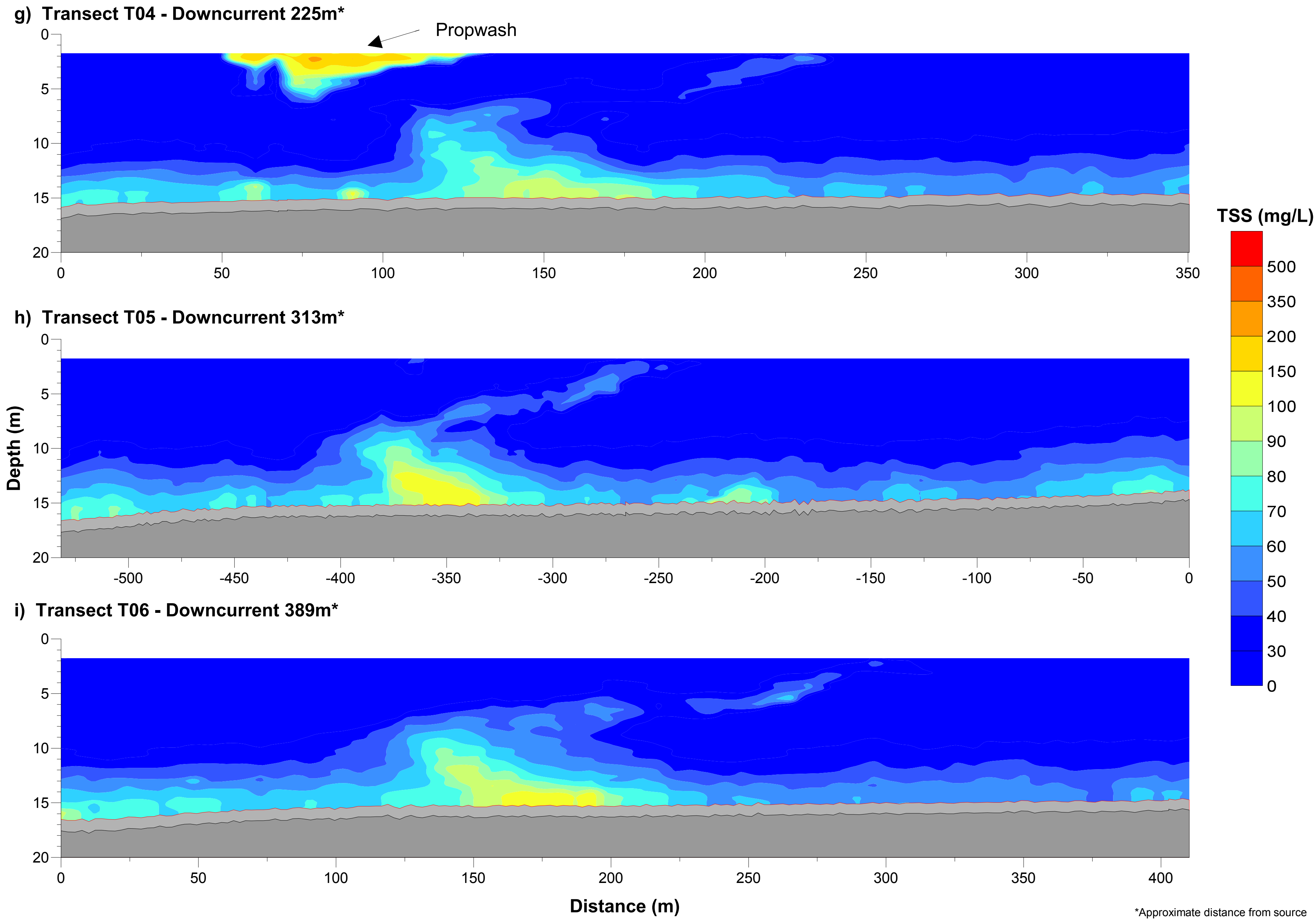
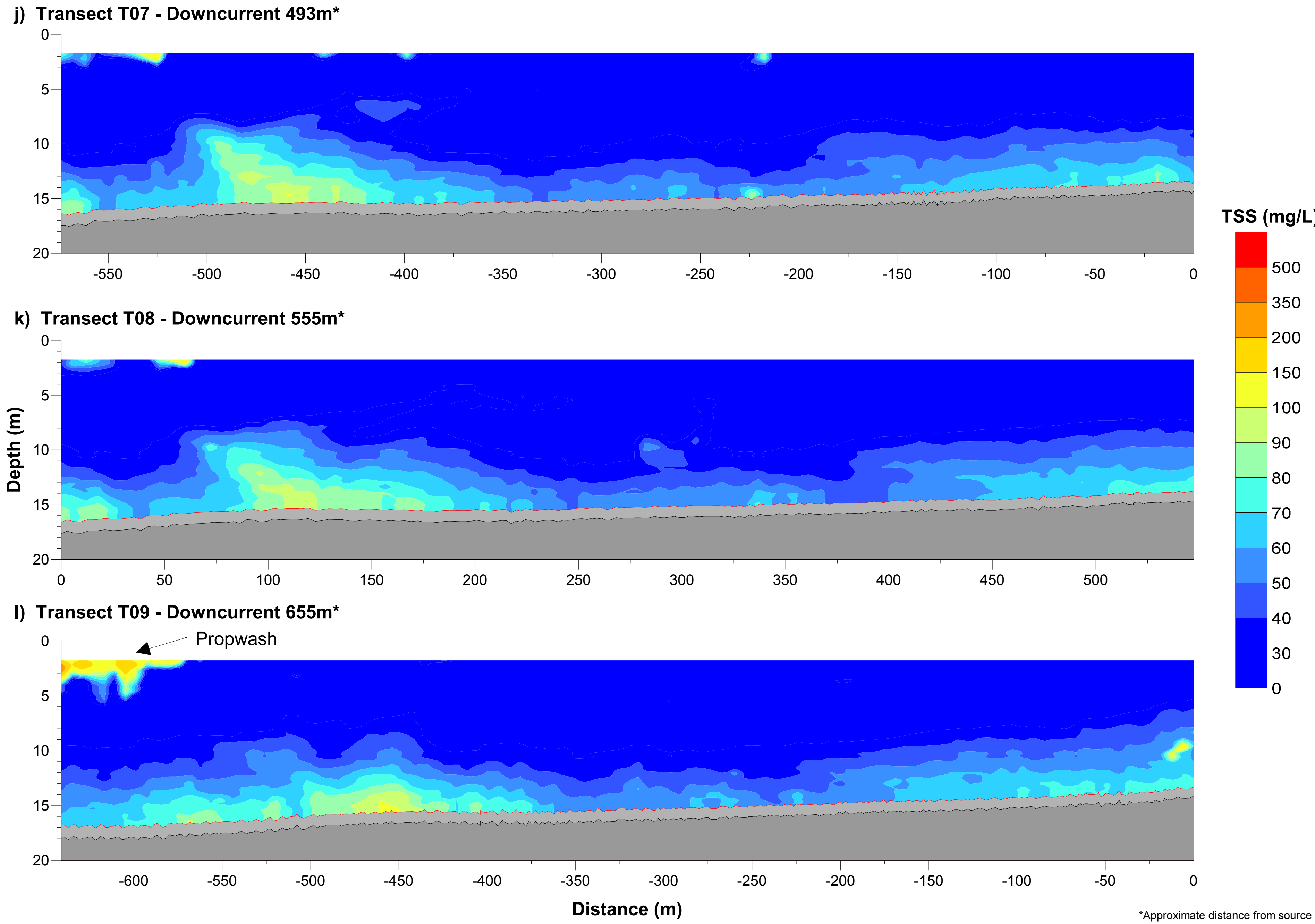


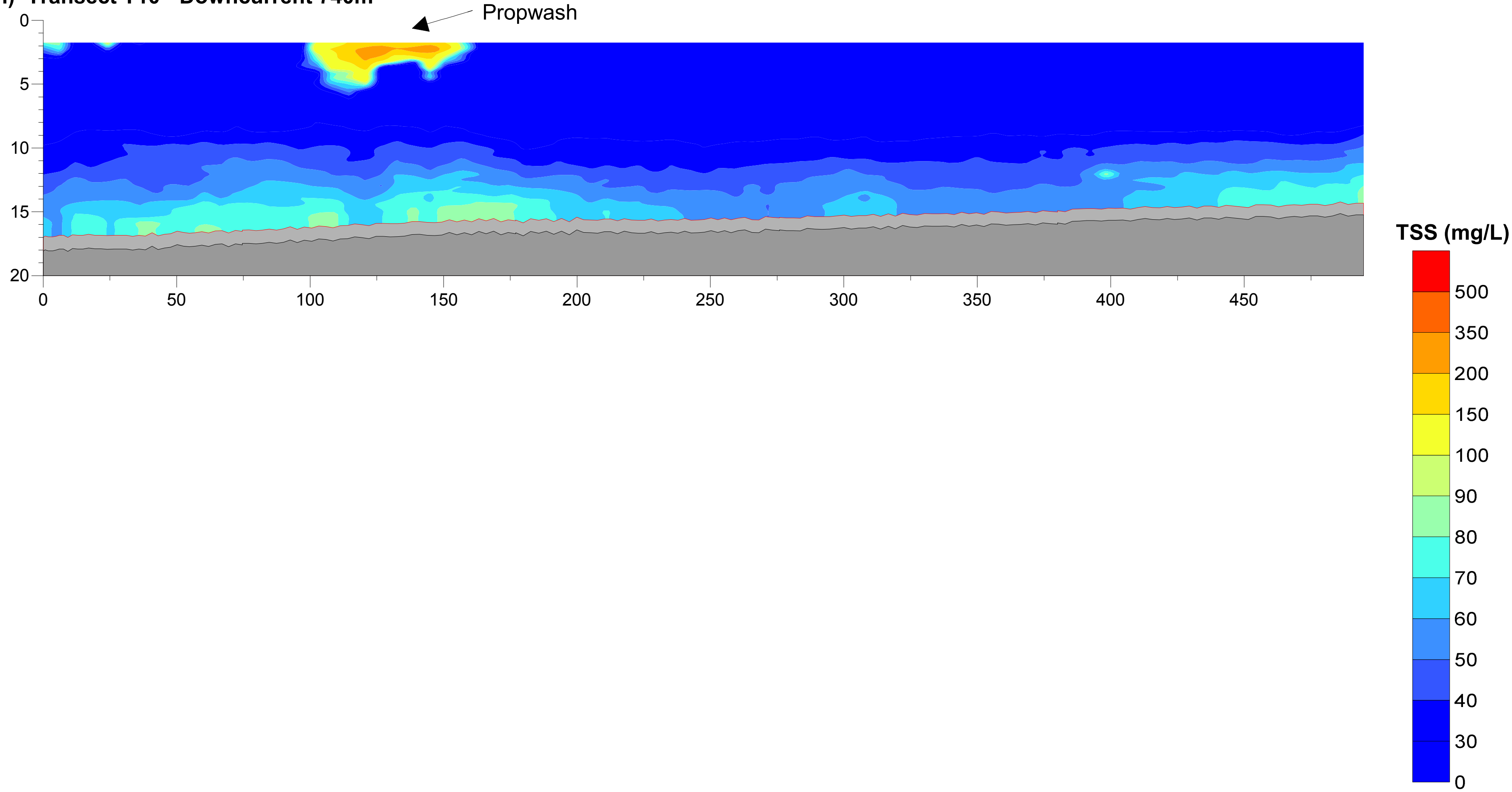
FIGURE	USACE Harborwide TSS *Far Field Survey* *HDP Contract Area: S-AN-2*	Vertical Profiles of ADCP Average TSS 05 January 2011	TIDE
6g-i			Flood



*Approximate distance from source

FIGURE	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	Vertical Profiles of ADCP Average TSS 05 January 2011	TIDE
6j-l			Flood

m) Transect T10 - Downcurrent 740m*



*Approximate distance from source

FIGURE	*USACE Harborwide TSS* *Far Field Survey* *HDP Contract Area: S-AN-2*	**Vertical Profiles of ADCP Average TSS** **05 January 2011**	TIDE
6m			Flood

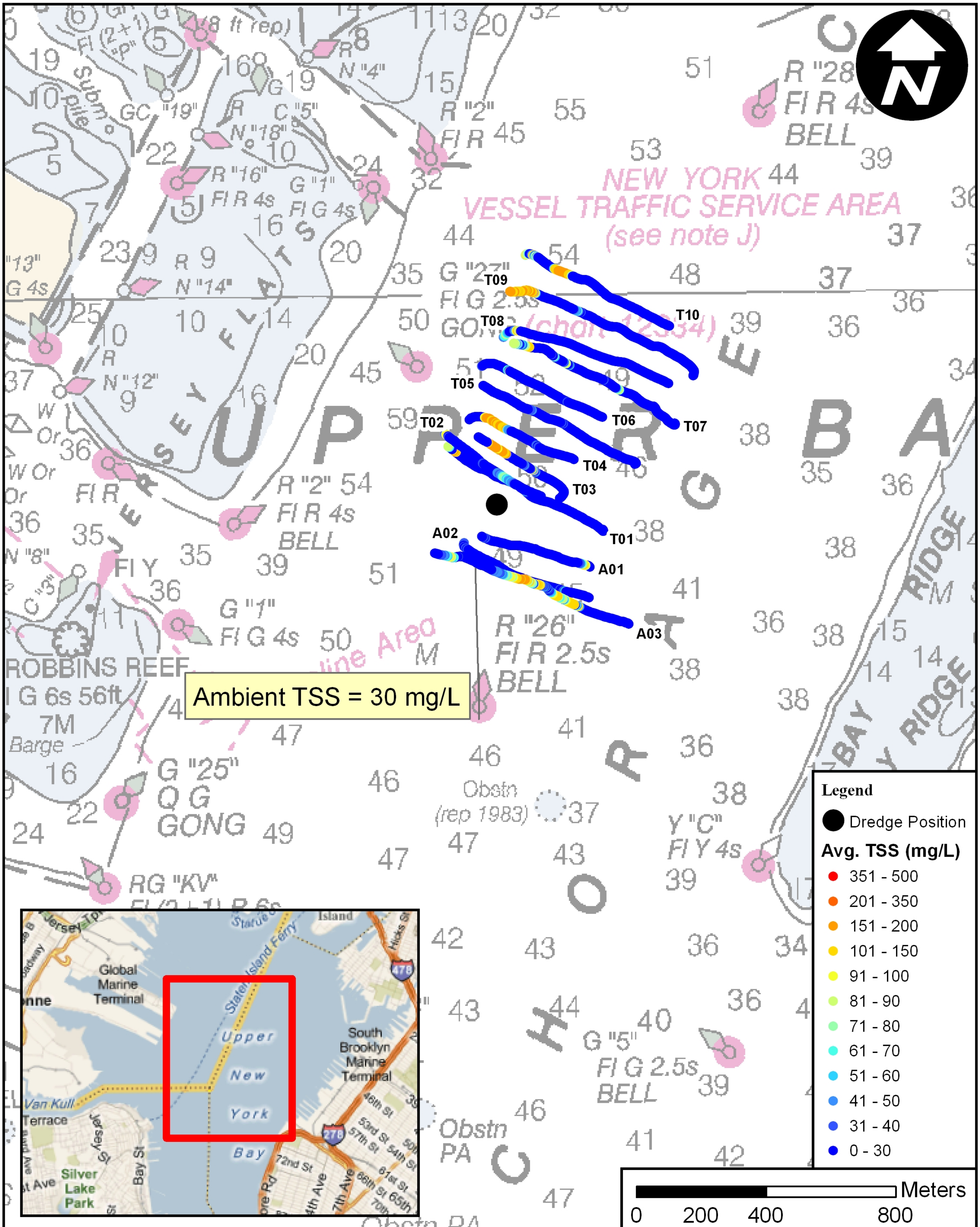


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	ADCP Average TSS - 05 January 2011 0-2 Meter Depth Interval	Tide
7a			Flood

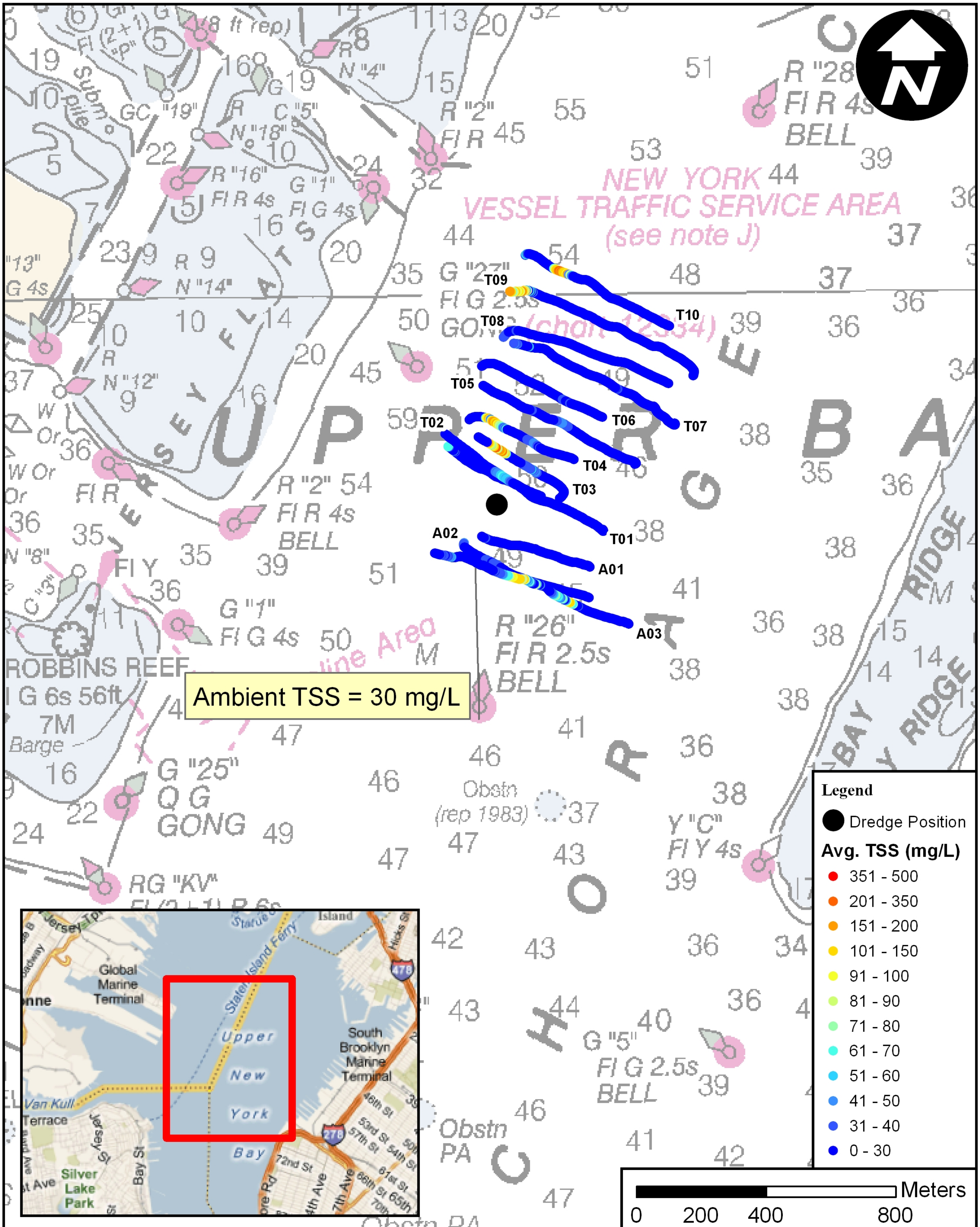
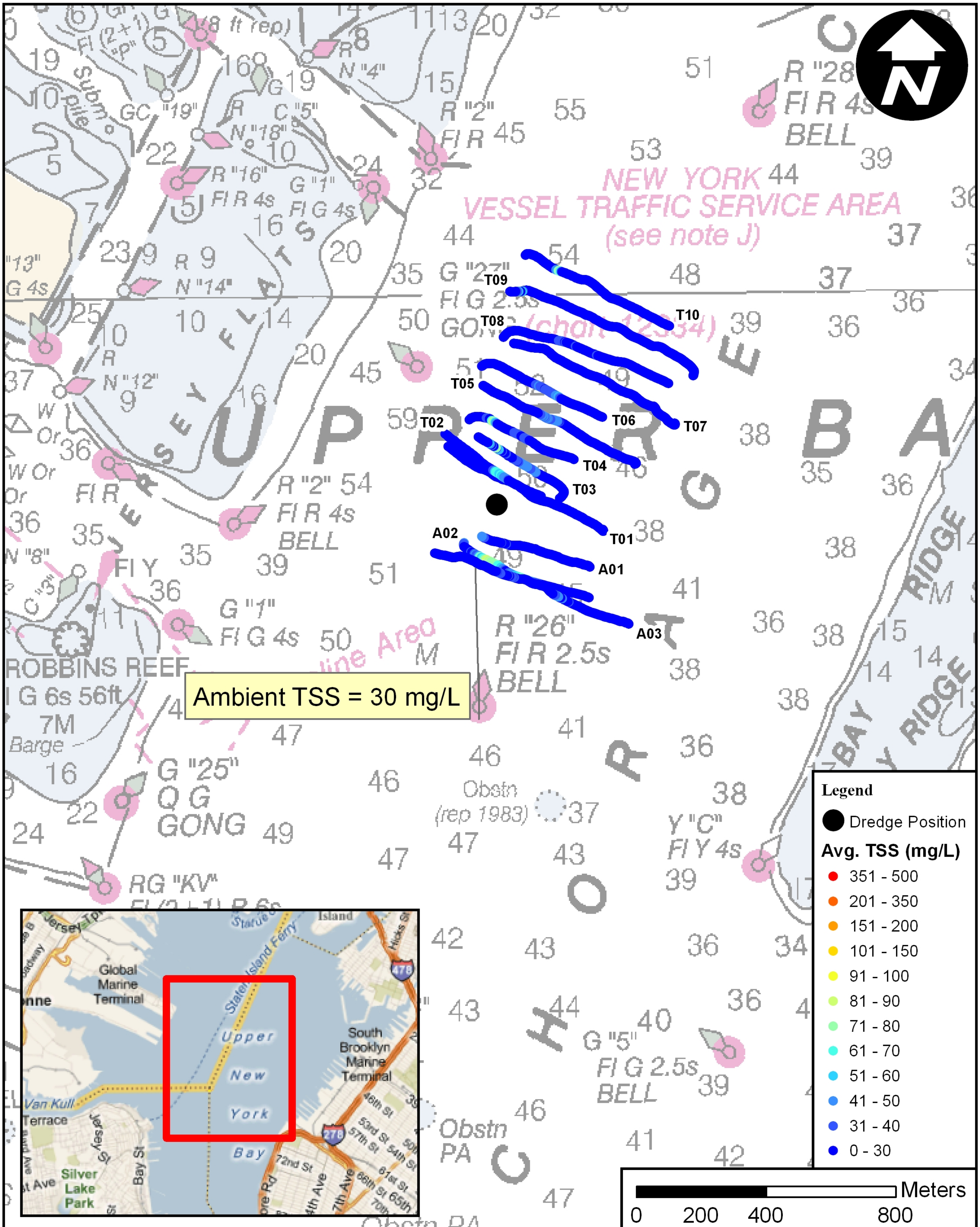


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	ADCP Average TSS - 05 January 2011 2-4 Meter Depth Interval	Tide
7b			Flood



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7c			Flood

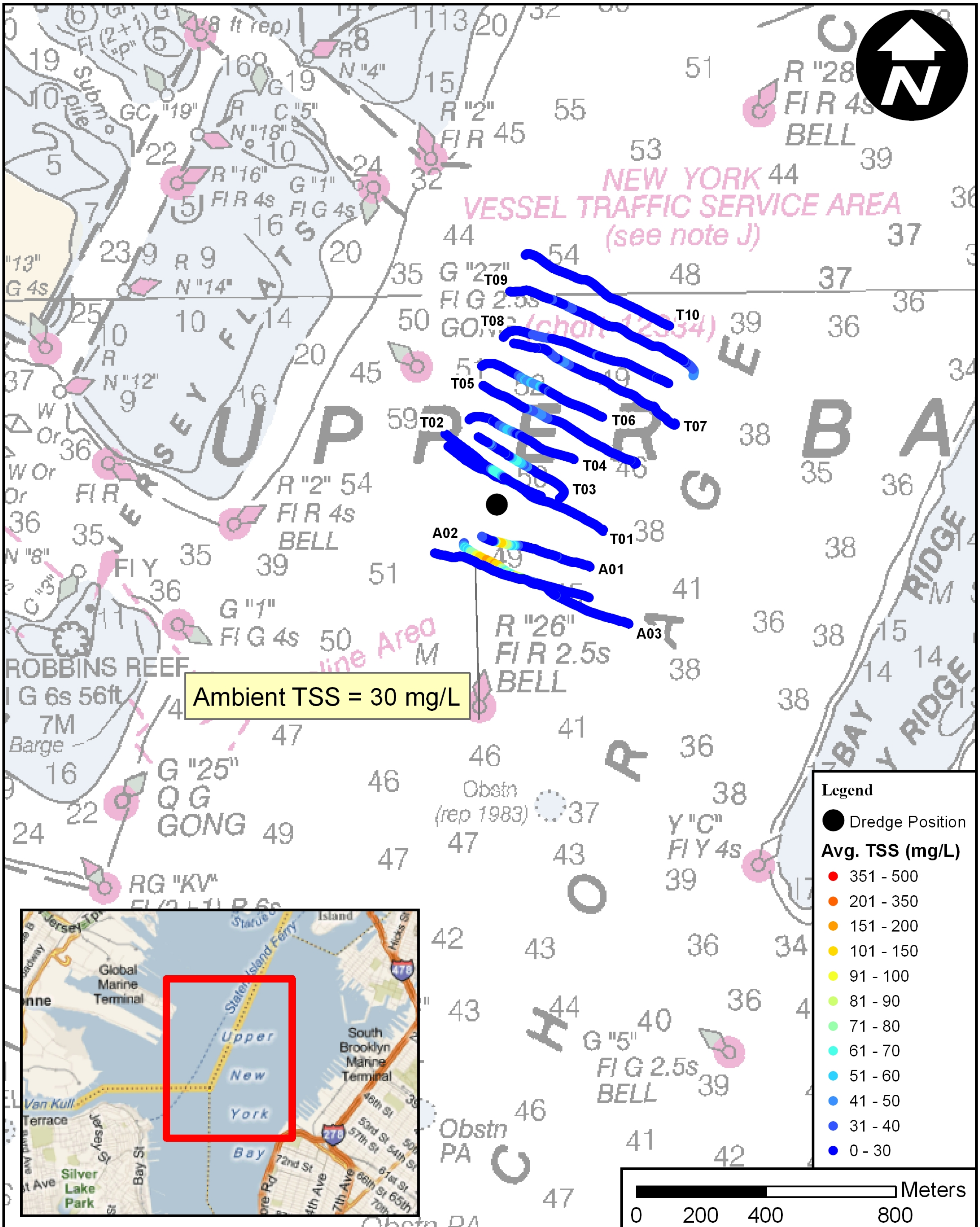
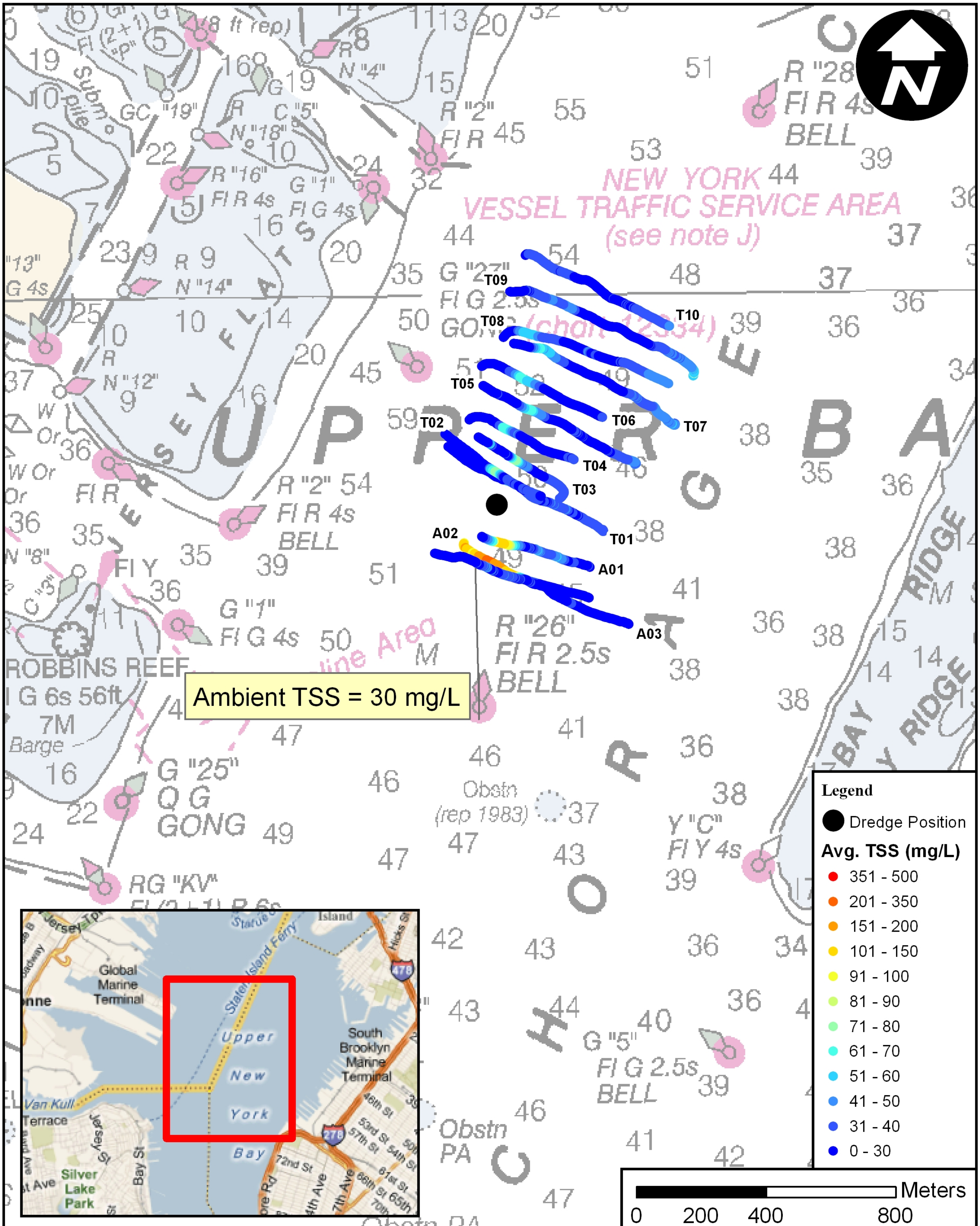


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	**ADCP Average TSS - 05 January 2011** **6-8 Meter Depth Interval**	Tide
7d			Flood



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7e			Flood

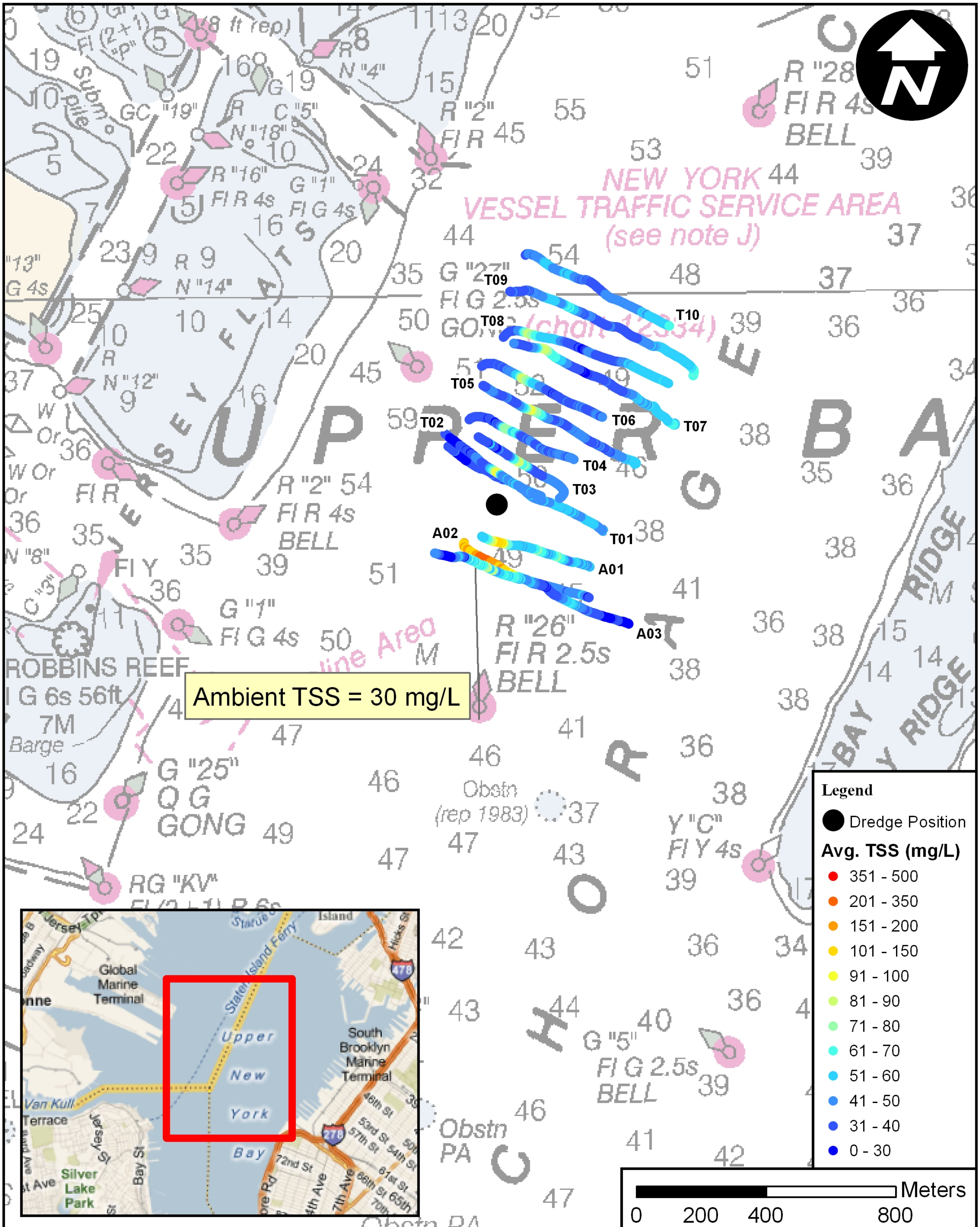


Figure	*USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2*	**ADCP Average TSS - 05 January 2011**	**Tide**
7f		**10-12 Meter Depth Interval**	**Flood**

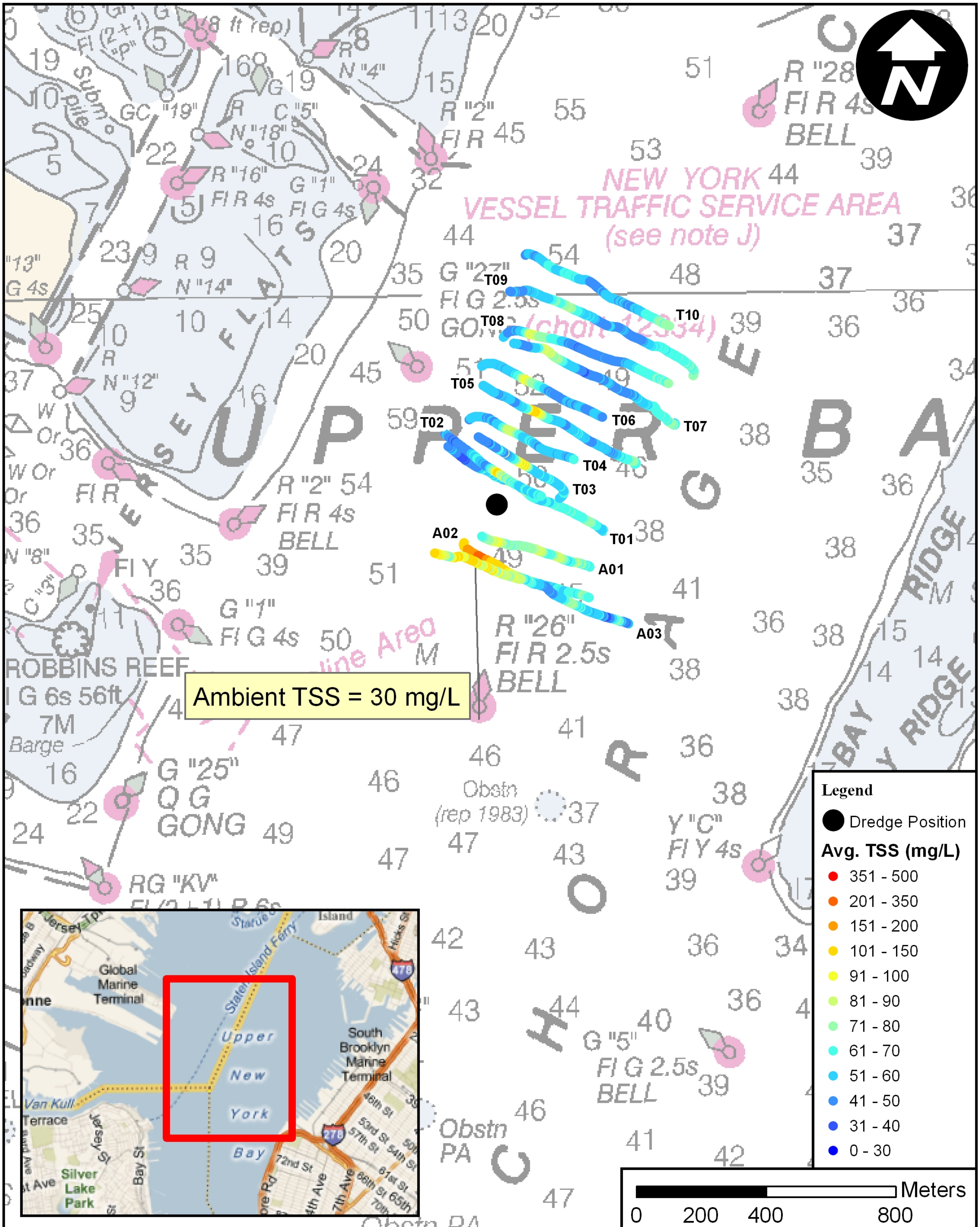


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	ADCP Average TSS - 05 January 2011 12-14 Meter Depth Interval	Tide
7g			Flood

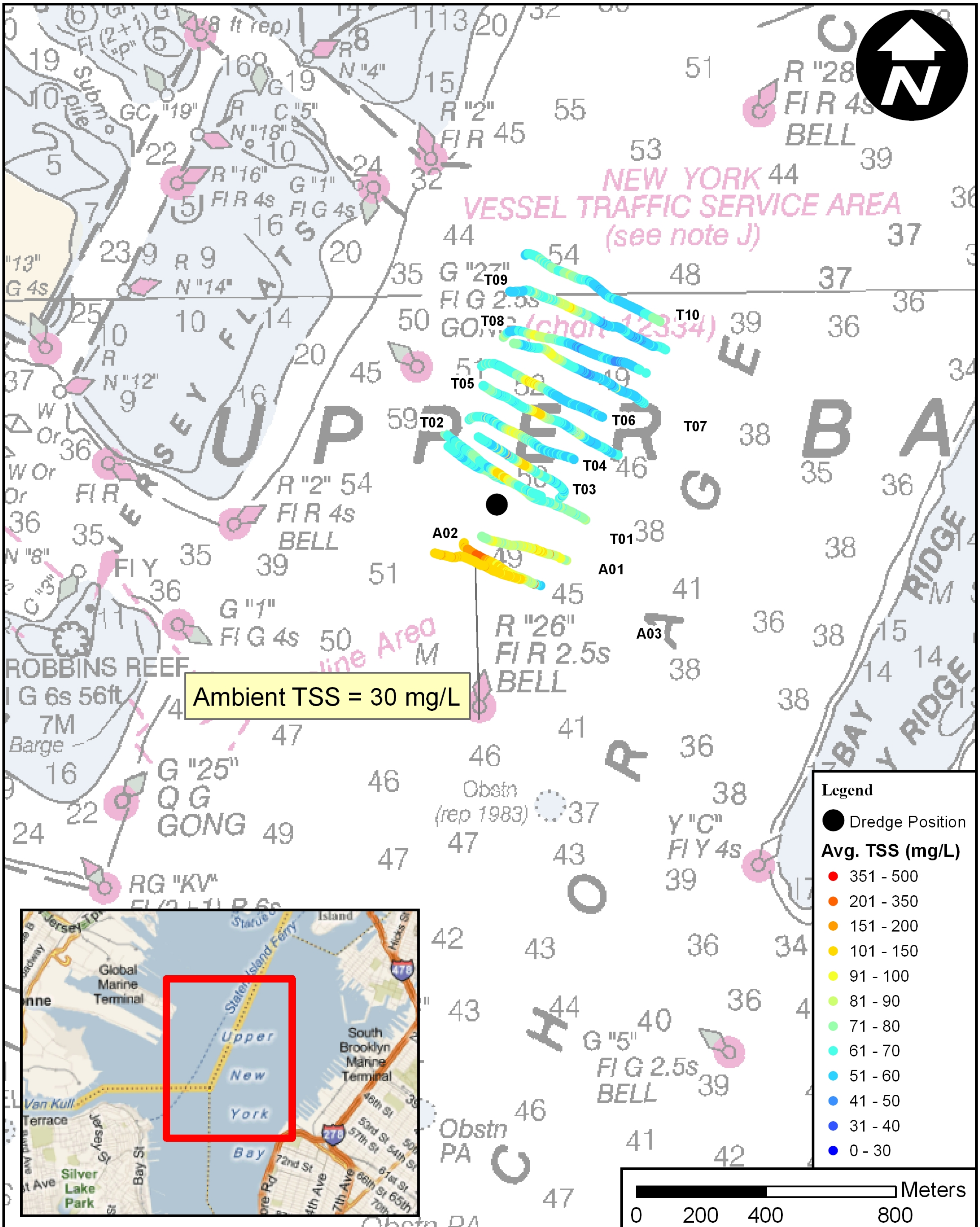
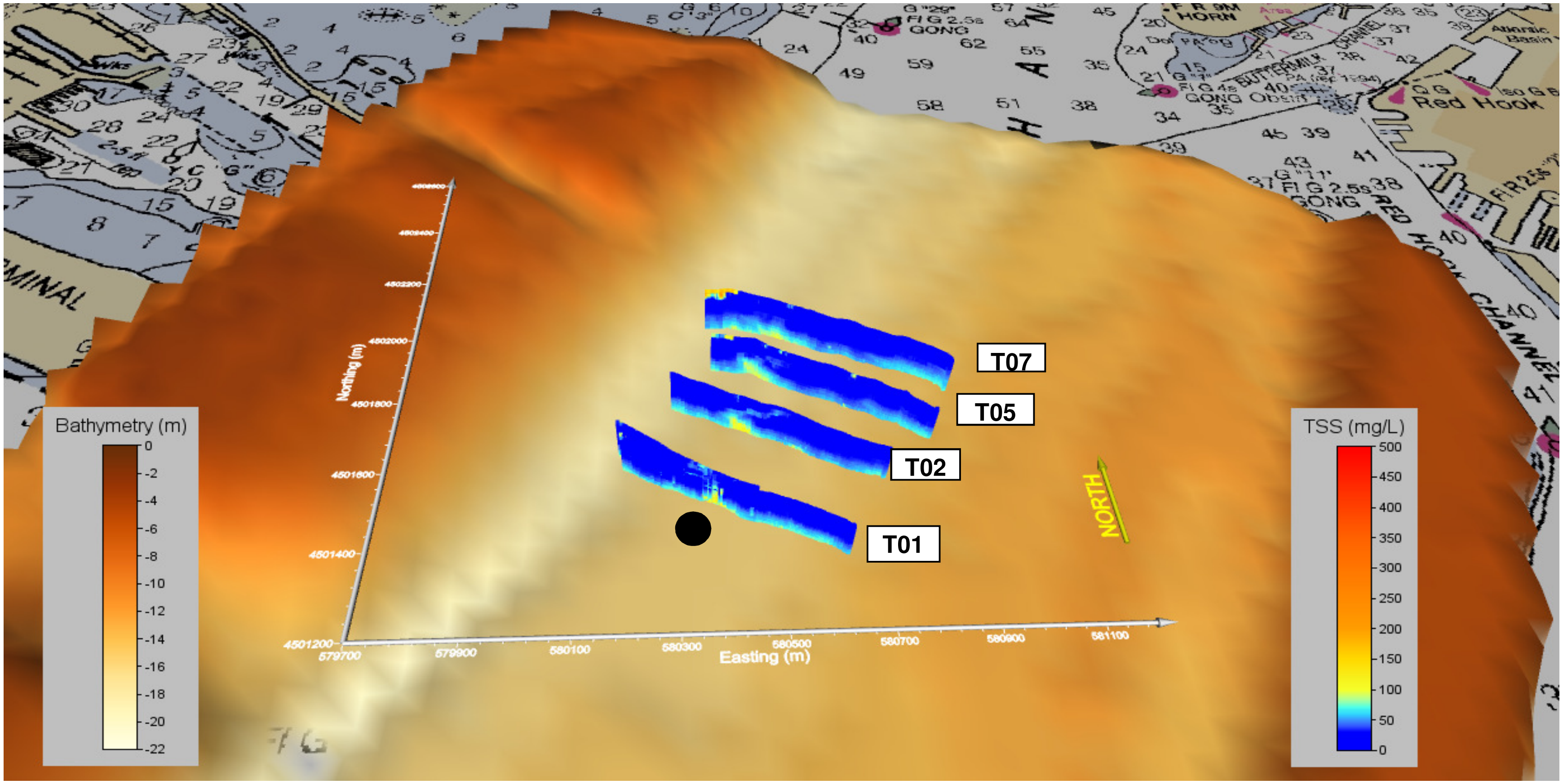


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	ADCP Average TSS - 05 January 2011 14-16 Meter Depth Interval	Tide
7h			Flood



Bathymetry produced by NOAA soundings ● = Dredge Location Z scale exaggerated 6X

Figure	*USACE Harborwide TSS*	ADCP Average TSS Values, 3D View of Selected Transects	Tide
8	*Far Field Survey* *HDP Contract Area S-AN-2*	Superimposed on Channel Bathymetry 05 January 2011	Flood

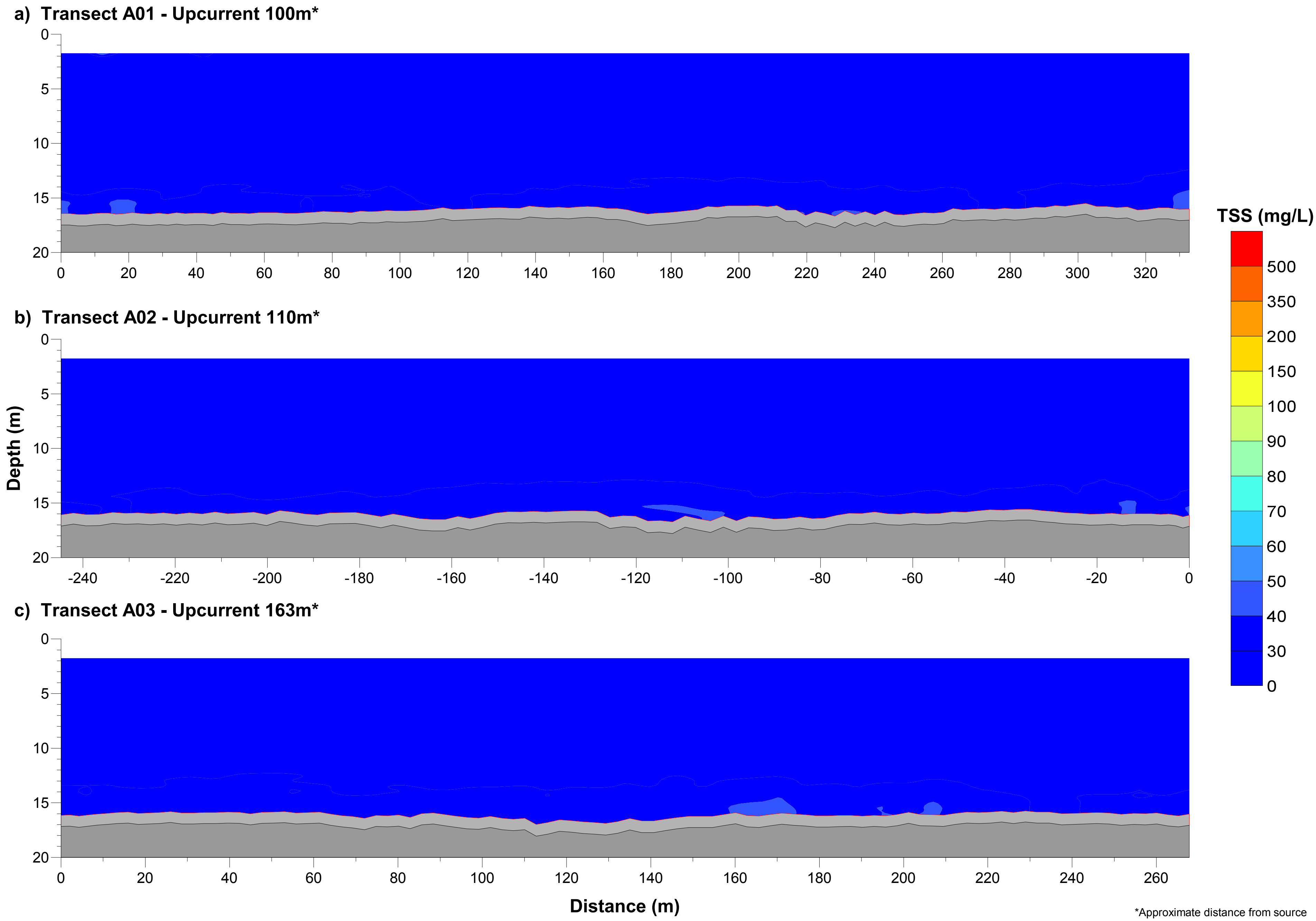


FIGURE	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	Vertical Profiles of ADCP Average TSS 06 January 2011	TIDE
9a-c			Flood

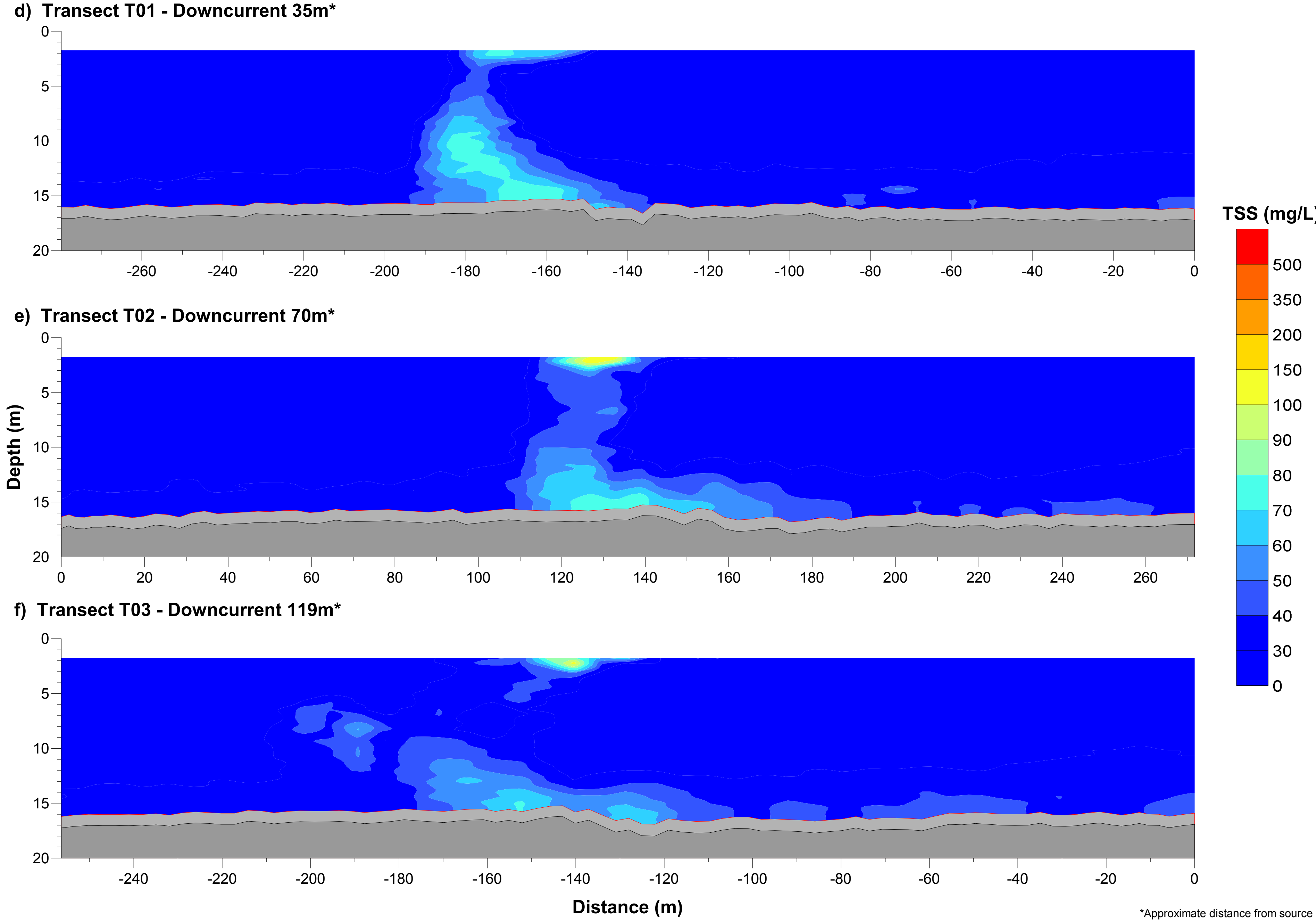


FIGURE	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	Vertical Profiles of ADCP Average TSS 06 January 2011	TIDE
9d-f			Flood

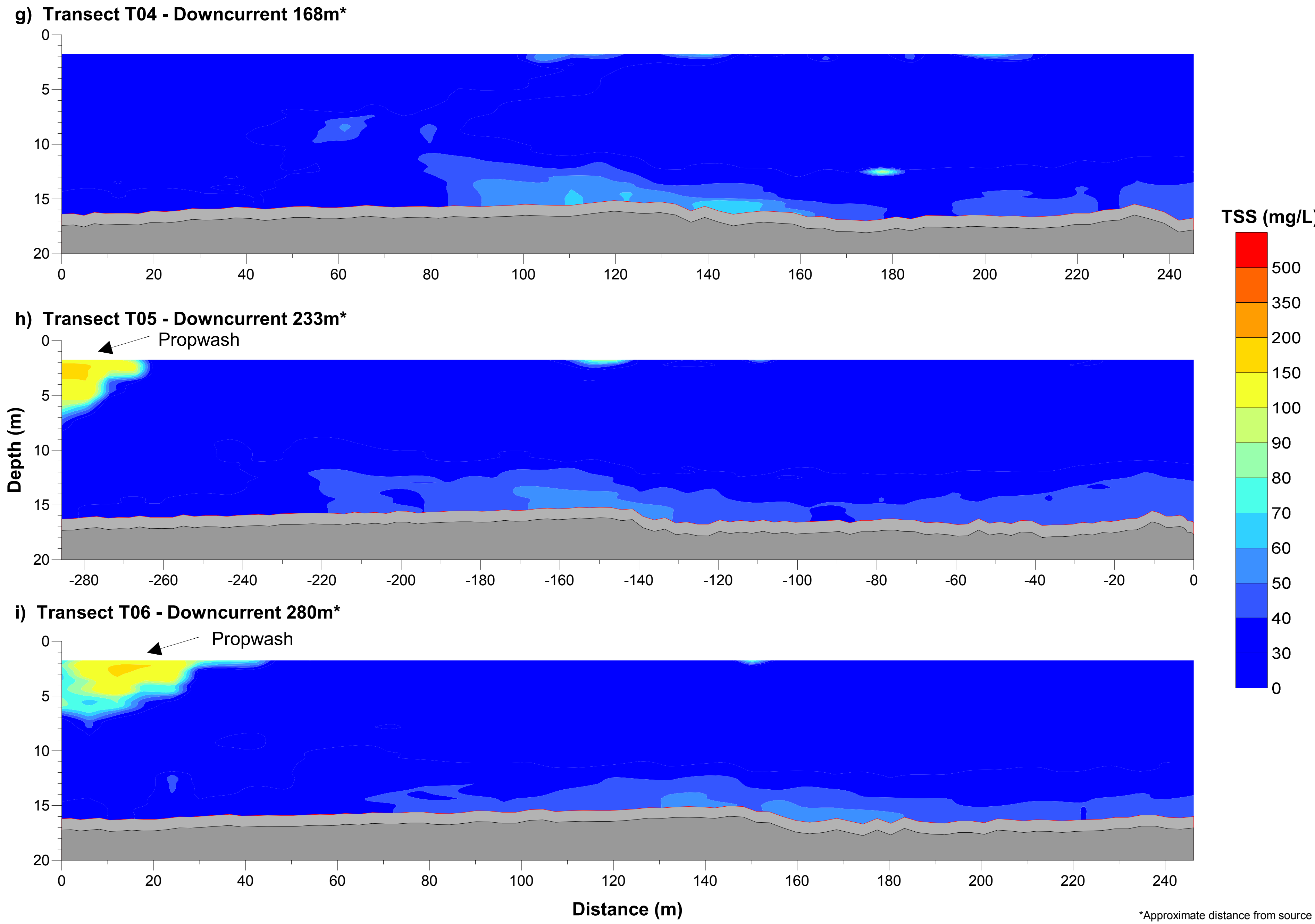


FIGURE	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	Vertical Profiles of ADCP Average TSS 06 January 2011	TIDE
9g-i			Flood

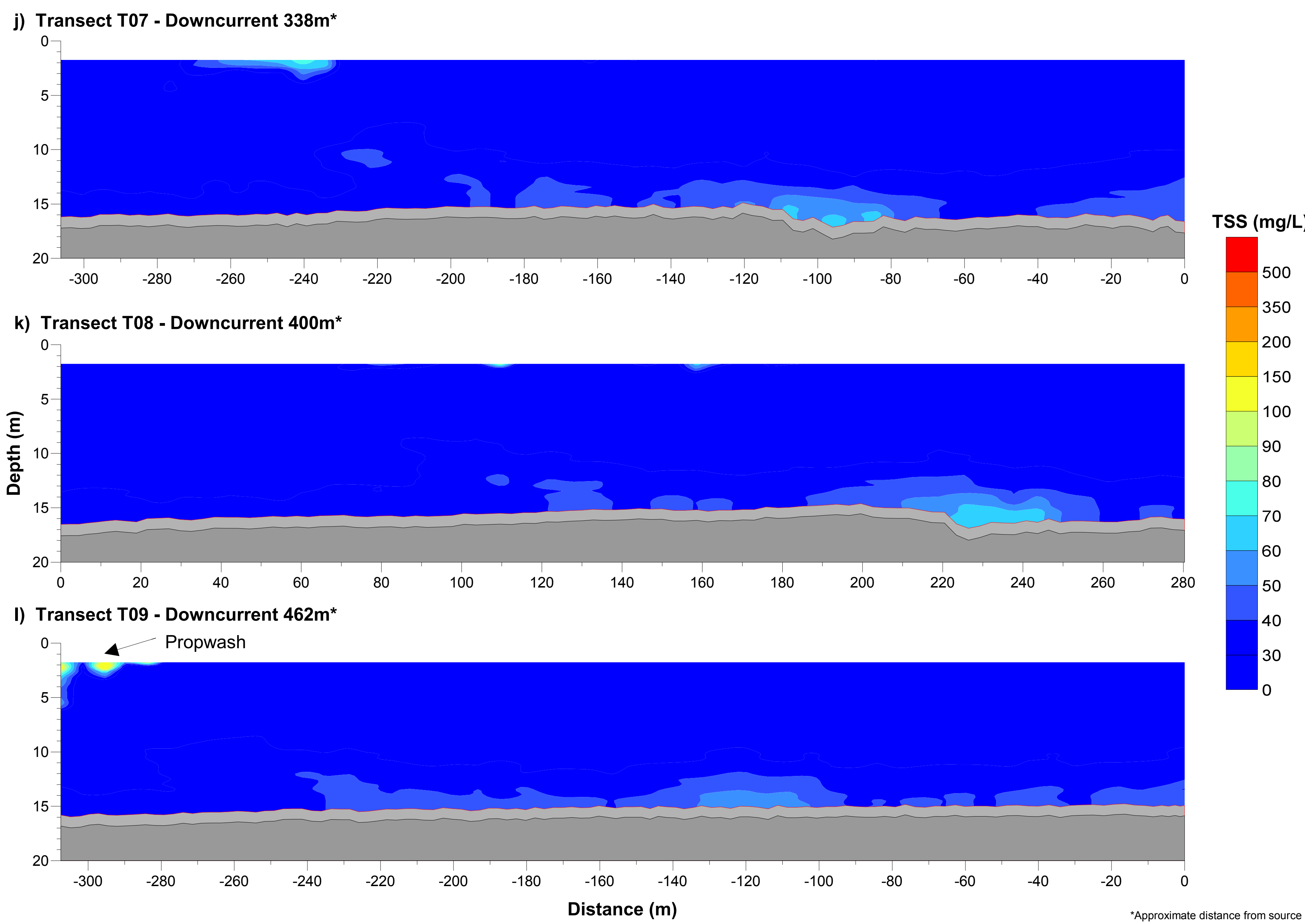
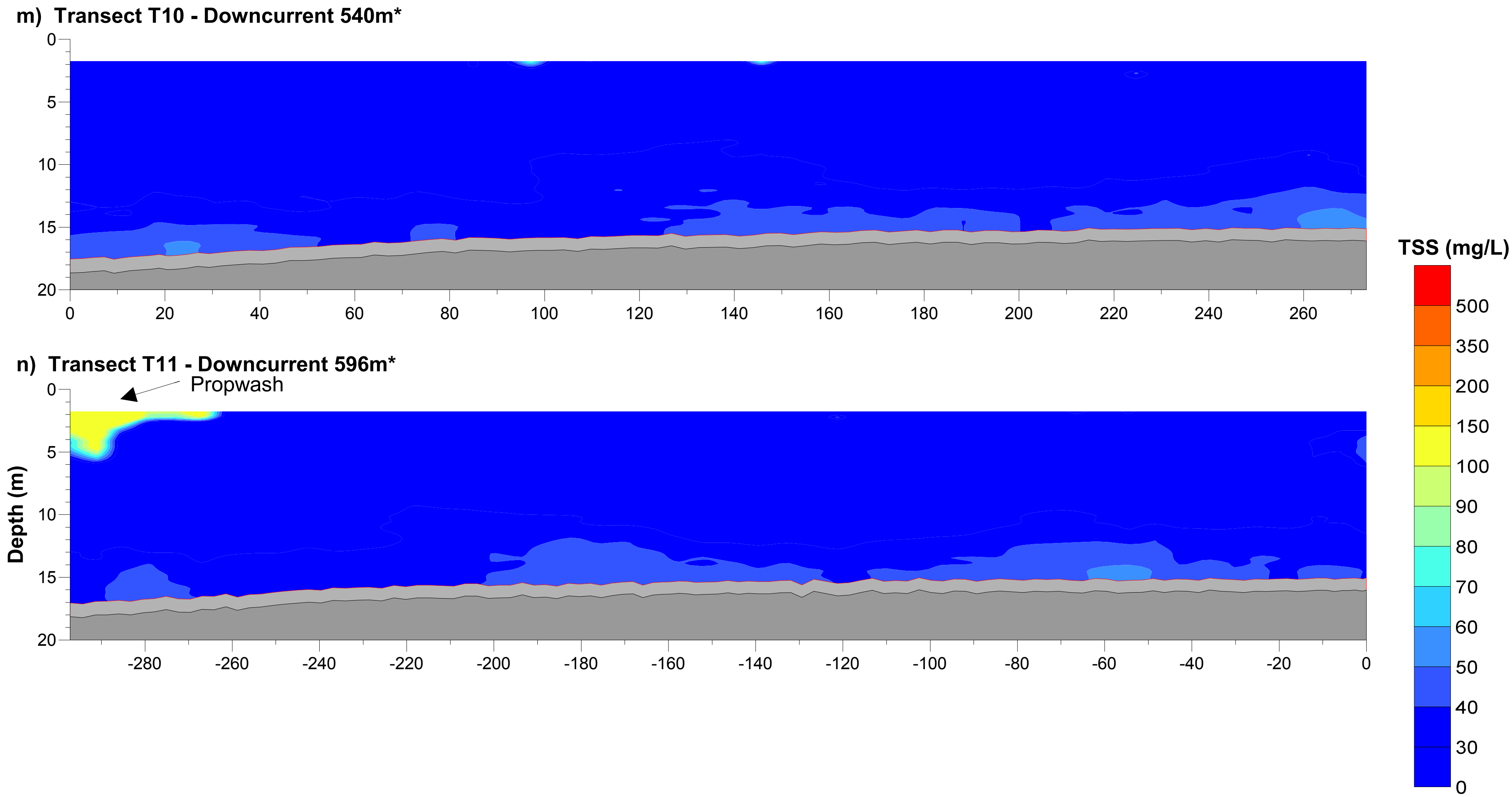


FIGURE	*USACE Harborwide TSS* *Far Field Survey* *HDP Contract Area: S-AN-2*	**Vertical Profiles of ADCP Average TSS** **06 January 2011**	TIDE
9j-l			**Flood**



*Approximate distance from source

FIGURE	*USACE Harborwide TSS* *Far Field Survey* *HDP Contract Area: S-AN-2*	**Vertical Profiles of ADCP Average TSS** **06 January 2011**	TIDE
9m-n			**Flood**

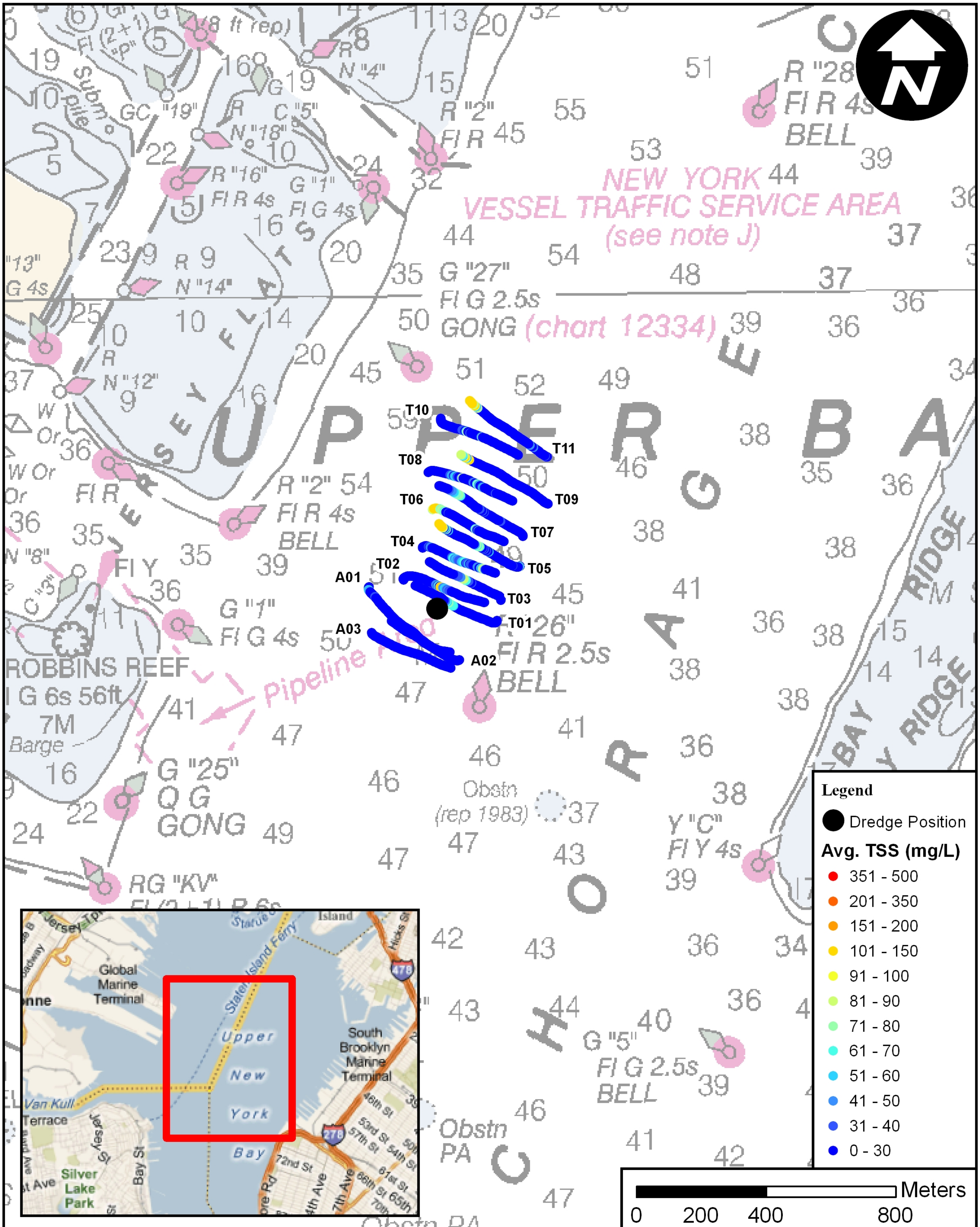


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	ADCP Average TSS - 06 January 2011 0-2 Meter Depth Interval	Tide
10a			Flood

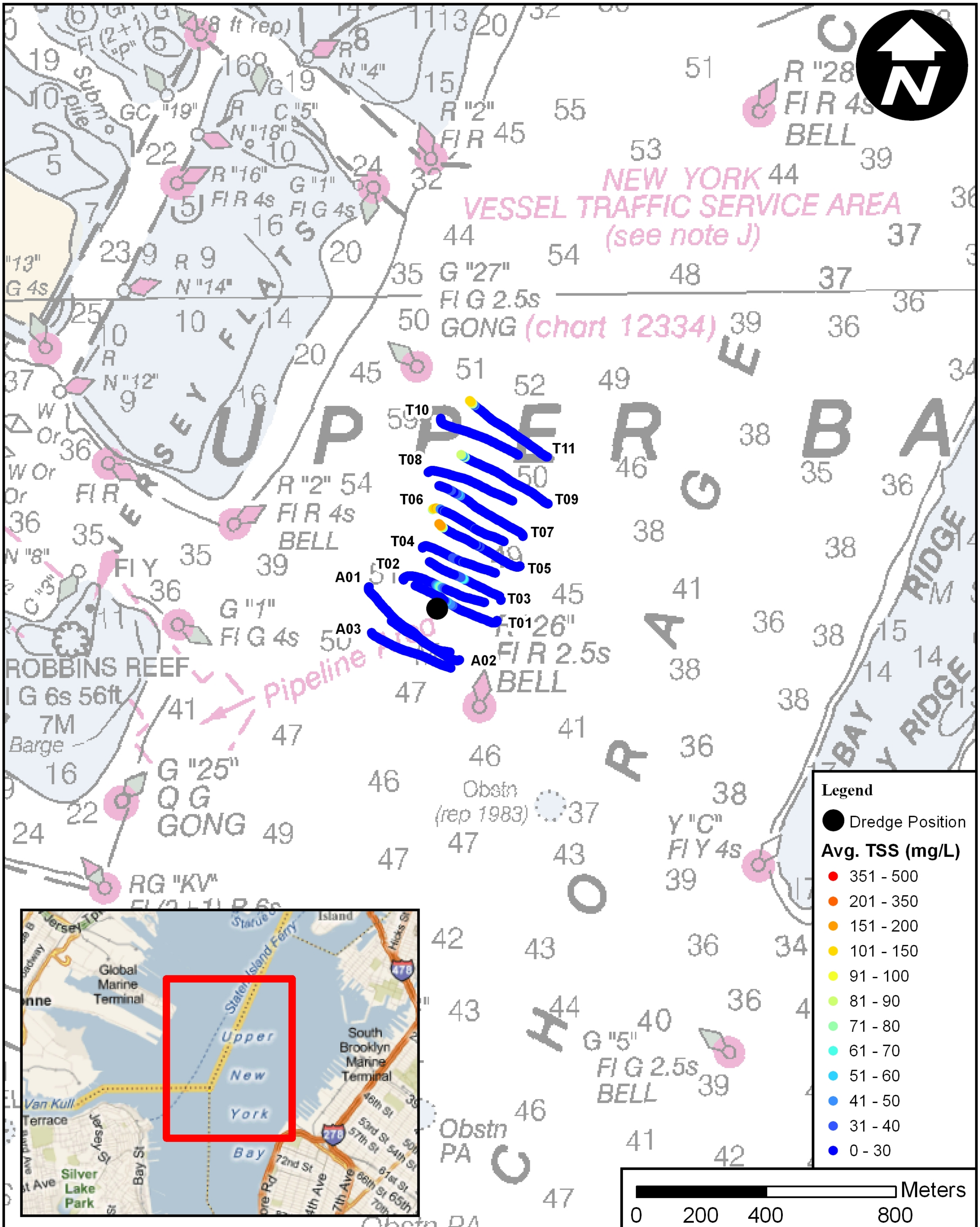


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	ADCP Average TSS - 06 January 2011 2-4 Meter Depth Interval	Tide
10b			Flood

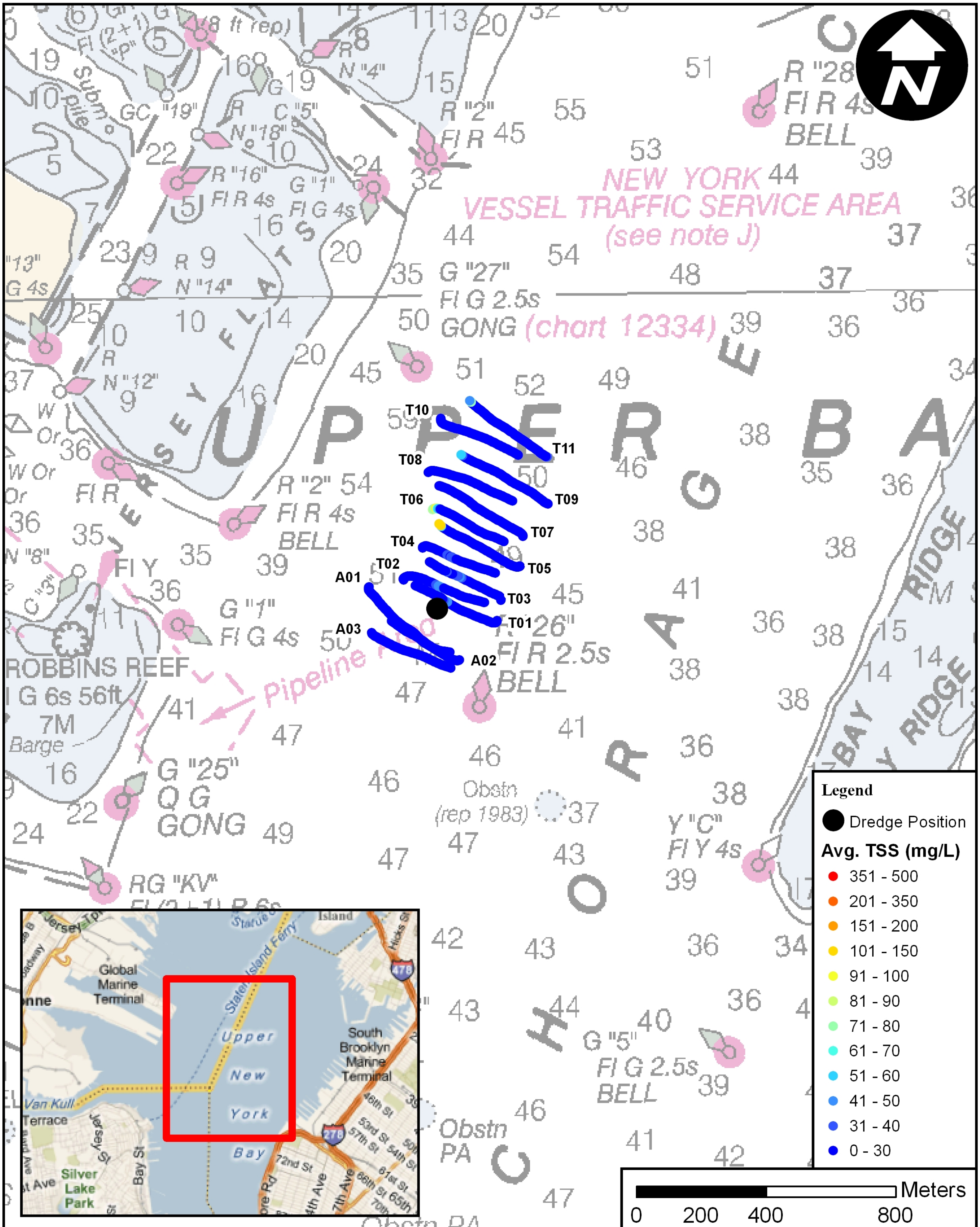


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	ADCP Average TSS - 06 January 2011 4-6 Meter Depth Interval	Tide
10c			Flood

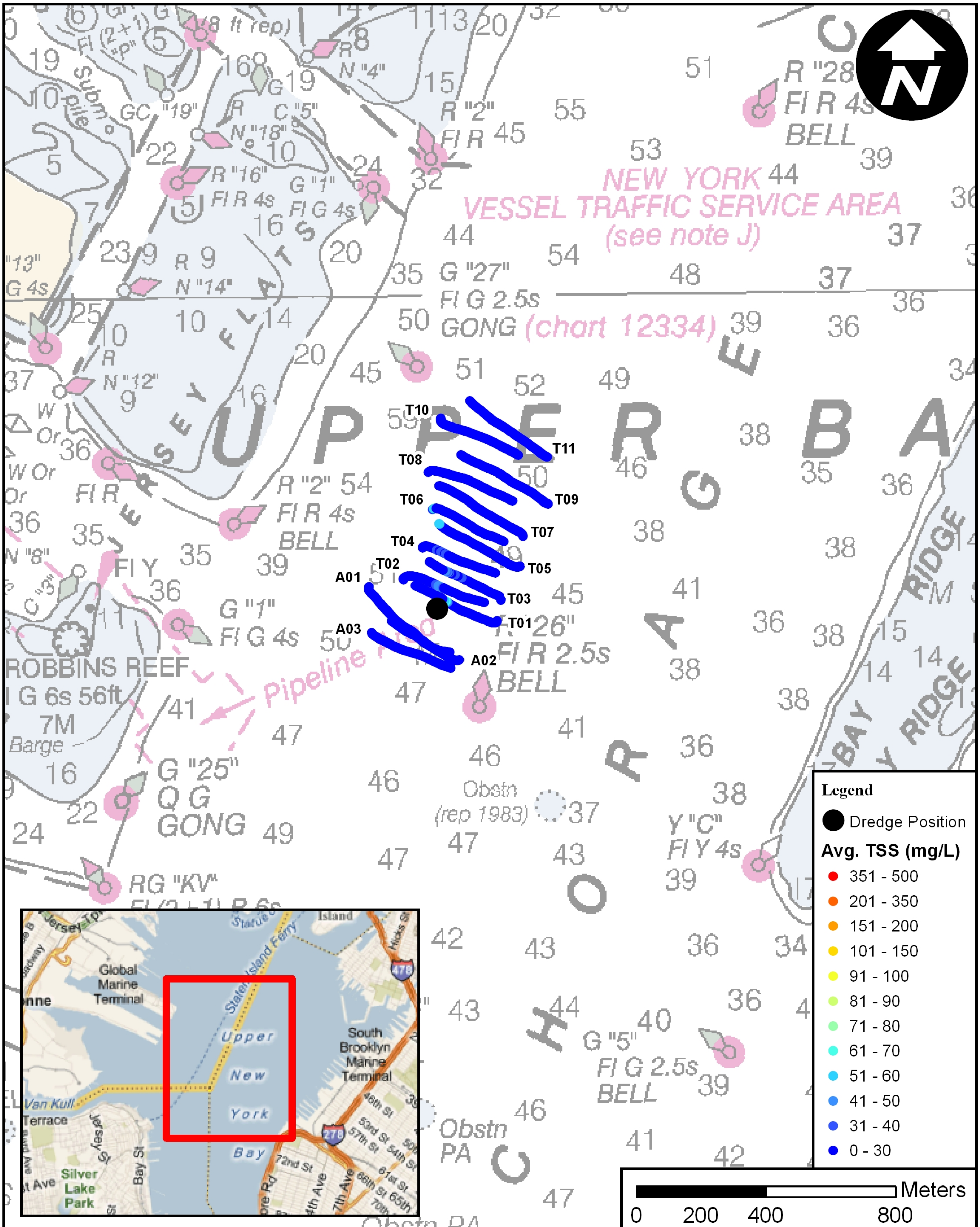


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	ADCP Average TSS - 06 January 2011 6-8 Meter Depth Interval	Tide
10d			Flood

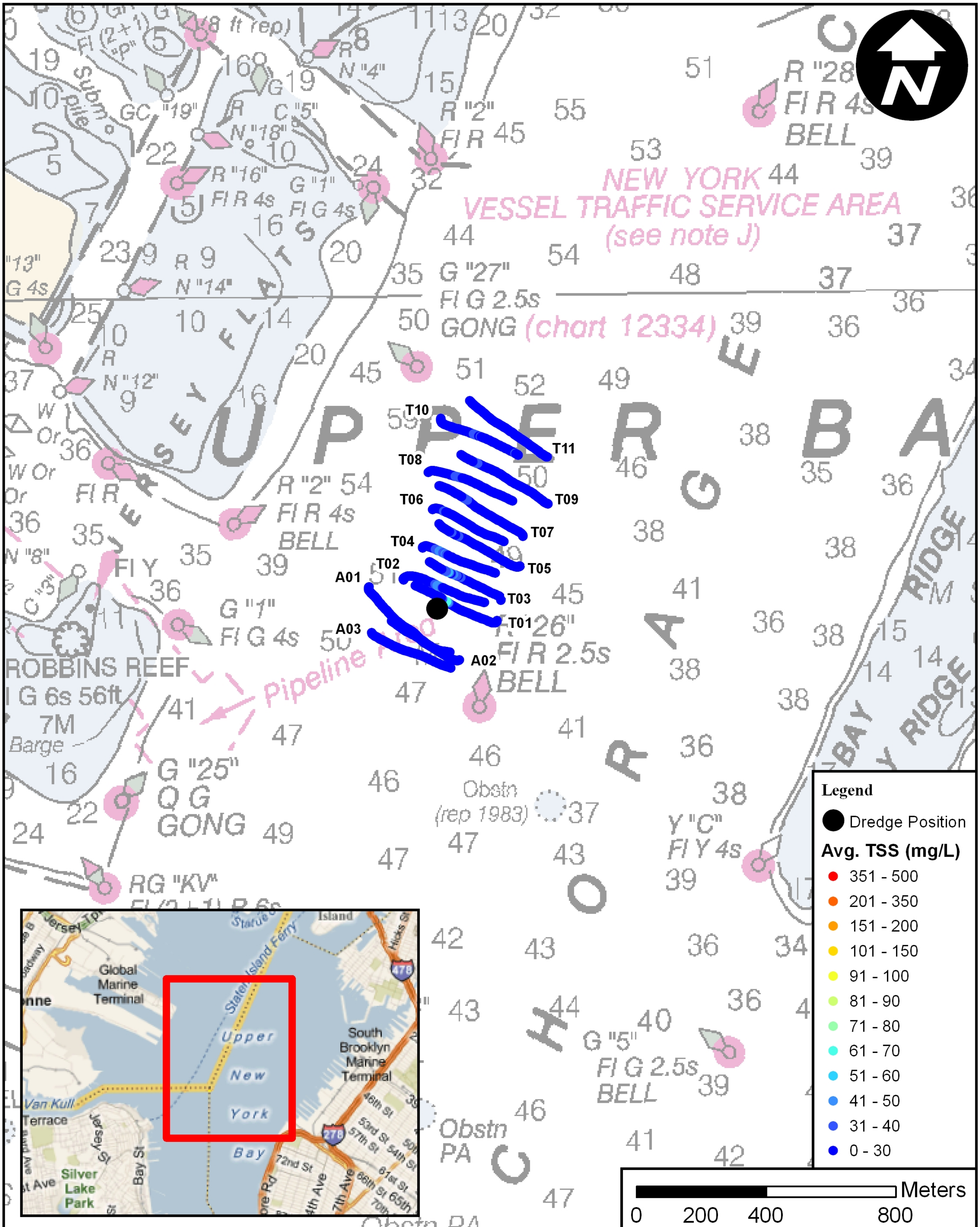


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	ADCP Average TSS - 06 January 2011 8-10 Meter Depth Interval	Tide
10e			Flood

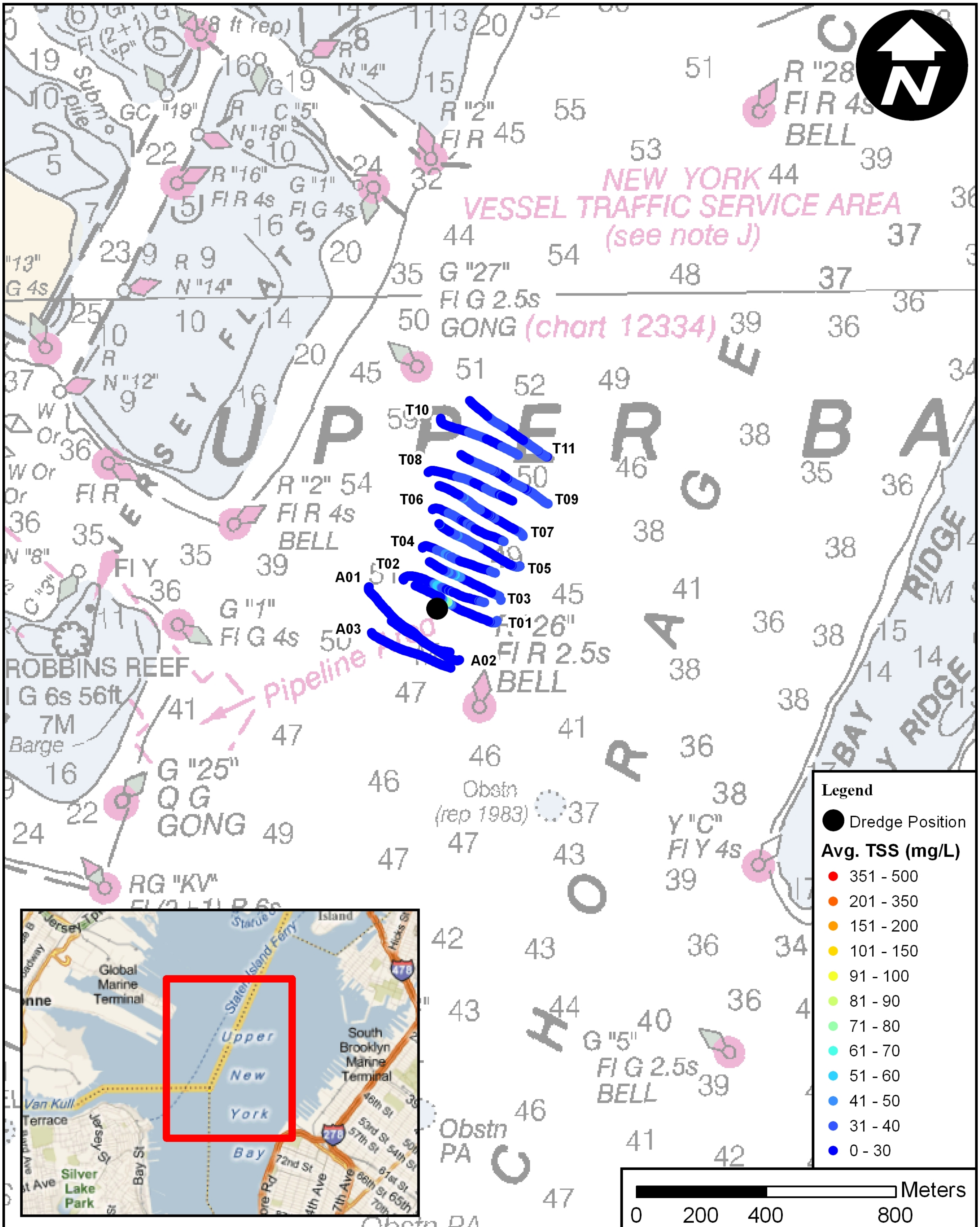


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	ADCP Average TSS - 06 January 2011 10-12 Meter Depth Interval	Tide
10f			Flood

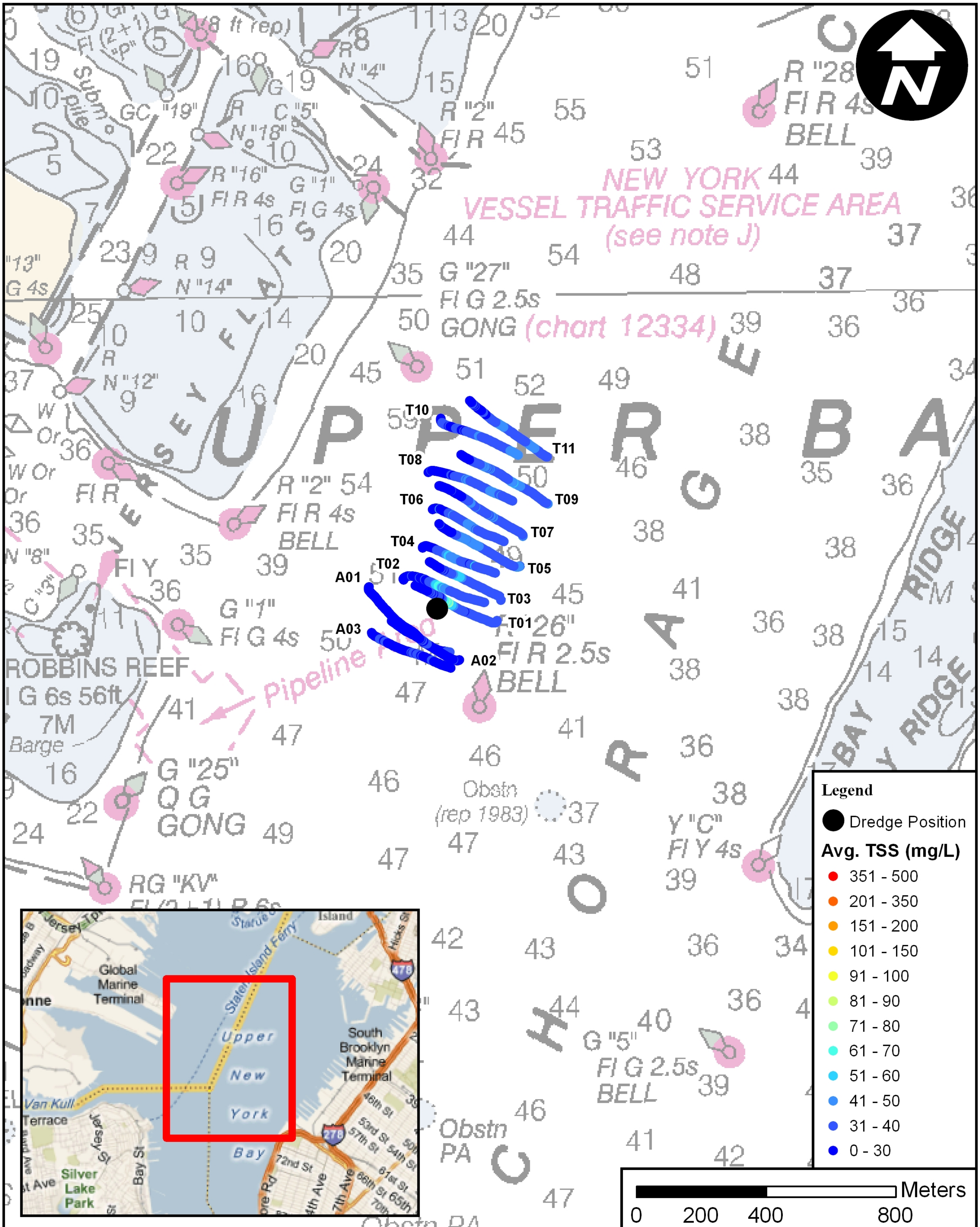


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	ADCP Average TSS - 06 January 2011 12-14 Meter Depth Interval	Tide
10g			Flood

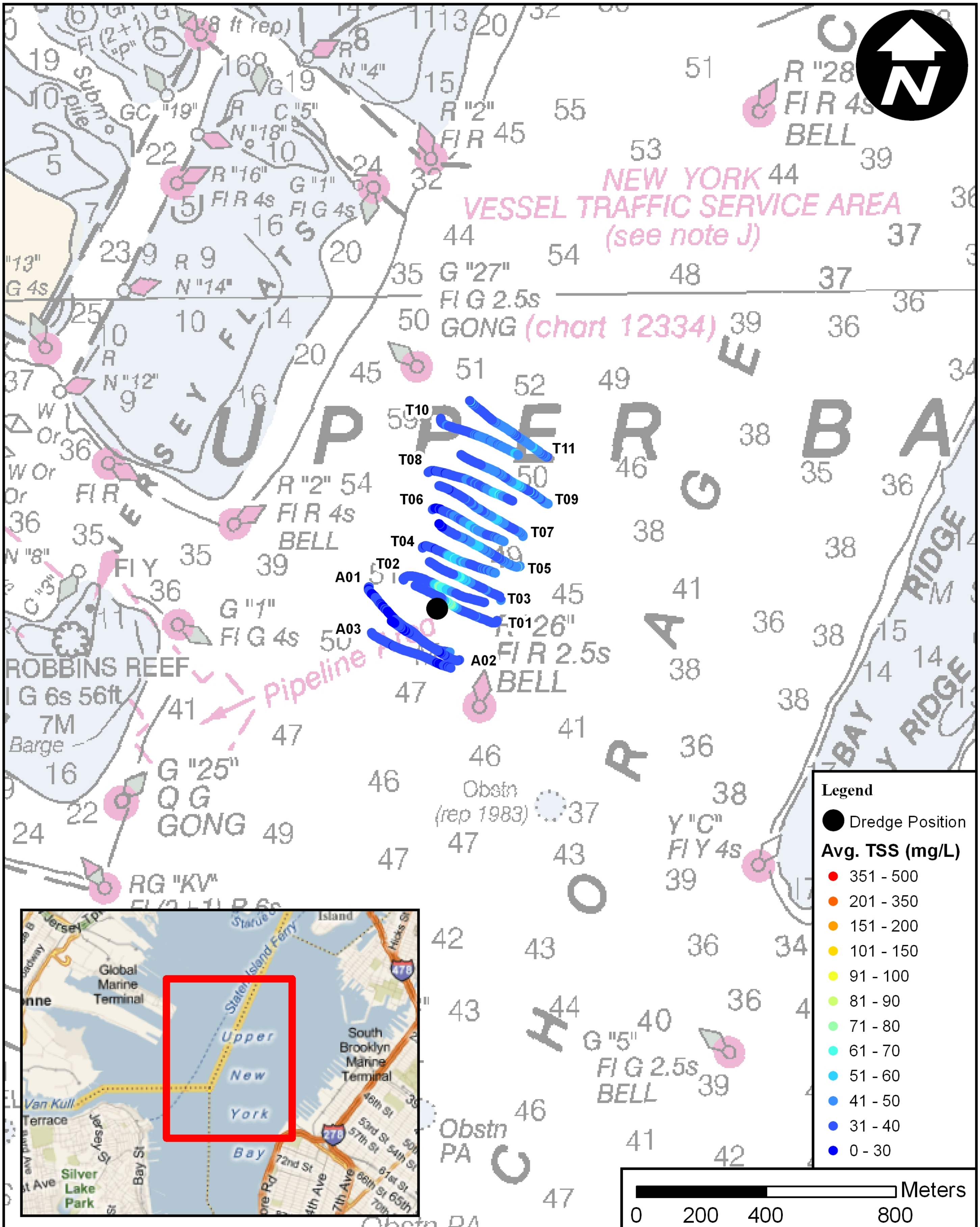
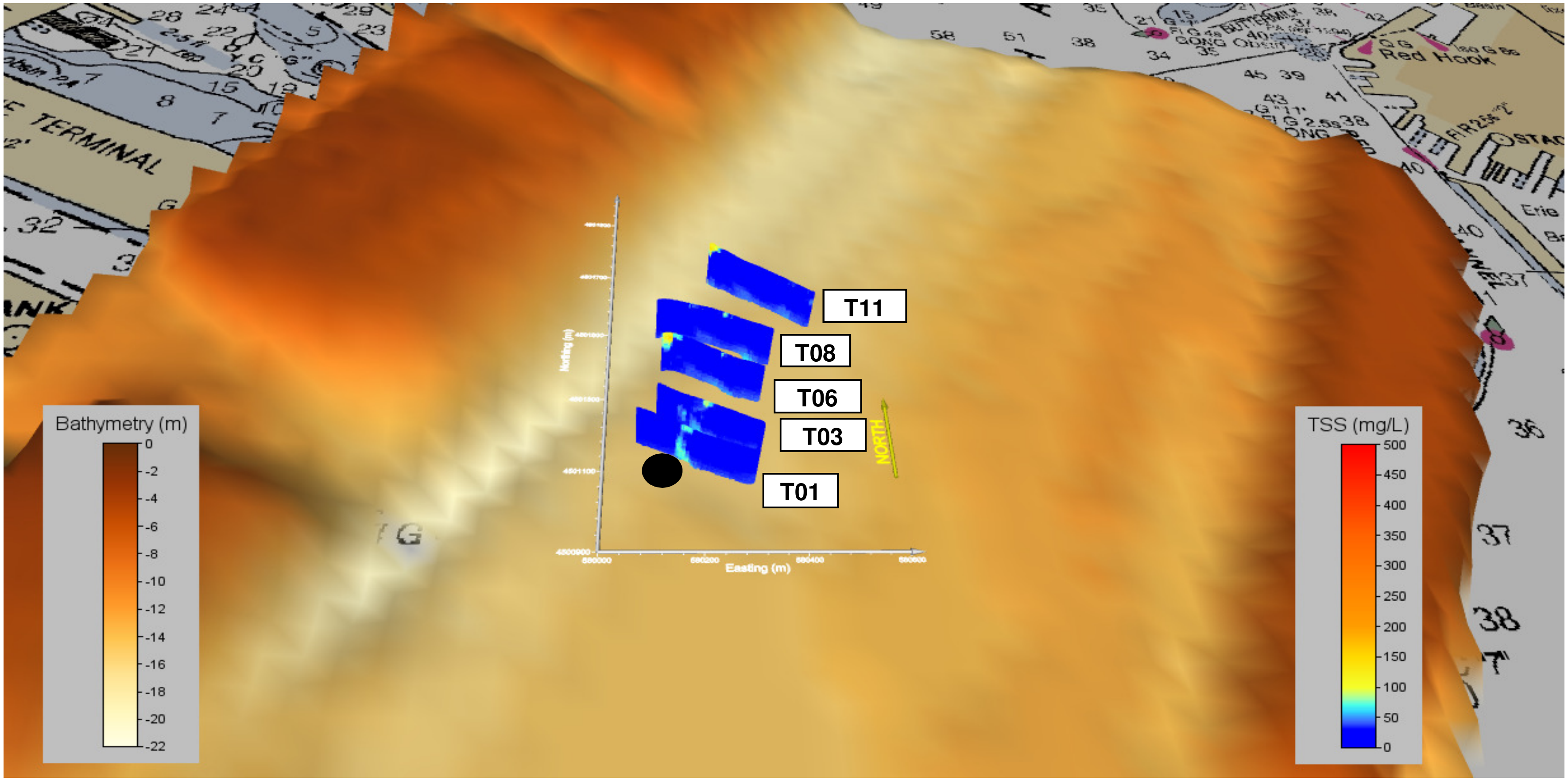
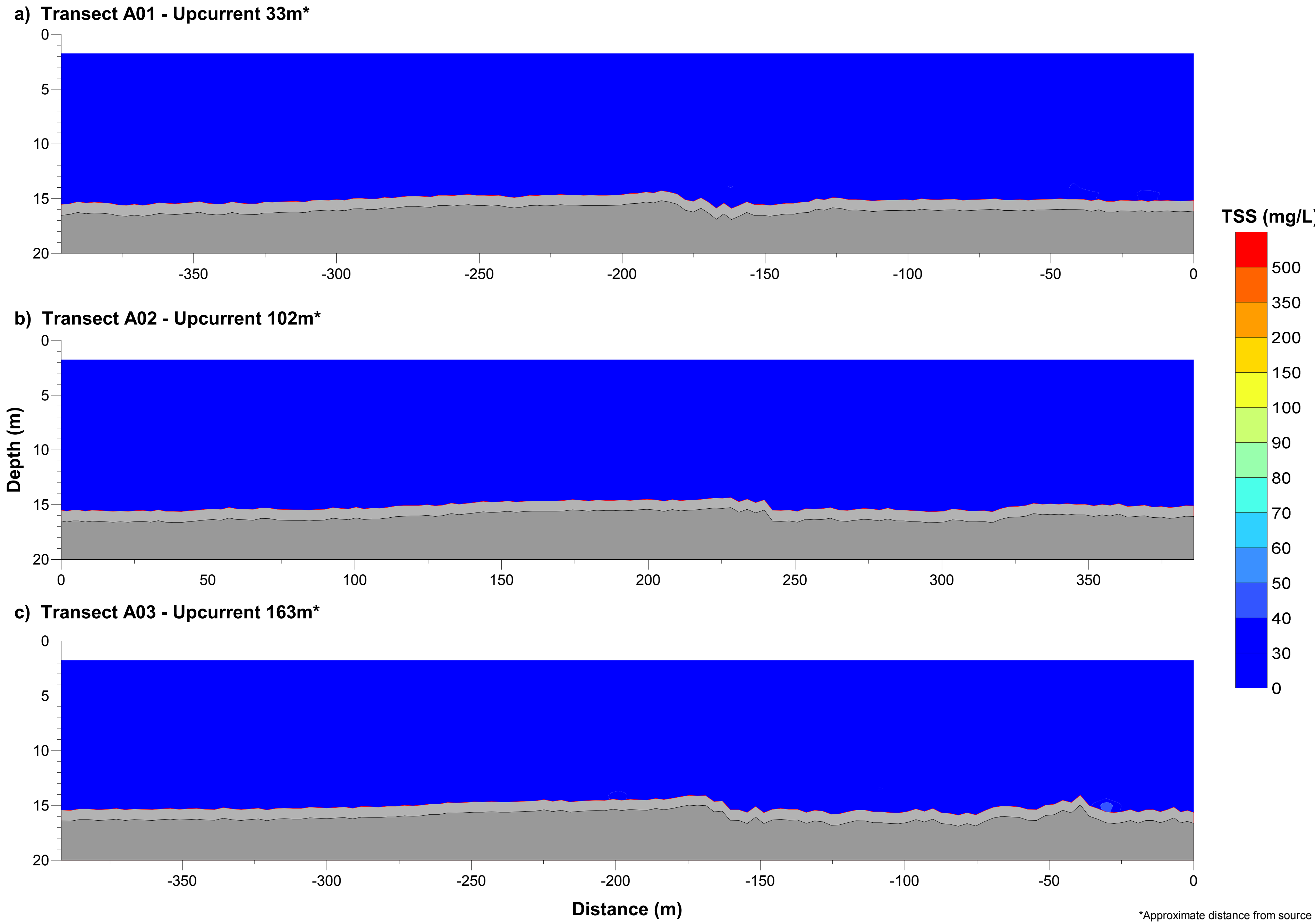


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	ADCP Average TSS - 06 January 2011 14-16 Meter Depth Interval	Tide
10h			Flood



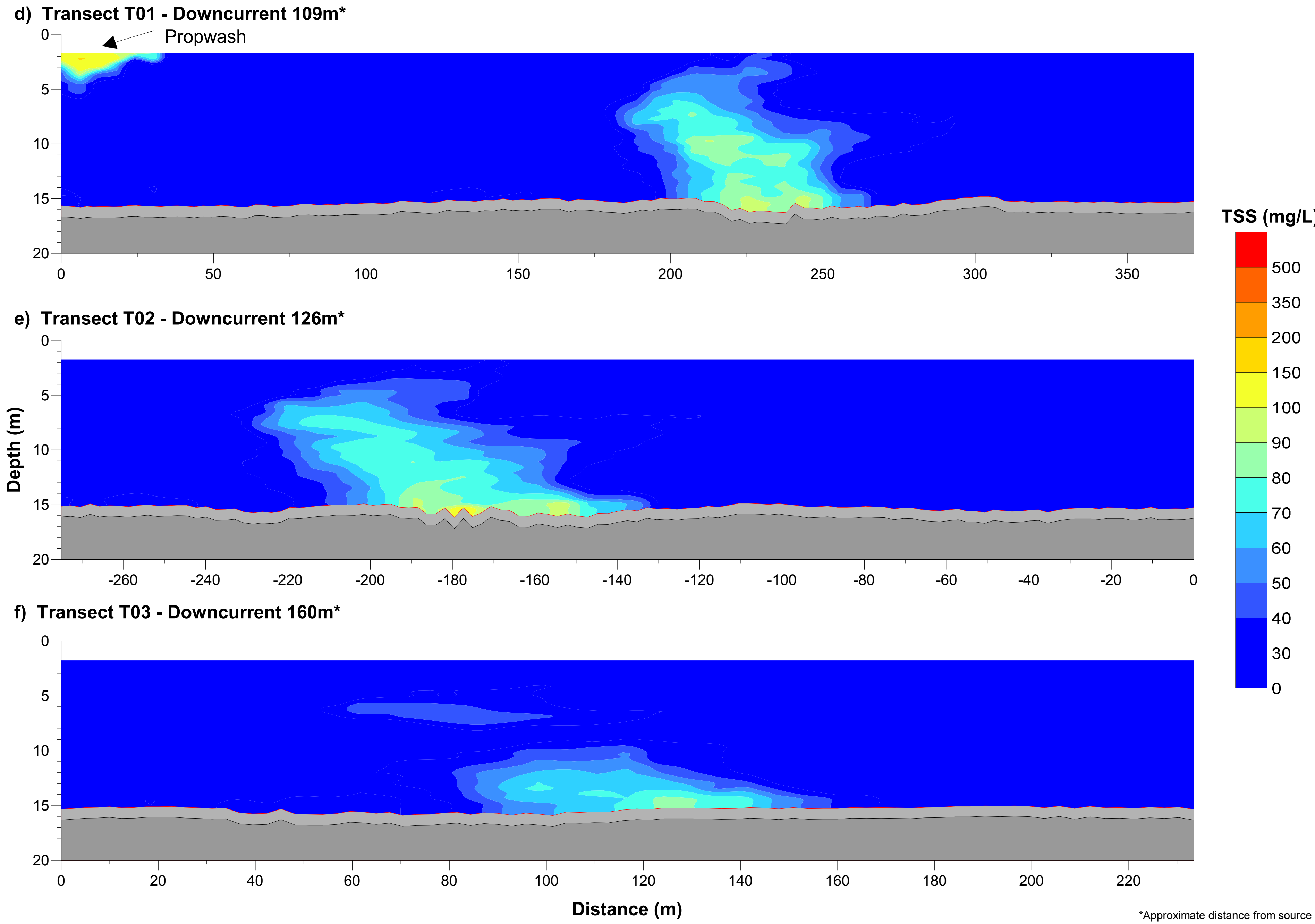
Bathymetry produced by NOAA soundings ● = Dredge Location Z scale exaggerated 6X

Figure	*USACE Harborwide TSS*	ADCP Average TSS Values, 3D View of Selected Transects	Tide
11	*Far Field Survey* *HDP Contract Area S-AN-2*	Superimposed on Channel Bathymetry 06 January 2011	Flood



*Approximate distance from source

FIGURE	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	Vertical Profiles of ADCP Average TSS 06 January 2011	TIDE
12a-c			Ebb



*Approximate distance from source

FIGURE	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	Vertical Profiles of ADCP Average TSS 06 January 2011	TIDE
12d-f			Ebb

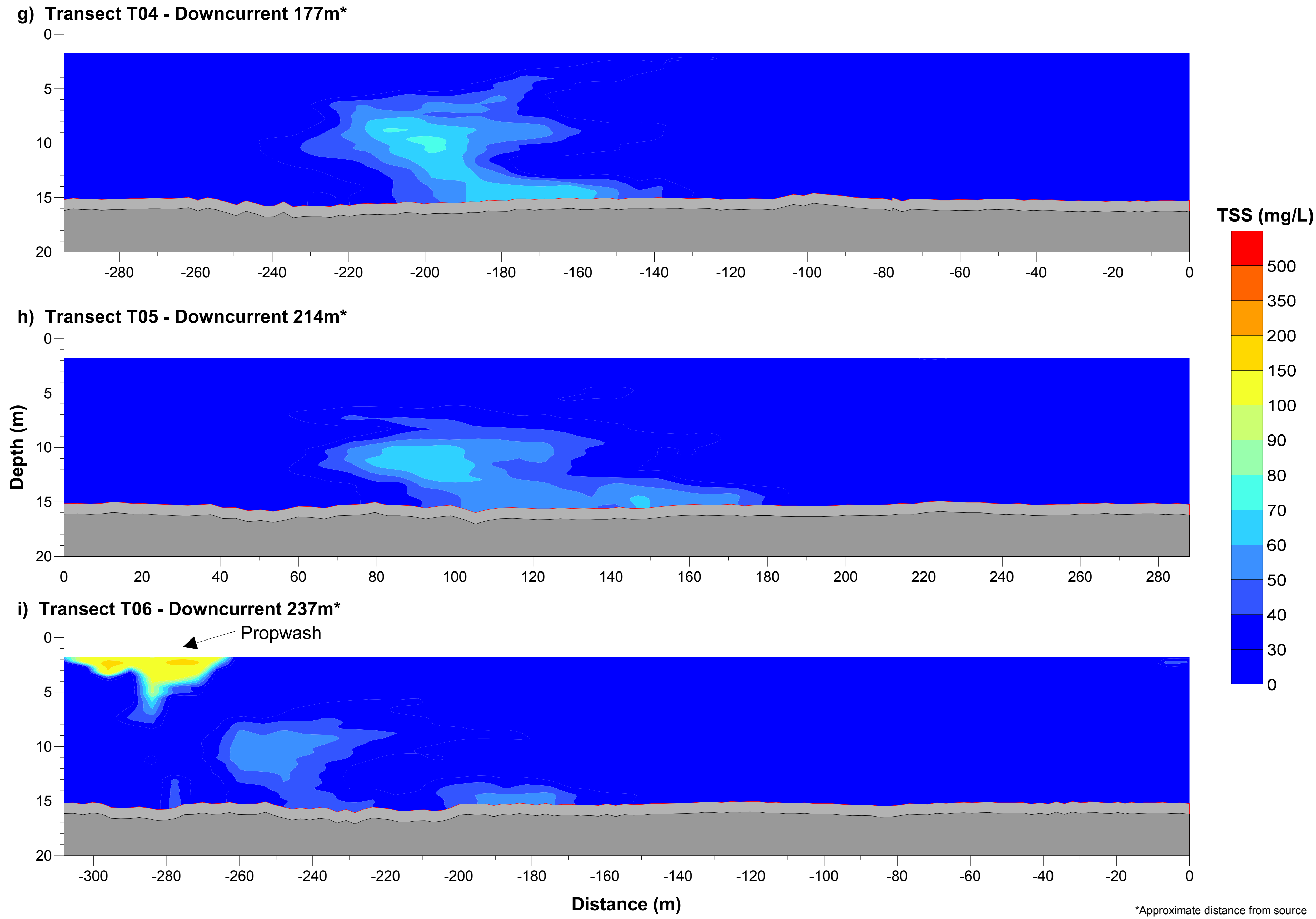
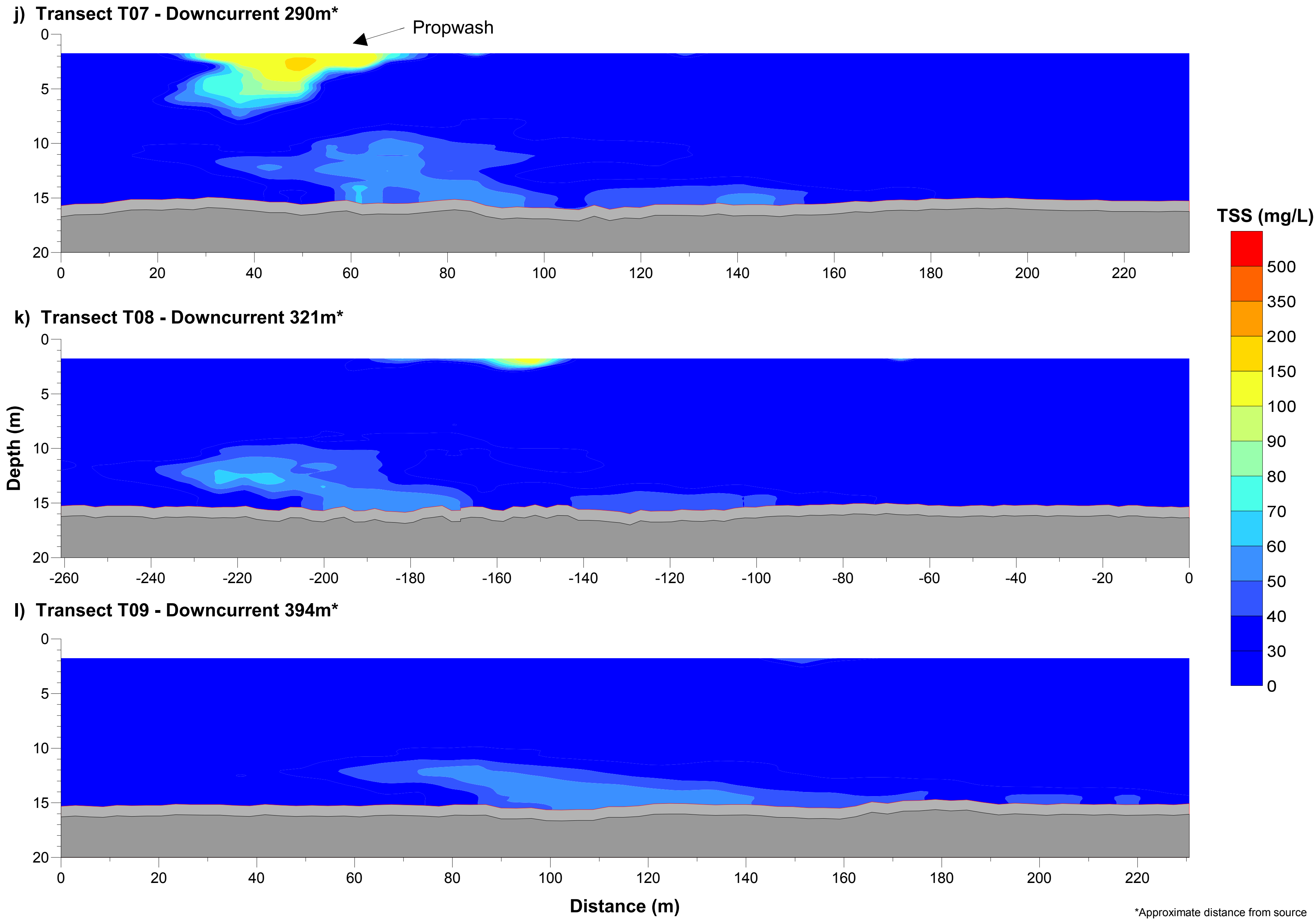


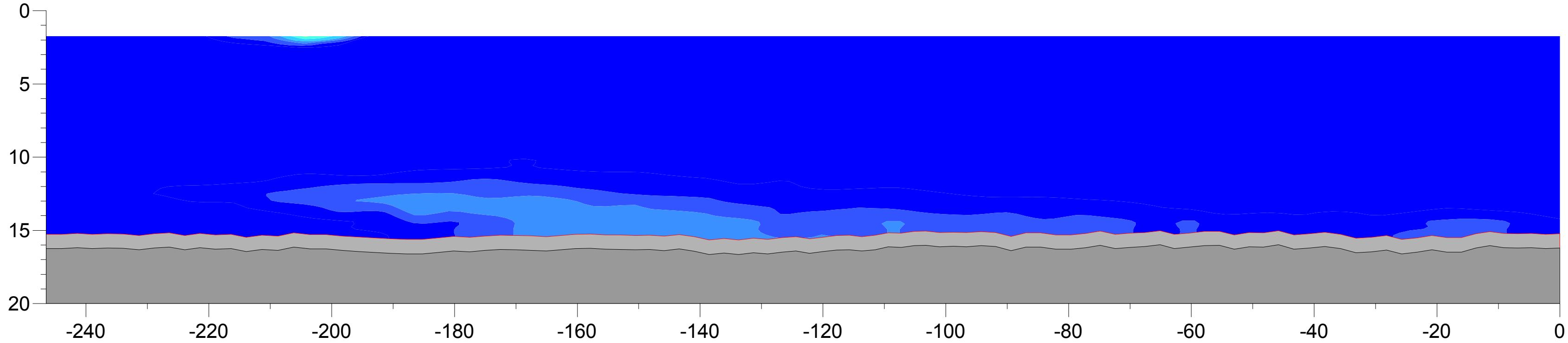
FIGURE	*USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2*	**Vertical Profiles of ADCP Average TSS 06 January 2011**	TIDE
12g-i			Ebb



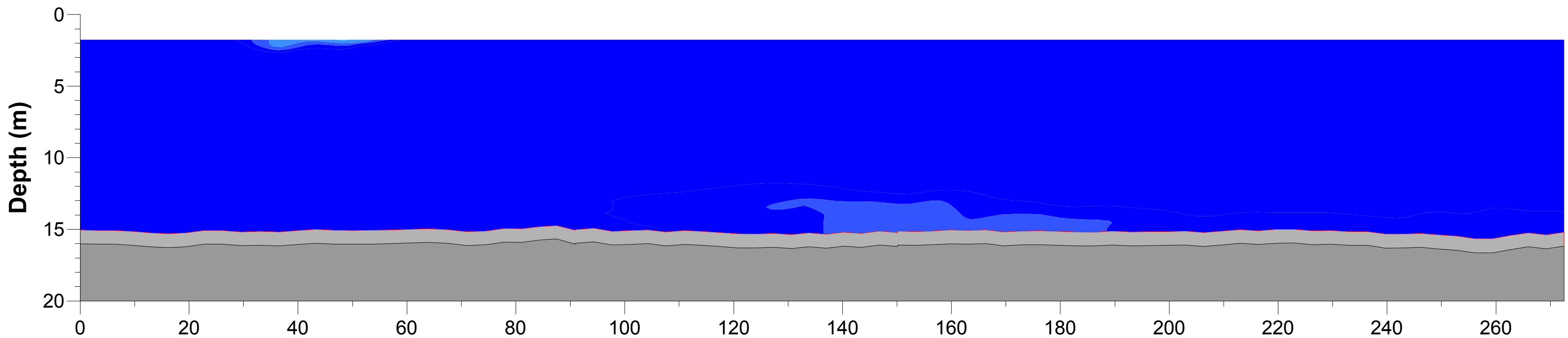
*Approximate distance from source

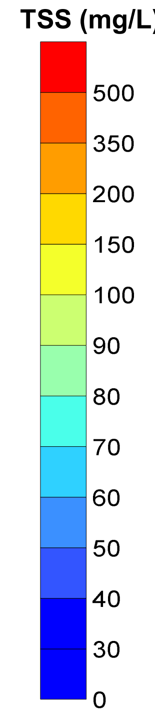
FIGURE	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	Vertical Profiles of ADCP Average TSS 06 January 2011	TIDE
12j-l			Ebb

m) Transect T10 - Downcurrent 425m*



n) Transect T11 - Downcurrent 517m*





*Approximate distance from source

FIGURE	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	Vertical Profiles of ADCP Average TSS 06 January 2011	TIDE
12m-n			Ebb

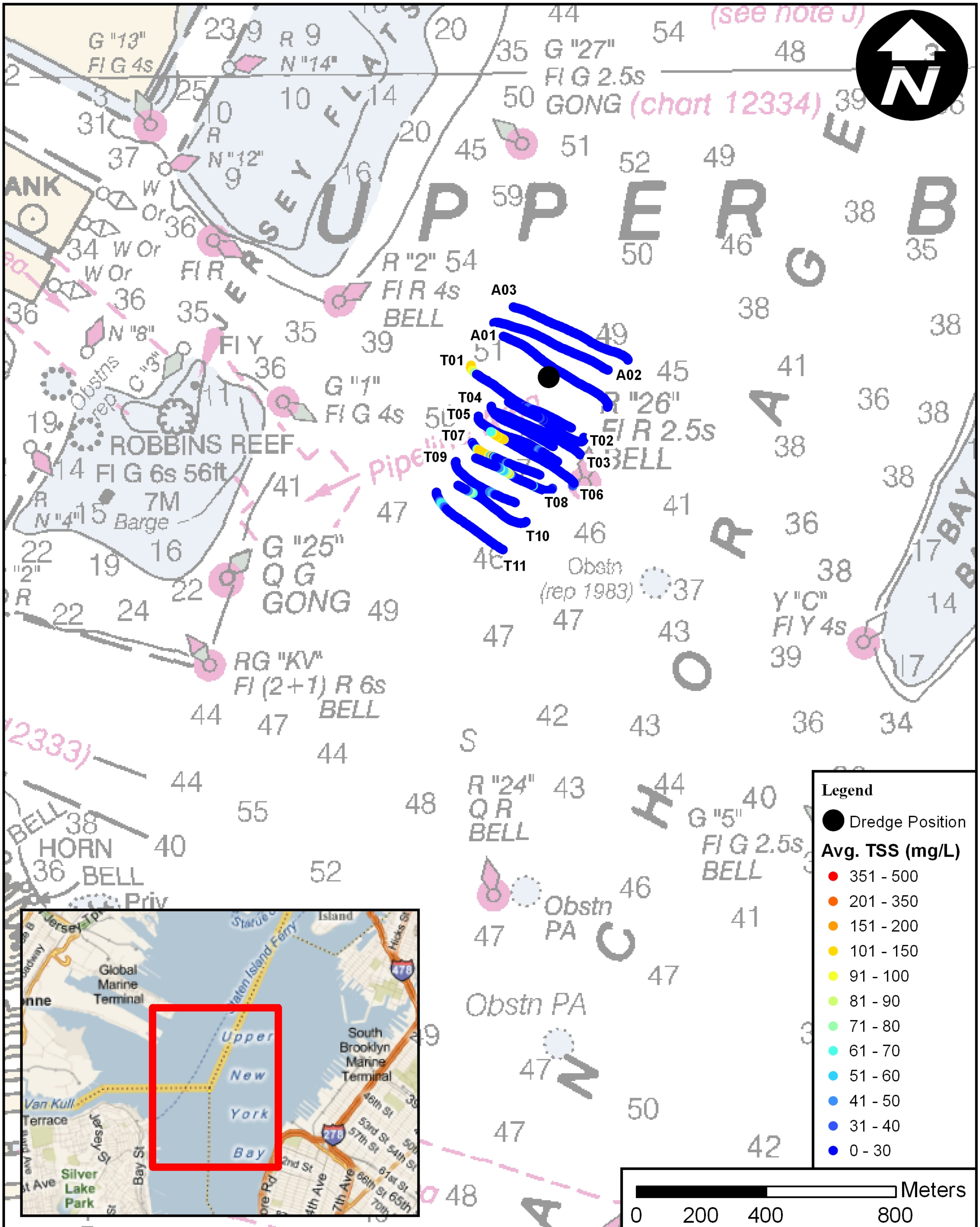


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	**ADCP Average TSS - 06 January 2011** **0-2 Meter Depth Interval**	Tide
13a			Ebb

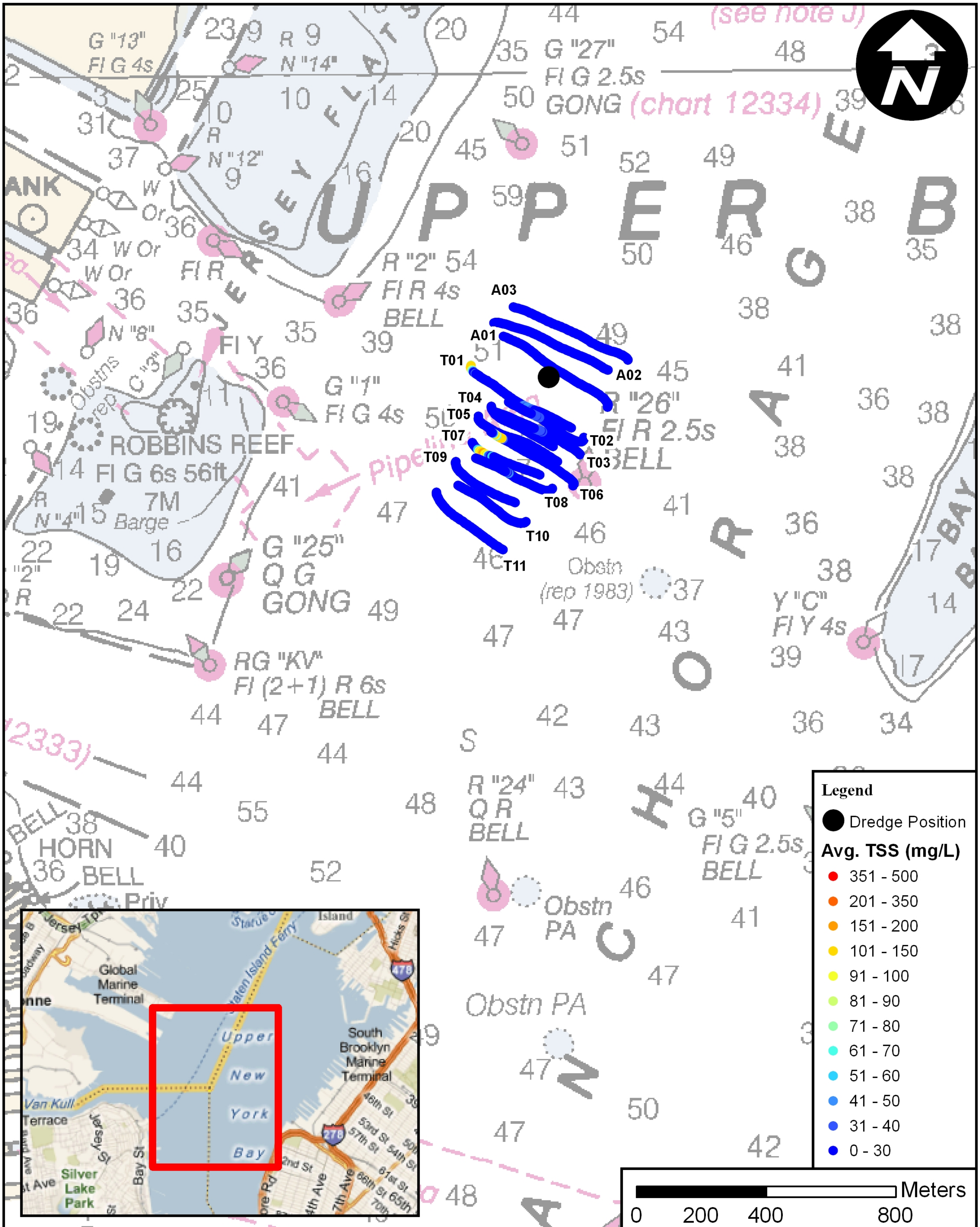


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	ADCP Average TSS - 06 January 2011 2-4 Meter Depth Interval	Tide
13b			Ebb

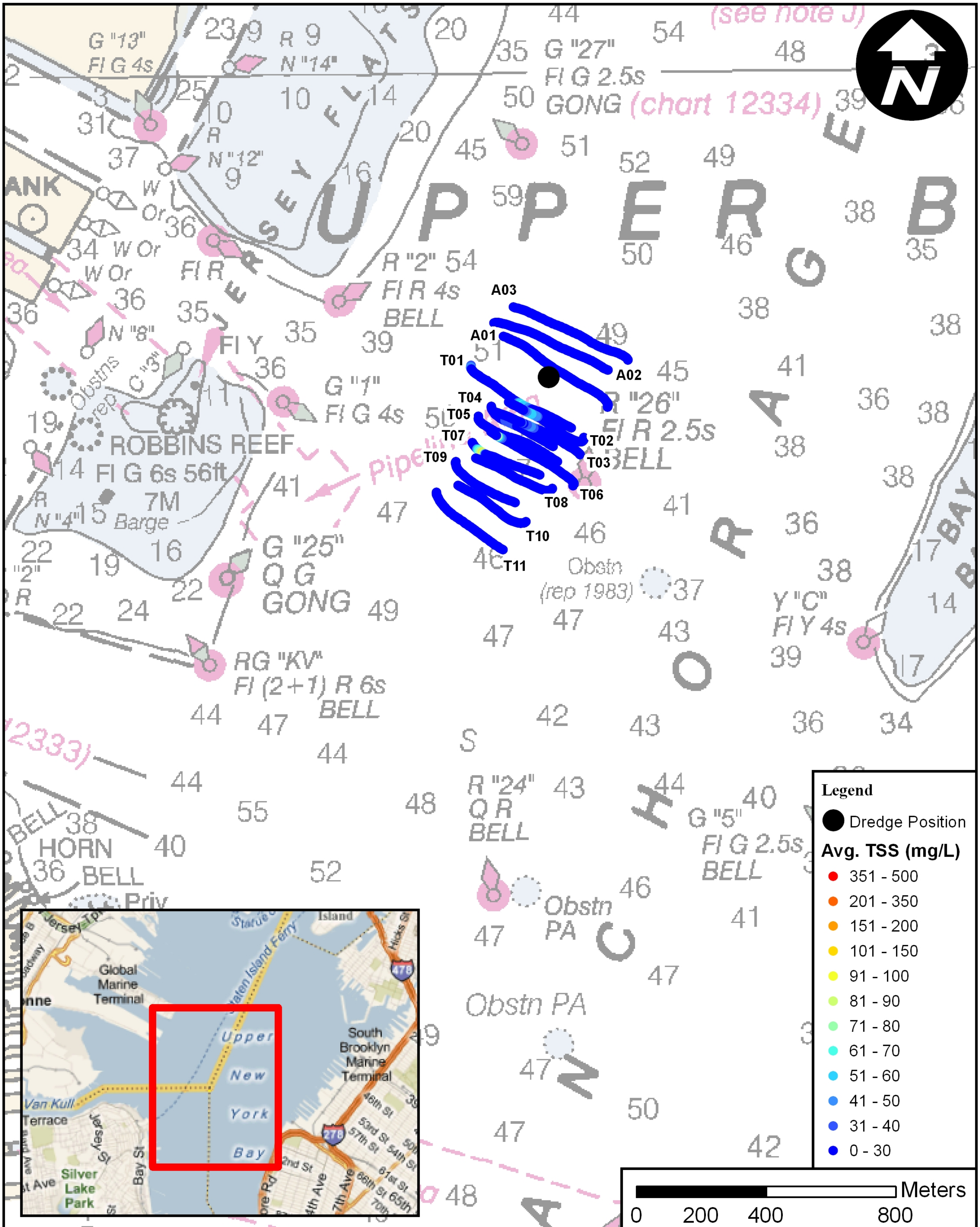


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	ADCP Average TSS - 06 January 2011 4-6 Meter Depth Interval	Tide
13c			Ebb

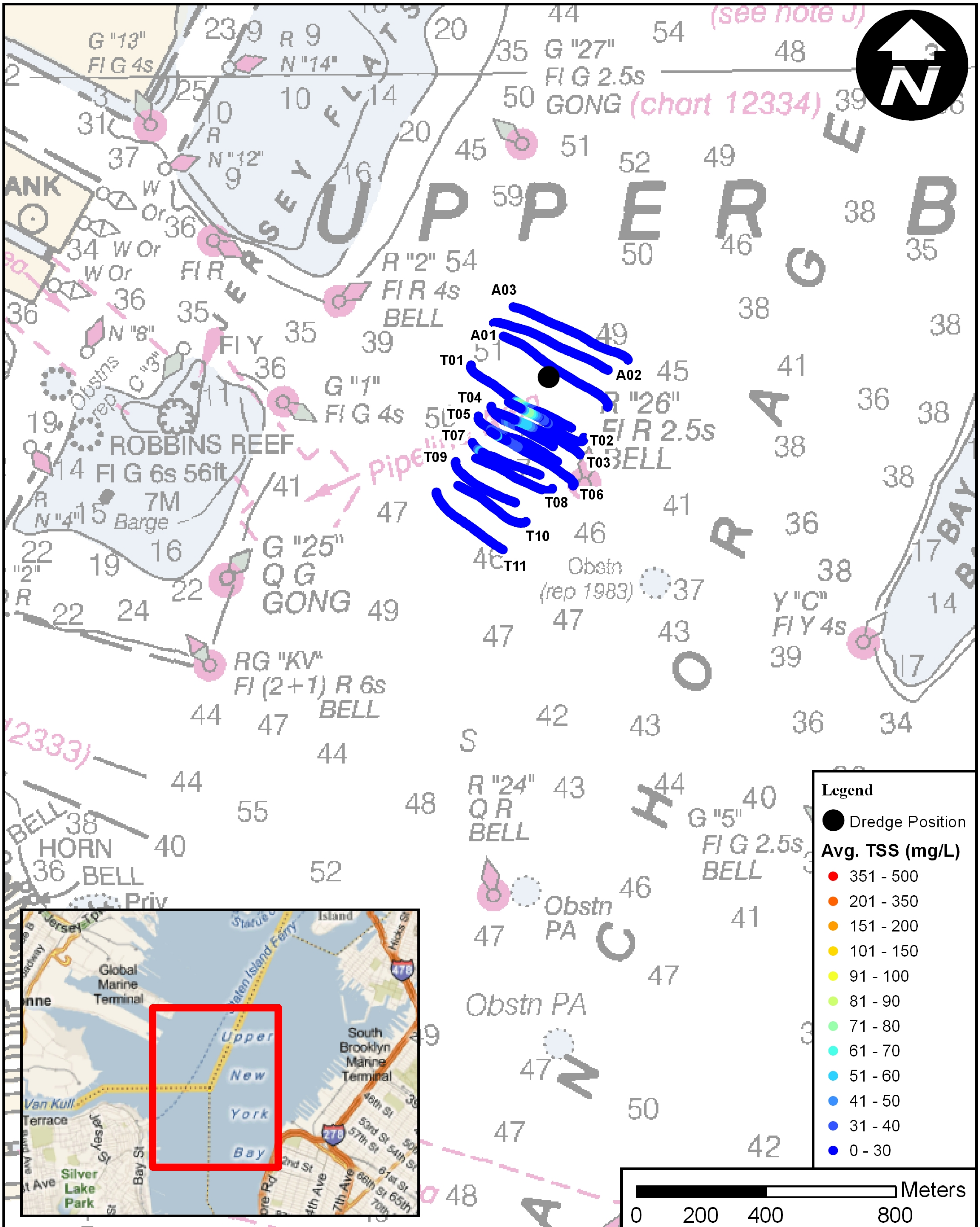


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	ADCP Average TSS - 06 January 2011 6-8 Meter Depth Interval	Tide
13d			Ebb

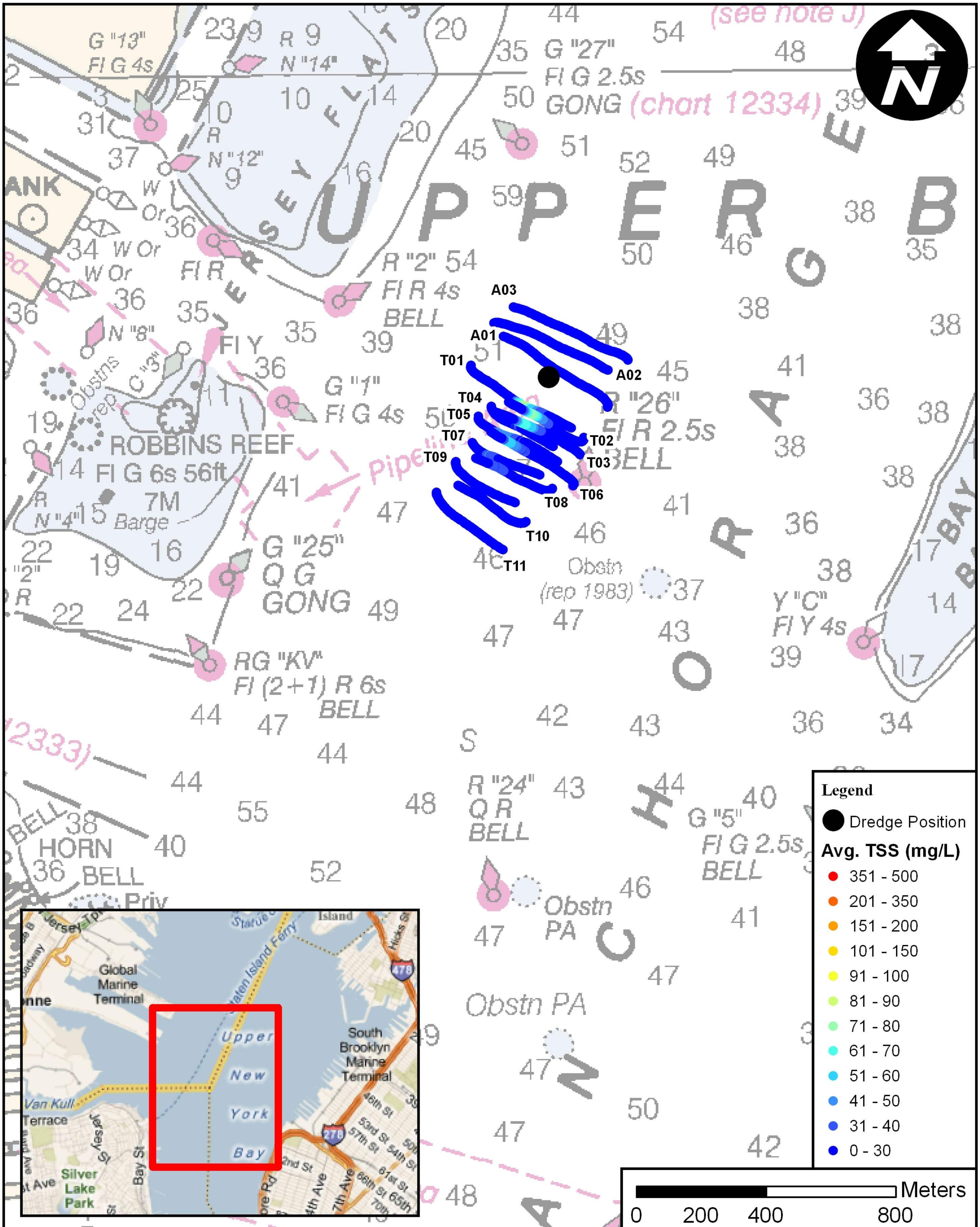


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	ADCP Average TSS - 06 January 2011 8-10 Meter Depth Interval	Tide
13e			Ebb

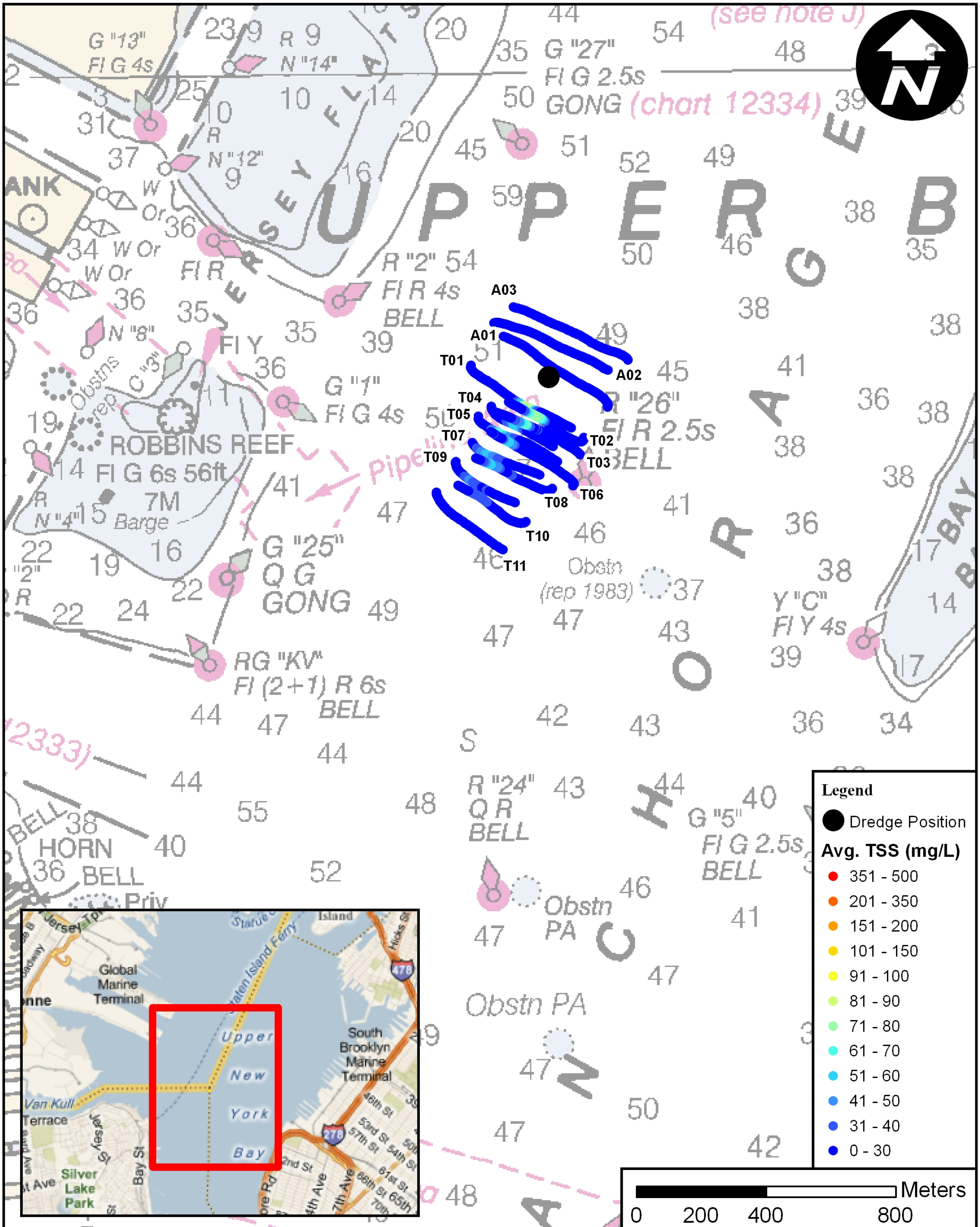


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	ADCP Average TSS - 06 January 2011 10-12 Meter Depth Interval	Tide
13f			Ebb

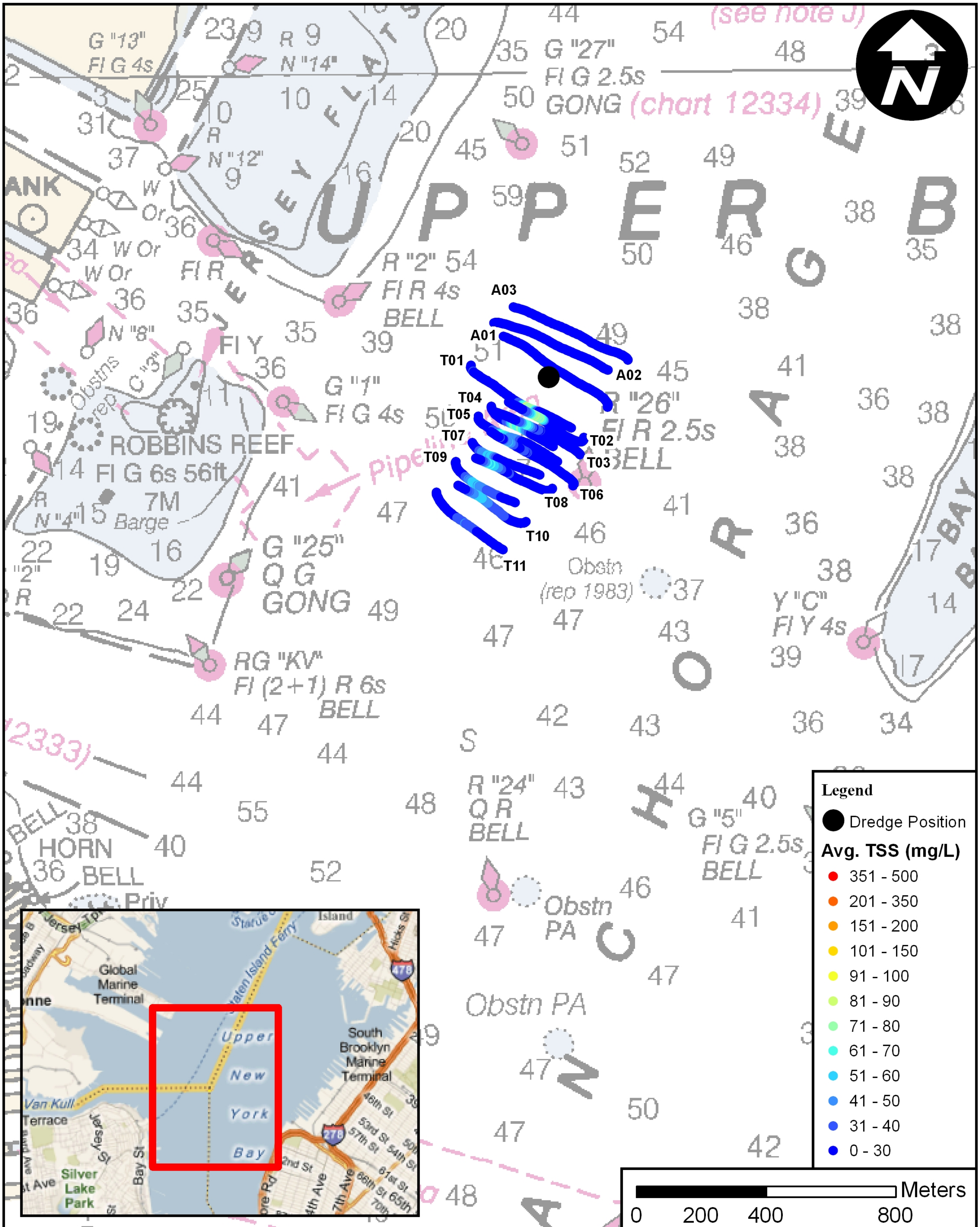


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	ADCP Average TSS - 06 January 2011 12-14 Meter Depth Interval	Tide
13g			Ebb

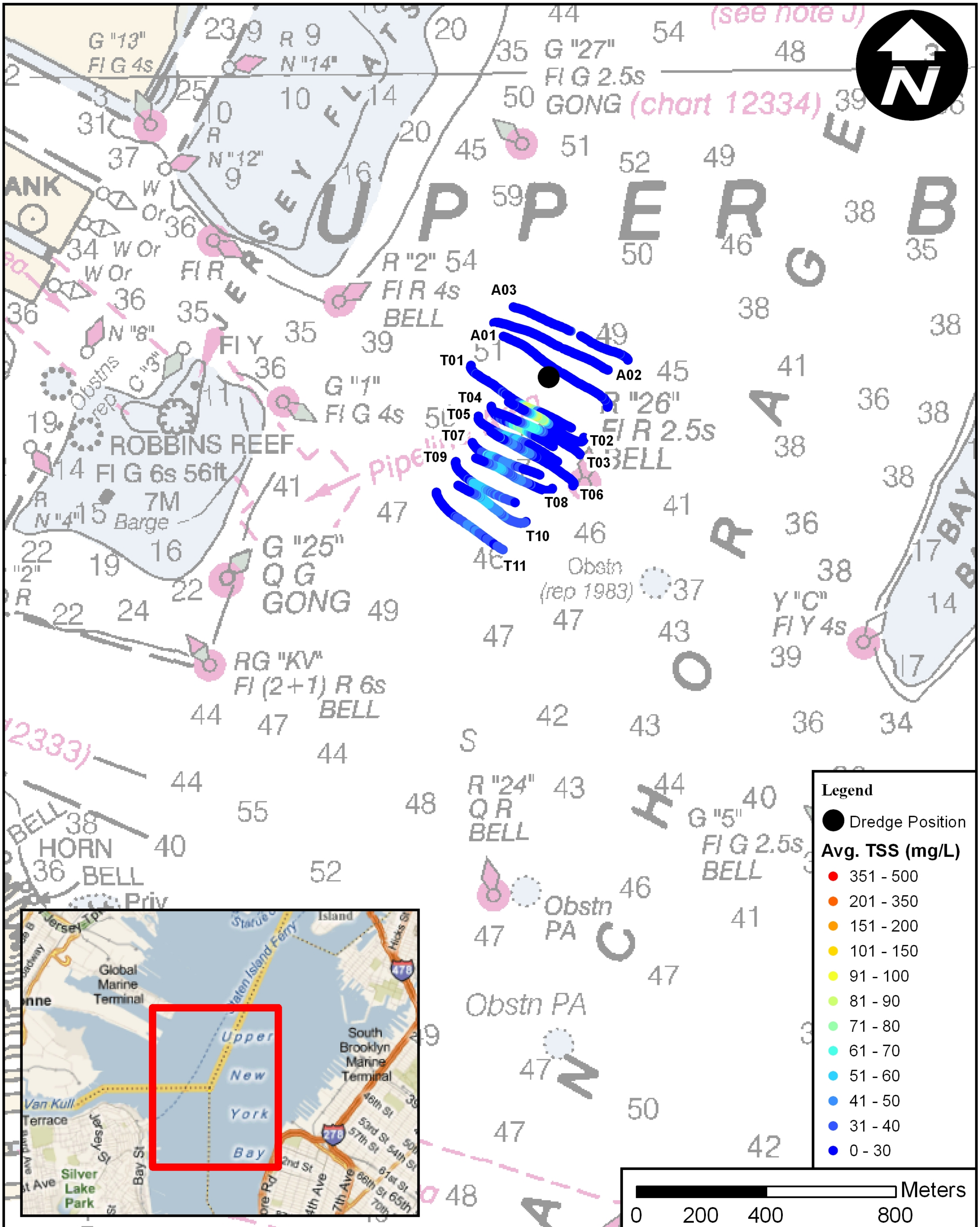
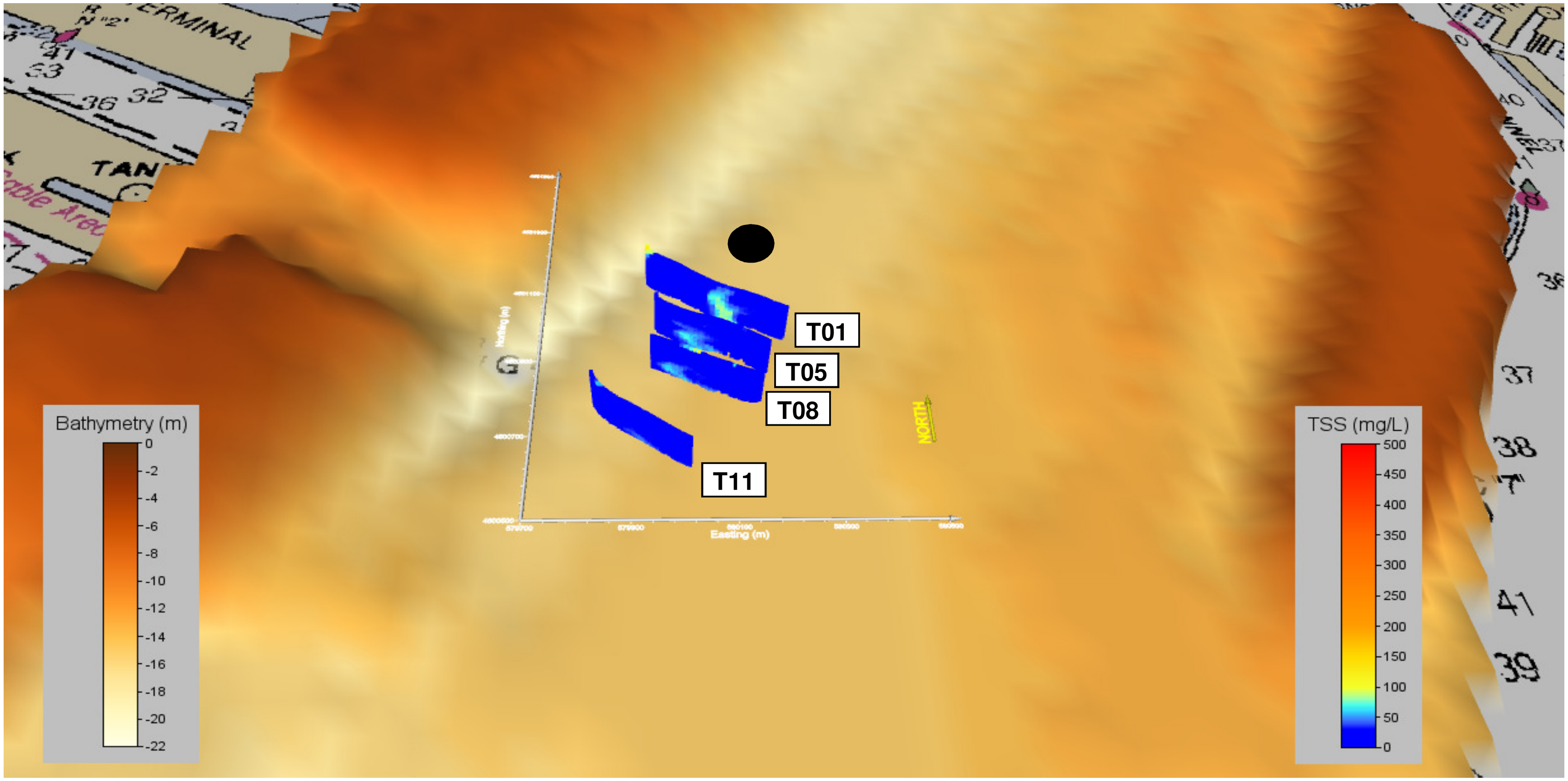


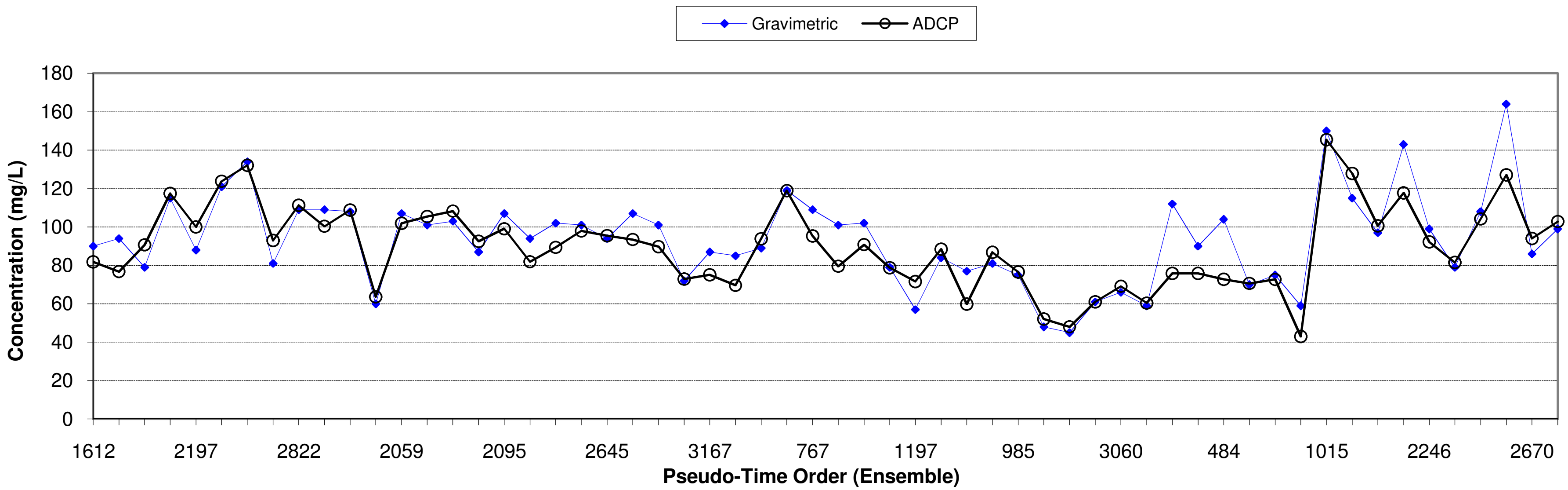
Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	ADCP Average TSS - 06 January 2011 14-16 Meter Depth Interval	Tide
13h			Ebb



Bathymetry produced by NOAA soundings ● = Dredge Location Z scale exaggerated 6X

Figure	*USACE Harborwide TSS*	ADCP Average TSS Values, 3D View of Selected Transects	Tide
14	*Far Field Survey* *HDP Contract Area S-AN-2*	Superimposed on Channel Bathymetry 06 January 2011	Ebb

a) Concentration vs. Time



b) ADCP Concentration vs. Gravimetric Concentration

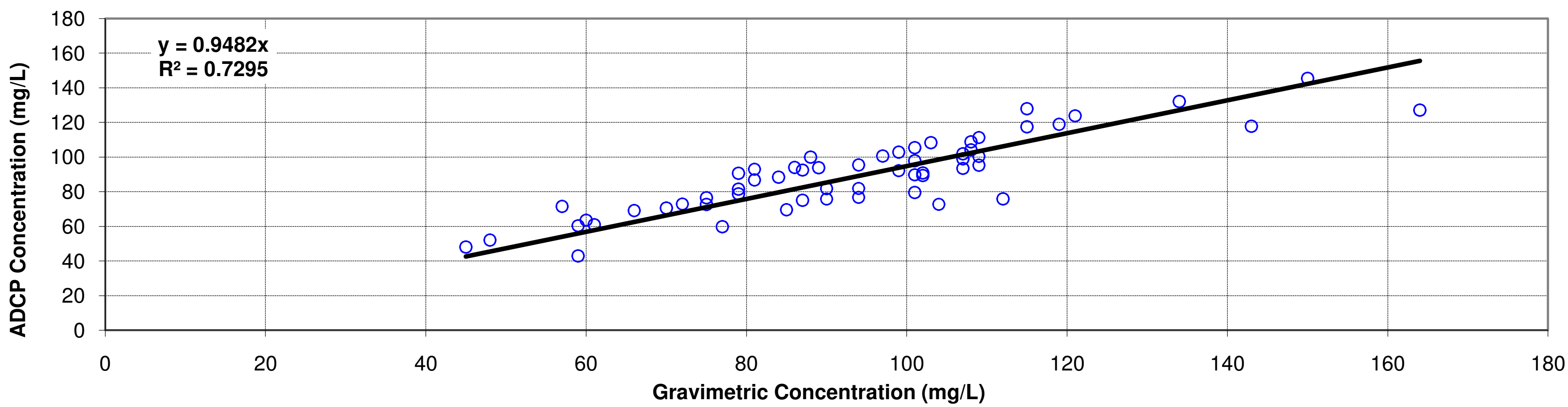


Figure	*USACE Harborwide TSS* *Far Field Survey* *HDP Contract Area: S-AN-2*	**Comparison of gravimetric and ADCP estimates of TSS concentration** **a) Concentration vs. Time b) ADCP Concentration vs. Gravimetric Concentration** **04 January - 07 January 2011 TSS Survey**	Tide
15a-b			N/A

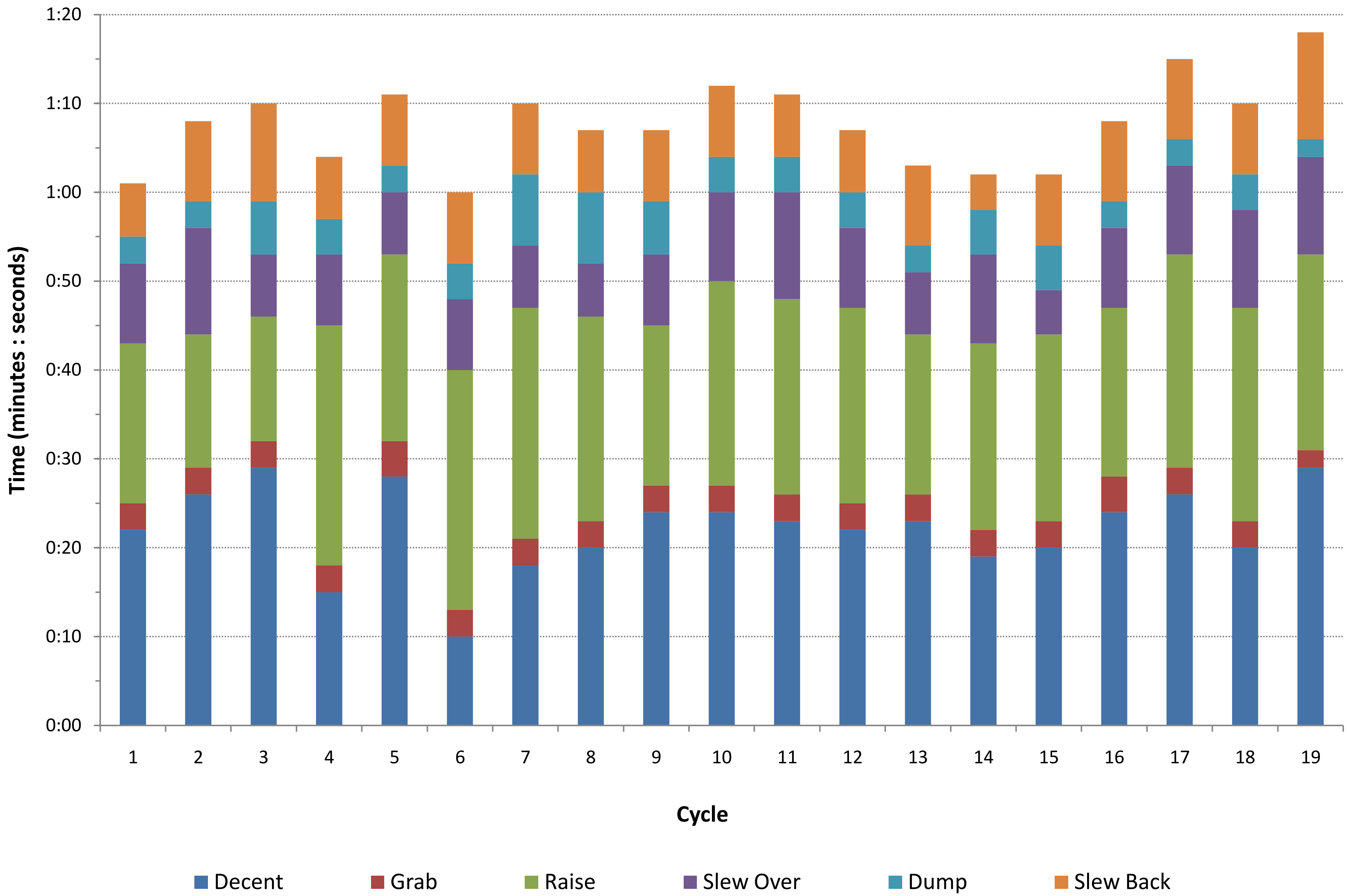


Figure	USACE Harborwide TSS Far Field Survey HDP Contract Area: S-AN-2	Elapsed Time of Six Separate Components of Dredge Cable Arm Bucket Cycles 07 Jan 2011	Tide
16			Flood