FINAL REPORT

NEAR FIELD TURBIDITY/TOTAL SUSPENDED SOLIDS PILOT STUDY

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

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ACRONYMS

ADCP – Acoustic Doppler Current Profiler

AES – Advanced Encryption Standard

BMP - Best Management Practice

CY – Cubic Yards

DGPS – Differential Global Positioning System

FTU – Formazin Turbidity Units

***g* –** g force

GLDD – Great Lakes Dredge and Dock Company

HARS – Historic Area Remediation Site

HDP – NY and NJ Harbor Deepening Project

NBSA – Newark Bay Study Area

NFT/TSS – Near Field Turbidity/Total Suspended Solids

NJDEP – New Jersey Department of Environmental Protection

NOAA – National Oceanic and Atmospheric Administration

NTU – Nephelometric Turbidity Units

OBS – Optical Back Scatter

TSS – Total Suspended Solid

WQC – Water Quality Certificate

1.0 Introduction

This report presents the results and findings of the Near Field Turbidity/Total Suspended Solids (NFT/TSS) Pilot Study as outlined in Appendix A of the Stipulation and Order of Settlement and Dismissal (ECF Case 05 Civ. 762-SAS) (Appendix A)[1,2]. To fully meet all of the requirements as set forth in the Stipulation and Order, the NFT/TSS Pilot Study was designed to evaluate the technical practicability of the design and/or deployment of a reliable, precise and accurate near-field turbidity data collection system. For the purpose of this study, "near field" is defined as the area at and immediately adjacent to the source

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[1] **Appendix A: Near Field Turbidity/Total Suspended Sediments Pilot Study**

1. The Defendants shall, consistent with United States Army Corps of Engineers Safety and Health Regulations EM 385-1-1, conduct a Near Field Turbidity/Total Suspended Sediments Pilot Study ("NFTTSS Pilot Study") within the S-NB-1 "narrow channel" contract area as set forth below.
2. The NFTTSS Pilot Study will test the near-field use of both optical (OBS) and acoustic (ADCP) sensors to collect near-field optical and acoustic backscatter measurements, which will then be converted into Total Suspended Sediments ("TSS") levels, by deploying OBS sensors mounted to the bucket, and OBS and ADCP sensors to the dredge platform. Specifically, the study will attempt to determine:
    a. whether either type of sensor, mounted as set forth above, is sufficiently reliable and resilient to continuously record and/or transmit data from which quantitative backscatter measurements can be obtained continuously and in real time, within a turbulent near-field environment, over a time span routinely involved in navigational dredging; and
    b. if either type of sensor were found to demand repair, maintenance, and/or recalibration, on a frequency that made continuous monitoring impractical, whether the sensor could be hardened to avoid the need for such repair, maintenance, and/or recalibration.

7 Following the completion of the field work described in paragraphs 1 and 2 of this Appendix, Defendants shall prepare a technical report (the "NFTTSS Pilot Study Report") that:

a. addresses each of the issues set forth in paragraphs 2.a and 2.b of this Appendix;

b. analyzes the feasibility of applying the pilot-tested configuration of optical and acoustic backscatter instrumentation and data collection capability or a refinement thereof to future HDP activities within the NBSA and the anticipated efficacy of such pilot-tested measures to assist in minimizing dredging-induced sediment resuspension during such dredging activities;

c. presents all measured optical and acoustic backscatter levels, with corresponding information describing, for each measurement, the location in the NBSA where it was taken, the date and time when it was taken, and the type of instrument used; and

d. presents all gravimetric water sample calibration data collected to generate the data set used to establish a relationship among optical backscatter measurements, acoustic backscatter measurements, and TSS concentrations. These calibration data are distinct from instrumentation calibrations that are performed by the manufacturer.

The 2008 Near Field Turbidity/Total Suspended Solids Report addresses Appendix A of the Stipulation and Order in the following sections: 7 a of the Stipulation and Order is addressed in Section 3.0; 7 b of the Stipulation and Order is addressed in Sections 5 and 6; 7 c of the Stipulation and Order is addressed in Section 5 and Report Figures; and 7 d of the Stipulation and Order is addressed in Figure 55.

[2] Please note that Appendix A to the Stipulation, which requires the Pilot Study and Report, defines "TSS" as "Total Suspended Sediments" while the draft report defines TSS as "Total Suspended Solids." References to the correct usage of this terminology can be found at websites for the American Society for Testing and Materials International (http://www.astm.org/) and the United States Geological Survey (http://water.usgs.gov/osw/techniques/sediment.html).

In brief, the term total suspended sediment solids refers to all non-dissolved constituents in a sample of water, and is given the acronym "TSS". The value derived from a TSS analysis is reported in weight units, primarily grams per milliliter after the sample has been filtered, dried, and weighed. Thus the sample contains not only inert sediment particles, but also detritus and plankton, among other possible organic constituents. In contrast, the term total suspended sediment refers specifically to the weight of inert sediment particles in a sample of water, and is given the acronym "SSC" (i.e. suspended sediment concentration), or suspended sediment concentration. The units are the same as for TSS, but in this case the organic constituents are generally removed by heating the sample at very high temperatures to produce an ash-free dry weight. The terminology used by a large majority of regulatory agencies is TSS, simply because TSS samples are less expensive to process.

In the present study the technical team used TSS in a manner consistent with accepted procedures for several reasons. First, the optical (OBS) and acoustic (ADCP) instruments used to collect field data on the dredging process do not distinguish sediment particles from organic constituents; therefore TSS is the appropriate term for purposes of data interpretation. Second, the study was conducted in February, a period of low biological activity, and an assumption that any difference between TSS and SSC would be trivial is justified.

of dredging-related resuspension (i.e. the "dredge zone" encompassing both the closed clamshell environmental bucket and the dredge platform).

The goal of this Pilot Study was to test the near-field use of both optical back-scatter (OBS) and Acoustic Doppler Current Profiler (ADCP) sensors to measure near-field turbidity levels, by deploying OBS sensors mounted to the closed clamshell environmental bucket, and OBS and ADCP sensors mounted to the dredge platform. The study was designed to assess the following:

a) Whether either type of sensor, mounted as set forth above, is sufficiently reliable and resilient to continuously record and/or transmit data from which quantitative backscatter measurements can be obtained continuously and in real time, within a turbulent near-field environment, over a time span routinely involved in navigational dredging.
b) If either type of sensor were found to demand repair, maintenance, and/or recalibration, on a frequency that made continuous monitoring impractical, whether the sensor could be hardened to avoid the need for such repair, maintenance, and/or recalibration.

The NFT/TSS Pilot Study was conducted within the "narrow channel" of the S-NB-1 contract area, in the far northern end of the B3 acceptance area (Figure 1). This particular location was selected due to the status and phasing of the ongoing Harbor Deepening Project (HDP), the depth and type of sediment strata, and the hydrodynamic flow field at the site.

2.0 Description of the Bucket Dredging Process

A basic understanding of the bucket dredging process is necessary to interpret the results and findings of the NFT/TSS Pilot Study. The mechanical process is inherently simple, yet different aspects of bucket dredging were important considerations in the design and execution of the study.

2.1 Bucket Design

Dredge bucket designs vary widely based on overall dimensions, volumetric capacity, mass, and configuration of vents, seals, and hoisting/closing cables. In this study, a modified version of a 26 cubic yard capacity Cable Arm™ bucket, owned and operated by Great Lakes Dredge and Dock Company (GLDD), was used (Figures 2 and 3). The bucket was originally classified as a "navigation bucket", which refers to a moderate capacity or larger bucket suitable for high production rates necessary for large volume dredging projects.

To comply with the Corps' contract specifications and the New Jersey Department of Environmental Protection's (NJDEP) Water Quality Certification (WQC) requirements pursuant to Section 401 of the federal Clean Water Act (33 USC 1251 et seq), the bucket was modified by the addition of seals along the lateral edges of the opposing halves and extension of the seals along the edges to the lateral hinge point. This modification served to bring the bucket into compliance with NJDEP WQC as a closed bucket designed to maximize containment of soft, fine-grained sediment.

The modified bucket performed similarly to any other such classified bucket since there are few, if any, consistent standards other than being “sealed” or “closed” that distinguish these buckets from other “open” buckets. The bucket used in this study had four rows of vents with individual flaps covering each vent (Figure 2). The bucket was modified with welded bars that permanently closed off the lowest row of vents in order to increase sediment retention and usable volume capacity of the bucket. Although the maximum capacity of the Cable Arm™ bucket used in this study was 26 cubic yards, the bucket is designed to be a “low fill” bucket, which reduces the effective volume capacity of the bucket. Note that the bucket closure and hoist wires are configured such that one side of the bucket always faces toward the derrick and the operator’s cab.

2.2 The Bucket Cycle

Dredging with a mechanical bucket is a repetitive or cyclical process. In essence the bucket simply excavates a section of the sediment bed and places that section into a waiting scow or barge for transport from the dredging site. Each bucket cycle in turn can be broken down into four principal components. Description of the components permits an understanding of how sediment is resuspended by various mechanisms, as well as how other factors, such as air entrainment, may influence the signals recorded by turbidity sensors.

A typical bucket cycle begins with **Component #1**, the **Descent Phase**. This phase includes the open bucket’s downward movement from a hovering position above the water’s surface, transition through the air/water interface, and descent through the water column to the point of contact with the sediment bed. Sediment remaining attached to the bucket following the previous cycle’s placement in the scow can be lost to the water column in this first phase by the washing action created by turbulent water flows moving across the bucket surface. Critical to this study is that the Descent Phase involves the entrainment, or trapping, of air into the water column as the bucket descends. Air can be entrained by the downward suction of water following the descending mass of the bucket, in a fashion analogous to a sinking ship. Likewise, as the bucket makes its downward transition through the water column, it is almost always in a completely open position. This maximizes the surface area of the bucket as it descends through the water column, resulting in a relatively large volume of temporarily trapped air within the bucket’s internal cavity.

Cable Arm™ buckets are fitted with vents and flaps arranged in several rows on both sides. This design allows air and water to escape as the bucket descends, thereby reducing the pressure wave advancing below the bucket. The pressure wave is one contributing factor to the total sediment resuspension budget of each bucket cycle. Depending on the sediment type, a pressure wave will cause localized high water velocities reflected off the sediment bed, which in turn displaces particles and increases the amount of sediment resuspension. Vents on the bucket used in this study allow a portion of the trapped air to escape as the bucket descends, and a substantial quantity of air is inserted into the water column, creating a "bubble curtain", which rises and dissipates as the bubbles ascend through the water column.

Component #2 of the bucket cycle is **contact with the sediment bed** and closure of the bucket. The physical disturbance of the substrate at impact causes some sediment resuspension, the amount of which is dependent on several factors, including the downward velocity of the bucket upon impact and the geotechnical properties of the *in situ* sediments. Fine sediments with high water content, for example, will have a higher resuspension rate than stiff sediments or coarse sandy sediments. As the bucket closes, the sediment bed is further disrupted. In moving from the open to closed position (Figure 3), trapped air from the bucket's internal cavities may be released. During closure of the bucket, the side vents allow water, accompanied by some sediment, to escape the bucket, facilitating equalization of hydraulic pressure inside the bucket with the external water column.

In contrast, a ventless closed bucket design (*i.e.* with a canopy to enclose the upper surfaces of the bucket) would generate higher velocity flows as water was squeezed outward by the steadily reduced volume within the bucket cavity. Vents in the bucket are designed to minimize resuspension loss associated with the escaping flows. On the GLDD dredge a signal is produced by a sensor on the hoist cable winch drum that alerts the dredge operator that the bucket is completely closed and ready to be raised. That point of complete closure is time-stamped by the GLDD bucket status software, which displays the bucket status and position on a computer screen in the operator's cab on the derrick.

Component #3 of the bucket cycle consists of the **Ascent Phase**. The initial ascent involves physically pulling the bucket out of the substrate. This can generate upward suction flows that entrain sediment from the bed. This is similar to the downward suction of air from the water's surface during the descent phase. The amount of resuspension caused by this action is once again dependent on the type of bucket and the geotechnical properties of the *in situ* sediments. In the case of the Cable Arm™ bucket, the act of closing produces a level cut, *i.e.* the depression created in the substrate has a relatively flat lower surface, whereas many other bucket designs produce a concave cut, with a deeper excavation profile at the center.

During ascent, the vent cover flaps serve to maximize sediment retention within the bucket. In practice, when dredging in cohesive sediments, as was the case in Newark Bay, the dredge operator controls fill to the highest level as permitted by the state's water quality certification, to optimize the overall production rate. Tradeoffs between production and sediment resuspension are inherently part of the dredging process in that some sediment loss is generated by extrusion of sediment through the vents, particularly as the bucket makes its upward transition through the water/air interface. At that point the water overlying the sediment inside the bucket drains rapidly with outward flow of water through the vents reaching peak velocities.

Component #4 of the bucket cycle consists of **slewing** the bucket laterally while suspended above the water and over the side of the scow. While breaking the water/air interface, the bucket is temporarily suspended over the water. Some sediment is invariably lost as slurry in draining water from the bucket's vents and seals, and as aggregate extruded through the vents if the low fill mark has been exceeded.

When cohesive silts and clays are extruded, the clumps fall back into the water and descend rapidly to the bottom, behaving as dense, heavy, particles. Some additional loss may occur as the outer surfaces of the clumps are washed during descent. In actual operations the dredge operator often begins lateral slewing of the bucket toward the barge soon after the bucket is raised off the bottom and while submerged, and the bucket breaks the surface closer to the barge than directly above the bottom contact point. This lateral movement of the bucket can affect the spatial distribution of sediment release on a relatively small spatial scale, but **should not** affect overall vertical distribution assuming that bucket hoist speed is consistent across cycles. The dredge operator also discharges the dredged material into the scow during this component of the dredging cycle. The bucket can experience significant jarring from either the opening of the bucket or from the occasional impact of the bucket with sides of the scow.

2.3 Dredging Pattern

In addition to the repetitive movement cycles associated with mechanical dredging as described above, there are also important movement patterns associated with the manner in which the dredge operator decides to dig and the overall dredging process. For example, as dictated by the configuration of the dredging plant in use during the NFT/TSS Pilot Study, a "bite" occurred each time the bucket closed. In general, five bites were typically conducted in an arc pattern from the derrick platform. First the boom was extended and an outer arc of five bites was conducted. Then the boom was moved and an inside arc of five bites was completed. For each arc, two passes were conducted to ensure complete removal of the soft, surficial silty material. The second pass is effectively the "clean-up" pass to ensure as much of the silt material has been removed as is feasible. Typically, there were 20 bucket cycles between dredge advances. Figure 4 shows a typical example of the distribution pattern of bucket bites on the bottom during a single between-advances sequence. In this Figure, the plan-view dimensions of the bucket in the open position are superimposed on the individual bucket bottom contact locations to illustrate the overlapping coverage achieved by each of the individual cuts. Over the course of a long-term test, the dredge completed several advances, producing the bucket impact distribution pattern exemplified by Figure 5.

These patterned movements of the bucket as part of a routine multiple-cycle cut are important to consider in relation to the specific location of the turbidity sensor. In the case of the sensors deployed from a fixed location on the dredge platform, as described below, the distance between the source of sediment release and the sensor is changing continuously. In the case of the sensor mounted on the bucket, that distance remains relatively constant. Different spatial and temporal scales are acting in either case insofar as sediment being disturbed and resuspended by the bucket and how and when that sediment is detected by the sensor. These spatial and temporal relationships are discussed in greater detail in the following sections.

3.0 Study Design

An initial site visit to the GLDD shore facility on Staten Island, New York was conducted to identify possible locations to mount the optical back-scatter (OBS) sensors on the bucket. Placing the sensor on the uppermost exposed flat surfaces of the bucket would subject the sensor to entanglement with hoist chains and cables while placement anywhere on the lower external surfaces of the bucket would bring the sensors in direct contact with the sediment bed. Alternatively, locations below the opening of the uppermost row of vent flaps would potentially subject the sensors to fouling from sediment escaping through the vents. Therefore, the preferred location for mounting the OBS sensor was under the bucket's upper cross-flange (Figure 6) because it offered the most protection from incidental damage during normal operation of the bucket and there was sufficient space for the mounting brackets. The OBS sensor was mounted to the central rib of the bucket, with the outer ribs serving as a contingency location if unanticipated problems occurred.

Acknowledging that data acquisition to compare sensor performance at several locations on the bucket could be informative, a second turbidity sensor was mounted on the outboard side of the bucket directly opposite the inboard location during a two-hour gap in dredging activity during the second long-term dredging test on 31 January 2008 (see section 5.6.2).. To evaluate sensor tolerance of spikes in forces that would frequently occur during the course of any mechanical dredging operation, and to assist in diagnosing any sensor failures that did occur during testing, an accelerometer was mounted in tandem with the primary bucket-mounted turbidity sensor (Figures 6 and 7).

Due to the experimental nature of this Pilot Study, and that repetitive bucket-mounted sensor failures were considered possible and even probable, OBS and Acoustic Doppler Current Profiler (ADCP) sensors were also deployed from the port side of the dredge platform bow in as close proximity to the bucket as possible (Figure 8). This location was chosen because scows were generally tendered off the starboard side of the dredge and it was as far removed as possible from potential entanglements with winch and anchor system wires. These considerations were particularly important from a safety perspective since the sensors were removed from their deployed location at the end of each day's field testing. Also, if the ADCP was mounted on the side of the bow adjacent to the scow, then the acoustic signal would be subject to interference from the scow, particularly when fully loaded and at its deepest draft in the water. Because the OBS sensors and accelerometers needed to be re-mounted to the bucket each morning, the dredge platform array was typically deployed first and recorded ambient data until actual dredging operations began.

Thus the overall study encompassed two separate sensor deployments: optical turbidity sensors mounted directly on the bucket, and both optical turbidity sensors and an acoustic

Doppler current profiler off the bow of the dredge platform. These separate efforts are referred to herein as the "Bucket Sensor Tests" and the "Dredge Platform Sensor Tests." To accomplish both the bucket sensor tests and the dredge platform tests, a schedule was developed which encompassed field mobilization, a dry run of equipment functions while the dredge was berthed at the GLDD shore facility, characterization of ambient turbidity at the study site, bubble tests, a series of short-term tests, and a series of long-term operational tests (described in greater detail in the following sections).

Field mobilization entailed setting up all gear aboard the dredge while at the dock. GLDD personnel welded mounting brackets for the turbidity sensors and accelerometers on the bucket as well as a bracket for clamping the ADCP mount to the dredge deck at the selected locations. All instrumentation necessary to conduct the tests was deployed and tested while at the dock. Once the gear had been set up, a "wet test" of the bucket mounted sensors was performed. This "wet test" consisted of a preliminary bubble test (described in greater detail below) which was conducted to establish that the sensors were active and functioning prior to moving the dredge to the Pilot Study site in Newark Bay.

3.1 Test Sequence

3.1.1 Bubble Tests

Following the preliminary dry run exercise at the GLDD dock facility, the dredge was relocated to the study site and testing began the next day on January 29, 2008. Table 1 provides the study schedule.

A major concern for mounting the OBS sensor on the bucket involved the potential corruption of data from the presence of air bubbles. All turbidity sensors currently on the market rely on either optical or acoustic signals. The question of utility of a given sensor in monitoring near field (at the source) dredging-induced resuspension therefore includes sensitivity to exposure to air bubbles. Air bubbles are known to be an extremely effective reflector of sound. The degree of sensitivity of optical sensors to the presence of air is less well understood. Assessment of the potential for masking, biasing, or contaminating sediment signals was therefore a major consideration in the design of the NFT/TSS Pilot Study.

An initial set of "bubble tests" was used to determine the degree of interference, if any, to the instruments caused by the presence of air bubbles inserted into the water column from the bucket. The bubble test was conducted during a typical bucket cycle as would normally be done in a production (dredging) mode, with the exception that the bucket was not allowed to impact the bottom. A maximum bucket depth of three meters off the bottom was selected in order to avoid resuspension of bottom sediments by the descending bucket's pressure wave. In order to have this test fully mimic the normal dredging cycle, the "dredged" water was discarded from the bucket into the adjacent scow. In this manner, air would be injected into the water column only as would normally occur during a production mode. Any response on the part of the deployed sensors above ambient conditions could be interpreted as a signal derived from air bubbles and the mixing of the vertical water column, and not as a result of dredging induced sediment resuspension.

3.1.2 Short-Term Tests

Following determination of sensor sensitivity to the presence of air bubbles, a series of three to five short duration tests were planned to determine if the bucket-mounted turbidity sensor could withstand shocks associated with routine bucket movements (Table 1). A target of twenty bucket cycles was used to define a short-term test. This number of bucket cycles represents the typical number of cycles between advances of the dredge. At the conclusion of each short-term test, the bucket was placed on deck to allow access to the instruments for data downloads.

3.1.3 Long-Term Tests

The sensors passed the short duration testing phase without technical problems or significant data loss issues. Sensor failure and data loss issues during the long duration testing are discussed in section 5.6.3 of this report. The field study then proceeded into the long-term tests, which were conducted on January 30, January 31, and February 1, 2008 (Table 1). The long-term tests were designed to determine whether the bucket-mounted turbidity sensors could perform consistently under actual and typical navigation channel production dredging conditions. In this case, the sensor was mounted at the beginning of the day and left attached to the bucket for the entire work day before putting the bucket on the deck and downloading the data. The dredge operator was instructed to use routine procedures for the entire day. Because the daily dredging production was limited by the availability of empty scows (which were limited due to constraints in processing and placing the dredged material at the approved upland site[s]), a routine work day consisted of the equivalent of one scow load, or approximately eight hours of dredging.

4.0 Instrumentation and Deployment

The following sections outline in more detail the instrumentation used during the Pilot Study and the rational for why and how they were deployed.

4.1 Optical Backscatter Sensor (OBS) – Bucket Deployment

During the course of the Pilot Study, D&A Instrument Company's OBS-3A series turbidity sensors were used to record optical turbidity measurements. The OBS-3A instruments can either internally record all sensor data and/or function as a remotely cabled sensor downloading sensor values in real time to a laptop computer. Because a connecting cable would pose a significant entanglement hazard during the normal dredging operation, it was impractical to hardwire the bucket-mounted OBS-3A. A solution to this problem was to use the OBS-3A in data logging mode and download the data at the end of each test.

While in self-contained battery powered data logging mode, the OBS-3A units can record 6,644 sets of measurements (each set corresponding to a single data line). Data can be recorded at a maximum rate of once every 5 seconds which equals approximately 9 hours and 13 minutes of recording time. The 5 second data recording limitation is a function of the instrument design. The instrument samples at 10 Hz (10 times per second) for 3 seconds, thereby accumulating 30 samples, calculates an average value, and then records the data. The unit then goes into “sleep” mode to save battery power and must “wake up” before the next recording cycle. It takes 1 second to write the data and go into “sleep” mode and then another second to “wake up”. Thus 1 second of wakeup, plus 3 seconds for data sampling, plus 1 second to store data and return to sleep requires a total of 5 seconds. The “sleep/wakeup” cycle is a function of the instrument design and cannot be turned off.

Because the range of turbidity values likely to be encountered by the bucket-mounted unit was unknown, the instruments were calibrated by the manufacturer to measure the greatest range possible between 0 and 4,000 Nephelometric Turbidity Units (NTU). The accuracy of the OBS-3A is +/- 0.125% of the calibration range. Therefore units used in this study were accurate to +/-5 NTU. The calibration values for each instrument were stored in the internal memory of the individual OBS-3A units. In addition to the optical turbidity sensor, each OBS-3A unit has a pressure sensor for measuring the depth of the instrument, a temperature sensor, and a conductivity sensor. The temperature and conductivity sensors are used to calculate salinity.

The OBS-3A instrument records and stores data as an ASCII text file with each line of the file representing a set of synoptic time and date stamped sensor measurements (OBS, depth, temperature, conductivity, and salinity). These raw data were then imported into an Excel spreadsheet and sorted by depth. Extraneous data, such as those measurements taken while the sensor was out of the water (depth of zero), were removed and each file was given a name following a consistent format that identified the specific bubble, short- or long-term test from which the data were derived. Raw data files were examined and turbidity values plotted versus depth to reveal any outliers. If outliers were detected then the time stamped record was checked against field notebook logs for possible explanations. Excel files for tests in which two OBS sensors were deployed on opposite sides of the bucket were merged to create one pooled data file for each test. Data pooling was used to generate a larger generic data set for characterization of the entire generated population of NTU values, not for statistical comparisons between the two sensors. That comparison is made separately elsewhere in the report (section 5.9), and not based on pooled data. Those statistical analyses employed conventional regression and analysis of covariance procedures. For each test, file plots were made of NTU versus time, NTU versus depth, standard deviation of NTU versus time, and standard deviation of NTU versus depth. Standard deviation of NTU was calculated as an indication of variation within the 30 samples that comprised each 5 second interval NTU record.

In addition to the data obtained from the OBS and ADCP, GLDD provided digital files of bucket position and exact closure time from their proprietary dredge management software for all test periods. Bucket position was determined by a differential Global Positioning System (DGPS) unit located on the derrick with a known distance offset to the bucket. DGPS accuracy is typically ≤ one meter under "ideal" conditions when real-time differential is achieved and no signal obstructions are present. Bucket closure time was derived from a sensor on the hoist winch system. Bucket position and closure time data were then added to the appropriate spreadsheet file and the OBS data were synchronized to the bucket closure times. The files were then examined and all the data points classified in relation to a particular bucket cycle component (*i.e.*, components 1 through 4) as described earlier in section 2.2. For example, increasing depth for successive data points indicated bucket descent while multiple data points at a steady maximum depth indicated bucket closing (verified by the dredge log) and decreasing depth on successive measurements indicated bucket ascent. Additional series of data points were classified by inspection of events noted at corresponding times in field notebooks. Periodic pauses in dredging cycles as the dredge advanced were readily identified in this manner. Bucket ascent speeds were calculated by dividing the ascent distance by the ascent time offset, based upon the 5 second interval between measurements.

4.2 Accelerometers – Bucket Deployment

To monitor the impact forces typically associated with mechanical dredging and to better troubleshoot the potential sources of instrument damage or failure (*i.e.*, bucket impact with the bottom, incidental collisions of the bucket with the scow, etc.), two data logging accelerometers were also mounted on the dredge bucket and set to record forces to 5*g* and 50*g*, respectively. The specific accelerometers used in this study were 3-axis MadgeTech Shock101 data recorders (MadgeTech 2008). The MadgeTech Shock101 accelerometer is capable of measuring and recording impact forces up to 50*g* in the three separate axes (X, Y, Z). The magnitude of the impact force is computed as:

$$V_{sum} = \sqrt{V_x^{\,2} + V_y^{\,2} + V_z^{\,2}}$$

Thus the maximum measurable value for V_{sum} equals 86.6*g* for the 50*g* 3-axis accelerometer.

The accelerometers were securely and rigidly mounted inside a tubular steel pressure housing. The housing/accelerometer package was then mounted side-by-side and parallel to the OBS-3A mounted on the inboard side of the bucket (*i.e.*, the side of the bucket facing the derrick). Both accelerometers were set to log simultaneously at 8 Hz (8 measurements per second). The accelerometers sample at 512 Hz (512 times per second) but only records the largest spike observed during each 1/8th of a second period. At the end of each sampling day, the accelerometer data were downloaded and then time synchronized with the OBS-3A data as closely as possible.

4.3 Optical Backscatter Sensor – Dredge Platform Deployment

The OBS array deployed from the dredge platform during the Pilot Study consisted of three instruments suspended vertically: one unit near the water surface at a depth of approximately one meter, one unit in mid-water column at a depth of approximately six meters, and one nearest the bottom at a depth of approximately 10 meters. Typical water depth in the immediate study area was approximately 15 meters or about 50 feet at mean high water with adjustment to the prevailing tidal amplitude. Distances between the surface and the specific depths of the three individual instruments were not altered between days. Each of the OBS-3A instruments were individually connected to three separate data logging laptops located in the pilothouse at the stern of the dredge, allowing for real-time display of the incoming data using the D&A software. In this configuration, the OBS-3A can output data once per second. The data file storage capacity in this case is limited only by the available hard drive space on the laptop and no data are stored internally in the OBS-3A instrument.

Because the voltage drivers in RS-232 devices (both the OBS-3A and laptop in this case) are generally designed for short cable runs of usually less than 30 meters (approximately 100 feet), the OBS-3A platform mounted array once deployed needed to use a two stage communication path with the submerged OBS-3A instruments first sending the sensor data above the water surface via a 25 meter watertight umbilical cable. This cable in turn connected to an AC powered 900 MHz RF wireless modem located in a water tight box on the bow of the platform. At the data logging end, a separate AC powered 900 MHz RF wireless modem was connected to the dedicated laptop for each of the three instruments. The wireless modems used on each end were Digi MaxStream 900 Mhz XTend RF modems (Digi 2008). Each wireless OBS-3A instrument and laptop pair was set up as a unique network such that only those two devices would communicate with each other. This prevented potential data corruption by interference with the other OBS-3A instruments. Each wireless link was bi-directional (*i.e*. the laptop and OBS-3A could both talk to and listen to the other) so the laptop remotely had full control over its partner OBS-3A, addressing scheme, frequency hopping spread spectrum, and 256-bit Advanced Encryption Standard (AES) encryption. The wireless modem links provide almost instantaneous retransmission of the incoming data, thus there was negligible data delay between the OBS-3A and laptops, providing essentially real-time data display. The wireless modem links proved to be very reliable with no known failures or interference observed throughout the testing period.

Data processing for the platform-deployed OBS units followed a protocol similar to that for the bucket-mounted OBS units. Raw text data were imported into Excel spreadsheet files and given names designating which test they represented. All of the relevant data from the three OBS units were then time synchronized, and the appropriate files were merged to create a full day’s record of sampling from the platform. Plots were then generated of NTU versus time for all files. Dredge log bucket position and closure time data were then added to each file and the OBS data were time synchronized with the bucket closures.

4.4 Acoustic Doppler Current Profiler – Dredge Platform Deployment

An RD Instruments 600 kHz Workhorse Mariner Acoustic Doppler Current Profiler (ADCP) was used to maintain a record of water current structure during the various sensor tests as well as to evaluate the feasibility of using the instrument as a turbidity sensor. In brief, ADCPs reflect sound off particles moving through the water column to determine velocities. Recently, ADCPs have been adapted to measure sediment flux in the water column by using the principle that the amount of sound backscattered from particles is also an index on suspended sediment concentration. The ADCP was connected by a 300 meter deck cable to a RD Instruments ADCP deck box located in the bridge of the dredge. The deck box provided power to the ADCP and communication to a laptop running RD Instruments WinRiver software.

5.0 Results

5.1 Ambient Turbidity

Interpretation of the data derived from deployment of dredge platform and bucket-mounted turbidity sensors first requires a determination of ambient water conditions. While the bucket mounted sensors were being re-mounted each morning, the dredge platform array was typically deployed first and allowed to record for at least 30 minutes to measure ambient turbidity prior to the initiation of bucket cycle testing. Figure 9 shows a typical set of ambient turbidity data as collected from the dredge platform OBS-3A array deployed in the upper, middle, and lower water column on January 31, 2008.

Ambient turbidity consistently ranged between 5 and 10 NTU at the study site (Figure 9). Turbidity in the upper water column remained below 7 NTU with very little variation. Ambient turbidities measured by the middle and lower water column sensors were slightly higher and somewhat more variable. For the example in Figure 9, a decline in mid- and low water column ambient turbidity is seen over the course of forty-five minutes. However, the absolute change with respect to amplitude was very small, within 5 NTU. This magnitude of absolute difference could also be accounted for by the accuracy of the OBS instruments, which had been calibrated to maximum turbidity ranges. The fact that ambient turbidity prevalent at the study site was relatively low created ideal conditions for the tests, allowing both bubble and plume signatures to be readily detected against that background. Several periods of high winds occurred during the study and at these times ambient turbidities were noted to rise slightly, but not sufficiently to mask detection of bubbles or suspended sediment plumes.

5.2 Bubble Signal Detection by Dredge Platform ADCP

Bubble tests were conducted during ebb, slack and flood tide stages on January 29, 2008 (Table 1) to determine whether currents carrying the suspended sediment plume and associated air bubbles away from the sensors would create different signals than currents moving towards the sensors.

Raw ADCP backscatter files for the ebb, slack, and flood tide bubble tests are depicted in Figures 10, 11, and 12, respectively. During the ebb tide, the dredge platform was oriented facing approximately north into the tide, which carried air bubbles toward the ADCP sensor mounted on the bow. Figure 10 shows the high degree of signal interference caused by the entrainment of air which was strong enough to cause loss of the bottom track for the majority of ADCP acoustic pings. Air bubble interference is evident as intense backscatter extending from the surface to below the bottom elevation across long data ensembles in sequence along the x-axis. During the slack tide test, the degree of interference is reduced, but remains sufficiently strong to cause extensive loss of the bottom track (Figure 11). By contrast, the ADCP backscatter signal observed during the flood tide test, when entrained air was mostly carried away from the ADCP sensor, showed little interference other than a diffuse signal along the upper one-third of the water column (Figure 12). Due to the high degree of bubble interference and the consequent loss of reliable signal data, the use of the ADCP backscatter data for conversion to total suspended sediment concentration was precluded for the remainder of the study because the data would not give accurate representation of field conditions. Consequently, the ADCP was removed from the platform after completion of the bubble and short-term tests on January 29, 2008.

5.3 Bubble Signal Detection by Dredge Platform OBS Instruments

During the Pilot Study, three OBS-3A instruments were deployed at surface, mid-water, and near-bottom depths off the bow of the dredge platform for the entire duration of the bubble tests conducted on January 29, 2008 (Table 1). The first test was conducted during a flood tide and due to the orientation of the dredge facing approximately north, the current carried the bubble "plume" away from the sensors. Consequently, there appears to be little to no bubble signal present at any depth (Figure 13). The surface time series of NTU measurements reflect ambient turbidities of approximately 5 NTU, while the mid depth and bottom sensors remained relatively stable at 9 to 12 NTU. Although a faulty cable connection caused the loss of the data stream from the deepest sensor approximately three quarters of the way through the test, enough data were received to determine that no bubble interference was occurring in this orientation.

The second bubble test was conducted during high slack tide conditions and surface turbidity measurements remained very low (Figure 14). However, several spikes in readings by the mid-depth and near-bottom sensors were evident. A sharp increase in turbidity was initially detected by the near-bottom sensor and coincided with the third closure of the bucket. Because the spike occurred at the near-bottom sensor it is improbable that the signal represents air entrainment. One likely explanation, however, could be that the dredge operator allowed the bucket to drop sufficiently close to the bottom that the bucket's downward pressure wave resuspended sediment. Prevailing slack tide conditions would account for the observed slow but steady decrease in turbidity detected by the near-bottom sensor over the next few minutes. Little evidence of sediment resuspension was noted in the mid-water data record for the same segment of time. Data recorded by the near-bottom sensor became highly variable after the prolonged spike described above. The sensor stopped recording in mid-test, again due to a faulty cable connection. The mid-water sensor data remained primarily within the range of ambient turbidity with the possible exception of increases to slightly above 20 NTU coincident with the final two bucket cycles of the test. Because no simultaneous significant increase is seen in the surface sensor data, the spikes may represent sediment resuspension due to a bucket pressure wave.

The third bubble test was conducted during an ebb tide, which carried the bubble "plume" toward the OBS sensors mounted on the bow of the dredge platform. Measurements from both the surface and mid-water instruments remained largely within the expected range of ambient turbidity of less than 10 NTU (Figure 15). However, a number of short-duration spikes of 10 to 25 NTU were recorded by the near-bottom sensor as well as a much more pronounced spike (up to 60 NTU) following the 16^{th} bucket cycle of the test, which again can best be explained by pulses of sediment created by the bucket's pressure wave.

5.4 *Bubble Signal Detection by Bucket-Mounted OBS Instruments*

Figure 16 plots all of the turbidity data points measured by the bucket-mounted OBS unit during the bubble testing conducted on January 29, 2008. Variation in NTU measurements is pronounced in the upper water column, and decreases with increasing depth. Measurements taken near the surface ranged from ambient (< 8 NTU) to over 500 NTU. At a depth of 8 meters the upper range of NTU measurements decreased to less than 30 NTU. Several high readings at the deepest measurement depth appeared to be outliers. Field notes indicated that two or more bucket cycles during the tests did disturb bottom sediment, possibly due to the bucket's pressure wave. Consequently these few data points are considered to be outliers.

To better quantify how air entrainment may be affecting the bucket-mounted OBS at various depths, mean NTU values were sorted into one-meter depth increments and plotted in Figure 17. The mean NTU value of all the data points recorded in the uppermost one-meter depth increment was approximately 92 NTU, or about 85 NTU above ambient. The bubble effect tapers off rapidly to approximately 25 NTU, or 18 NTU above ambient, in the second depth increment, followed by mean values consistently less than 15 NTU in the deeper portions of the water column (Figure 17).

This observed bubble effect pattern is consistent with air being entrained into the water column during bucket entry and the subsequent release of that air as the bucket descends and then closes (Figure 18). As a check on this explanation, all the bucket cycles conducted during the bubble tests were inspected on an individual basis, and the corresponding data from the OBS were segregated based on descent versus ascent portions of the bucket cycle. For example, consecutive readings from the descending bucket could be discerned from increasing depth readings derived from the OBS unit's pressure gage. High NTU values were clearly associated with the bucket descent component. In the typical bucket cycle, two to three data points would be collected during the bucket descent component, corresponding to a ten to fifteen second time segment. In Figure 18, the end of the bucket descent-closure phase is indicated by a yellow triangle marking the complete closure time of the bucket as derived from the GLDD bucket status software. In tandem with the corresponding depth data, the structure of the bucket cycle can be determined with relatively high accuracy, although a several second offset between the different parameters is possible. Following bucket closure, the NTU data consistently remained low throughout the bucket ascent component. Gaps in the data between consecutive bucket cycles represent the intervals of time the OBS unit was above the water's surface and being slewed to and from the attendant scow.

5.5 Bucket-Mounted OBS Data: Short-Term Dredging Tests

The primary objective of the short-term dredging tests was to demonstrate whether or not an OBS instrument mounted on the bucket would survive the typical forces encountered during complete bucket cycles, including those forces associated with bucket insertion and removal from the substrate. Short-term dredging tests were conducted alternately with bubble tests for each tidal stage on January 29, 2008 (Table 1).

Between the short-term dredging test and the next bubble test the bucket was placed on the deck of the dredge and the instrument was downloaded for immediate inspection of the data. No evidence of physical damage to the instrument was observed, and in all three cases data were successfully retrieved. At the conclusion of the third short-term dredging test the onboard technical team agreed that the OBS instruments were operating normally with no apparent need for repair, and that testing should proceed to long-term tests. Contingencies built into the study design for diagnostics of instrument failure and "hardening" of the sensors should repetitive failures occur were concluded to be unnecessary.

By design, the duration of the short-term flood, high slack, and ebb dredging tests were relatively short, consisting of 24, 26, and 15 bucket cycles, respectively. These data are depicted in Figures 19 though 24. During the flood short-term test (Figure 19), two phases can be discerned, with the data collected between approximately 11:15 and 11:35 being typical of dredging sweeps, whereas the ensuing data through 12:05 are typical of the clean-up phase. Although significant variation is observed in the peak turbidities measured in each phase, a general trend for lower turbidities is apparent during the clean-up phase. This is consistent with the bucket removing less sediment mass in those bucket cycles. A somewhat similar pattern is observed in the high slack short-term test data (Figure 20), with generally lower turbidities prevalent during the clean-up phase (approximately 2:25pm to 2:40pm). The spikes that occur in the data after 2:45pm are likely due to deck washing operations. The third short-term test had a truncated number of bucket cycles because the dredge needed to shut down at 5:00pm (Figure 21). Thus the first ten to twelve bucket cycles were collected in a dredging mode, followed by a short series of clean-up cycles. The resultant data are entirely consistent with the preceding short-term tests.

The next three figures (Figures 22 – 24) are scatter plots of the turbidity measurements versus depth collected during the short-term tests. Recalling that the objective of this portion of the study was to demonstrate the survivability of the sensors/instruments as deployed, the data for the short-term tests represent fewer data points than derived from the long-term tests (described in later sections). Hence no detailed analysis is given at this point. However, the scatter plots do give the reader an accurate sense of the variability inherent in the data at all depths. All three plots produce a similar spread of data. A complete analysis of comparable data is given in the treatment of the long-term test data.

5.6 Bucket-Mounted OBS Data: Long-Term Dredging Tests

In order to collect adequate data points representing all segments of the mechanical dredging process, data collection progressed into a series of long-term dredging tests, each representing a typical "dredging day" equivalent to eight to twelve hours of operation. The day included pauses and interruptions in the dredging that are routinely seen during periodic maneuvering of attendant barges, equipment maintenance, dredge advances, dredge re-location to allow commercial vessel passage, dredge crew shift changes, and other stoppages characteristic of dredging operations. Data were collected for 145, 125, and 194 bucket cycles, respectively, for a total of 464 bucket cycles over the course of three days of long-term testing (Table 1).

5.6.1 First Long-Term Dredging Test

The first long-term dredging test occurred on January 30, 2008. Dredging began at approximately 0912 hours and concluded at approximately 1625 hours during which the dredge completed 145 bucket cycles over the course of eleven series of bites (Figure 25). Each series, with the individual bucket-bottom contact time indicated as a yellow triangle on the x-axis, represents a series of cuts in which the dredge typically used 20 bucket cycles before needing to advance the dredge (see Section 2.3). Shorter series represent bucket cycles used to clean up patches of sediment remaining within the footprint of the cut, or routine interruptions in mid-series. Superimposed on the NTU time series data are tide elevations obtained from the NOAA Bergen Point gage. Although some amount of lag in the elevation data is likely to be present in making comparisons to elevations at the study site, the general progression of tide phases coinciding with the times of turbidity measurements can be discerned. Thus the first long-term dredging test began on a flood tide and ended on an ebb tide.

Figure 26 plots all of the data points collected from the bucket mounted OBS sensor during the first long-term dredging test on January 30, 2008. NTU values on that day ranged from ambient (<5 NTU) to almost 1,000 NTU. However, a substantial portion of the measurements were below 400 NTU. In order to discern patterns in the data associated with different components of the bucket cycle, each data point was classified based upon point by point examination of the data record using depth data and relationships between successive points in the time series progression, remembering that the OBS unit recorded one measurement every five seconds. In this manner, a total of 2,942 data points were classified into bucket descending, bucket ascending, digging (arrival at maximum depth to closure of bucket and first decrease in depth), and "moving" categories. Moving, in this case, refers to data points collected while the bucket was resting on the bottom and the dredge platform was maneuvering forward into the next cut. The 26cy bucket was routinely used as a leveraging point to pull the dredge forward while "stepping" the spuds. The data clearly indicate that high turbidities were also recorded while the bucket was held relatively stationary on the bottom. These measurements reflect bottom disturbance by the bucket as well as sediment resuspended by the insertion and withdrawal of spuds into and out of the bottom.

Thus Figure 26 includes 403 data points representing the descending bucket, 732 data points representing the ascending bucket, 649 data points representing bucket digging, and 1,158 data points representing the bucket sitting on the bottom while the dredge advances. These data give a good indication of the time budget of a typical dredging day for that portion in which the bucket is below the water's surface. Data indicate that the descending phase was shortest in overall duration (because fewer data points were collected), followed by increasing segments of time involved in digging, ascending, and dredge moving, respectively. The fact that time spent in bucket descent is substantially less than bucket ascent reflects the best management practice of a maximum hoist speed when dredging this type of material of two feet per second or less. Bucket descent speed did not have a specific limitation, but was governed by the operator to optimize penetration of the bucket to achieve the intended elevation. Average bucket descent speed, calculated from depth changes between successive OBS measurements, was approximately 4.3 feet per second over the course of the three long-term tests (Table 2). The high number of "dredge moving" data points simply reflects the proportionally longer period of time spent by the bucket resting on the bottom.

To examine sediment resuspension signals during the repetitive bucket cycles exclusive of the dredge advancing phase, "moving" data points were deleted (Figure 27). In this depiction, the "digging" component of the bucket cycle generates NTU values within a tight depth increment, primarily between 13 and 15 meters, and within a broad NTU range, from ambient to over 800 NTU.

Figures 28 and 29 display the measurements taken during the descent and ascent components of the bucket cycle, respectively. During the descending component, a slight trend for reduced NTU values with increasing depth is seen. Highest NTU values primarily occur within the uppermost 4 meters of the water column. NTU values measured below 4 meters remained below 500 NTU with a single exception. Linear regression of the data yields a trend line with a slightly negative slope with increasing depth. However, the data are highly scattered such that the calculated regression coefficient ($R^2 = 0.142$) is very low. In contrast, data points collected during the ascent portion show a trend of slight decrease in turbidity with decreasing depth. NTU values greater than 500 NTU occur only below a depth of 4 meters, and range as high as 800 NTU. Linear regression of the data yields a relationship with a positive slope with increasing depth, and consistent with the descent data, a high degree of scatter ($R^2 = 0.146$).

5.6.2 Second Long-Term Dredging Test

The second long-term dredging test was conducted on January 31, 2008. As shown in Figure 30, data were collected in three series separated by various lengths of non-activity. Testing began at approximately 0900 hours and concluded at approximately 1615 hours. As in the previous test, dredging progressed in bouts representing at least six different series of bites as the dredge advanced. As previously, an OBS instrument and accelerometer were deployed on the inboard (facing the derrick) side of the bucket. Note that the bucket closure and hoist wires are configured such that one side of the bucket always faces toward the derrick and the operator's cab. During an early afternoon two-hour gap in dredging activity, the bucket was placed on deck and a second OBS instrument mounted on the outboard side of the bucket directly opposite the inboard location (Figure 31). The second long-term test began under slack-low tidal conditions and progressed through a flood tide phase in the morning hours. After adding the second OBS instrument, the afternoon's data collection effort coincided with slack-high through ebb tide conditions (Figure 30).

All data points collected by the inboard OBS instrument are depicted in Figure 32. A total of 1,857 measurements were taken. In terms of a general distribution pattern, this test yielded results similar to those of the first long-term dredging test. Although measurements as high as 825 NTU were recorded, the majority of measurements fell below 400 NTU. The highest density of measurements occurred below a depth of 12 meters, again consistent with the greater proportion of bucket-in-water time spent either digging or in a stationary mode while the dredge was advancing. Of the total, 266 data points represented bucket descent, 530 represented bucket ascent, 643 represented bucket digging, and 418 represented the dredge moving component. In Figure 33, the dredge moving data points have been deleted, revealing a distribution pattern similar to that of the previous long-term dredging test's data. The bucket dredging data fall almost entirely within the 12 to 15 meter depth stratum. Figures 34 and 35 display the bucket descent and ascent data, respectively. With the exception of fewer data points in the very high NTU range in the uppermost two meters of the water column, the pattern is essentially identical to that of the first long-term test descent data. Turbidity measurements tended to decline with increasing depth within a similar ambient to 650 NTU range, with significant scatter present (R^2 = 0.054). As observed in the first long-term test, NTU measurements tended to decrease slightly with decreasing depth during the bucket ascent component of the cycle. Once again, significant scatter was evident among the data (R^2 = 0.136) in all depth strata.

The 623 data points collected by the outboard OBS instrument during the afternoon of January 31, 2008 are shown in Figure 36. Of the total, 88 data points represented bucket descent, 161 represented bucket ascent, 201 represented bucket digging, and 173 represented the bucket resting on the bottom while the dredge advanced. In Figure 37, the "moving" data points have been deleted, revealing the pattern of dredging measurements at depths primarily below 11 meters. NTU values for dredging data points ranged as high as 990 NTU with a relatively high number of data points above 600 NTU. Bucket descent data points from the outboard OBS unit were consistent with earlier tests in having a trend for slightly reduced turbidity measurements with increasing depth (Figure 38). The degree of scatter was again very high (R^2 = 0.054). Bucket ascending data points showed a pattern consistent with prior test data as well, with a trend for slight increases in turbidity with increasing depth (Figure 39). These data were characterized by a high degree of scatter (R^2 = 0.079).

5.6.3 Third Long-Term Dredging Test

The third and final long-term dredging test was conducted on February 1, 2008. The test began shortly after 0800 hours and concluded at approximately 1610 hours (Figure 40). Although two OBS instruments were mounted on the bucket as in the previous long term dredging test, data were successfully collected only from the outboard sensor. Accelerometer data indicated that a single very high *g*-force event associated with the bucket striking the side of the scow caused a disruption in the power delivered to the inboard sensor. Although the instrument remained operable once reset, the data had been deleted from the instrument's memory. During the third long-term test, slack-low conditions extended through the morning hours until a shift into flood tide conditions remained through most of the afternoon's data collection efforts (Figure 40).

This test produced 2,858 data points, of which 417 represented measurements during bucket descent, 801 represented bucket ascent, 1,001 represented bucket digging, and 639 represented measurements while the bucket sat on the bottom during dredge advances, or so-called "dredge moving" (Figure 41). Once again, the recorded data were consistent in all respects with those derived from the prior long-term tests. Removal of the "dredge moving" data reveals the sharply defined distribution pattern of digging data points at depths of 12 to 15 meters and those taken during bucket ascent and descent (Figure 42). The trend for decreasing turbidity with increasing depth displayed by the bucket descent data presented a very shallow slope (Figure 43), and the data are highly scattered (R^2 = 0.013). The bucket ascent data (Figure 44) again show a slight trend for increasing turbidity with increasing depth with a high degree of scatter (R^2 = 0.033).

5.7 Dredge Platform OBS Data: Long-Term Dredging Tests

Figures 45, 46, and 47 present time series plots of measured turbidity from the three unit OBS array deployed from the bow of the dredge platform for each of the three days of long-term testing. During the long-term dredging tests, the OBS sensors deployed from the platform produced a consistent pattern of higher turbidity with increasing depth.

During the first long-term dredging test (Figure 45), turbidity measurements at the surface sensor remained relatively low, less than 20 NTU, throughout the initial series of 20 bucket cycles, then spiked above 50 NTU for much of the next two cuts. The mid-water sensor showed a similar lag, with spikes above 100 NTU occurring with greater frequency as the tide continued to flood. Highest turbidities were recorded at the near-bottom sensor, with several peaks above 250 NTU during the morning measurements. At approximately 1130 hours, the turbidities recorded at all three sensors fell back to ambient levels, although the dredge continued to dig. The low turbidities persisted through two complete dredge advances, or approximately 40 bucket cycles, before turbidities rose again with the onset of the dredge cut at 1420 hours when turbidities detected by the three sensors returned to the pattern of spikes occasionally exceeding 200 NTU at the near bottom sensor (Figure 45). The mid-depth sensor recorded much lower peak turbidities not exceeding 50 NTU, which were substantially lower than at the same depth in the morning data. In the afternoon, few spikes above ambient occurred at the surface sensor, until just prior to the end of the test, and were likely associated with bucket cycles used to wash the deck of the scow.

The observed sharp reduction in turbidity between approximately 1130 and 1430 corresponded to a change in tidal conditions from a flood to an ebb tide, which based on the orientation of the dredge to the south, carried the sediment plume away from the sensors. After three hours of a strong ebb, the tide appeared to flood and then almost slack out but the varied tidal conditions may have been a result of extreme weather conditions that afternoon that sent wind gusts approaching 50 mph. Strong winds blew continuously from west to east during most of the afternoon and one possible explanation for the lower turbidities, especially at the surface and mid-water depths, as compared to the morning was that winds altered current flows sufficiently to deflect the plume away from the sensors.

Deployment of the OBS instruments from the dredge platform during the second long-term dredging test on January 30, 2008 produced similar turbidity patterns as the day before, although turbidities appeared to be more consistent and less affected by tidal and weather conditions (Figure 46). Generally high turbidities were recorded by the near bottom sensor in the 150 to 350 NTU range as the tide flooded through the morning hours. Mid-water turbidities primarily remained within the 50 to 150 NTU range. Few spikes above 20 NTU were recorded by the surface sensor until the end of the morning session, when several bucket cycles were used to wash the deck of the scow. At 1300 hours the test was temporarily shut down to allow the dredge to be moved to the side of the navigation channel while a large commercial vessel passed. Instruments were re-deployed when the dredge had been re-positioned at approximately 1445 hours. The gap in the data shown in Figure 46 corresponds to the time the instruments were brought on deck. Turbidities recorded by the near bottom sensor were somewhat higher during the afternoon session, which coincided with slack-high and the onset of ebbing tide conditions. Several spikes in turbidity near the bottom exceeded 400 NTU.

Turbidities recorded by the three dredge platform-deployed OBS instruments during the third long-term dredging test are presented in Figure 47. Turbidities in the 50 to 300 NTU range characterized the near bottom sensor record through the morning hours while the tide elevation remained low, then decreased to less than 200 NTU after the tide began to rise. This pattern is also seen in the mid-water turbidity data. A number of spikes in turbidity to 100 NTU at the surface sensor are seen during the morning hours, including prominent spikes at the end of a dredge cut at 1230 hours when the scow deck was washed.

5.8 Patterns in Turbidity Data Linked to Bucket Cycle Components

Because the bubble tests clearly demonstrated that turbidity measurements can be affected by air entrainment, especially during the descent component of the bucket cycle, further examination of the data for consistent patterns was conducted. Figure 48 plots the depth-stratified average turbidity measurements for both descent and ascent components of the bucket cycle. The descent data include all 1,174 data points recorded by bucket-mounted OBS instruments during the three long-term dredging tests. The ascent data include the corresponding 2,224 data points. Linear regression trend lines for the descent ($R^2 = 0.75$) and ascent ($R^2 = 0.97$) components of the bucket cycle are superimposed on the depth stratified data. Readily apparent is the variation in the descent data in the form of departures from the trend line. For example, the 1-2 meter depth interval departs significantly above the general trend, whereas the 8-9 meter interval departs significantly below the trend. This merely reflects the limitation of sample size as the somewhat random distribution of measurements produced comparatively fewer data points in those depth strata. The larger number of measurements taken during the ascent component of the bucket cycle, because of the restricted hoist speed, produced a smoother distribution around the trend line of slightly increasing turbidity with increasing depth and/or variation due to the influence of bubbles.

Taken as composite data for the individual components of the bucket cycle, it would appear to be theoretically possible with sufficient data, to develop a qualitative relationship that describes each portion of the cycle for a specific bucket working in sediments of known geotechnical properties. Such a correlation, though, would need to be made based on data measurements taken using a variety of bucket types and sizes, and conducted in a myriad of hydrodynamic, bathymetric, and *in situ* sediment bed conditions. The issue of air contamination of the descent signal, moreover, would be a technical obstacle confronting the calculation of any correction factor.

5.9 Patterns in Turbidity Data Linked to Sensor Location on the Bucket

If qualitative relationships could be determined describing turbidity generated by the various components of the bucket cycle as described above in section 5.8, then specificity of that relationship to sensor location on a given bucket would also need to be determined. In the present study a comparison can be drawn between two sensor placements on opposite sides of a bucket.

Figure 49 compares turbidity measurements of the descent component taken during the second long-term dredging test by both the inboard (side facing the derrick) and outboard-mounted OBS instruments. Large departures from the linear regression trend line for both sensors are present, reflecting the limitation of sample size for data points within each depth stratum. Not surprisingly, a high degree of scatter is present in the data collected by both the inboard ($R^2 = 0.25$) and outboard ($R^2 = 0.10$) sensors. The trend lines themselves, however, reveal a relatively close fit shared by the two sensors, as the intercepts of the data with the Y-axis would indicate a similar average turbidity of approximately 320 to 325 NTU in the surface stratum. In the 12-13 meter depth stratum, the average turbidities of both sensors would be predicted to fall in the 200 to 250 NTU range.

By comparison, Figure 50 shows turbidity measurements of the ascent component taken by the inboard and outboard sensors. The greater number of data points per depth stratum yield linear regression relationships with substantially less scatter (inboard R^2 = 0.85; outboard R^2 = 0.58). A more pronounced separation between the synoptic measurements taken by the two sensors is evident. At the surface, average turbidities predicted by the regressions were 200 NTU on the inboard side of the bucket and 275 NTU on the outboard side. In the 12-13 meter depth stratum, the separation was slightly smaller; approximately 390 NTU for the inboard sensor and 420 NTU for the outboard sensor.

The bucket descent and ascent turbidity data shown in Figures 49 and 50, respectively, were analyzed statistically using linear regression and analysis of covariance procedures. With respect to the bucket descent data, the slopes of the lines in Figure 49 were not found to be significantly different from each other ($F = 0.22$, $P = 0.6376$). There was no significant difference in the depth adjusted data collected by either the inboard or outboard OBS instruments ($F = 0.49$, $P = 0.4838$). However, the slopes of both lines were found to be significantly different from zero ($F = 9.8$, $P = 0.0024$ inboard; $F = 4.92$, $P = 0.0292$ outboard). Similarly, with respect to the bucket ascent data, the slopes of the lines shown in Figure 50 were not found to be significantly different from each other ($F = 1.12$, $P = 0.2913$). A significant difference was found in the depth adjusted ascent data obtained by the two OBS instruments ($F = 46.28$, $P = <0.0001$). The slopes of the two ascent turbidity data lines were found to be significantly different from zero ($F = 34.06$, $P = <0.0001$ inboard; $F = 13.72$, $P = 0.0003$ outboard).

Collectively these data indicate that location on the bucket could be an important factor that would influence the actual measurements of turbidity associated with a given bucket. One unknown is the degree of offset due to the use of different instruments. Another unknown is the magnitude of sediment release across different areas of the bucket. As configured in the present study, turbidity measurements at a central, upper surface location may indeed be representative of loss in that zone, but not representative of loss elsewhere across the bucket's outer surface.

5.10 Patterns in Turbidity Data Linked to Operational Factors

In previous sections, turbidity data were examined in relation to conditions prevailing at the sensor locations within the components of individual bucket cycles. Ensuing sections depict turbidity patterns observed that can be accounted for across a series of dredge cuts and advances. Repetitive patterns can be seen in the records of the bucket-mounted and dredge platform-deployed instruments. For example, inspection of the time series data for the bucket-mounted OBS for the first long-term dredging test reveals a repeated rise and fall in turbidity measurements as data collection proceeded through each 20-bucket series of cuts. Various events that help to explain the observed pattern were discerned from time verified field notes. Field notes were used to add labels denoting activities that coincided with the turbidity record in Figure 51. Thus each series of dredge cuts, usually comprised of 20 consecutive bucket cycles, can be distinguished by gaps in time during which the dredge advanced, or by periodic washing of the scow deck and re-painting of the markers on the bucket hoist and closure cables.

Closer inspection of a single dredge advance series of 20 bucket cycles is presented in Figure 52. This one-hour record represents the same dredge series depicted in Figure 4. For clarity, the NTU measurements in Figure 52 are presented on a logarithmic scale on the Y-axis. Note that actual dredging began with the first bucket cycle at approximately 0913 hours. However, spikes in turbidity well above ambient were recorded prior to the initiation of dredging and represent resuspended sediment arriving at the sensor as the spuds were raised and lowered. While the dredge was being maneuvered into position, the bucket had been sitting on the bottom. Four series of sweeps were required to ensure that as much of the soft, surficial silty material was removed as was feasible before advancing the dredge forward. Each series of cuts consisted of five bucket cycles. By referring to Figure 4, the sequence of bucket cycles and lateral movements can be identified and compared to the turbidity measurements depicted in Figure 52.

The first set of five bucket cycles removed a relatively thick layer of surface sediments in a swath arcing outward from the scow immediately in front of the derrick. This cut was followed by five bucket cycles with the derrick lowered to enable surface sediments to be removed from an outer swath across an arc again moving outward from the scow. The operator then used a series of five bucket cycles to dredge, or “clean-up”, the remaining silt material in the outer arc proceeding outward from the scow. Finally, the derrick was raised and the operator used five bucket cycles to dredge the remaining silt material from the inner arc. In this fourth series of cuts, the five bucket cycle sequence proceeded from the outermost position toward the scow.

The relative amount of sediment removed in each bucket was qualitatively verified by review of videotaped records taken during the tests. The two first-pass arcs appeared to remove thicker layers of sediment than the two second-pass, or clean-up, arcs. In the video record, the first-pass arcs produced spillage primarily consisting of cohesive clumps of sediments in combination with comparatively high sediment content slurries, whereas the second-pass arcs produced spillage consisting primarily of a high water content slurries. Bucket closure time stamps on the x-axis of Figure 52 give a point of reference for each bucket cycle in the series. In the approximately 5 bucket cuts made during the first-pass of the inner arc moving outboard, the turbidity gradually increases from approximately 10 to over 100 NTU. The tide at this time was in the initial stages of changing from slack-low to flood. Because dredging began after a prolonged period of inactivity, the trend for increasing turbidity may represent an accumulation of residual suspended sediment not removed from the immediate vicinity by currents during the intervals between cycles. The trend for increasing turbidities with each cycle continued through the end of the first-pass of the outer arc with turbidity measurements at the end of this arc peaking at between 400 and 500 NTUs. As the dredging progressed into the second-pass arcs, the trend in turbidity measurements reversed, with an immediate and progressive decrease in turbidities from 500 NTU down to between 30 and 60 NTU during the final bucket cycles in the series. One explanation for this pattern could be that less mass of sediment was released while the dredge was removing the thinner layer of remaining sediment overburden in the second-pass. This would explain the consistent pattern of increasing and then decreasing turbidity apparent in many of the series of bucket cycles between dredge advances.

Of note, was the occurrence of very high turbidities in the 0950 to 0959 hours recorded in Figure 52. Although the dredge was not digging, turbidities ranged between 200 and 650 NTU. Once again, use of the bucket as leverage on the bottom while spuds are raised and lowered appeared to produce a significant turbidity signal.

5.11 Bucket Descent and Ascent Speeds

Table 2 presents a summary of the bucket descent and ascent speeds measured during the three long-term dredging tests. Although some degree of variation occurred among dredging cycles, as indicated by the ranges in observed speeds, the average descent and ascent speeds were remarkably consistent across tests. This is not unexpected, especially for the ascent speed, which is restricted to two feet or less per second (as noted earlier) by a BMP in the WQC and is regulated independent of the operator by electronic programming.

Bucket descent speed on average was almost double the ascent speed, ranging between an average of approximately 4.1 and 4.4 feet per second. Speeds measured by the outboard sensor represented only the afternoon portion of the second long-term dredging test, which accounts for the slight variation in measured speeds in comparison with the inboard sensor, which recorded data for the entire test.

5.12 Accelerometer Results

Results obtained by mounting the two data logging accelerometers on the bucket provide a time series characterization of impact forces encountered during mechanical dredging as exemplified by the bucket cycle process as conducted in this study. To our knowledge these data have never been collected previously. Thus it is important to note that forces exerted on instruments mounted on a different bucket operated under different conditions (*e.g.*, less skilled operator, coarser or more compacted *in situ* sediments) could produce significantly different results. Given this caveat, the data derived in the present study are useful in describing the forces that instruments and sensors must endure in normal day to day dredging operations. Figure 53 presents accelerometer data recorded during a typical seven minute (= four cycles) period of dredging during a long-term test on January 31, 2008. Peak impact forces of approximately 10*g* were consistently observed, which corresponded to moments when the bucket was fully opened to the point of contact between metal "stops" on opposite halves of the bucket, when the bucket impacted the sediment bed, and when the bucket was fully closed prior to hoisting. Figure 54 shows the sequence of data at the moment of a 75*g* impact, the maximum force recorded during the Pilot Study. Based upon field observations, this event was apparently associated with an event in which the bucket struck the side of the barge, and coincided with a malfunction of a bucket-mounted OBS unit during the long-term test on February 1, 2008 as described earlier in Section 5.6.3.

6.0 Discussion

In the following Sections we present the Pilot Study findings of the near-field use of both optical back-scatter (OBS) and Acoustic Doppler Current Profiler (ADCP) sensors to measure near-field turbidity levels, by deploying OBS sensors mounted to the closed clamshell environmental bucket, and OBS and ADCP sensors mounted to the dredge platform. As noted earlier, the overall objective of the NFT/TSS Pilot Study was designed to assess whether either type of sensor, mounted as set forth above, was sufficiently reliable and resilient to continuously record and/or transmit accurate and reliable data from which a quantitative measure of turbidity can be obtained over a time span routinely involved in mechanical navigational dredging of silty material using a closed clamshell environmental bucket.

6.1 Platform Deployed Sensors

In this Pilot Study, both acoustic (ADCP) and optical (OBS) turbidity sensors were deployed from the bow of the dredge platform in the immediate vicinity of an active dredge bucket. As clearly shown in the ADCP and OBS data, interpretation of any data derived from platform deployments would involve procedures to account for changing tidal conditions and periodic changes in dredge orientation. Superimposed on the continuously changing distance between the sensor and the source would be the slowly but constantly changing flow vectors and velocities associated with changing tide conditions, winds, freshwater inflows etc. Moreover, with a single measurement point, distinguishing dredging induced resuspension from other natural or anthropogenic causes of resuspension (e.g., passing ship) would pose an obvious challenge to interpreting the data.

6.1.1 ADCP

Data derived from the bubble tests clearly demonstrated that an acoustic sensor (ADCP) placed in close proximity to the bucket, in this study off of the bow of the dredge platform, is subject to extreme disruption of the backscatter signal due to interference by air bubble reflection of the emitted sound.

Acoustic sensors of many types are known to be affected by the presence of air bubbles in the water column, but the actual scales of these effects are the subject of debate. Consequently, it is not surprising that the placement of the ADCP within a short distance from the operating bucket resulted in high degrees of signal contamination. Nevertheless, the ADCP data did illustrate that a sensor deployed from a fixed position on the bow of the dredge platform would be subject to large variations in plume signal and interference simply due to the constantly changing location of the source (*i.e.* the bucket) as well as the constantly changing tidal conditions. As the bucket moves through each arc of the lateral sweep, it would be extremely difficult in terms of production dredging and practicability to re-adjust the position of the sensor to maintain a constant distance from the source.

6.1.1 OBS Units

Bubble detection by optical backscatter turbidity sensors has previously been reported by Vincent et al. (1991), Thorne and Hanes (2002), Puleo et al. (2006), and others. Debate persists on the magnitude of interference caused by the entrainment of air, although no prior research has documented performance of OBS instruments under bubble-inducing conditions associated with dredging operations.

Unlike the ADCP, data from the OBS array deployed from the dredge platform indicates that little, if any, air bubble interference occurred during any of the tide stage tests and that the distance between the bucket and the sensors was sufficient at all times to allow entrained air bubbles to dissipate to a level that would not effect the synoptic operation of the OBS instruments. This is not unexpected given that the two instruments work using two entirely different methods of energy reflection (*i.e.*, the OBS uses light, whereas the ADCP uses sound).

Moreover, the two instruments operate on different spatial scales with the ADCP sampling a vastly greater volume of water than the OBS sensor. The multiple ADCP transducers are arrayed to probe an expanding volume of water with increasing distance from the instrument (*e.g.*, tens of meters), whereas the OBS instrument probes the water in a fixed aspect from the sensor for a relatively short distance (*e.g.*, millimeters). Some theoretical evidence supports an assumption that the ADCP is very sensitive to large bubbles, whereas nephelometers such as the OBS instrument may only "see" small bubbles. Because air bubbles rise from their point of release in the water column, even the relatively short distance between the bucket and the platform deployed OBS instruments, may have been an adequate distance for most of the bubbles to rise above the depths at which the OBS sensors were sampling. In contrast, the ADCP response would be affected by even a thin, dense layer of bubbles very near the surface but below the faces of the ADCP's transducers.

In this Pilot Study, the utility of deploying optical sensors at a fixed location off the dredge platform was found to be impractical due to the variation in signal intensity noted under varying tide conditions. Interestingly, this basic approach was used by Hayes et al. (2000) and Welp et al. (2001) to compare sediment releases in Boston Harbor by a Cable Arm™, conventional closed, and conventional open buckets. Depth-averaged turbidities, reported as Formazin Turbidity Units (FTU), as measured by OBS instruments suspended from the centerline of the deck platform, were 57.2, 31.0, and 12.0 FTU for the conventional open, Cable Arm™, and conventional closed buckets, respectively. It is important to note that the Boston Harbor turbidity data were collected only during periods when the flows were carrying plumes away from the sensors. If FTU and NTU are considered equivalent units of turbidity, then the Boston Harbor dredging operations appear to have produced turbidity measurements quite similar to those derived in the present study under comparable tide conditions and dredge orientation with prevailing flows. Direct comparison with the Boston Harbor data is somewhat difficult, however, by the fact that the FTU to mg/L relationship presented by Hayes et al. (2000) was non-linear. Also, the Hayes et al. (2000) methodologies are not described in sufficient detail to discern if data recorded during gaps in the bucket cycling process were deleted.

Data obtained in this Pilot Study suggest that the design of the Boston Harbor study may underestimate overall sediment loss rates. For example, examining data from dredge platform deployed OBS instruments during short-term dredging tests in the present study, average turbidities at the surface were 3.2, 27.8 and 35.1 NTU on flood, slack, and ebb tides, respectively. Average turbidities at the deep instrument were 26.3, 32.9, and 19.9 NTU on flood, slack, and ebb tides, respectively. The observed variations in sediment detection based on orientation of the dredge to prevailing currents would appear to preclude estimation of loss rates based solely on flow-away-from-the-sensor data. In this Near Field Turbidity/Total Suspended Solids Pilot Study, data showed substantial differences based on tide, which indicates that accurate loss rate estimates cannot be obtained when the plume is flowing away from sensor.

6.2 Bucket Mounted Sensors – Bubble Tests

The effect of air entrainment on the bucket mounted OBS units was consistent with a pattern of air being entrained into the water column during bucket entry and the subsequent release of that air as the bucket descended and then closed. In theory, the relationship between this bubble effect and depth could be converted to a "bubble effect correction factor." However, the efficacy of a real-time application is doubtful as each data point would have to be distinguished based on representation of descent versus all other components of the bucket cycle, then the depth of the data point established, and finally a correction factor applied. The bubble tests conducted in this Study would only apply to the GLDD 26 cubic yard bucket as configured and operated during the tests. An accurate correction factor would need to be established for any change in bucket specifications and operational measures. A larger or smaller bucket with a different open versus closed "footprint" or different arrangement of vents may have a different air entrainment pattern. The air entrainment pattern may also be heavily influenced by bucket descent speed or differences in execution by the bucket operator. For example, beginning a rapid descent from a bucket starting position above the water's surface may entrain substantially more air than slowly lowering the bucket below the surface before beginning a powered descent. Likewise, a conventional open clamshell bucket would be expected to have a substantially different air entrainment pattern than a closed clamshell bucket. Consequently, similar bubble tests would potentially have to be performed for a large number of bucket types, sizes, and modes of operation to be able to see if a "standard" correction factor can be done, much less what it is.

The results of the bubble tests showed that the sensor detects air entrained into the water column, and that the air signal dissipates with increasing depth. The bubble test data suggest that on average the sensor detects a 90 NTU air signal in the uppermost two meters of the water column, which quickly falls to 20 NTU and steadily decreases to 10 NTU (or ambient) at 13 meters. As measured in the long-term dredging tests, with the sensor located in the same location and orientation on the bucket, turbidity measurements consist of a combination of air and resuspended sediment. It is extremely difficult to distinguish the air versus sediment contributions to any given data point in the descent component of the bucket cycle. Therefore, any correction factor would have to be applied in post-processing mode to pooled and averaged data rather than in real-time for incoming data points. For example, because the scatter in the sediment signal is so great, subtracting a 90 NTU correction factor from all descent measurements taken in the uppermost depth stratum would frequently produce negative values.

Results of the bubble tests indicated that the air signal had essentially dissipated upon closure of the bucket, so in theory a correction factor would not need to be applied to bucket ascent data points. Nevertheless, some inherent limitations in interpreting the obtained data must be addressed. One important factor is relating the sediment signal to the location of the sensor on the bucket. Constraints of placement dictated that the OBS instrument be mounted above the uppermost row of vent flaps. Given the vertical dimensions of the bucket, when in the bucket-closed phase, the instrument would be located approximately 10 feet (or three meters) above the point of cutting edge closure. Consequently, during ascent the sensor would be pulled upward in advance of the sediment flowing out of the vents. Also, the sensor would transition the water/air interface in advance of the lower half of the closed bucket, thereby missing any release in the upper several meters of the water column. Sediment loss can occur as the bucket makes the water to air transition. As configured, the OBS instrument would not capture data related to sediment loss for this potentially important segment of the bucket cycle. At least when considering the type of bucket used in this study, moving the sensor to a more exposed location lower on the side of the bucket did not appear to be feasible. The sensor would be subject to a higher level of impact and its ability to record data would be compromised.

6.3 Bucket Mounted Sensors – Dredging Tests

Another major objective of the Pilot Study was to determine the survivability of a turbidity sensor mounted on a dredge bucket and exposed to the rigors of a routine navigation dredging operation. It is important to distinguish between instrument survivability, sensor survivability, and data survivability. In all test cases, the instruments (*i.e*. the housing, internal batteries and circuitry, and integrated sensors) survived. In only one instance was the data collected by a bucket-mounted instrument lost. This event coincided with the occurrence of a single bucket-against-barge impact that produced forces in excess of 75*g*. The tests succeeded in proving that the battery powered OBS-3A instruments can survive at least 8-hour deployments if properly mounted to a dredge bucket. The tests also proved that the OBS sensor itself is sufficiently rugged to withstand routine deployment mounted on a dredge bucket.

The thousands of turbidity measurements collected by OBS instruments on the bucket provide an excellent data set for in-depth evaluation and a number of salient findings were made. The instruments do in fact detect the presence of air entrained into the water column and this signal contamination effect must be considered when interpreting the derived data. This contamination of the signal is almost entirely confined to the descent portion of the bucket cycle. Turbidity measurements are definitely subject to wide variation as evidenced by very high degrees of scatter in data points associated with all water depth strata and all components of the bucket cycle. Within very broad bounds, trends can be discerned, particularly in the descent and ascent components of the bucket cycle.

Additionally, any interpretation of the bucket-mounted turbidity data must consider the location of the sensor on the bucket. Although on a smaller spatial scale than affects the off-bucket sensors, the location of the bucket-mounted sensor constantly changes in relation to the sources of sediment resuspension throughout the bucket cycle. For example, in the bucket-open position the sensor is centrally located and removed from sediment surging laterally and outward from the outer flanges of the bucket caused by the descent pressure wave. During ascent, the sensor is drawn upward through the water column in advance of sediments escaping the bucket's vents. Finally, the sensor exits the water column before the lower mass of the bucket, thereby missing any pulse of sediment released as the bucket transitions the water/air interface. It is impossible to ascertain from the collected data if these factors equate to either a significant over or underestimation of the actual release by the bucket at any point in the bucket cycle. Results also indicated that sensor location on the bucket could contribute to high or low measurements. This demonstrates that a turbidity sensor would have to be calibrated based on location for every common type of bucket used by dredging contractors. The calibration procedure would necessarily consist of tests similar to those done in the present study with sensors mounted at multiple locations on specific buckets.

A limitation of real-time turbidity monitoring that pertains to both on and off-bucket sensors involves the often unconsidered requirement of calibrating the sensor to site-specific sediment parameters. As reported by Clarke and Wilber (2008), optically measured turbidity serves as a surrogate parameter for total suspended solids concentration as the basis for monitoring dredging projects throughout the United States. Despite their surrogate status, optical measures of turbidity have gained acceptance largely due to expediency and logistical ease of collecting data when results are needed quickly (Gray and Glysson 2002). Direct measurement of total suspended solids concentration using gravimetric analysis in the laboratory requires intensive field collection efforts and substantial processing time. Although the advantages of measuring turbidity rather than total suspended solids are real, research has clearly demonstrated that a nephelometric turbidity unit (NTU) is a relative term (McCarthy et al. 1974, Telesnicki and Goldberg 1995, Thackston and Palermo 2000, Davies-Colley and Smith 2001, Smith and Davies-Colley 2002, Ankcorn 2003, and Downing 2006). Different sensors measuring turbidity in the same standard suspension will produce different NTU values, and the differences in absolute values can be significant (McCluney 1975, Downing 2006). Since NTUs are not a direct measure of sediment mass, nephelometric turbidity is not an ideal parameter for estimating sediment losses. Monitoring plumes associated with dredging operations has conventionally entailed turbidity sensors in recognition of the logistical obstacles inherent in measuring suspended sediment concentrations gravimetrically. Processing water samples for gravimetric data cannot be done in real-time. Consequently almost all compliance monitoring of dredging projects consists of measuring turbidity as a surrogate parameter.

In order to use turbidity as an estimate of suspended sediment concentration, an NTU to mg/L conversion relationship specific to each turbidity sensor must be established. Importantly, the relationship is specific to *in situ* sediments. Should the dredge move from silty sediments to sediments with higher coarse fractions, the new NTU to mg/L relationship would have to be determined (Thackston and Palermo 2000). This requirement could be problematic for any real-time monitoring system designed to provide adaptive feedback for rapid management of dredging activities. A NTU to mg/L conversion was determined in the laboratory using water samples collected on site using a mini-rosette water bottle system. The collected water samples were processed in the laboratory both gravimetrically for total suspended solids (TSS) concentration and for turbidity. Although the water samples were collected in tandem with a contemporaneous far-field plume characterization within the Newark Bay study area, they were collected within the same time frame and in the immediate vicinity of the same dredge using the same bucket and dredging the same contract area sediments as the NFT/TSS Pilot Study. The relationship for samples collected at the study site is shown in Figure 55 and is specific to the laboratory turbidity meter.

Collectively the turbidity data obtained in this study do provide some valuable insights into the dredging process and sediment resuspension in particular. The data comprise a picture of turbidity collected from an OBS instrument mounted on a mechanical bucket. All data points fall within the ambient to 1,000 NTU range, but data points above 500 NTU are comparatively rare and tend to be associated with either the shallowest or deepest depth strata. When plotted on a cumulative percent versus NTU basis (Figure 56) for each component of the bucket cycle and dredge moving process, the data indicate that measurements above 450 NTU are very rare. Fifty percent of the measurements for bucket descent, ascent, digging, and dredge moving fell below 230, 245, 225, and 173 NTU respectively. Thus when a long-term turbidity on the bucket data set is viewed as a whole, very similar patterns emerge (Figure 56).

6.4 Bucket Hoist Speed

Because bucket speed in either descent or ascent mode could potentially affect sediment losses, for example by increasing washing of sediment off inner and outer surfaces of the bucket, it should be acknowledged that the data presented herein do not allow an estimation of the magnitude of that effect. It should be noted, however, that factors such as bucket speed could interact alone or in tandem with other factors, including sensor location on the bucket, to preclude generation of a single turbidity reading in real-time that represents an accurate estimate of sediment release.

Bucket speed could affect the interpretation of the data derived from the present study in several meaningful ways. One confounding factor involves data record rates. Recall that the OBS instruments used on the bucket integrate 30 separate measurements into a single NTU value, and that the actual burst of measurements occurs within seconds 2-4 of the five second interval. Assume that the average bucket descent speed is 4.3 feet per second and the average ascent speed is approximately 2.1 feet per second. Thus in five seconds the bucket travels 21.5 feet in the downward direction and 10.5 feet in the upward direction. During the actual measurement bursts the bucket travels 12.9 feet downward or 6.3 feet upward. In addition to the differential sample size with respect to data points for the same number of bucket cycles, one must also consider the fact that if the three second burst of 30 measurements occurs while the instrument is entering or exiting the water column then some unknown portion of the 30 measurements will have been taken while the instrument was above the surface. These measurements could produce a saturated signal and skew the calculated average upwards to an erroneously high NTU value. In theory, the bias would be less on the ascent because the bucket is not traveling as far in the same interval of time. This inherent bias in the bucket turbidity data could provide an alternative explanation for the "bubble effect" in that the observed pattern of average NTUs above ambient in the shallow depth strata may simply reflect an artifact due to the manner in which the instrument records measurements.

7.0 Conclusions

As stated in the Introduction Section, the goal of this Pilot Study was to test the near-field use of both optical back-scatter (OBS) and Acoustic Doppler Current Profiler (ADCP) sensors to measure near-field turbidity levels, by deploying OBS sensors mounted to the closed clamshell environmental bucket, and OBS and ADCP sensors mounted to the dredge platform. The study was designed to assess the following:

> a) Whether either type of sensor, mounted as set forth above, is sufficiently reliable and resilient to continuously record and/or transmit data from which quantitative backscatter measurements can be obtained continuously and in real time, within a turbulent near-field environment, over a time span routinely involved in navigational dredging., and
>
> b) If either type of sensor were found to demand repair, maintenance, and/or recalibration, on a frequency that made continuous monitoring impractical, whether the sensor could be hardened to avoid the need for such repair, maintenance, and/or recalibration.

For the duration of the Study, repair, maintenance, and/or recalibration of the sensors was not a factor.

Based on Stipulation and Order Appendix A. Section 7 Part b. Following the completion of the field work described in paragraphs 1 and 2 of this Appendix, Defendants shall prepare a technical report (the "NFTTSS Pilot Study Report") that:

> "analyzes the feasibility of applying the pilot-tested configuration of optical and acoustic backscatter instrumentation and data collection capability or a refinement thereof to future HDP activities within the NBSA and the anticipated efficacy of

> such pilot-tested measures to assist in minimizing dredging-induced sediment resuspension during such dredging activities."

Based on the data and evaluations from this Pilot Study, the utility of deploying optical sensors at a fixed location off the dredge platform was found to be impractical due to the variation in signal intensity noted under varying tide conditions. This Study also found that although an OBS sensor attached to a bucket can physically survive and produce data, the data derived from the sensors highlight a number of gaps in knowledge that must be filled as prerequisites to routine applications of a bucket-based sensor system. In addition, this study found that an acoustic sensor (ADCP) placed in close proximity to the bucket is subject to intense disruption of the acoustic backscatter signal caused by the entrainment of air. The data illustrated that an ADCP deployed from a fixed position on the dredge platform would also be subject to large variations in signal intensity similar to that of the OBS sensor due to the constantly changing distance between the sensor and the source (i.e. bucket) and due to constantly varying tidal conditions.

As discussed in Section 6 of this report, the feasibility of deploying a real-time turbidity monitoring system, incorporating the Pilot Study test configuration to future HDP activities, is impractical based on the following:

- Variation in signal intensity noted under varying tide conditions. This indicates that accurate loss rate estimates cannot be obtained when the plume is flowing away from the sensor.
- The difficulty in distinguishing air versus sediment contributions to any given data point in the descent component of the bucket cycle due to air entrainment. In addition, the air entrainment pattern may also be heavily influenced by bucket descent speed or differences in execution by the bucket operator. Therefore, any correction factor would have to be applied in post-processing mode to pooled and averaged data rather than in real-time for incoming data points.
- A requirement to frequently, possibly daily, calibrate the OBS sensor to site-specific sediment parameters.

The implementation of a robust real-time turbidity monitoring system to future HDP activities in the NBSA in the near future is, therefore, deemed not feasible based on the sensor configuration of optical and acoustic backscatter instrumentation and data collection capabilities evaluated in this Pilot Study.

At present, the near field collection of real time turbidity data and the conversion of this data to accurate losses in terms of sediment mass poses daunting technical (i.e., equipment), physical (i.e., complex hydrodynamic flows) and spatial (i.e., active navigational use in existing channels) challenges. Many of these challenges are beyond the scope of the study as defined in the settlement agreement.

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Table 1. Sequence of bubble and dredging tests with prevailing tide stage and number of bucket cycles recorded for each test.

Test	Tide	Dredge Orientation[1]	Date	Time	# Bucket Cycles	Instruments Used
Bubble 1	Flood	North	Jan 29	0945-1045	23	Bucket = OBS (s/n 36) Platform = OBS Surf (s/n 71) OBS Mid (s/n 37) OBS Bottom (s/n 29)
Bubble 2	Slack (high)	North	Jan 29	1300-1330	16	Bucket = OBS (s/n 38) Platform = OBS Surf (s/n 71) OBS Mid (s/n 37) OBS Bottom (s/n 36)
Bubble 3	Ebb	North	Jan 29	1530-1615	20	Bucket = OBS (s/n 29) Platform = OBS Surf (s/n 71) OBS Mid (s/n 37) OBS Bottom (s/n 36)
Short Term 1	Flood	North	Jan 29	1115-1215	24	Bucket = OBS (s/n 38) Platform = OBS Surf (s/n 71) OBS Mid (s/n 37) OBS Bottom (s/n 36)
Short Term 2	Slack (high)	North	Jan 29	1400-1450	26	Bucket = OBS (s/n 38) Platform = OBS Surf (s/n 71) OBS Mid (s/n 37) OBS Bottom (s/n 36)
Short Term 3	Ebb	North	Jan 29	1630-1700	15	Bucket = OBS (s/n 38) Platform = OBS Surf (s/n 71) OBS Mid (s/n 37) OBS Bottom (s/n 36)
Long Term 1	Flood to Slack (high) to Ebb	South	Jan 30	0815-1630	145	Bucket = OBS (s/n 38) Platform = OBS Surf (s/n 71) OBS Mid (s/n 37) OBS Bottom (s/n 36)
Long Term 2	Slack (low) to Flood then Slack (high) to Ebb	South	Jan 31	0800-1630	125	Bucket (inboard) = OBS (s/n 29) Bucket (Outboard) = OBS (s/n 38) Platform = OBS Surf (s/n 71) OBS Mid (s/n 37) OBS Bottom (s/n 36)
Long Term 3	Slack (low) to Flood	South	Feb 1	0745-1615	194	Bucket (inboard) = OBS (s/n 29) Bucket (Outboard) = OBS (s/n 38) Platform = OBS Surf (s/n 71) OBS Mid (s/n 37) OBS Bottom (s/n 36)

[1] Dredge orientation refers to the approximate direction that the bow of the dredge platform and bucket were facing.

Table 2. Summary of bucket descent and ascent speeds during the long-term dredging tests.

Bucket Speed (feet/second)	Descent		Ascent	
	Mean	(Range)	Mean	(Range)
Long-Term Test #1	4.15	(2.20 – 5.40)	2.13	(1.85 – 2.24)
Long-Term Test #2 Inboard	4.44	(1.71 – 5.43)	2.17	(2.03 – 2.25)
Long-Term Test #2 Outboard	4.32	(2.45 – 5.15)	2.15	(2.09 – 2.20)
Long-Term Test #3	4.36	(2.30 – 5.30)	2.13	(1.53 – 2.19)

a)

b)

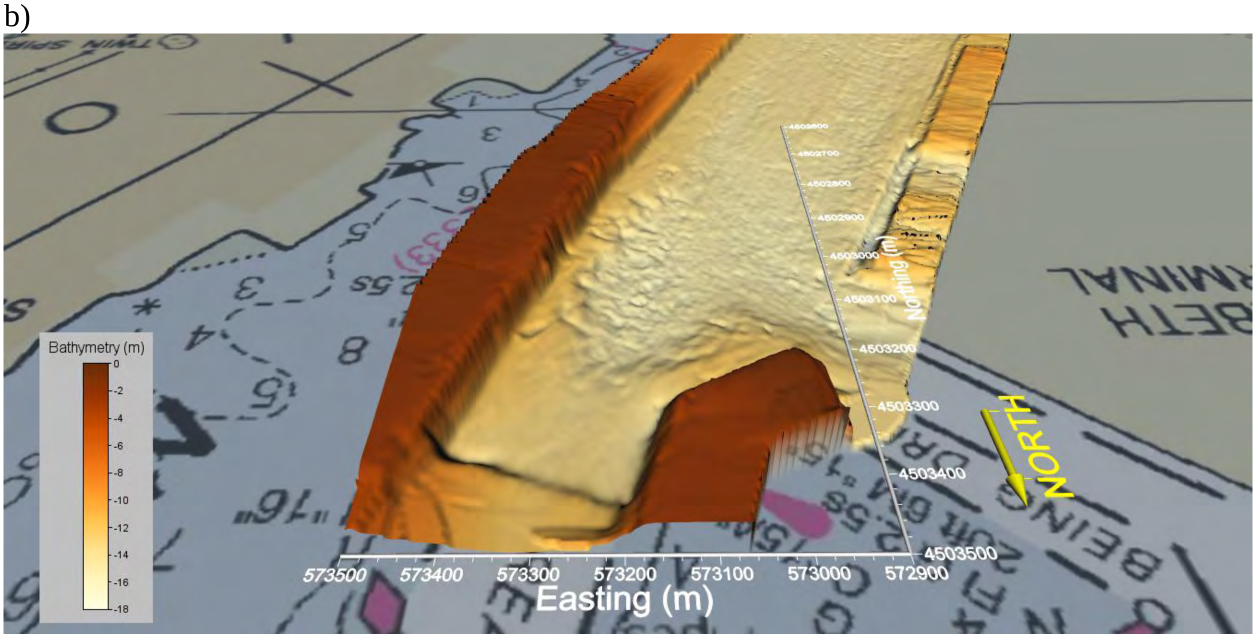

Figure 1. a) Option areas of the S-NB-1 Contract area of the NY/NJ Harbor Deepening Project and b) bathymetry of S-NB-1 dredge contract area during the Pilot Study.

Figure 2. Cable Arm bucket in the open position. Note that the lowest row of vents has been closed by welding metal strips across the flaps.

Figure 3. Cable Arm bucket in the closed position.

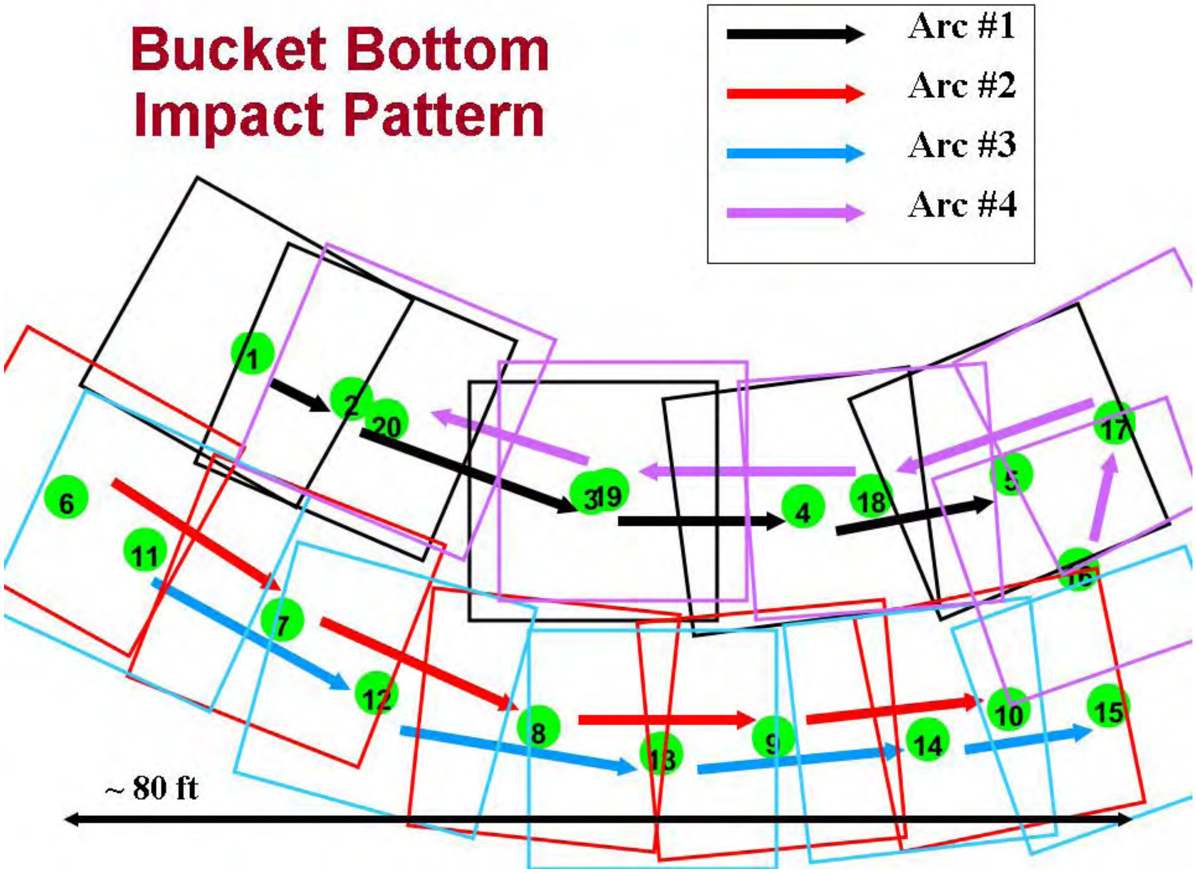

Figure 4. Bucket impact position for a typical series of four arcs conducted between advances of the dredge. A sequence of 20 bucket cycles is shown as numbered green dots. The example progression is based on an actual DGPS record of bucket impact points during a long-term test on January 30, 2008. The color coded rectangles centered on each dot represent the approximate plan-view dimensions of the bucket in the open position as it would come in contact with the bottom.

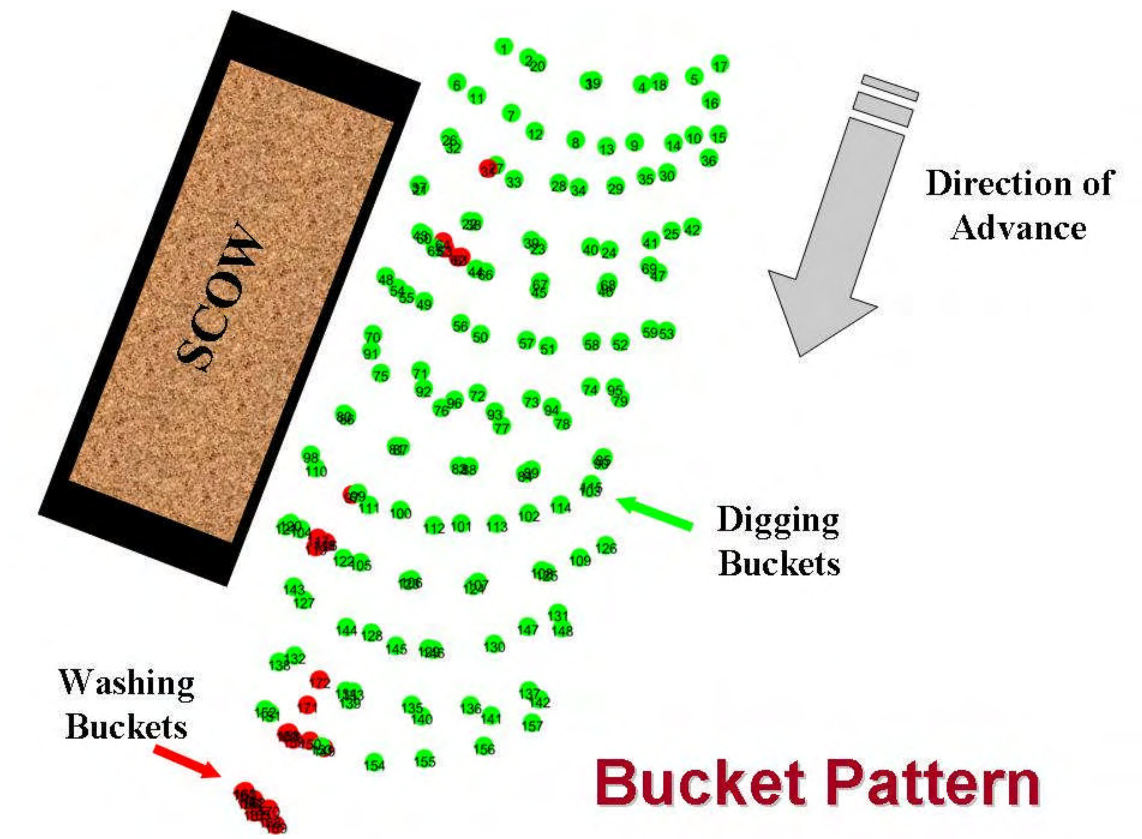

Figure 5. Plan-view distribution of bucket impact points on the bottom in relation to orientation of the receiving scow. Each numbered green dot represents a single bucket impact location based on DGPS offset data derived from a known reference point on the derrick. The scow is not drawn to scale. The numbered red dots represent non-digging bucket cycles used to collect water to wash the deck of the scow. Data from long-term dredging test on January 30, 2008.

Figure 6. Instrumentation as mounted on the bucket. Upper orange canister contains an accelerometer array. Lower white and black unit is a battery-powered optical backscatter sensor (OBS-3A) with the sensor facing laterally outward from the central bucket support rib and outboard in relation to the bucket's internal axis. When the bucket was closed the instruments were oriented horizontally. When the bucket was open the instruments were oriented at an approximately 45 degree angle from the vertical.

Figure 7. Sensor location. The orange accelerometer canister and white OBS housing are visible attached to the bucket's central support rib. This sensor array is on the "inboard" side of the bucket, which always faces the derrick and operator's cab.

Figure 8. Location of sensors deployed from the dredge platform. The vertical tube supports the ADCP transducer assembly just below the water's surface. A string of three OBS units was deployed outboard from the ADCP mount.

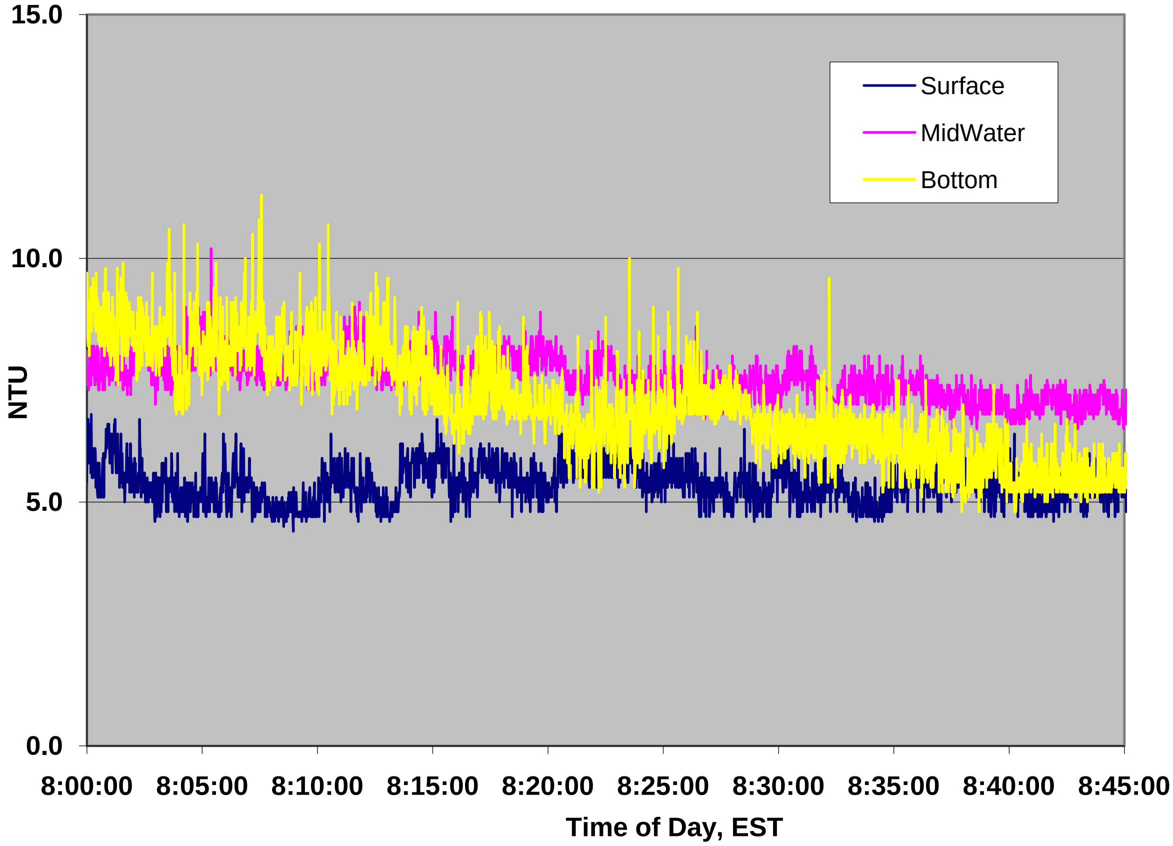

Figure 9. Example of ambient turbidity data collected by platform OBS units on January 31, 2008.

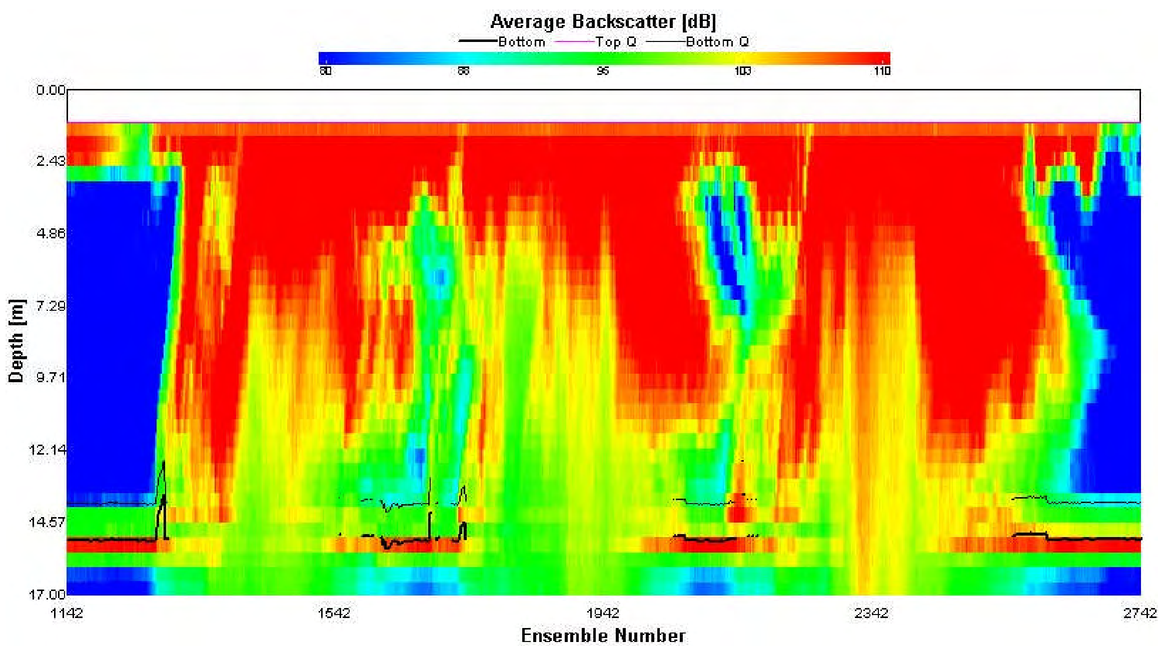

Figure 10. ADCP backscatter signal during the ebb tide bubble test on January 29, 2008.

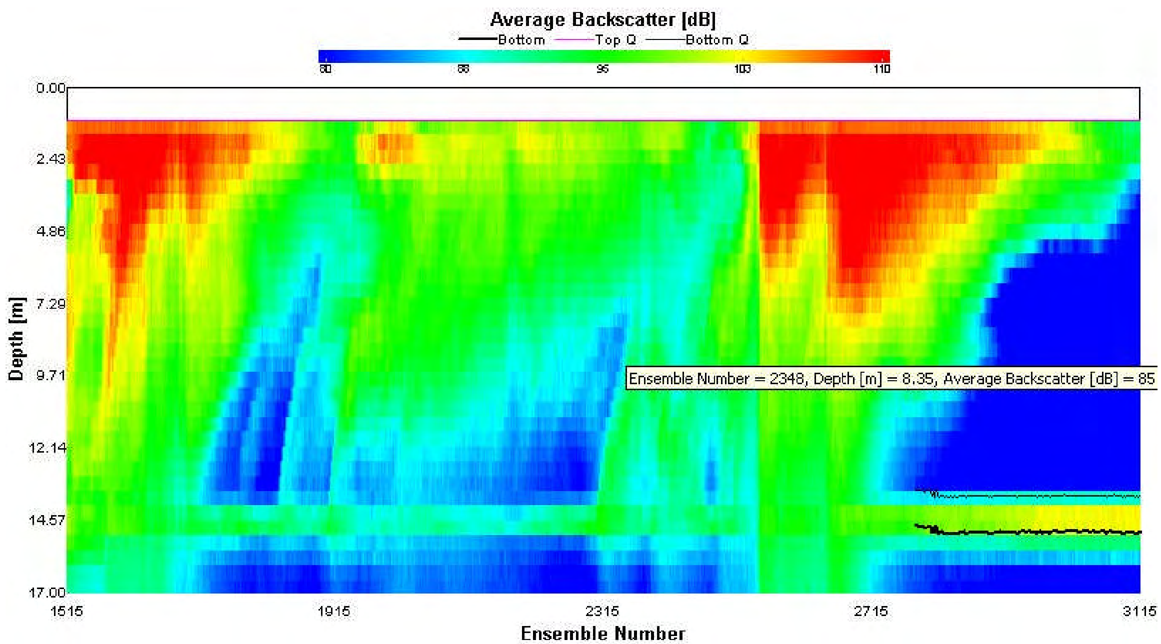

Figure 11. ADCP backscatter signal during the slack tide bubble test on January 29, 2008.

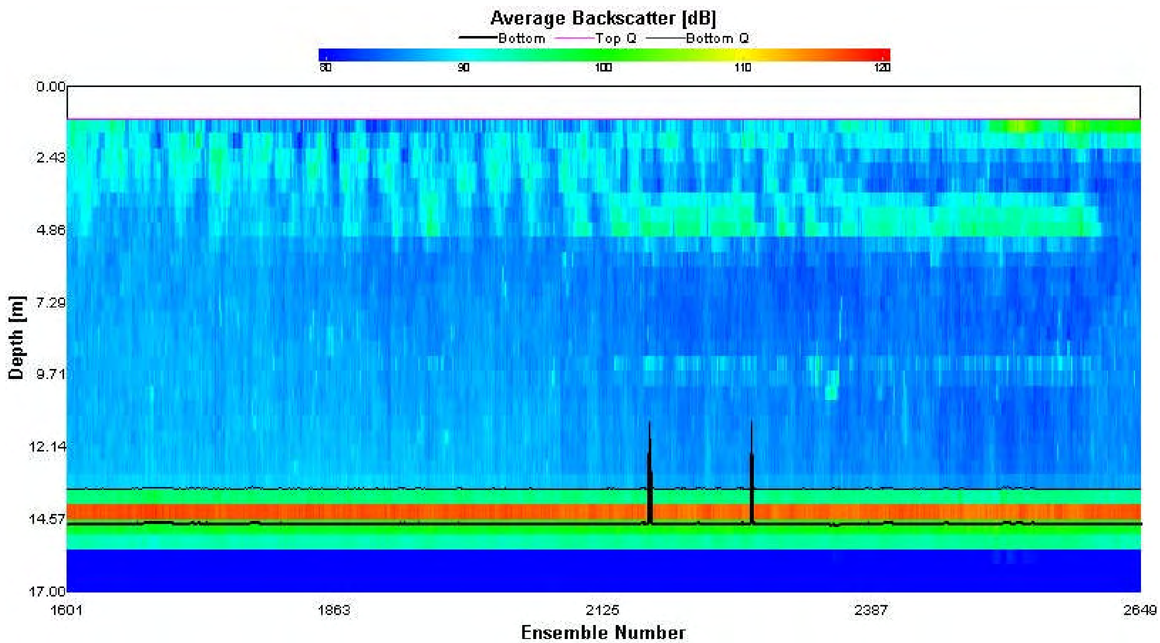

Figure 12. ADCP backscatter signal during the flood tide bubble test on January 29, 2008.

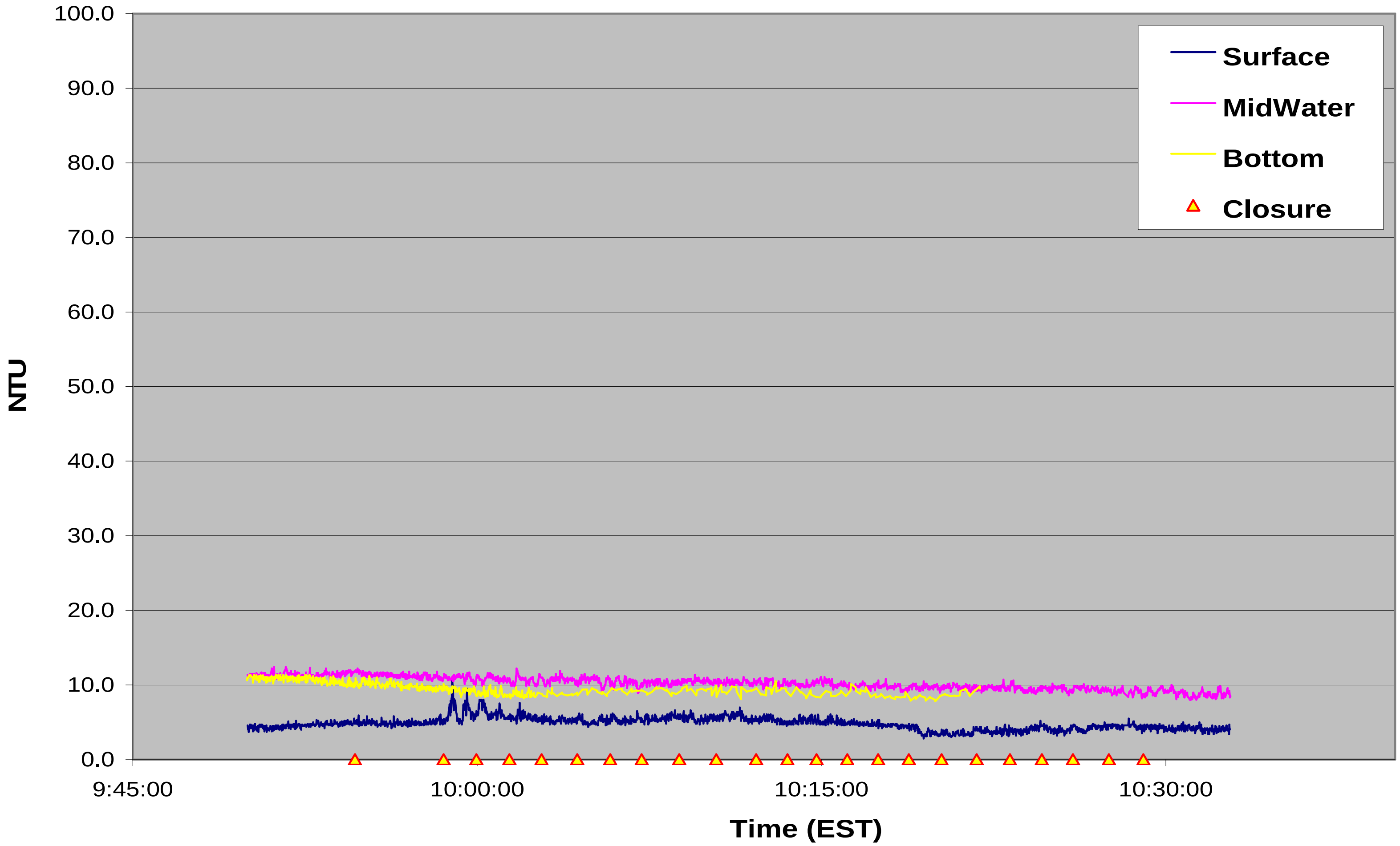

Figure 13. Turbidity measurements obtained by OBS instruments deployed from the dredge platform during the first bubble test, which occurred on a flooding tide on January 29, 2008.

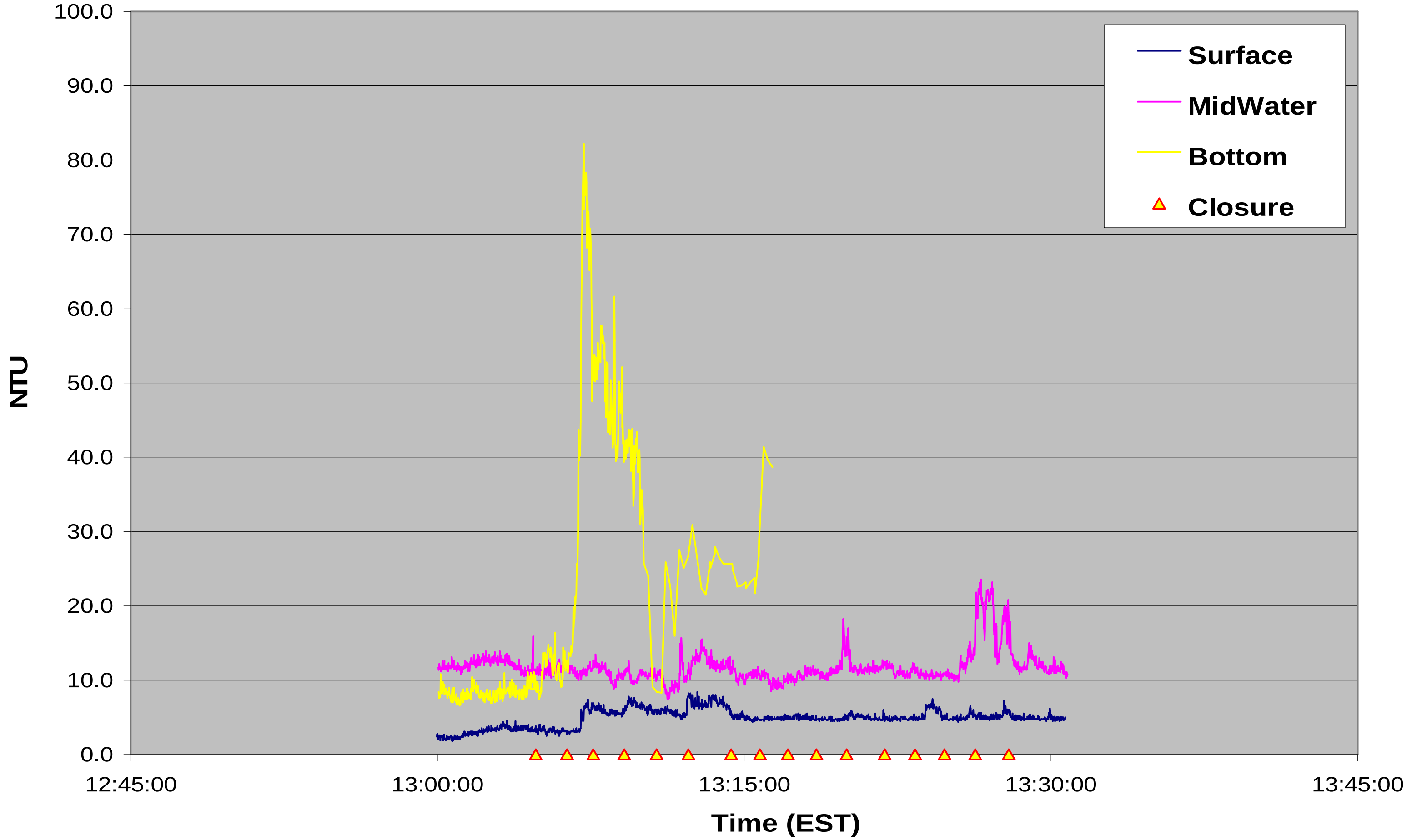

Figure 14. Turbidity measurements obtained by OBS instruments deployed from the dredge platform during the second bubble test, which occurred during slack tide on January 29, 2008.

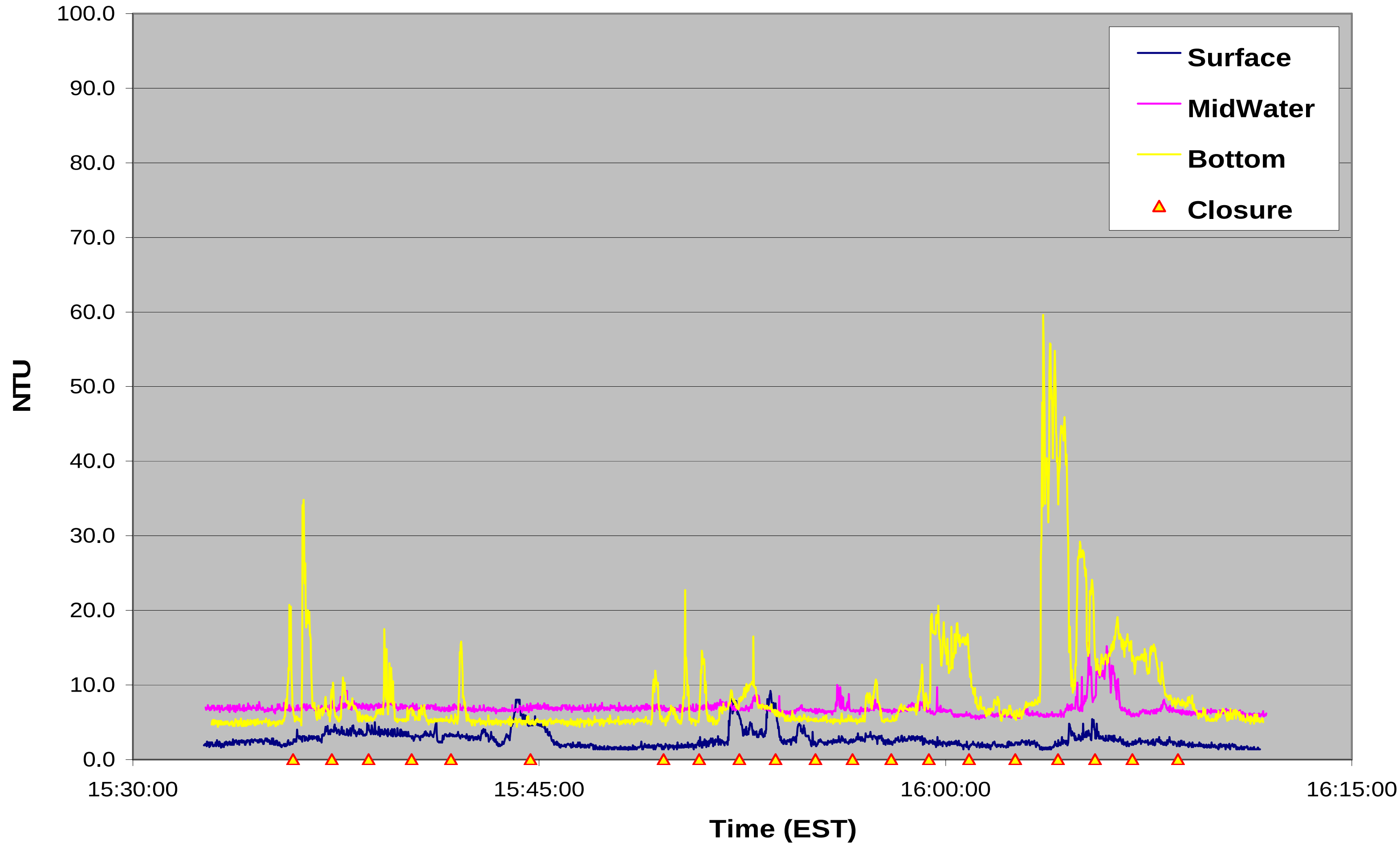

Figure 15. Turbidity measurements obtained by OBS instruments deployed from the dredge platform during the third bubble test, which occurred on an ebbing tide on January 29, 2008.

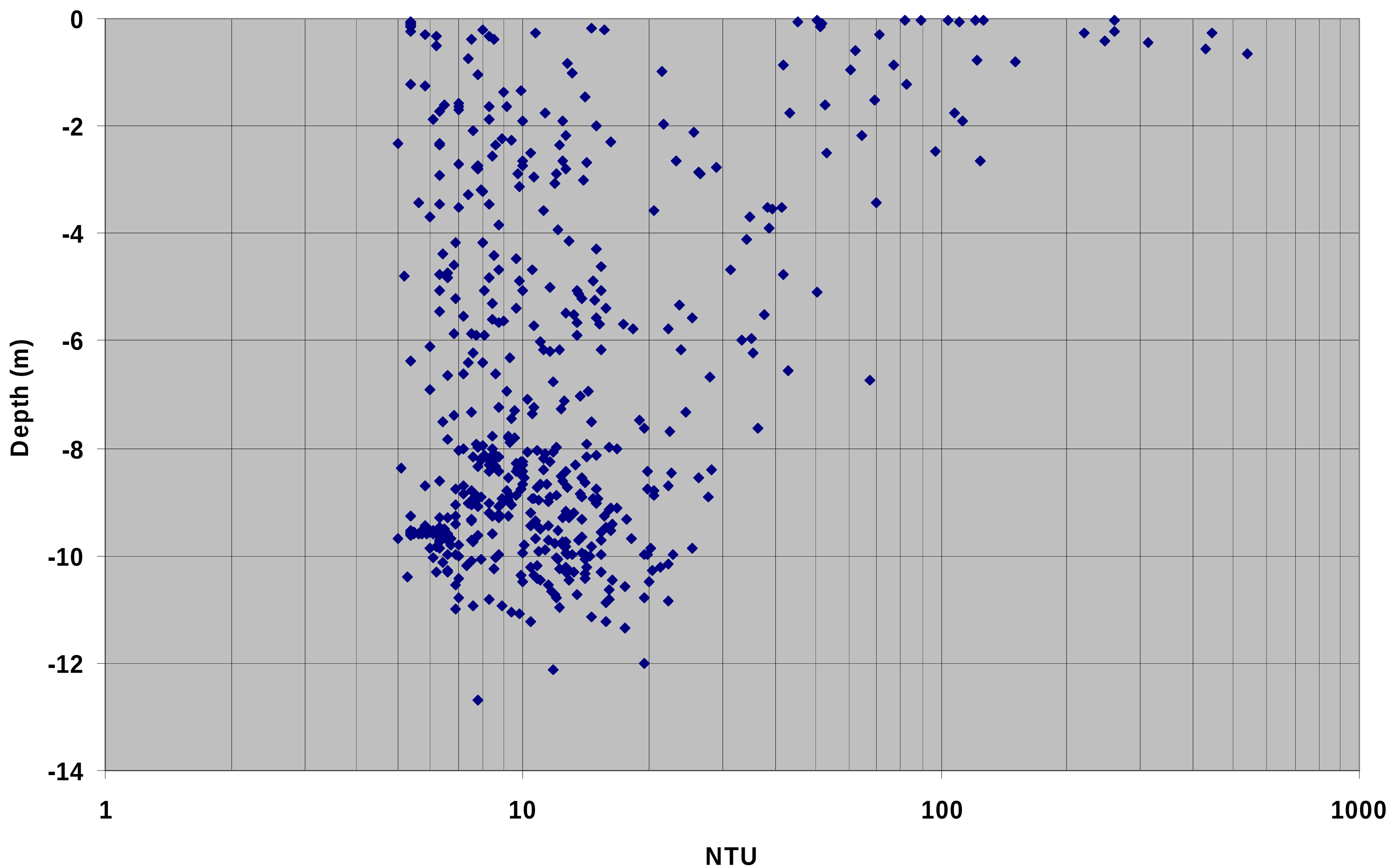

Figure 16. Turbidity data plotted against depth for bucket-mounted OBS instrument for all bubble tests. Note logarithmic scale of X-axis.

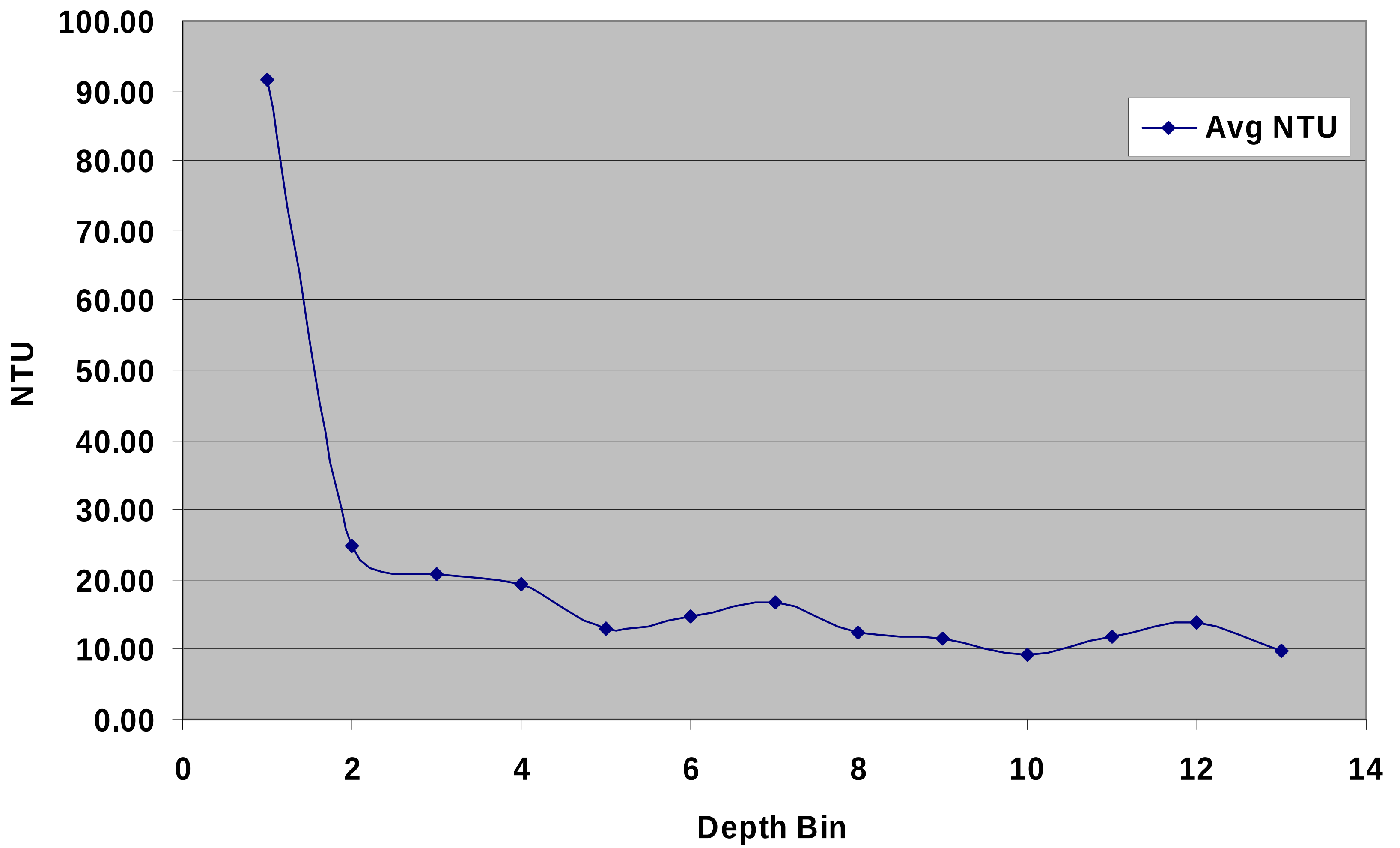

Figure 17. Average turbidity measurements by depth strata for a bucket-mounted OBS instrument during all bubble tests.

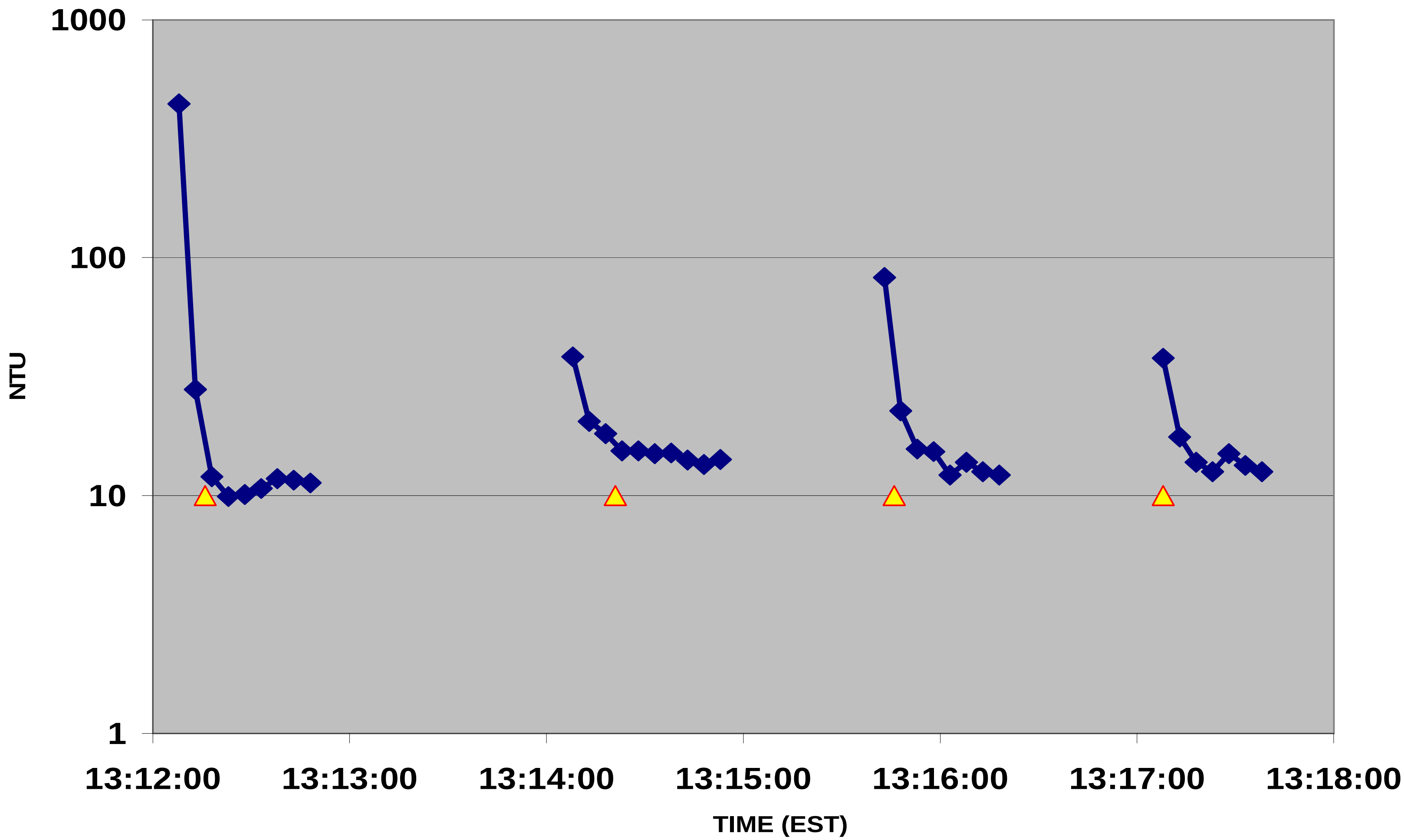

Figure 18. A typical series of turbidity measurements from a bucket-mounted OBS instrument during a bubble test. Yellow triangles represent synchronized bucket closure times. The gap between successive bucket cycles result from deletion of measurements made while the bucket was above the surface of the water.

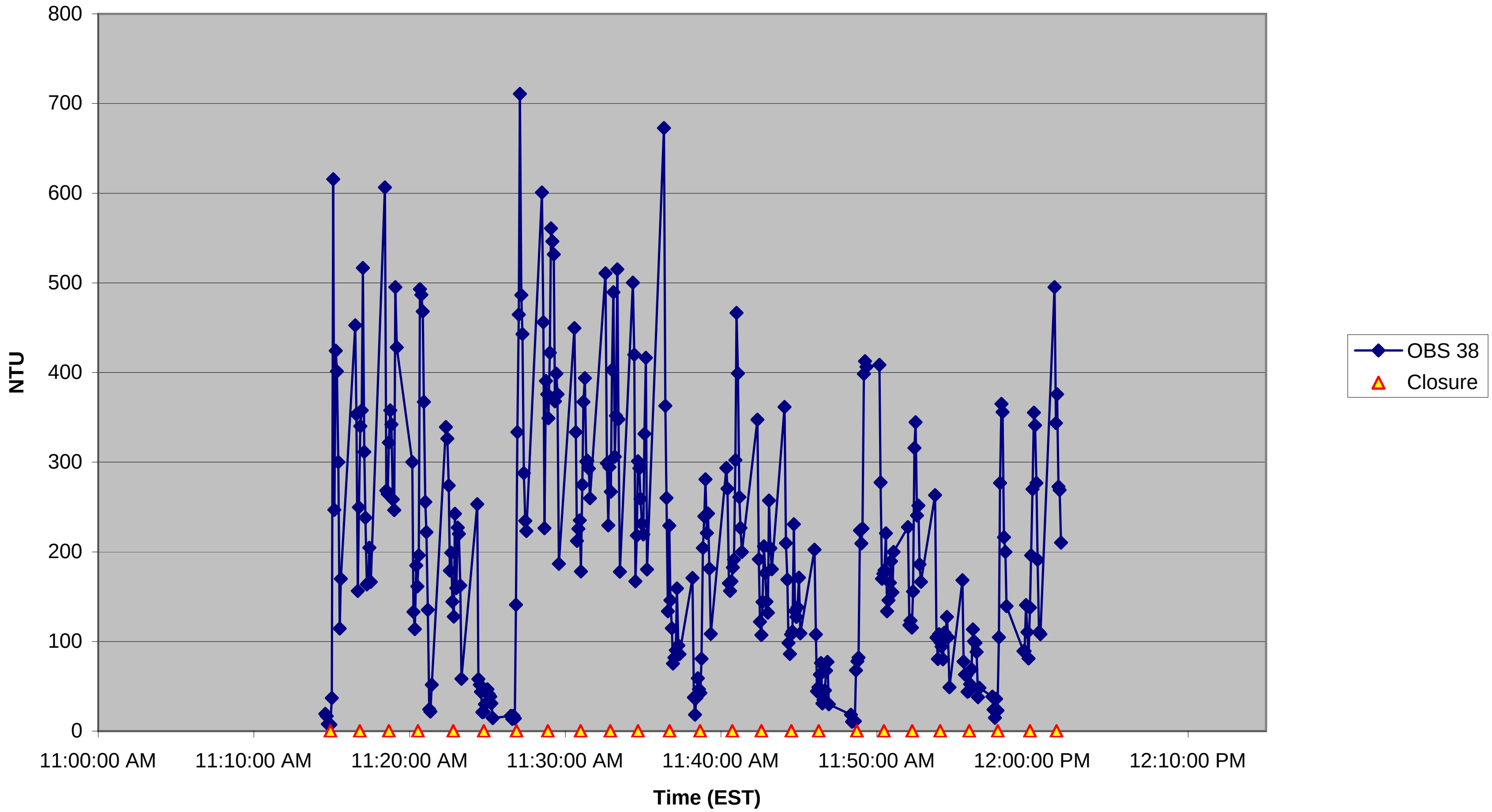

Figure 19. Turbidity measurements obtained from the bucket mounted OBS Unit during the first short-term duration dredging test (flood tide) on January 29, 2008.

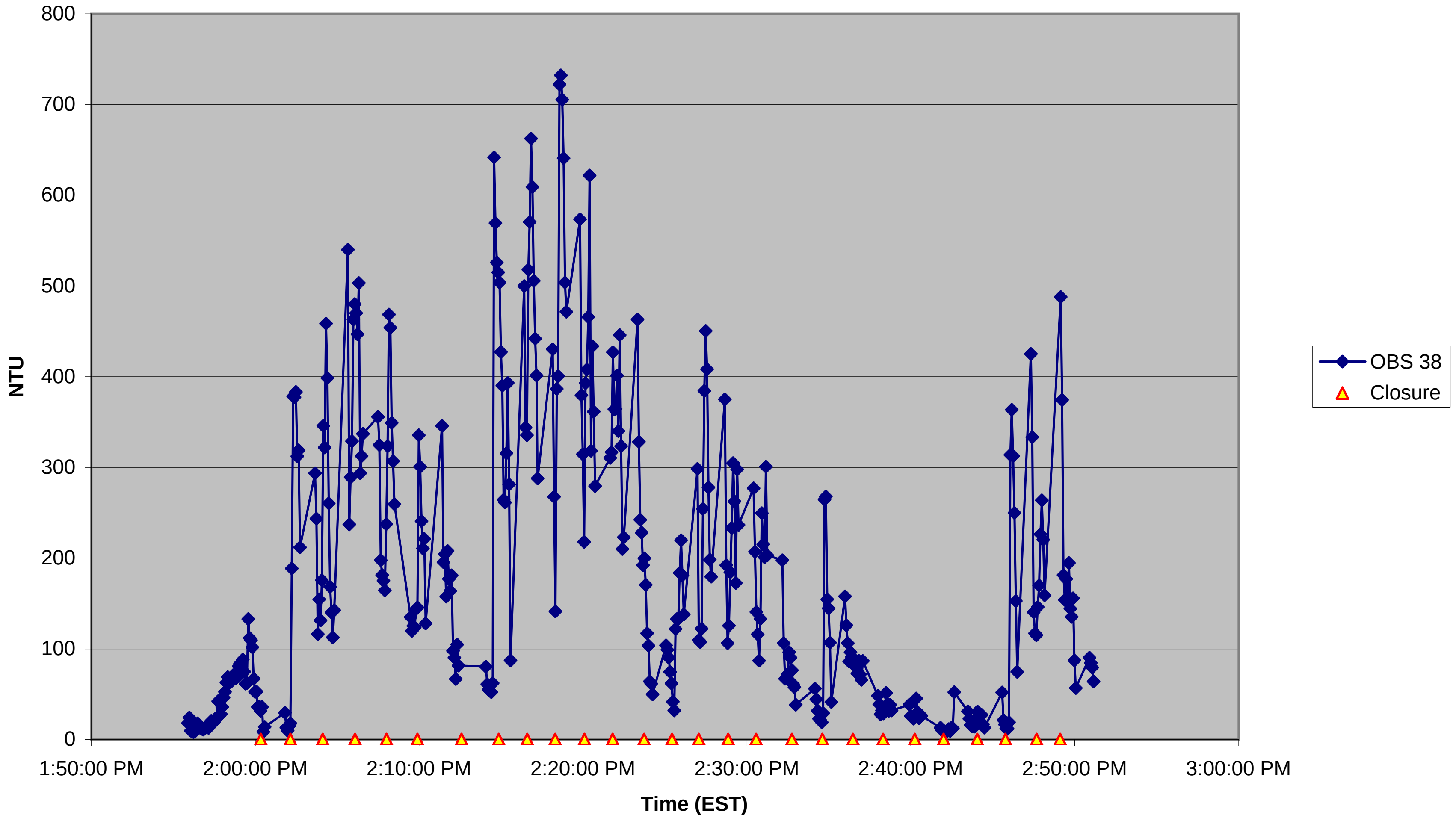

Figure 20. Turbidity measurements obtained from the bucket mounted OBS Unit during the second short-term duration dredging test (high slack tide) on January 29, 2008.

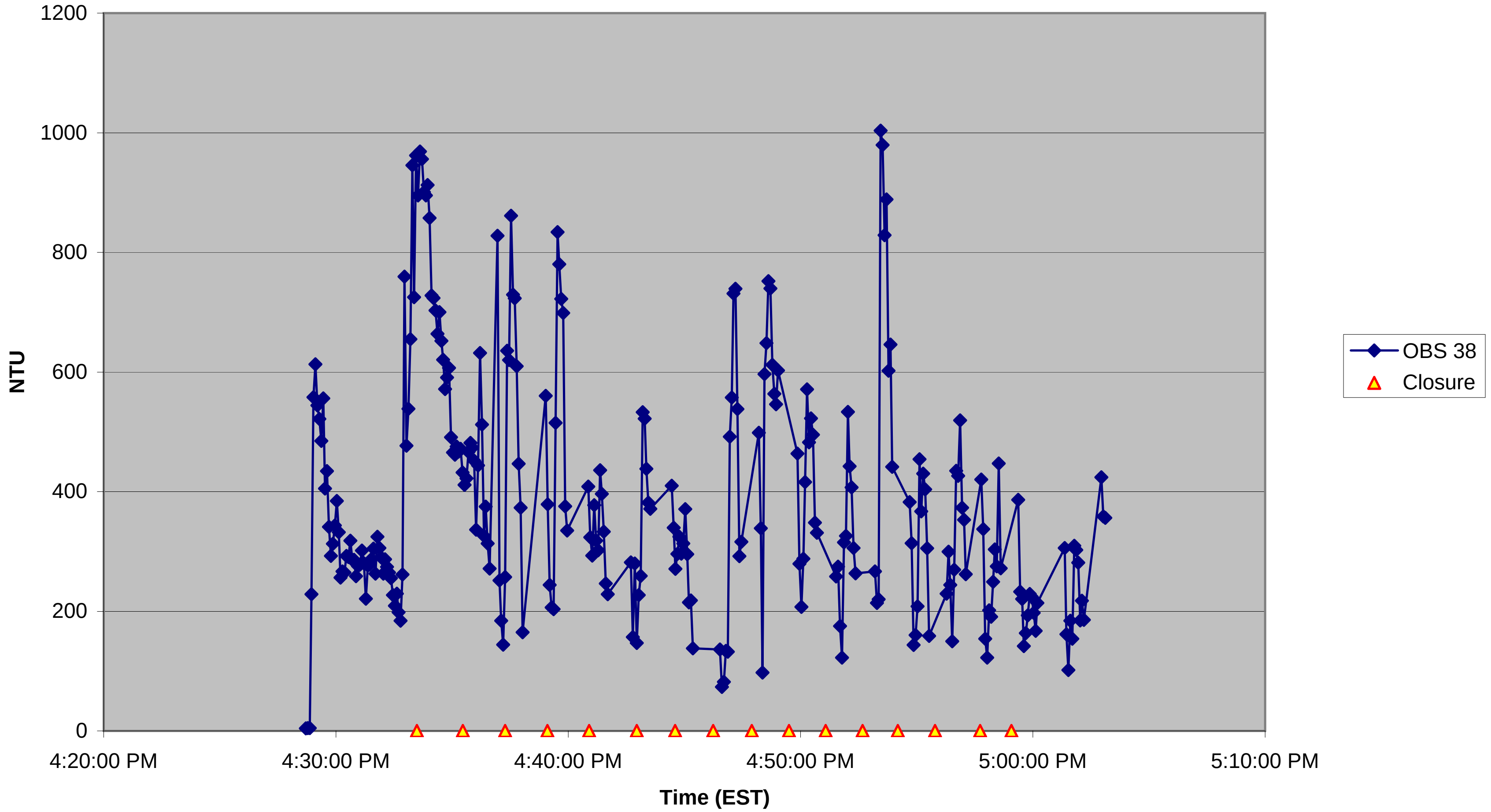

Figure 21. Turbidity measurements obtained from the bucket mounted OBS Unit during the third short-term duration dredging test (ebb tide) on January 29, 2008.

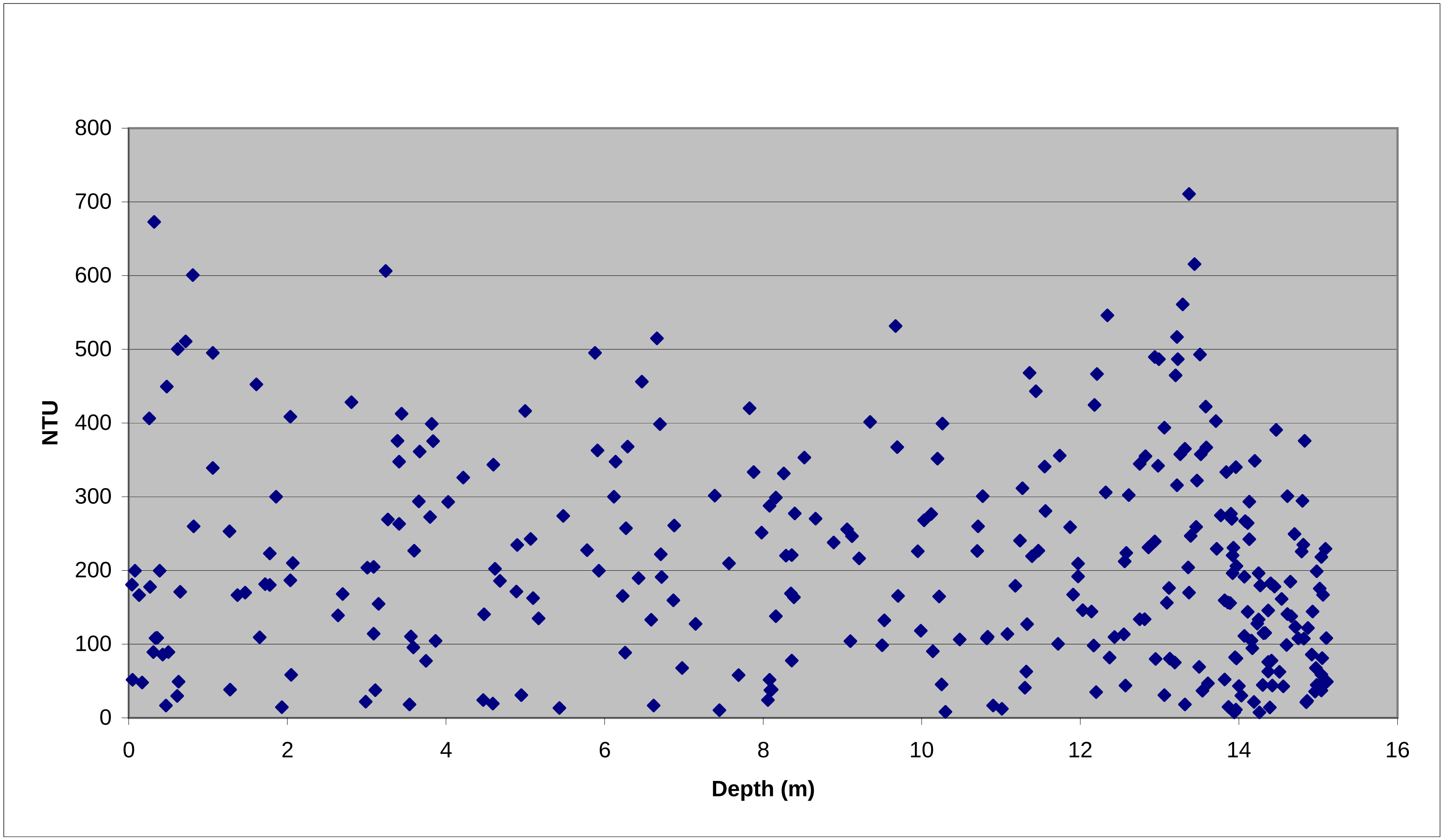

Figure 22. Turbidity measurements plotted versus depth and obtained from the bucket mounted OBS Unit during the first short-term duration dredging test (flood tide) on January 29, 2008.

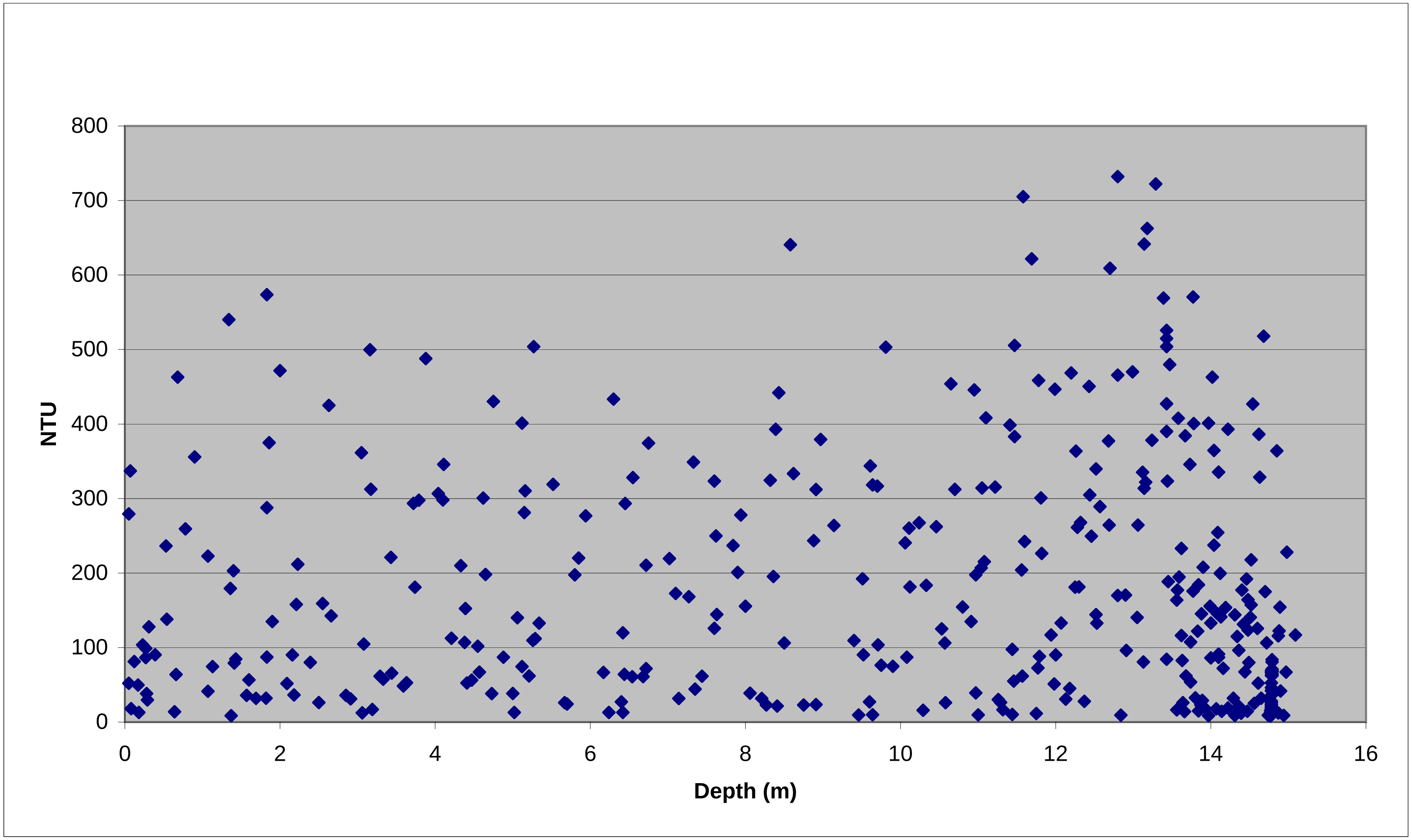

Figure 23. Turbidity measurements plotted versus depth and obtained from the bucket mounted OBS Unit during the second short-term duration dredging test (high slack tide) on January 29, 2008.

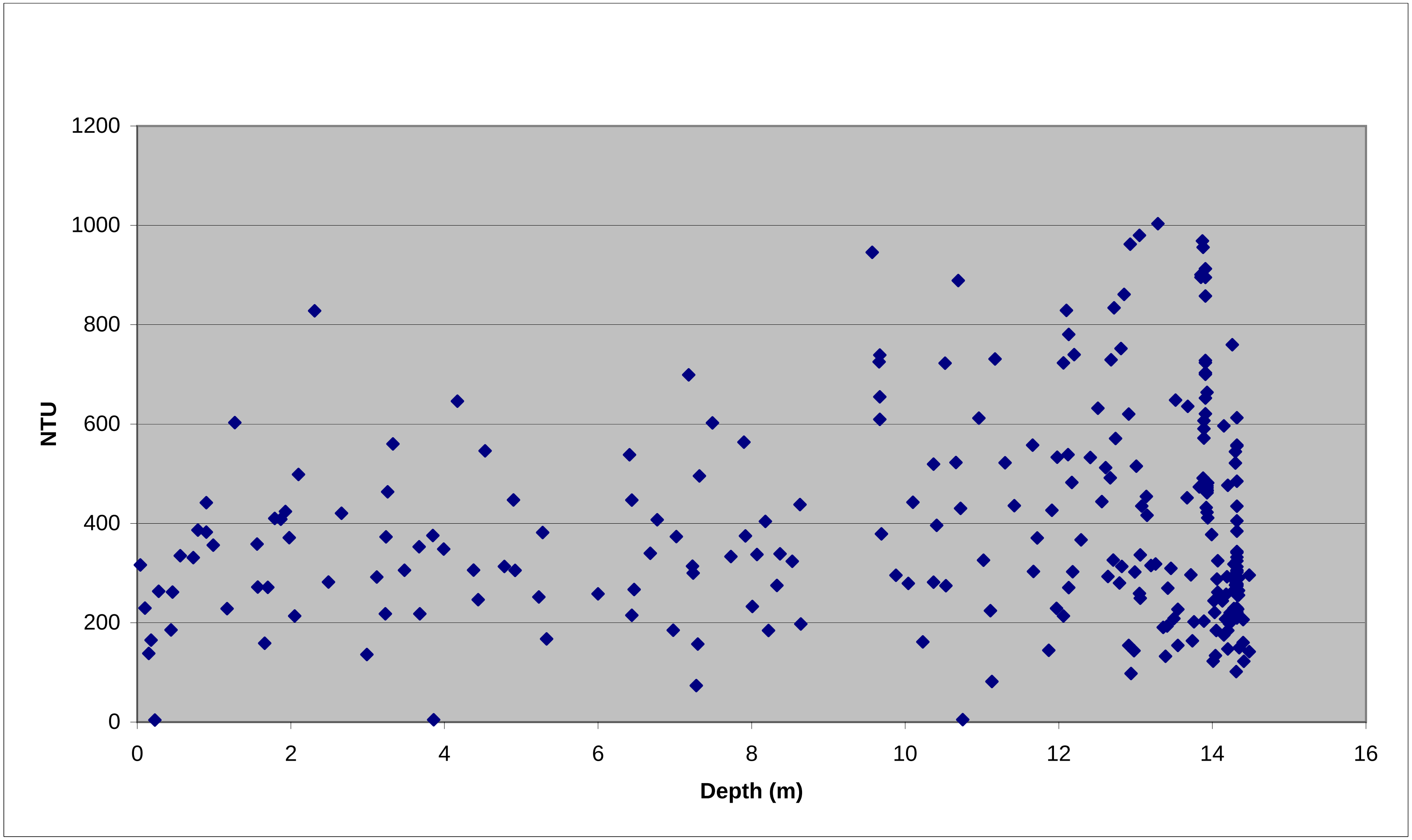

Figure 24. Turbidity measurements plotted versus depth and obtained from the bucket mounted OBS Unit during the third short-term duration dredging test (ebb tide) on January 29, 2008.

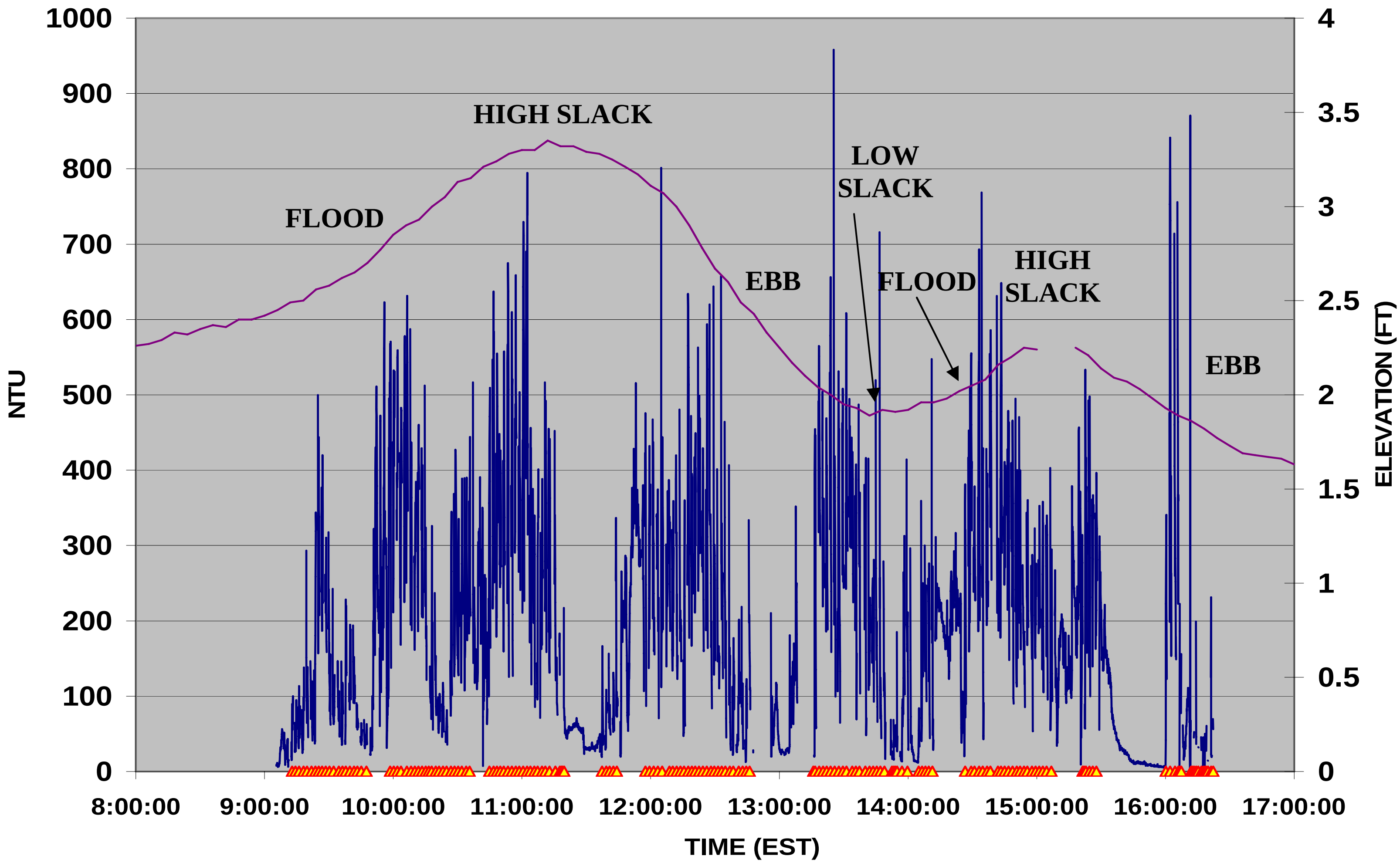

Figure 25. Turbidity measurements obtained by a bucket-mounted sensor during the first long-term dredging test on January 30, 2008.

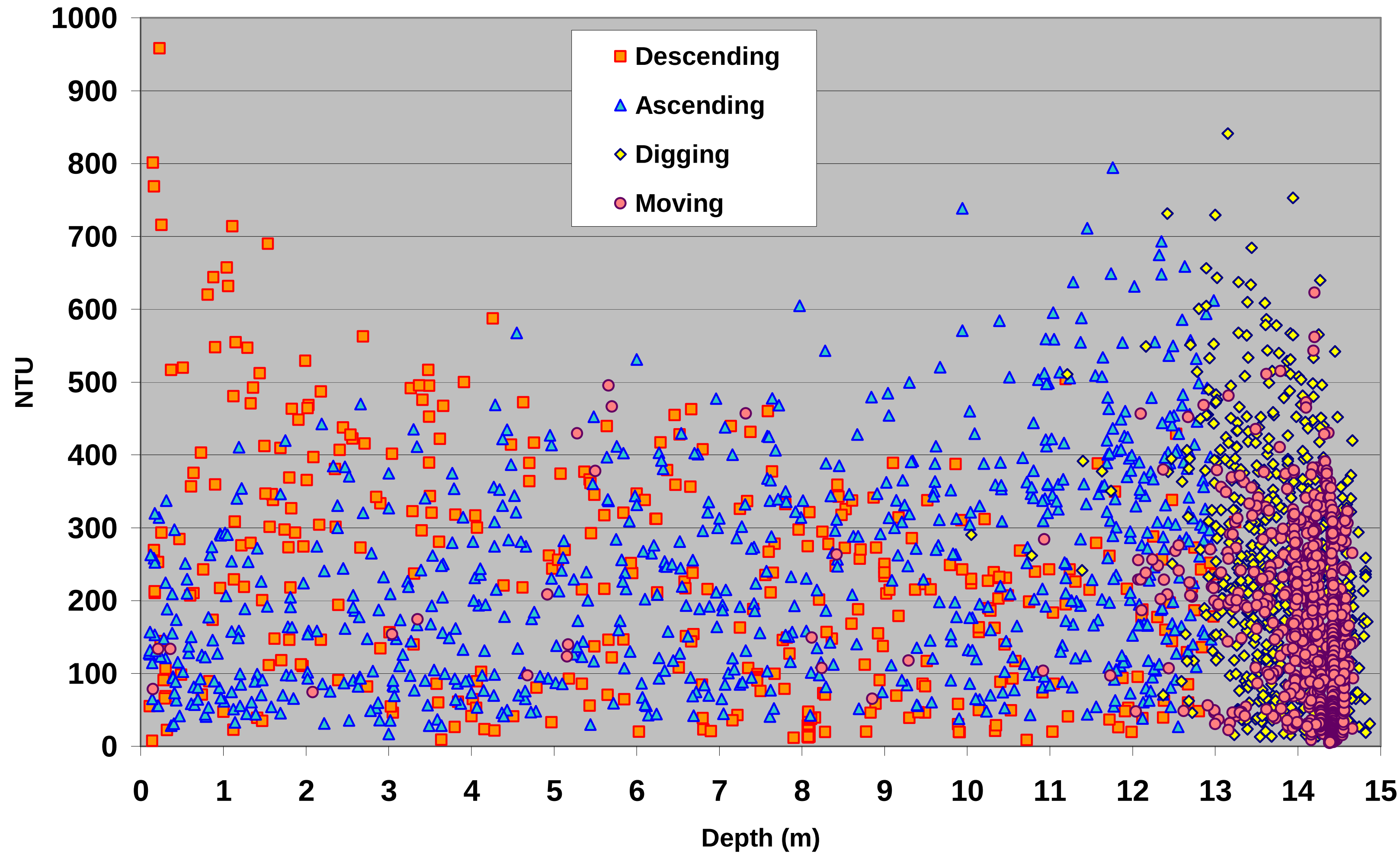

Figure 26. All turbidity measurements obtained by a bucket-mounted sensor during the first long-term dredging test on January 30, 2008.

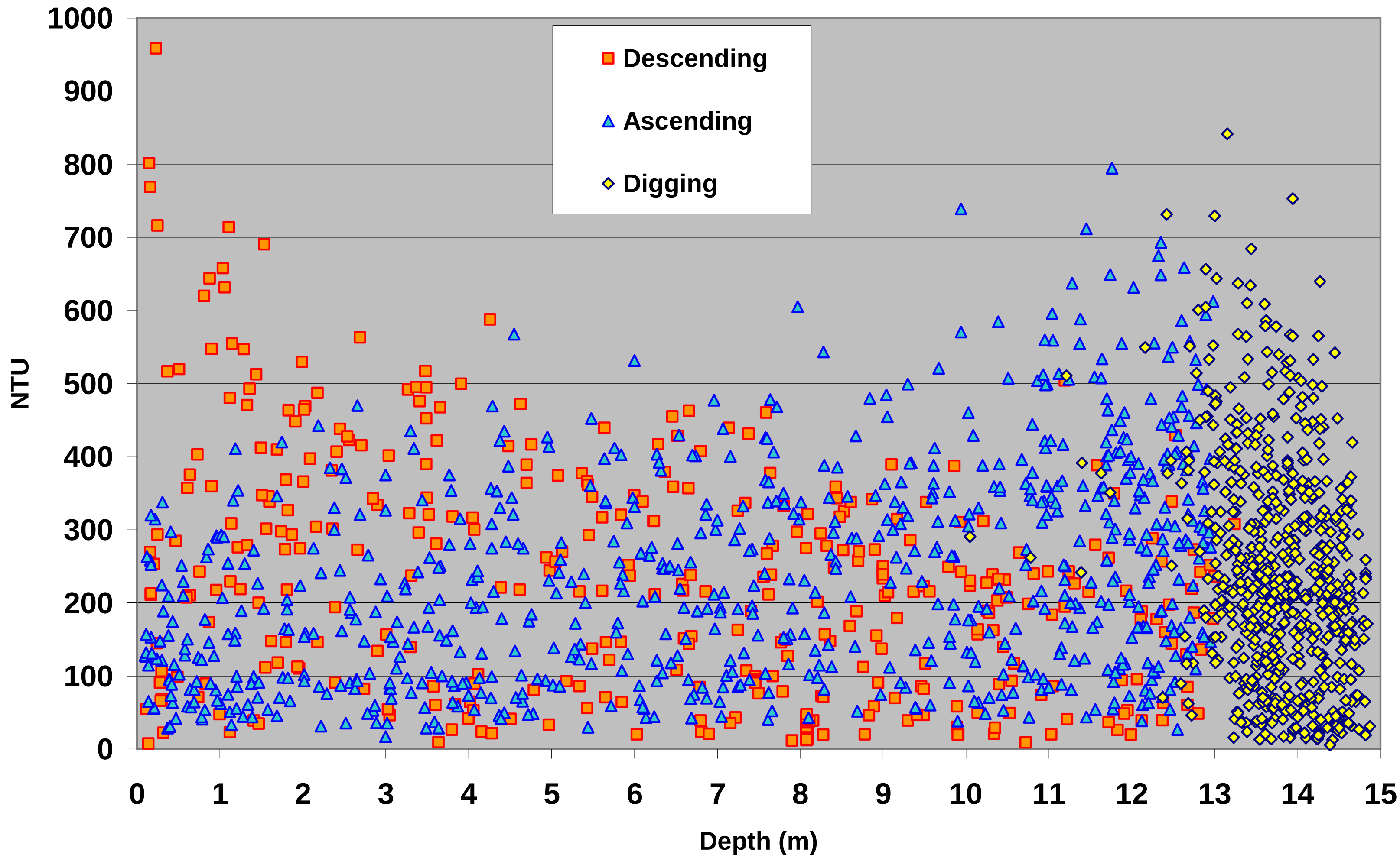

Figure 27. Bucket-mounted turbidities during the first long-term dredging test on January 30, 2008; descent, ascent and dredging data only.

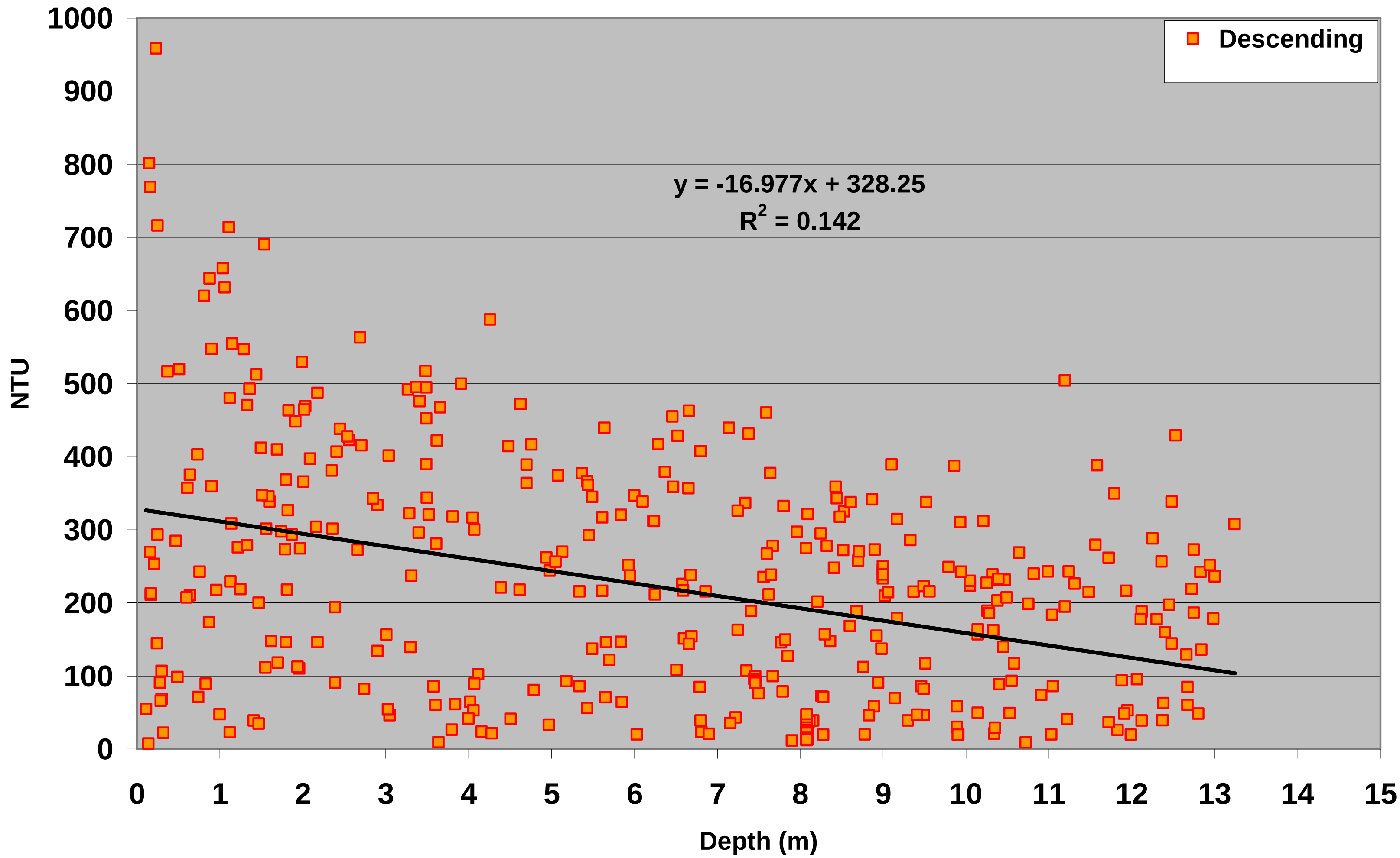

Figure 28. All turbidity measurements obtained by a bucket-mounted sensor during the descent component of the bucket cycle during the first long-term dredging test on January 30, 2008.

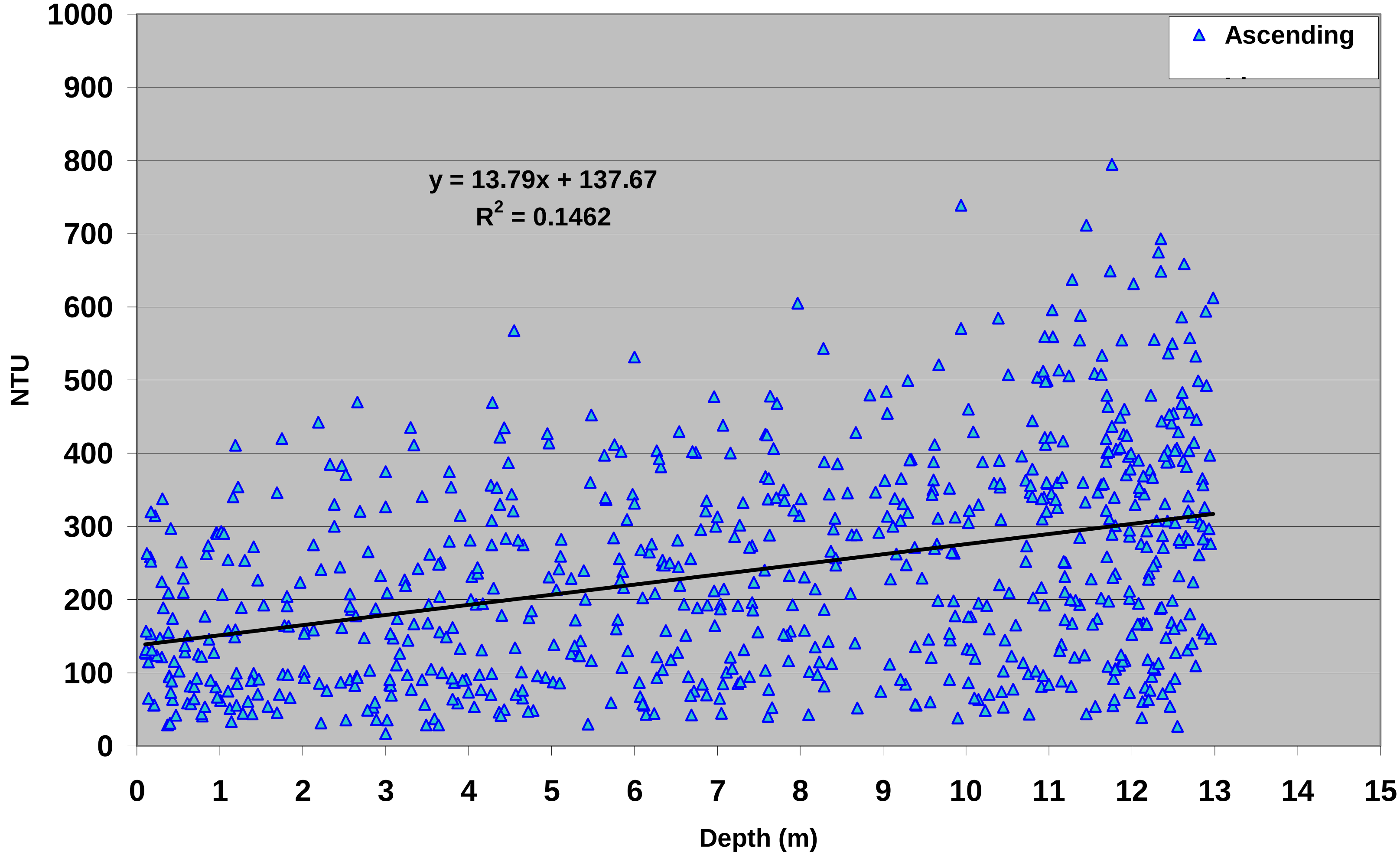

Figure 29. All turbidity measurements obtained by a bucket-mounted sensor during the ascent component of the bucket cycle during the first long-term dredging test on January 30, 2008.

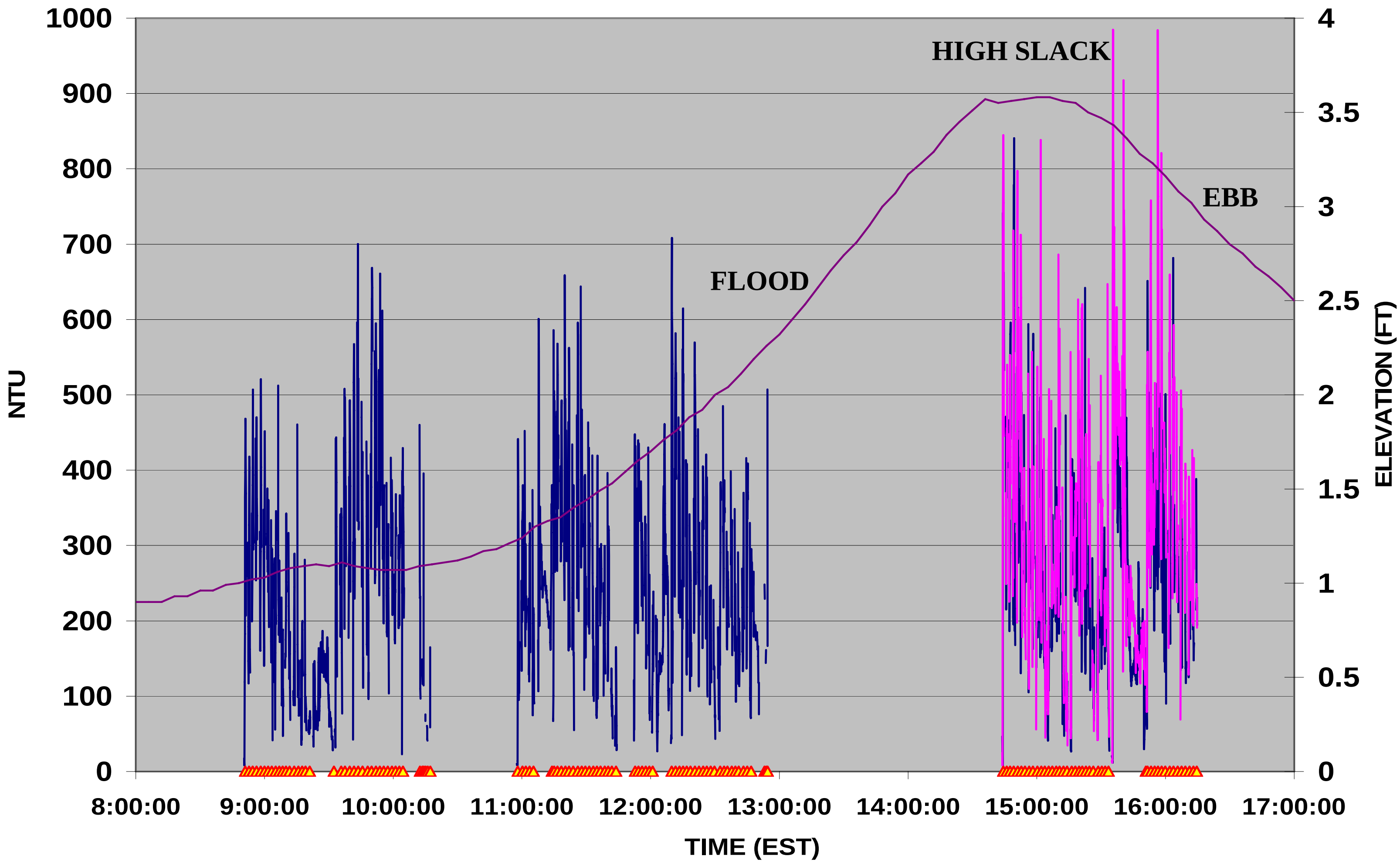

Figure 30. Turbidity measurements obtained by a bucket-mounted sensor during the second long-term dredging test on January 31, 2008. Note two sensors were mounted on opposite sides of bucket: inboard sensor (blue) & outboard sensor (purple).

Figure 31. Location of OBS instrument on the outboard side of the bucket.

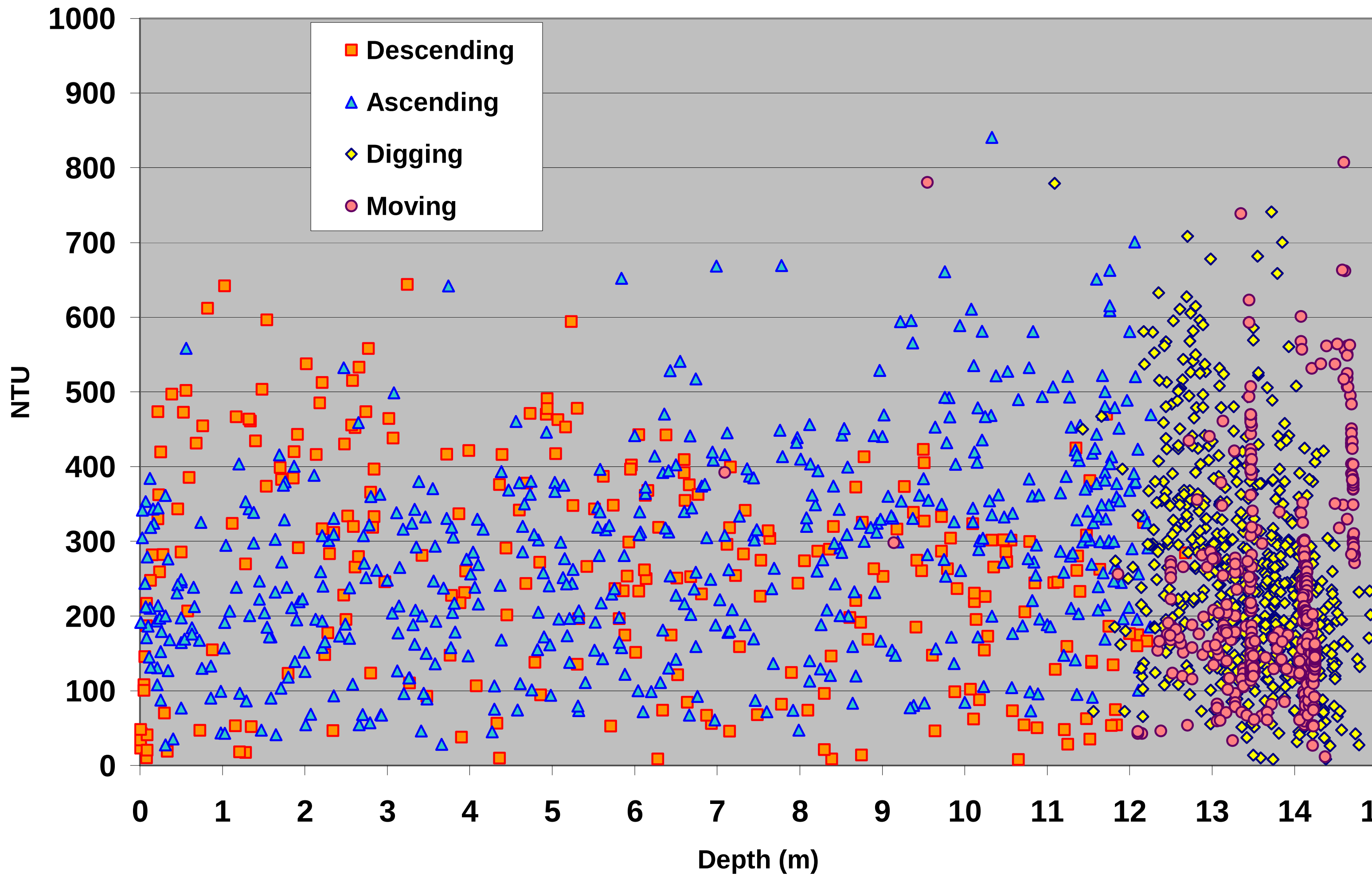

Figure 32. All turbidity measurements obtained by a bucket-mounted sensor (inboard side) during the second long-term dredging test on January 31, 2008.

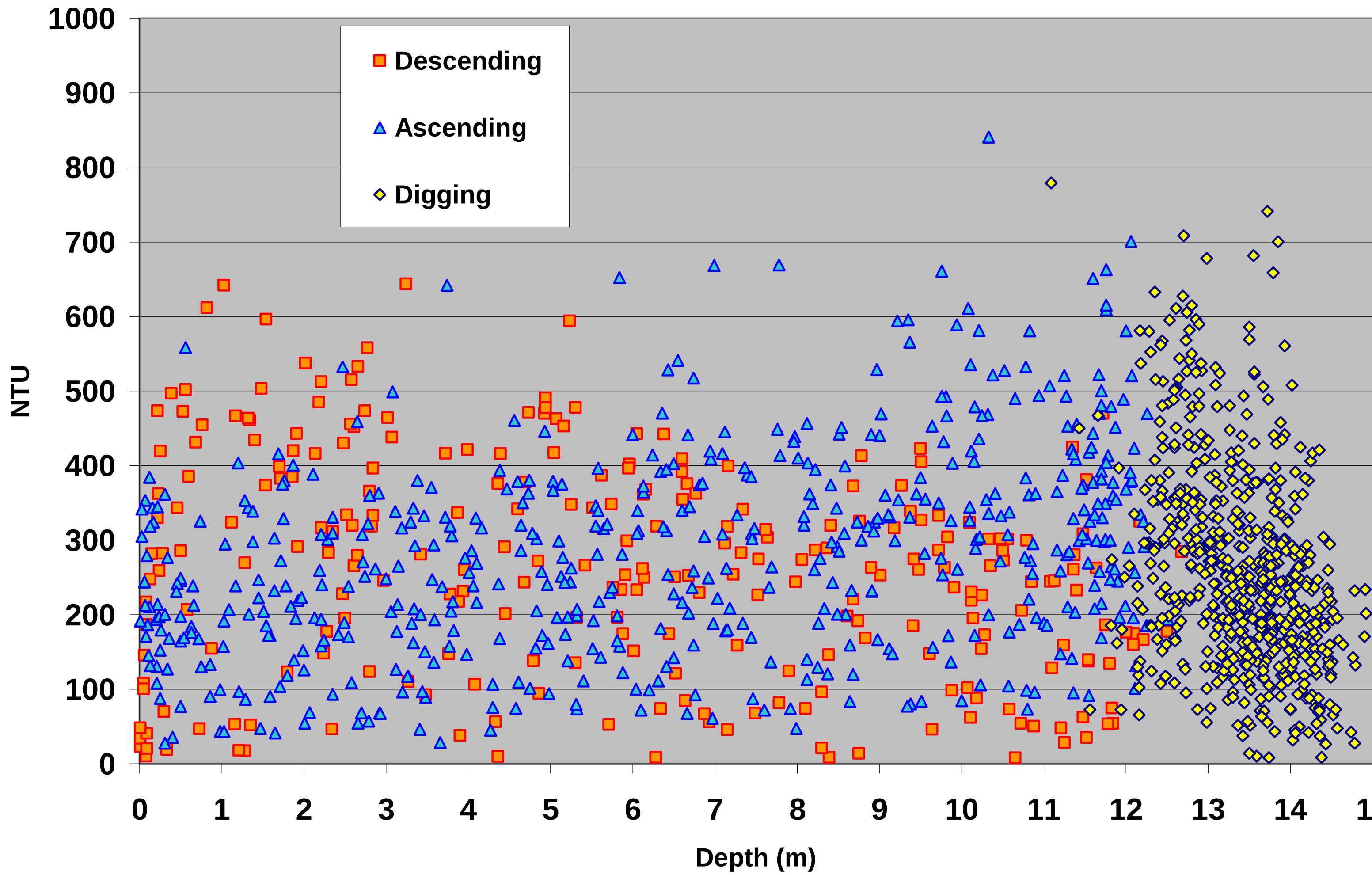

Figure 33. All turbidity measurements obtained by a bucket-mounted sensor (inboard side) during the second long-term dredging test after removal of all data for dredge advances on January 31, 2008.

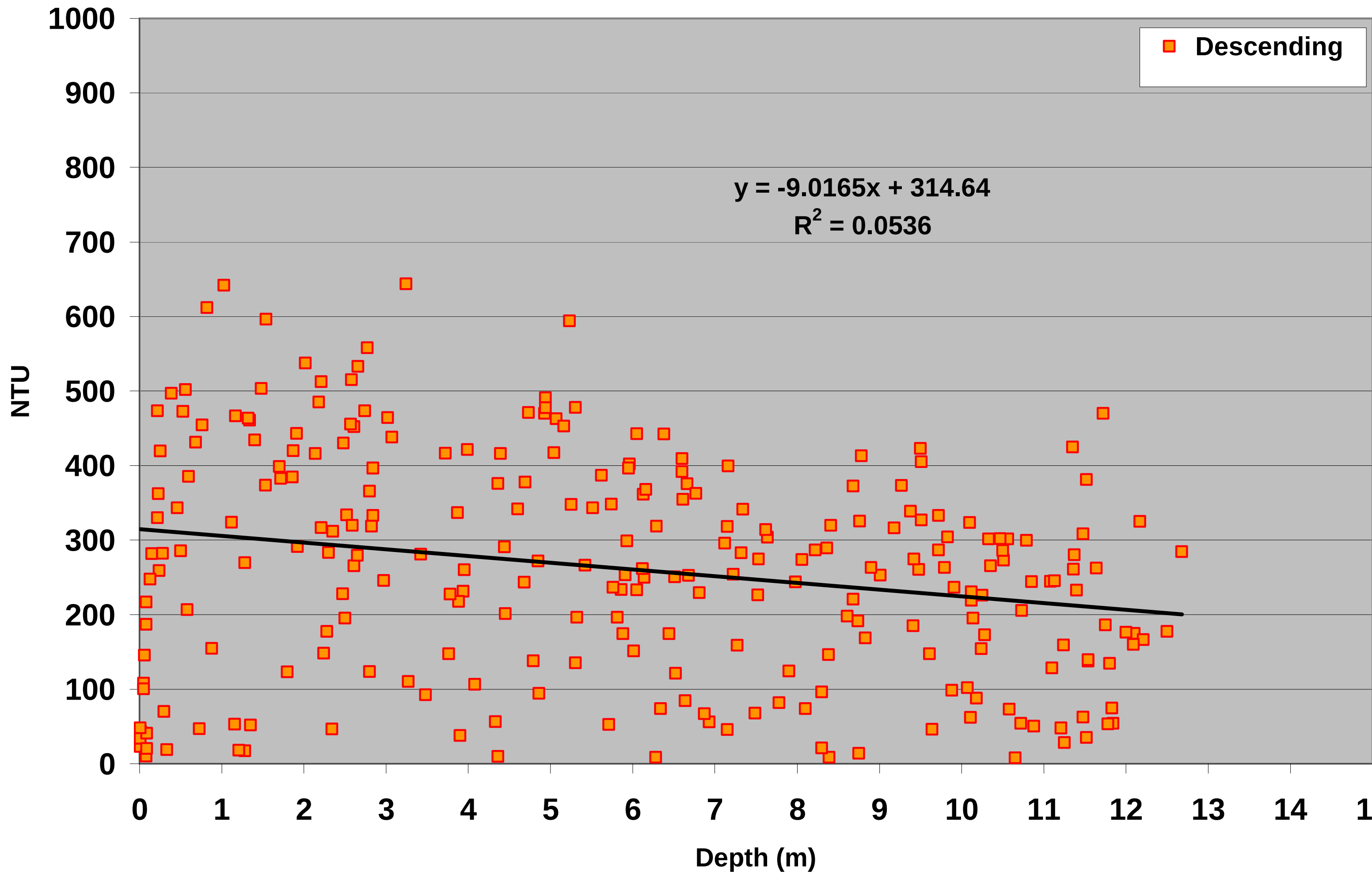

Figure 34. All turbidity measurements obtained by a bucket-mounted sensor (inboard side) during the descent component of the bucket cycle during the second long-term dredging test on January 31, 2008.

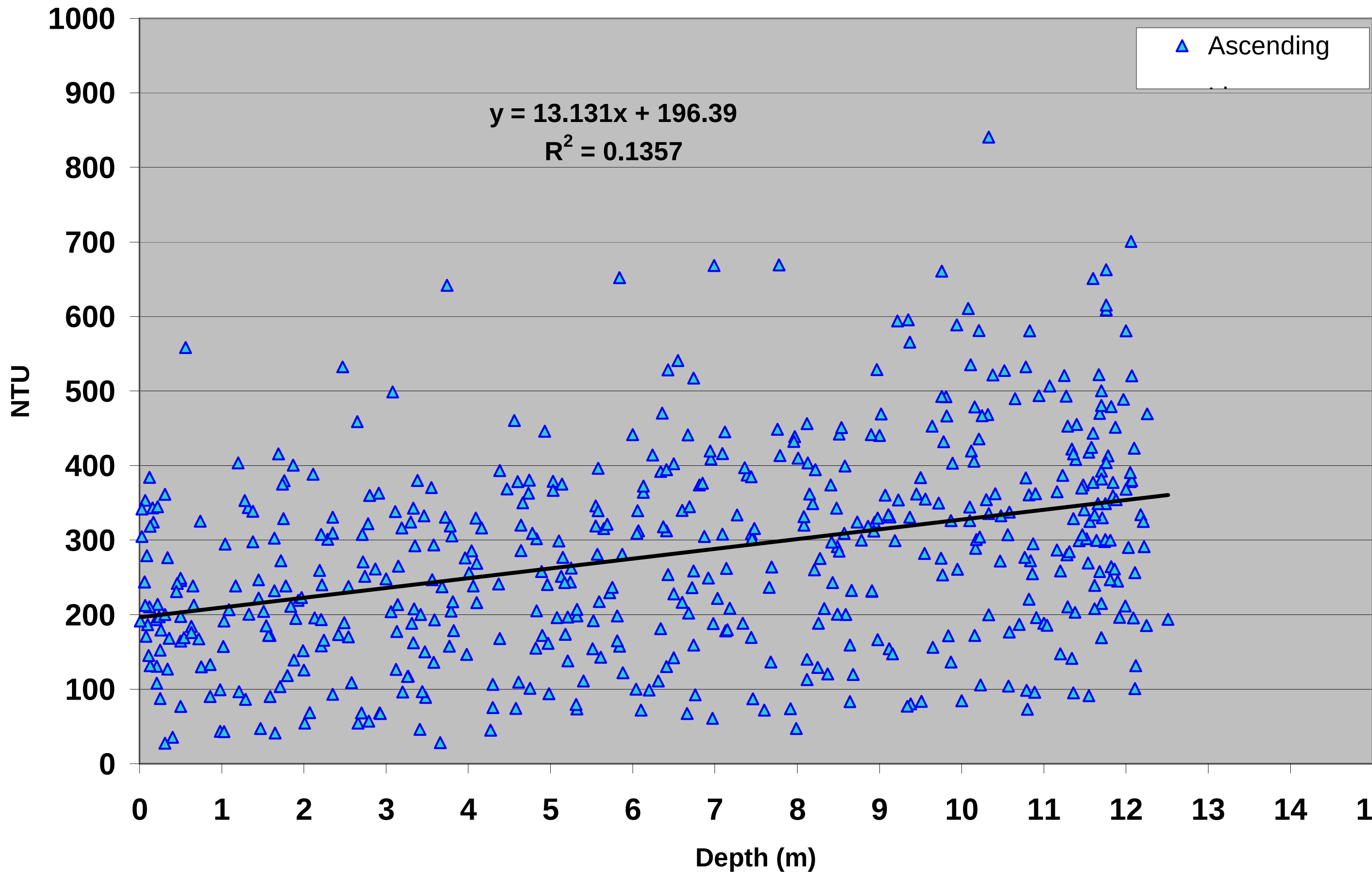

Figure 35. All turbidity measurements obtained by a bucket-mounted sensor (inboard side) during the ascent component of the bucket cycle during the second long-term dredging test on January 31, 2008.

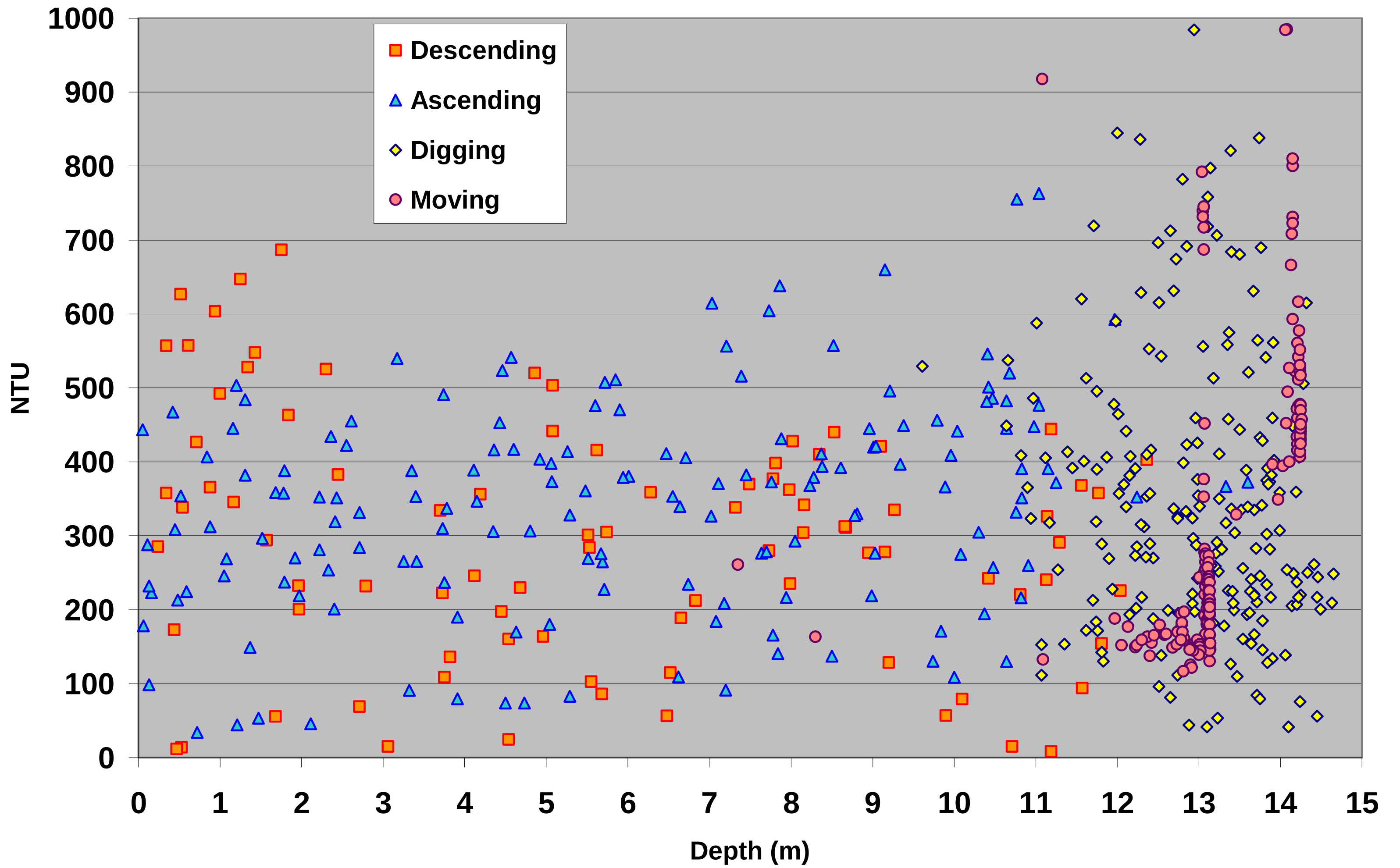

Figure 36. All turbidity measurements obtained by a bucket-mounted sensor (outboard side) during the second long-term dredging test on January 31, 2008.

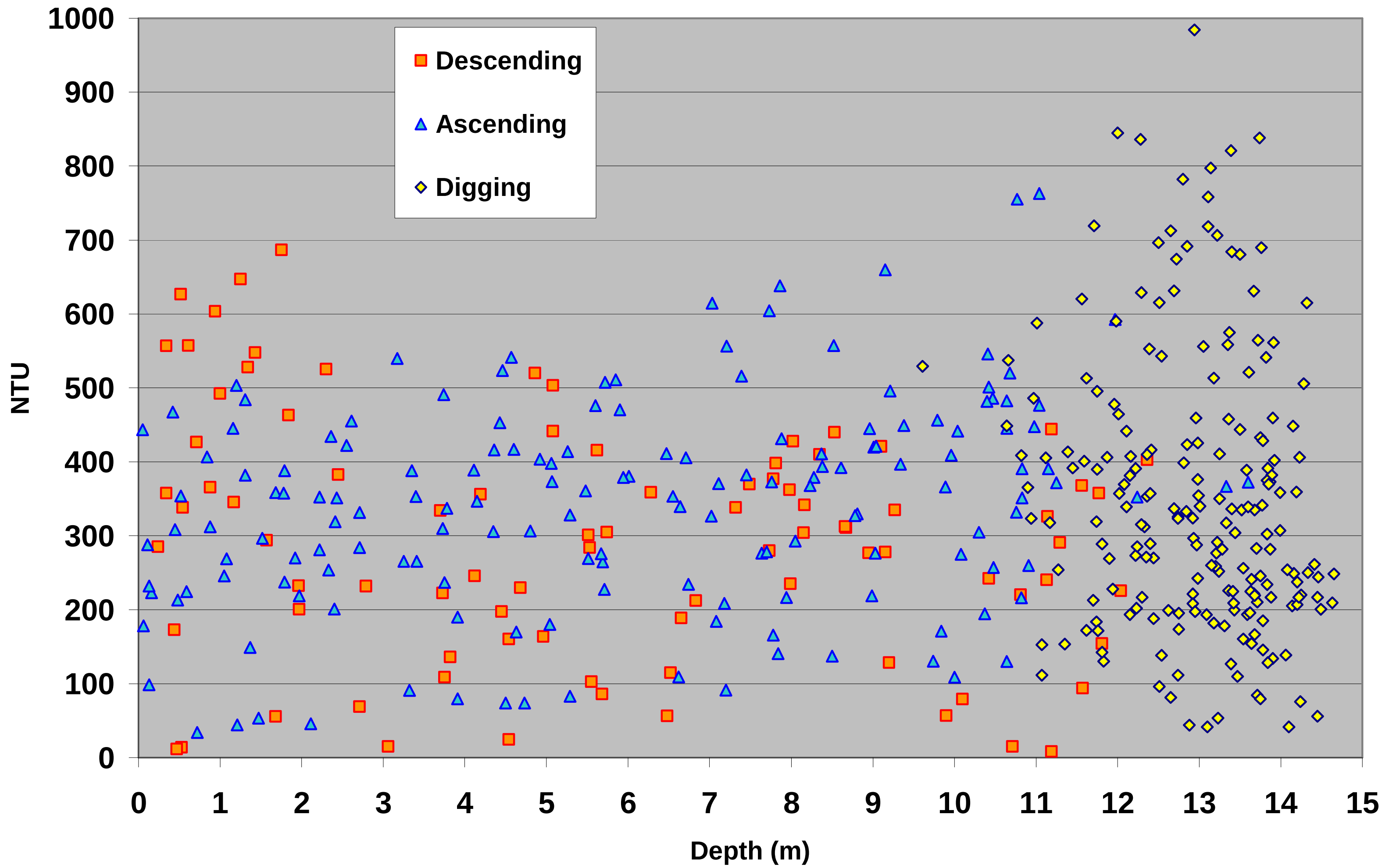

Figure 37. All turbidity measurements obtained by a bucket-mounted sensor (outboard side) during the second long-term dredging test after removal of all data for dredge advances on January 31, 2008.

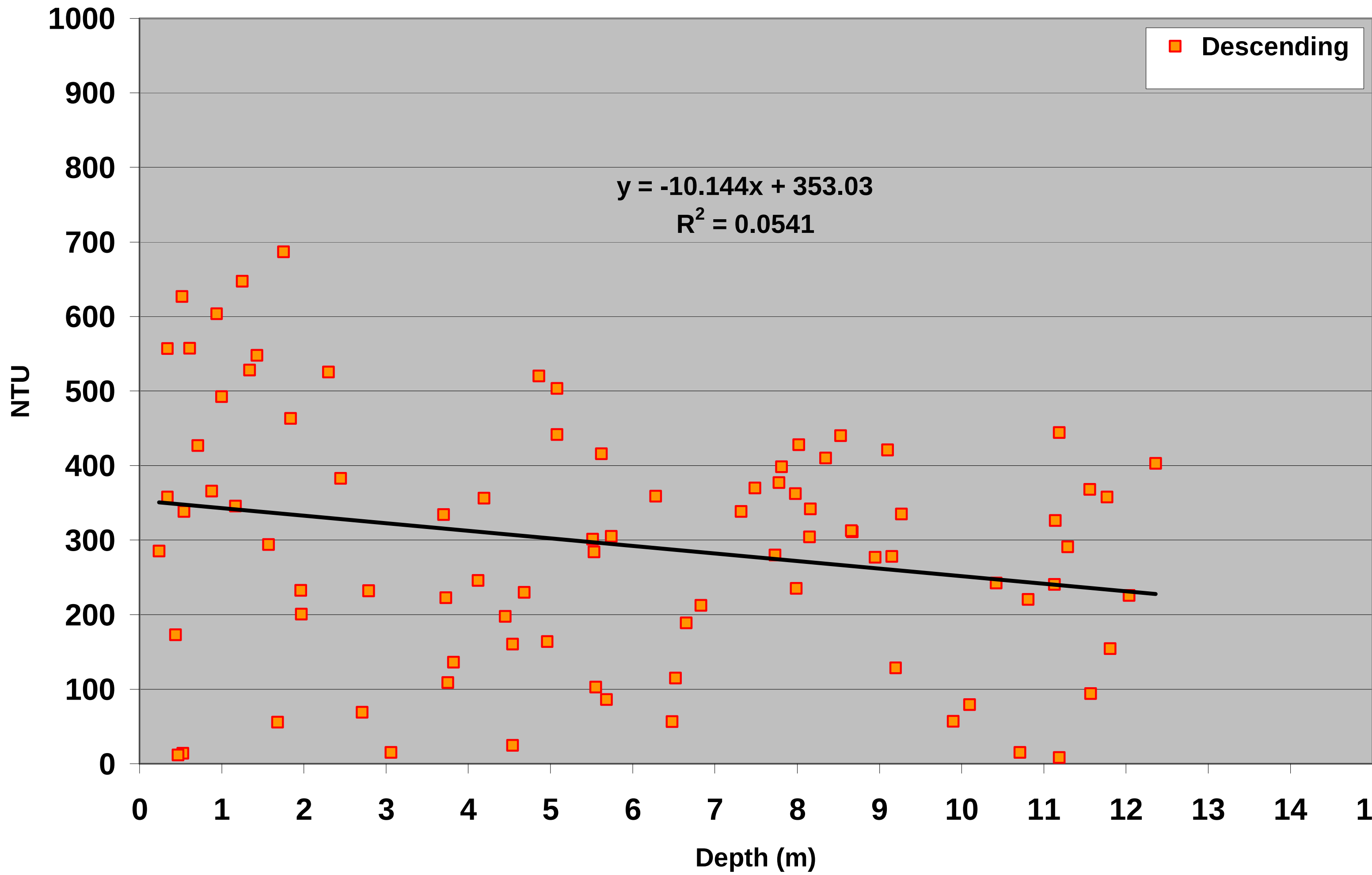

Figure 38. All turbidity measurements obtained by a bucket-mounted sensor (outboard side) during the descent component of the bucket cycle during the second long-term dredging test on January 31, 2008.

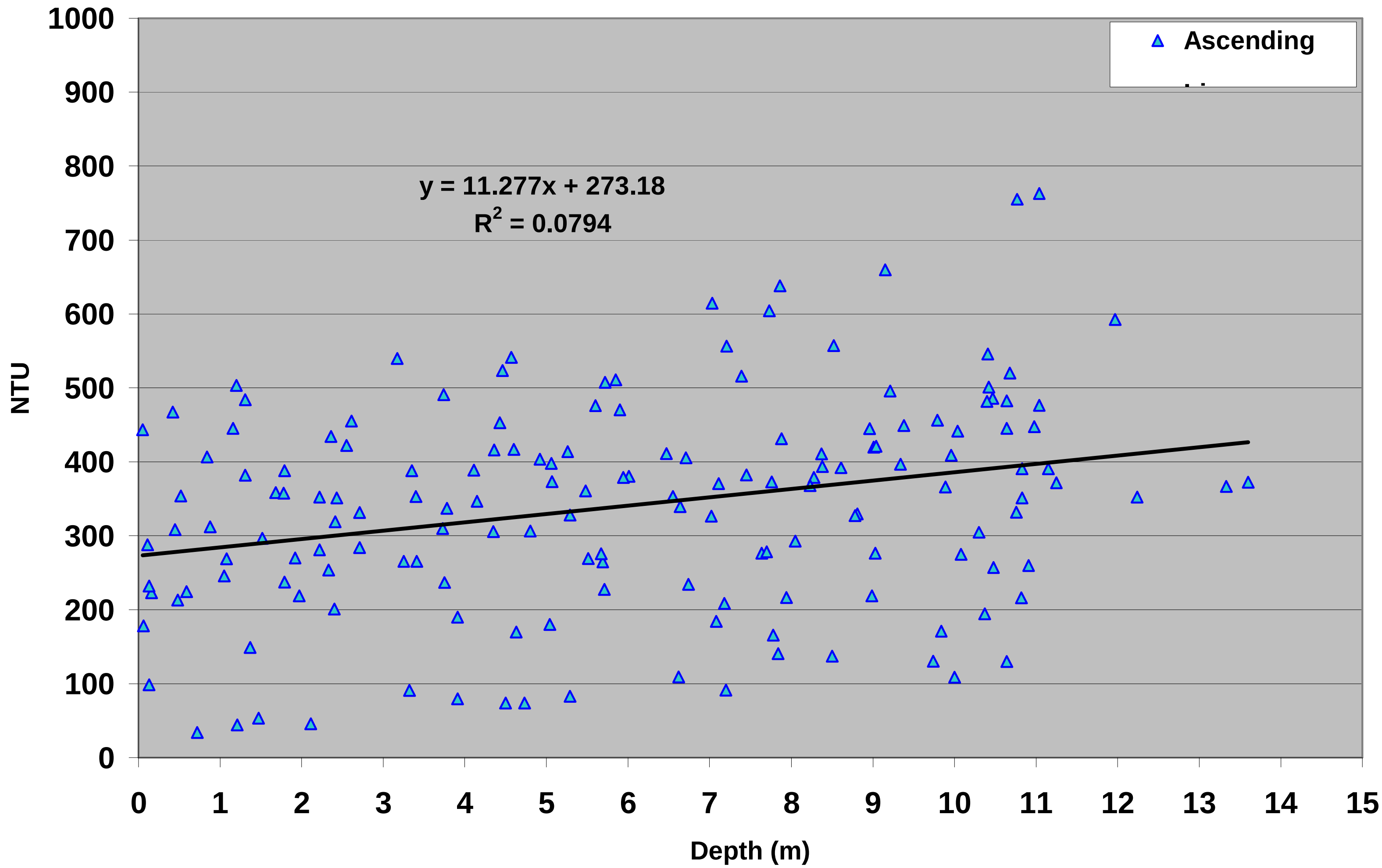

Figure 39. All turbidity measurements obtained by a bucket-mounted sensor (outboard side) during the ascent component of the bucket cycle during the second long-term dredging test on January 31, 2008.

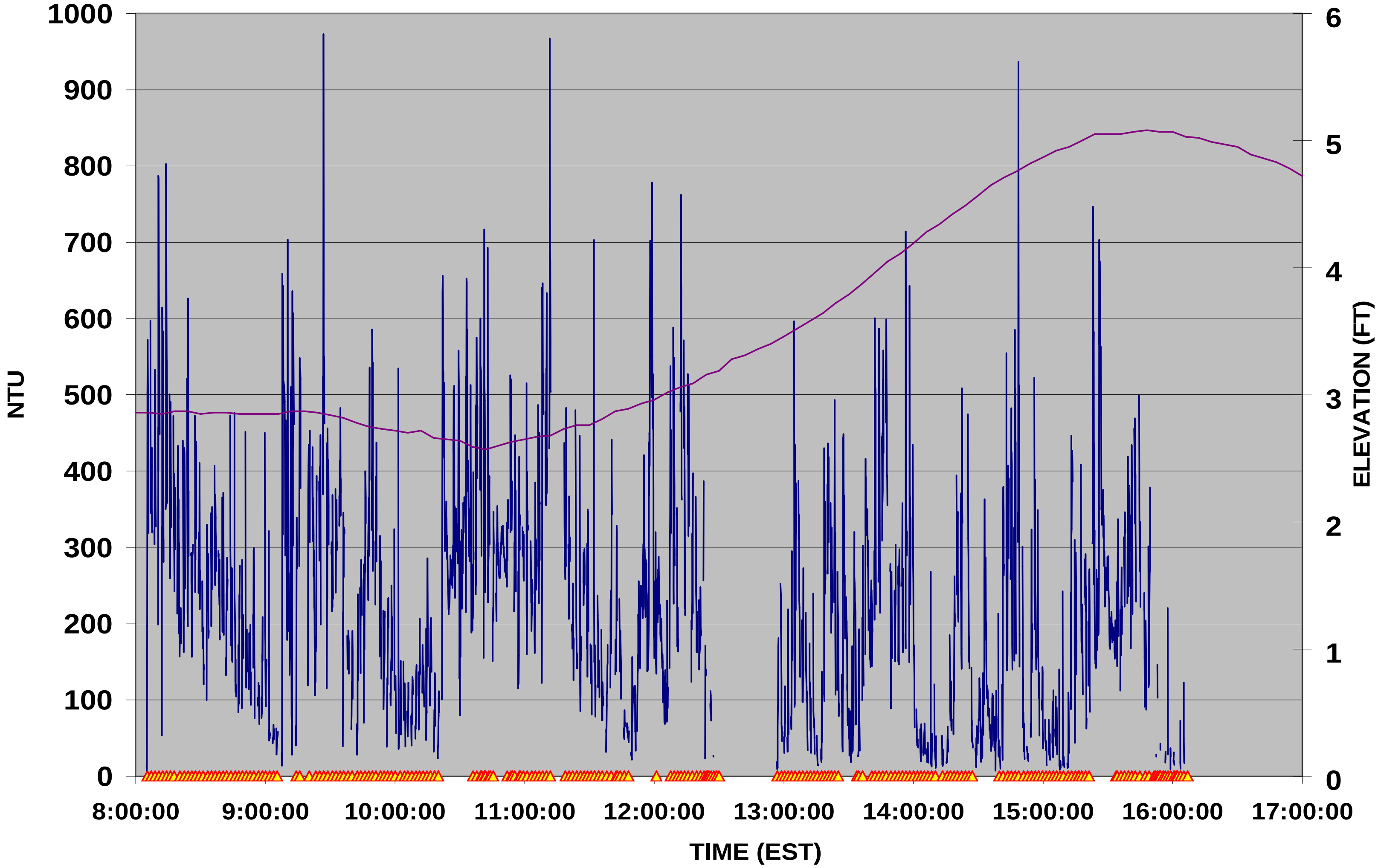

Figure 40. Turbidity measurements obtained by a bucket-mounted sensor during the third long-term dredging test on February 1, 2008.

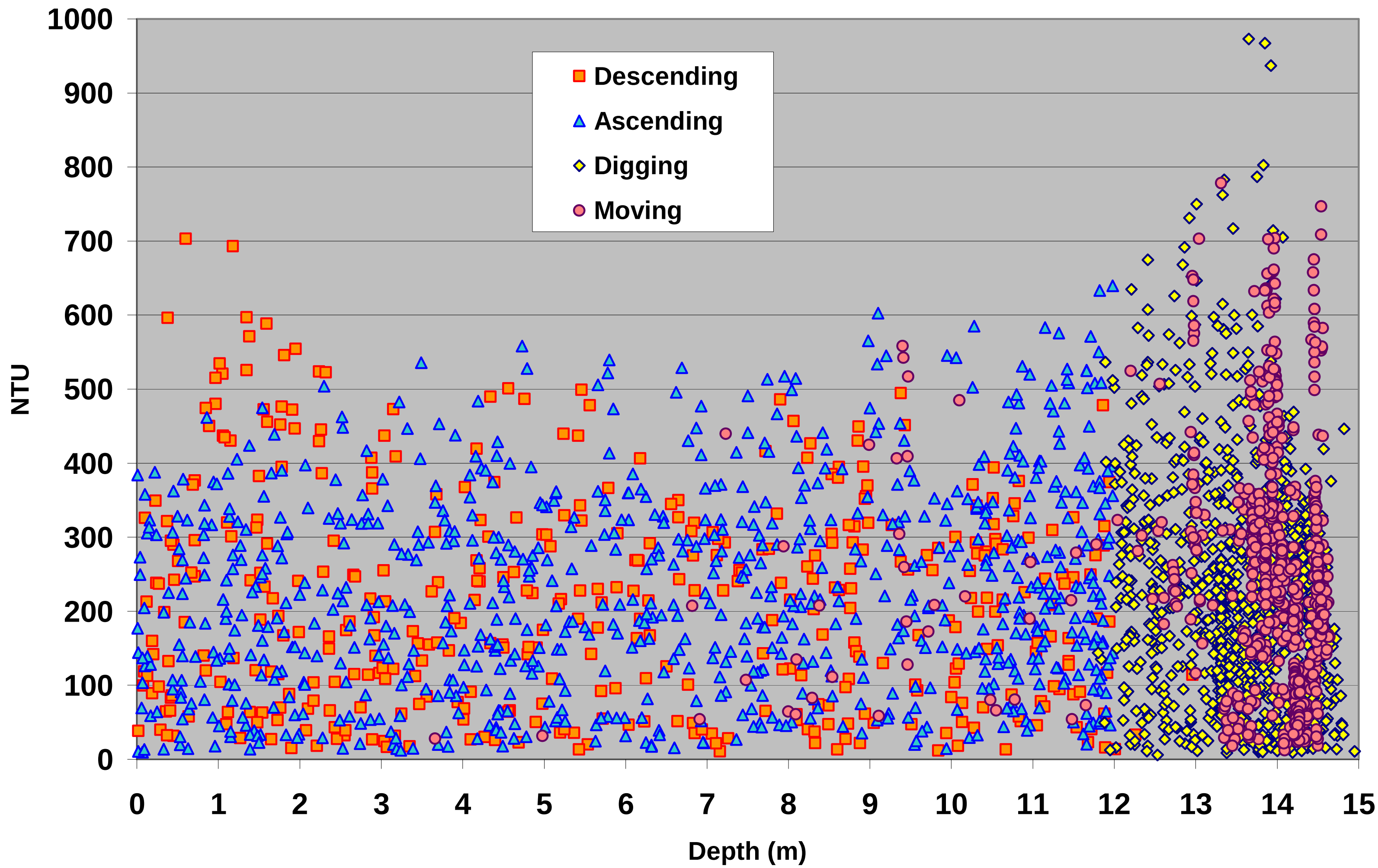

Figure 41. All turbidity measurements obtained by a bucket-mounted sensor (outboard side) during the third long-term dredging test on February 1, 2008.

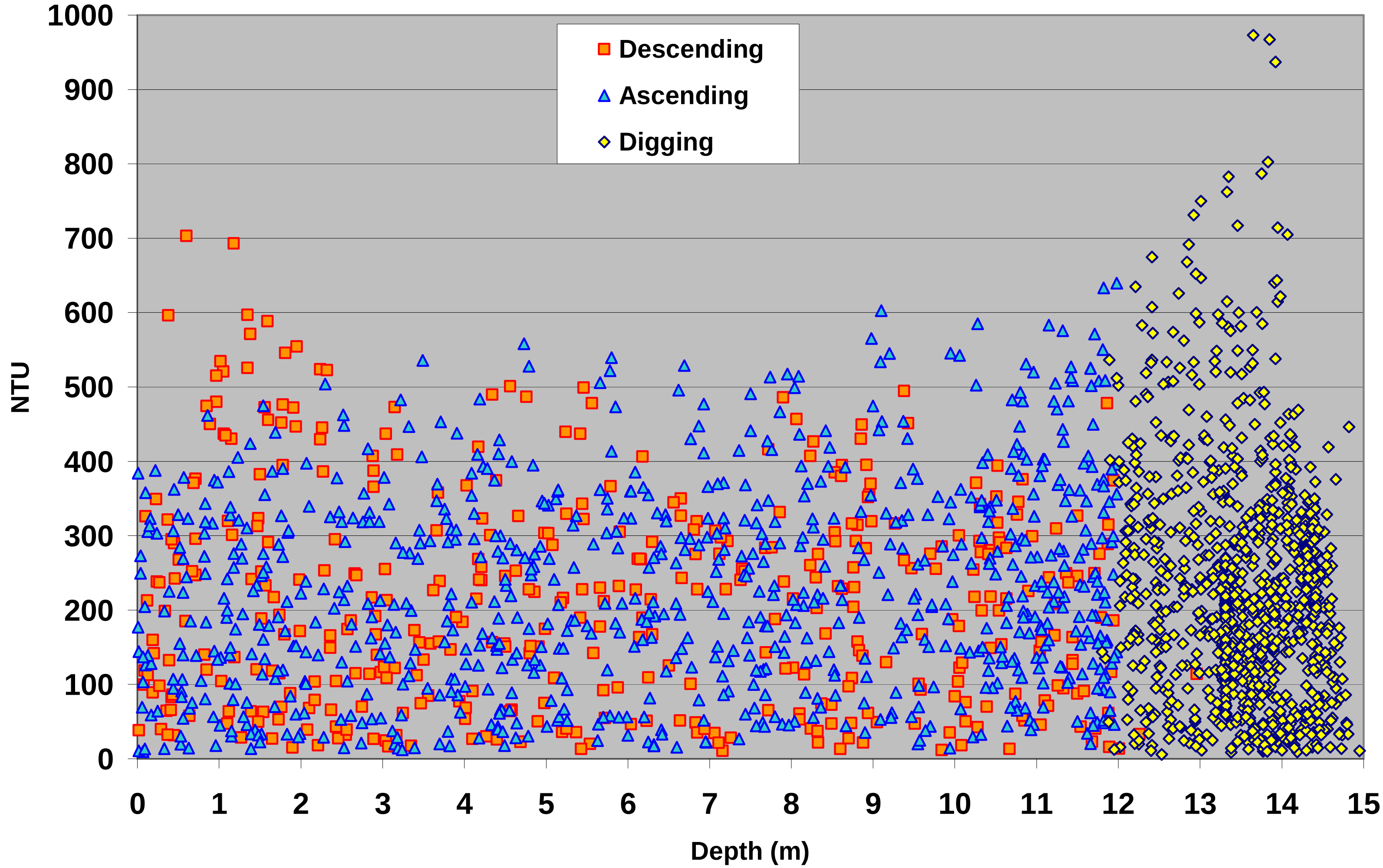

Figure 42. All turbidity measurements obtained by a bucket-mounted sensor (outboard side) during the third long-term dredging test after removal of data associated with dredge advances on February 1, 2008.

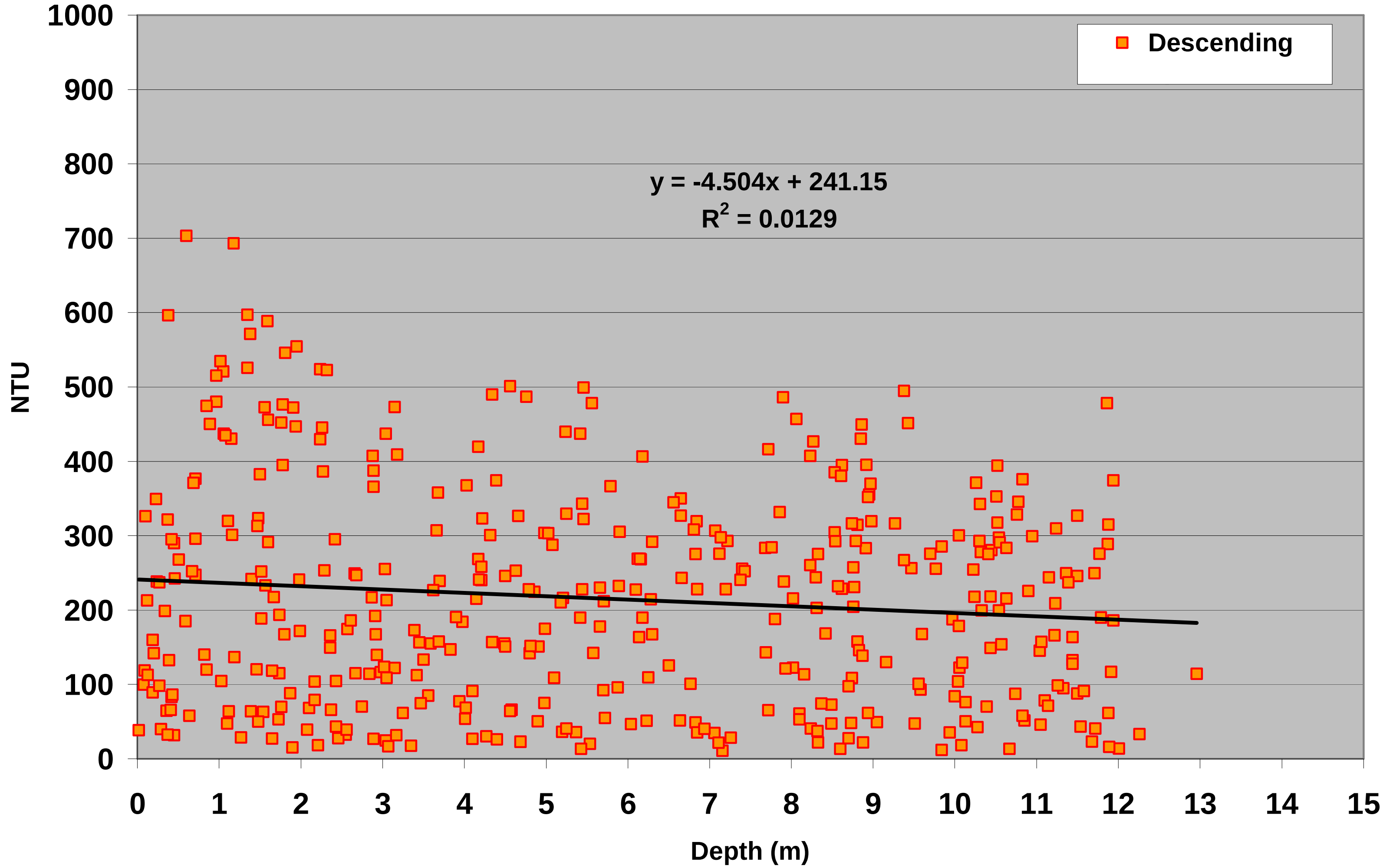

Figure 43. All turbidity measurements obtained by a bucket-mounted sensor (outboard side) during the descent component of the bucket cycle during the third long-term dredging test on February 1, 2008.

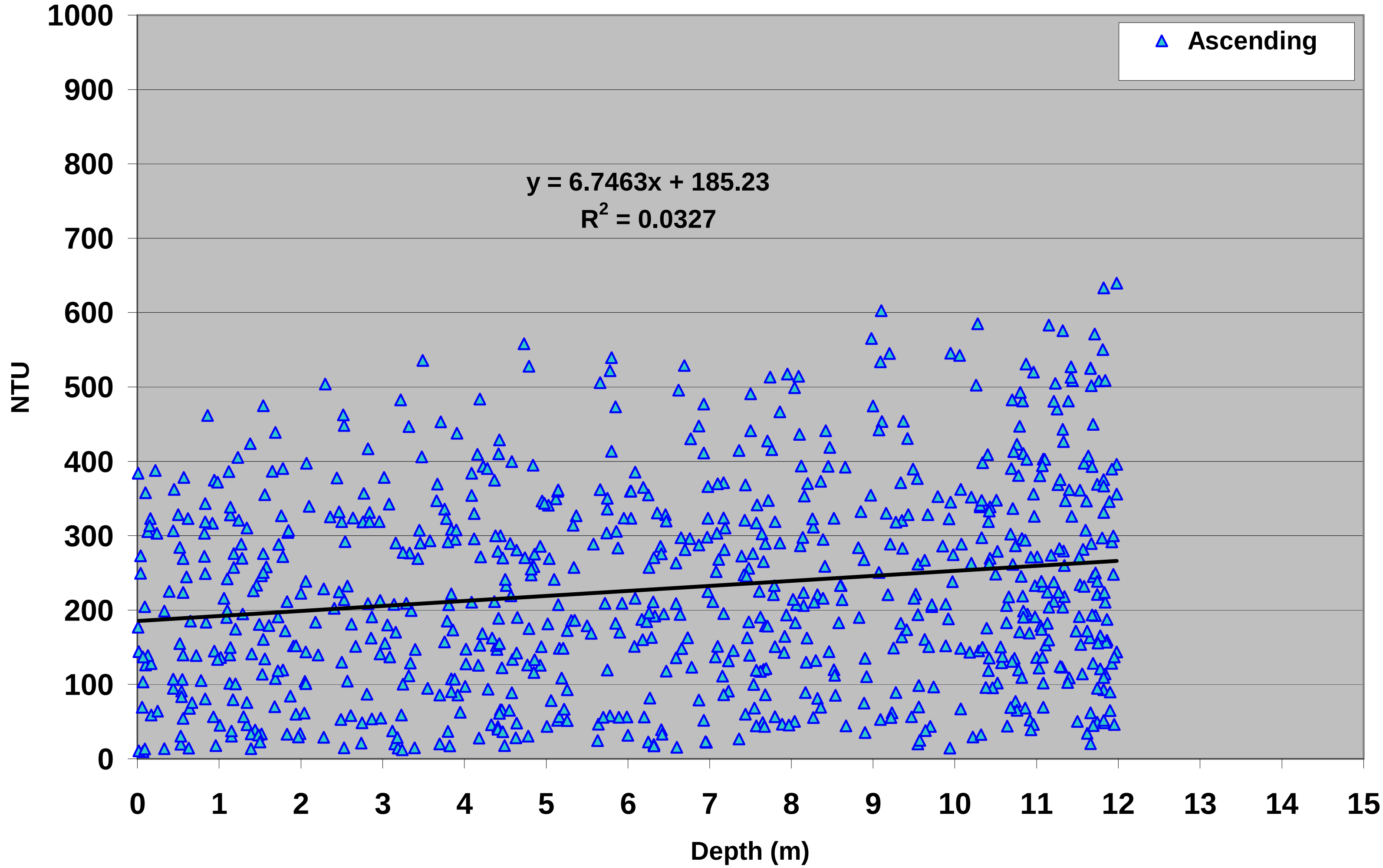

Figure 44. All turbidity measurements obtained by a bucket-mounted sensor (outboard side) during the ascent component of the bucket cycle during the third long-term dredging test on February 1, 2008.

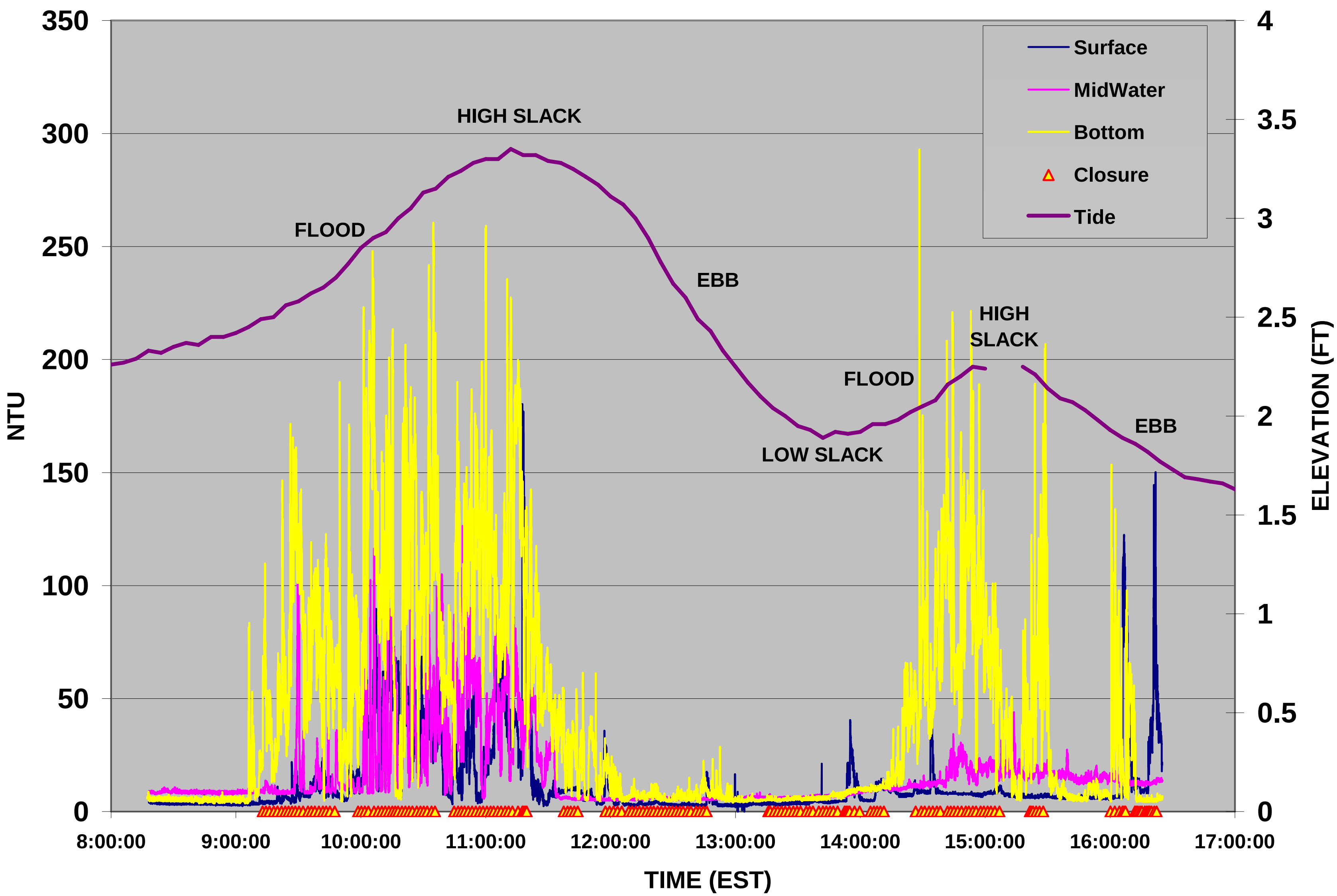

Figure 45. Turbidity measurements from dredge platform OBS instruments during the first long-term dredging test January 30, 2008.

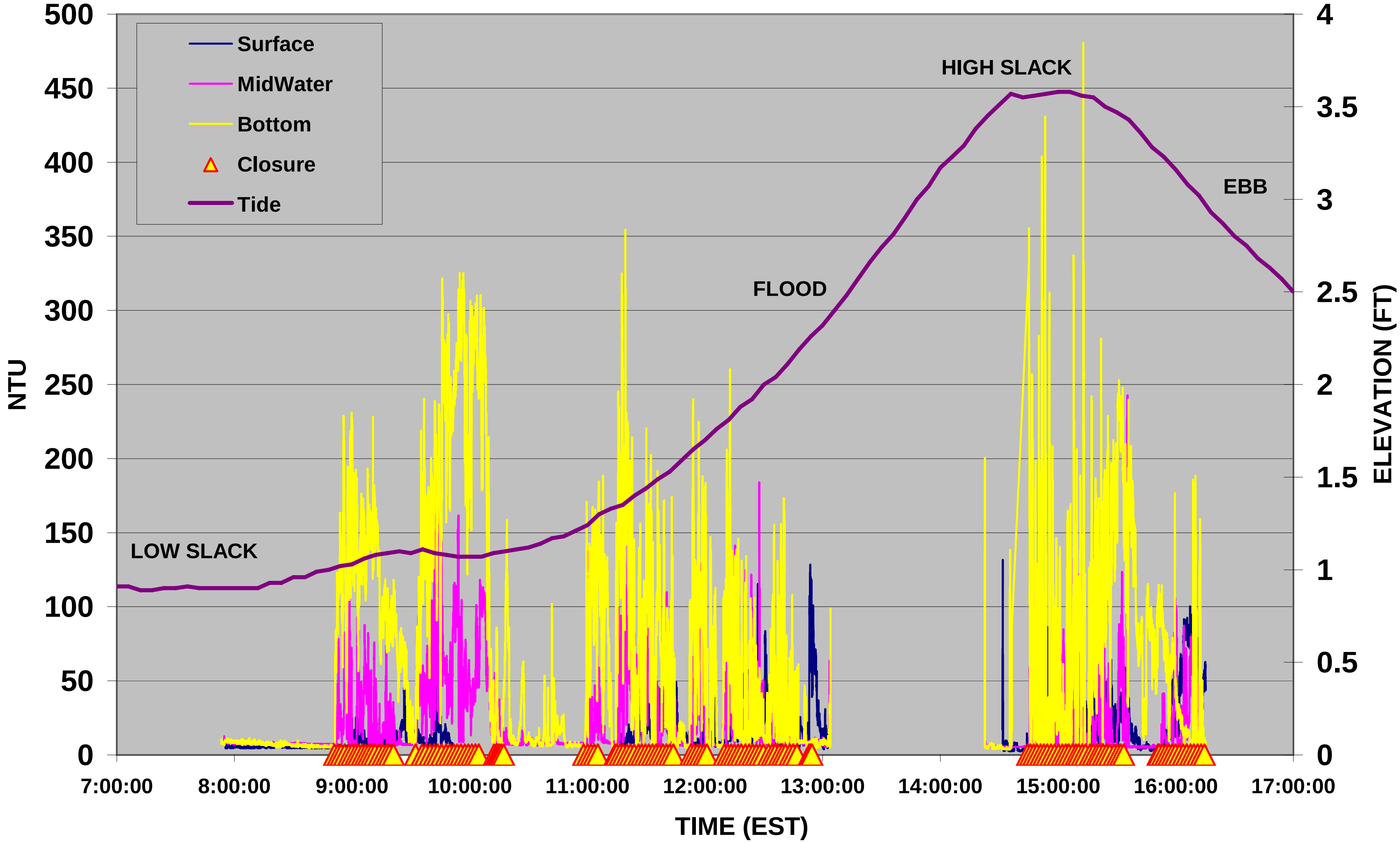

Figure 46. Turbidity measurements from dredge platform OBS instruments during the second long-term dredging test January 31, 2008.

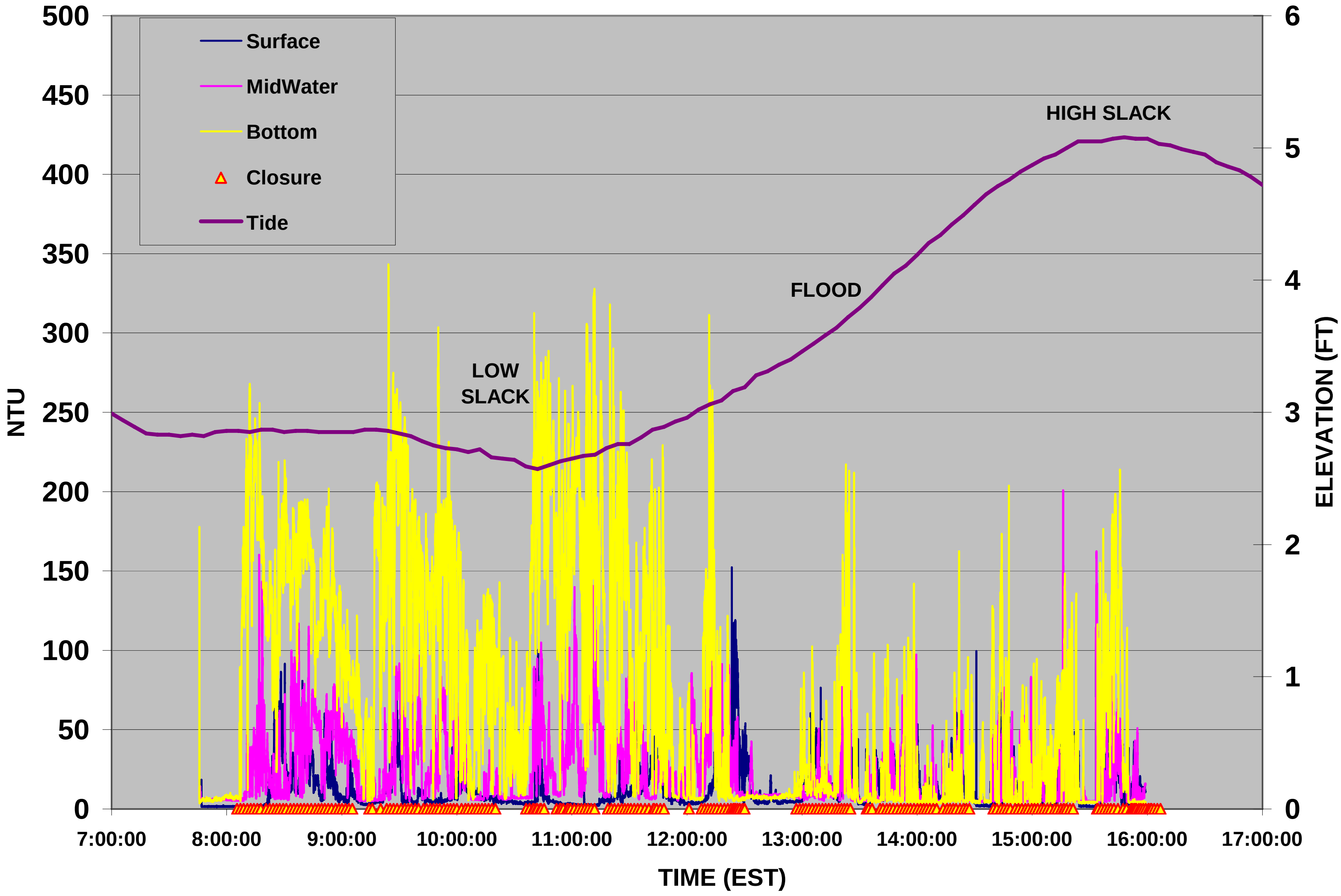

Figure 47. Turbidity measurements from dredge platform OBS instruments during the third long-term dredging test February 1, 2008.

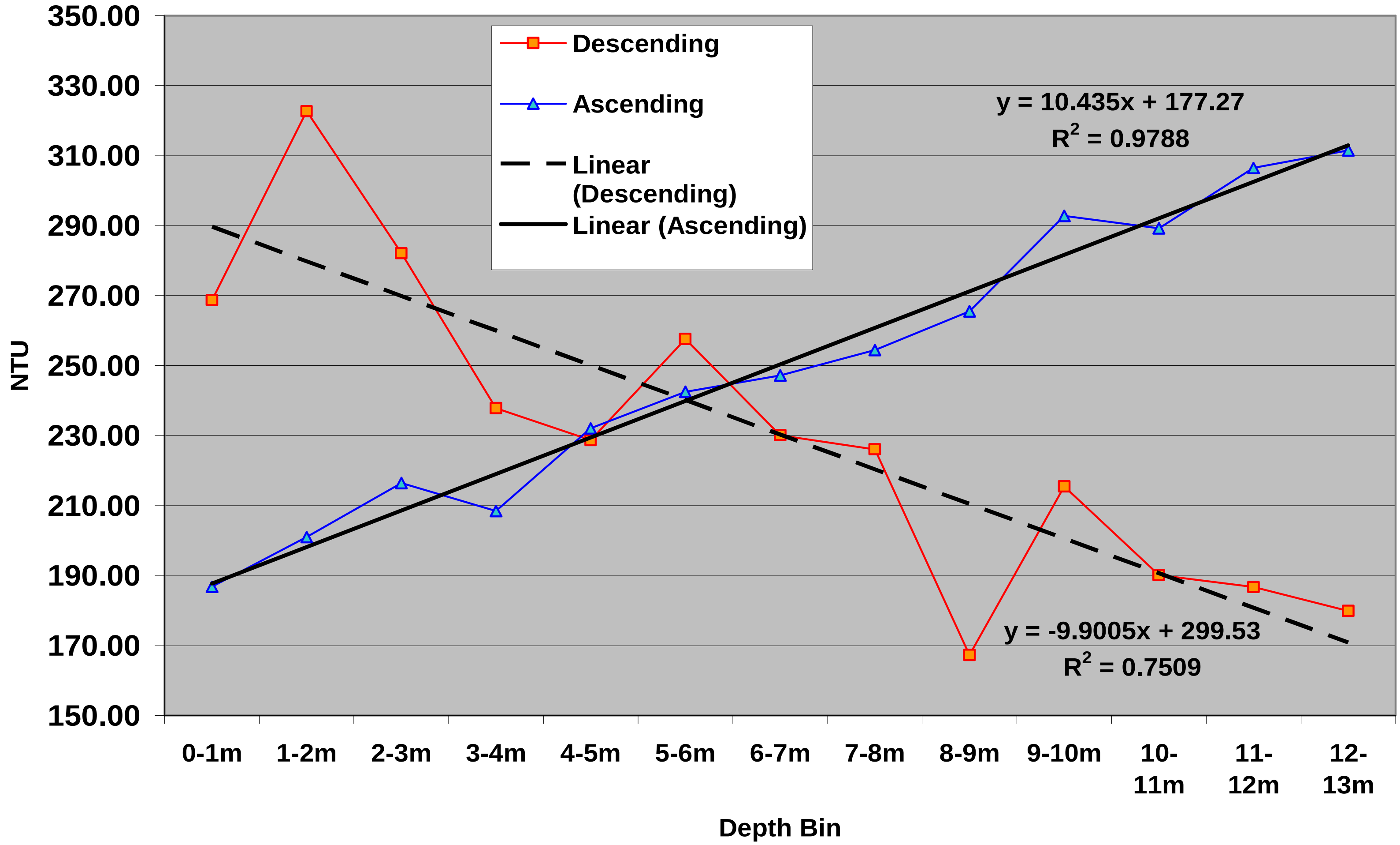

Figure 48. A comparison of trends observed in the descent and ascent components of the bucket cycle based on all turbidity measurements obtained by bucket-mounted sensors during the three long-term dredging tests.

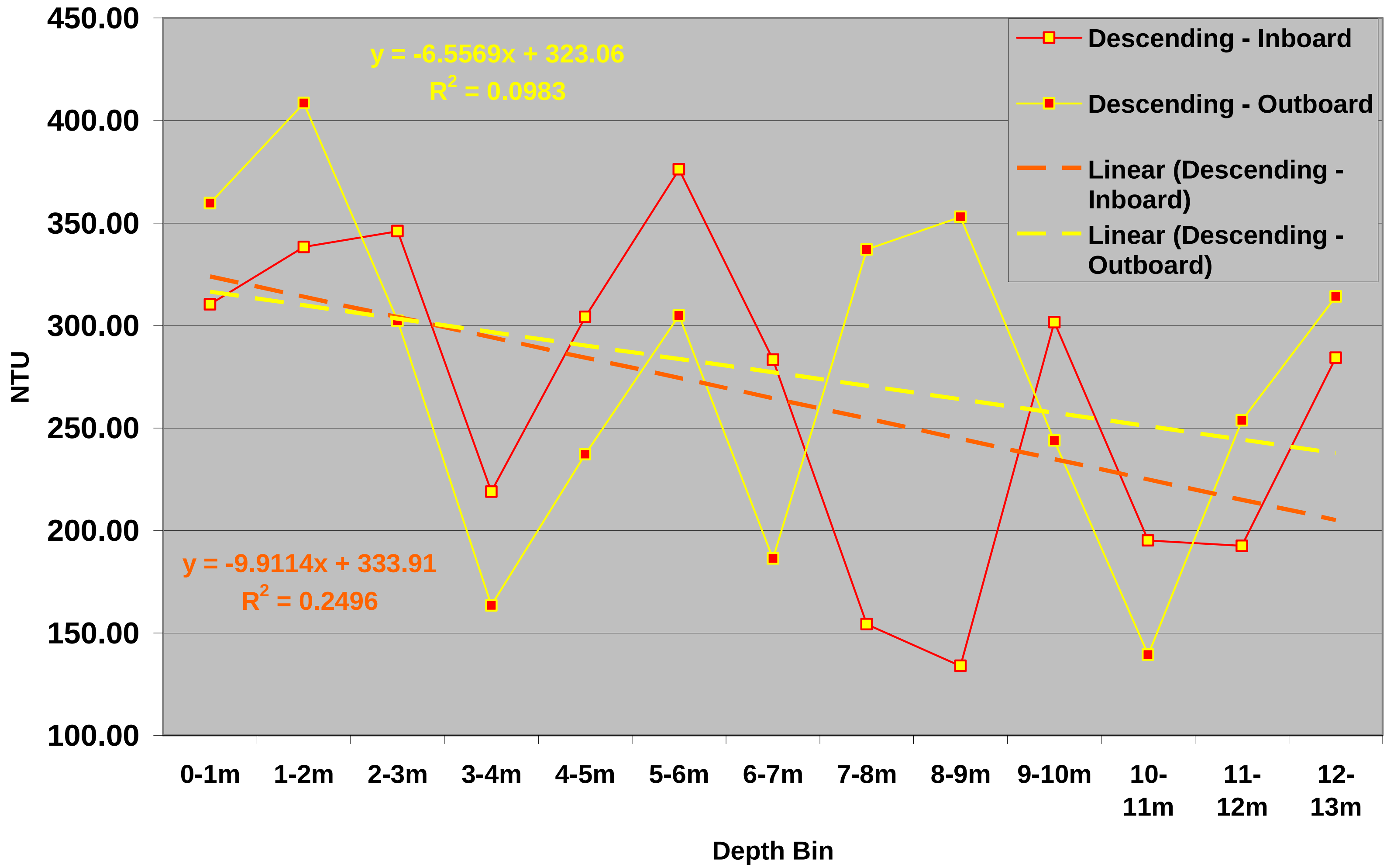

Figure 49. A comparison of synoptic turbidity measurements taken by sensors located on opposite sides of the bucket during the descent component of the bucket cycle during the second long-term dredging test on January 31, 2008.

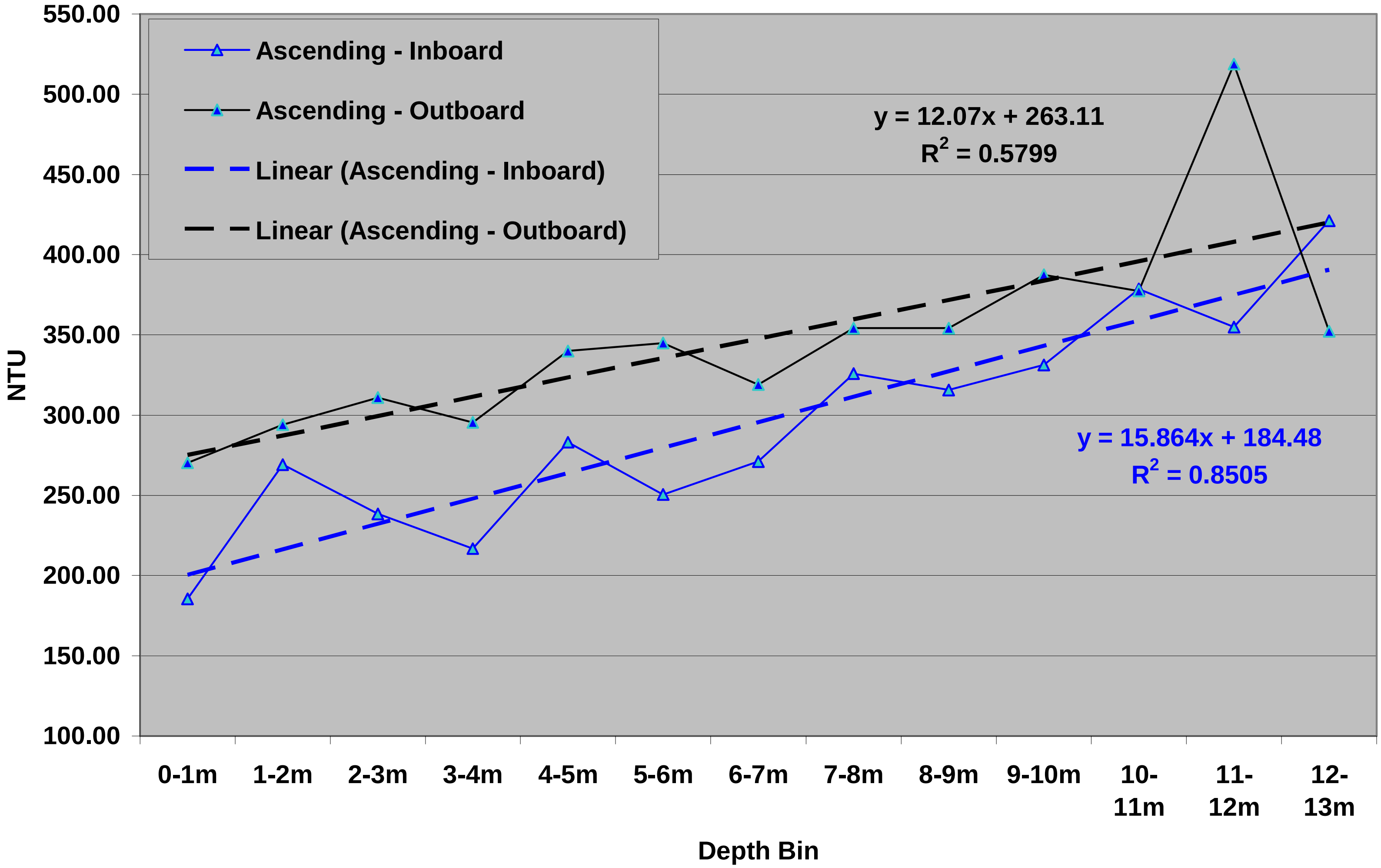

Figure 50. A comparison of synoptic turbidity measurements taken by sensors located on opposite sides of the bucket during the ascent component of the bucket cycle during the second long-term dredging test on January 31, 2008.

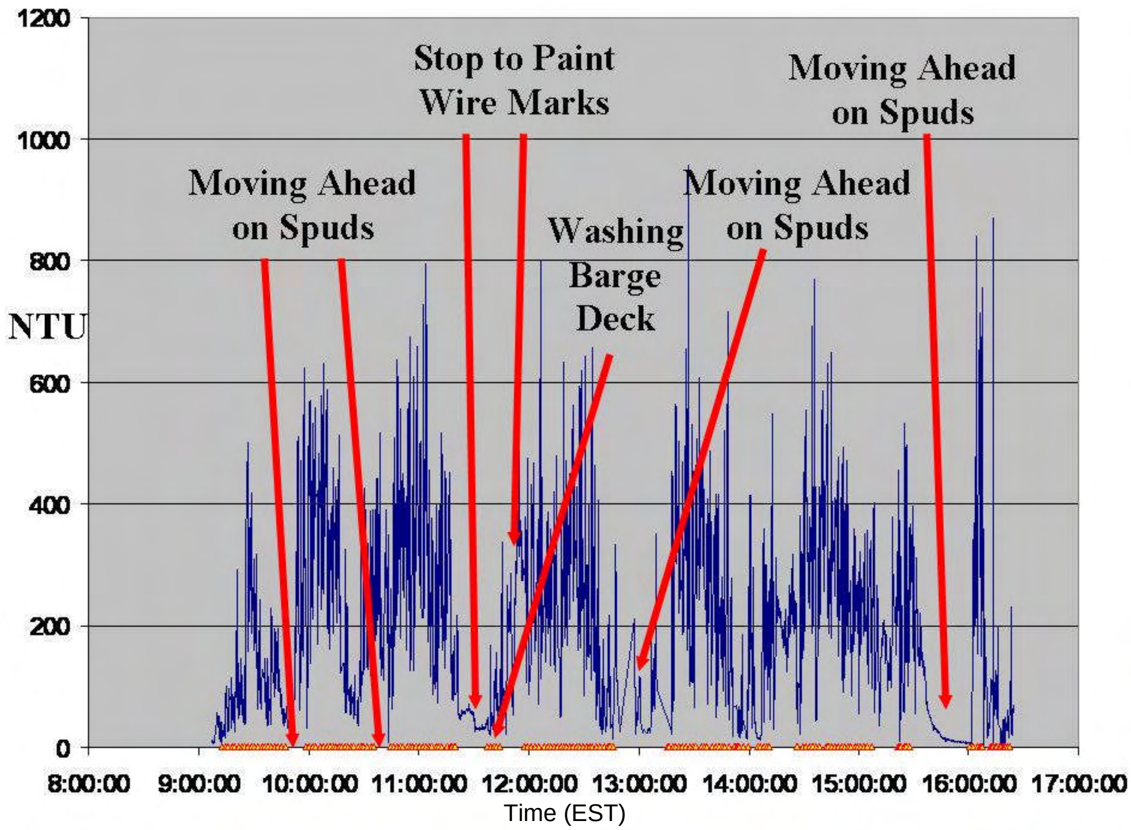

Figure 51. Identification of dredging process events that occur in tandem with bucket cycles that account for large-scale patterns in the long-term dredging test turbidity data on January 30, 2008.

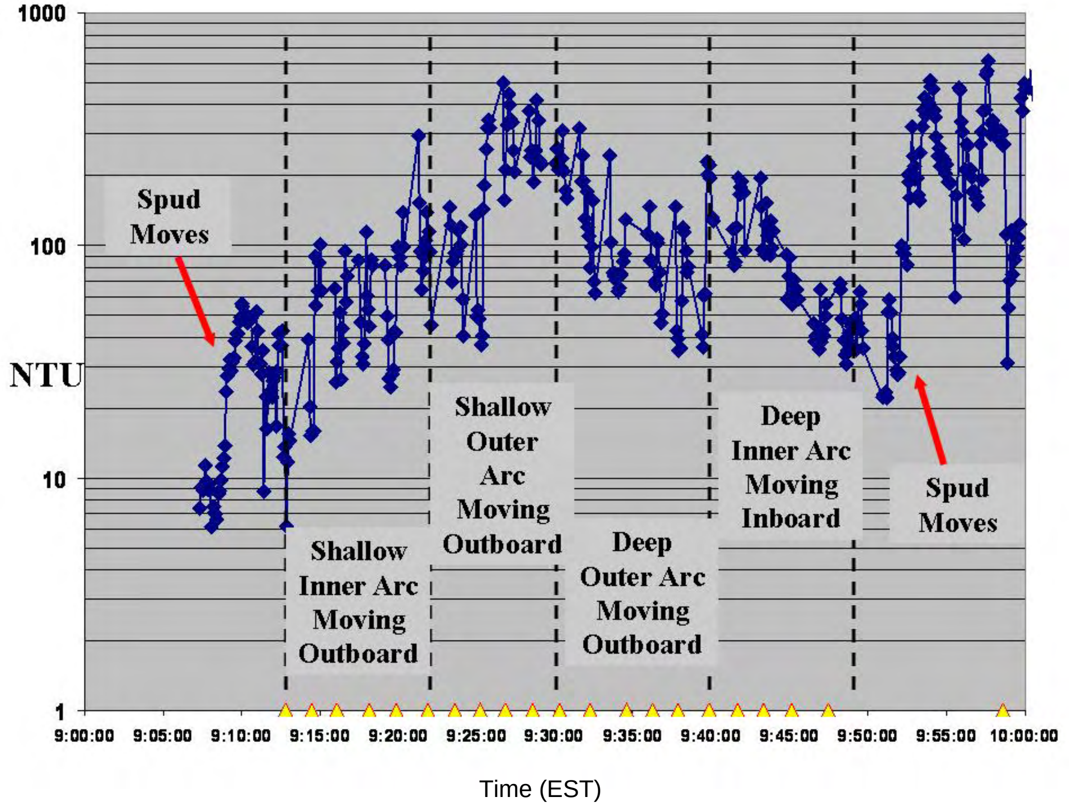

Figure 52. Bucket-mounted turbidity sensor turbidity measurements for a 20 bucket cycle sequence that comprised a single dredge advance. Figure based on the same bucket cycle sequence shown in Figure 4 from the long-term test on January 30, 2008.

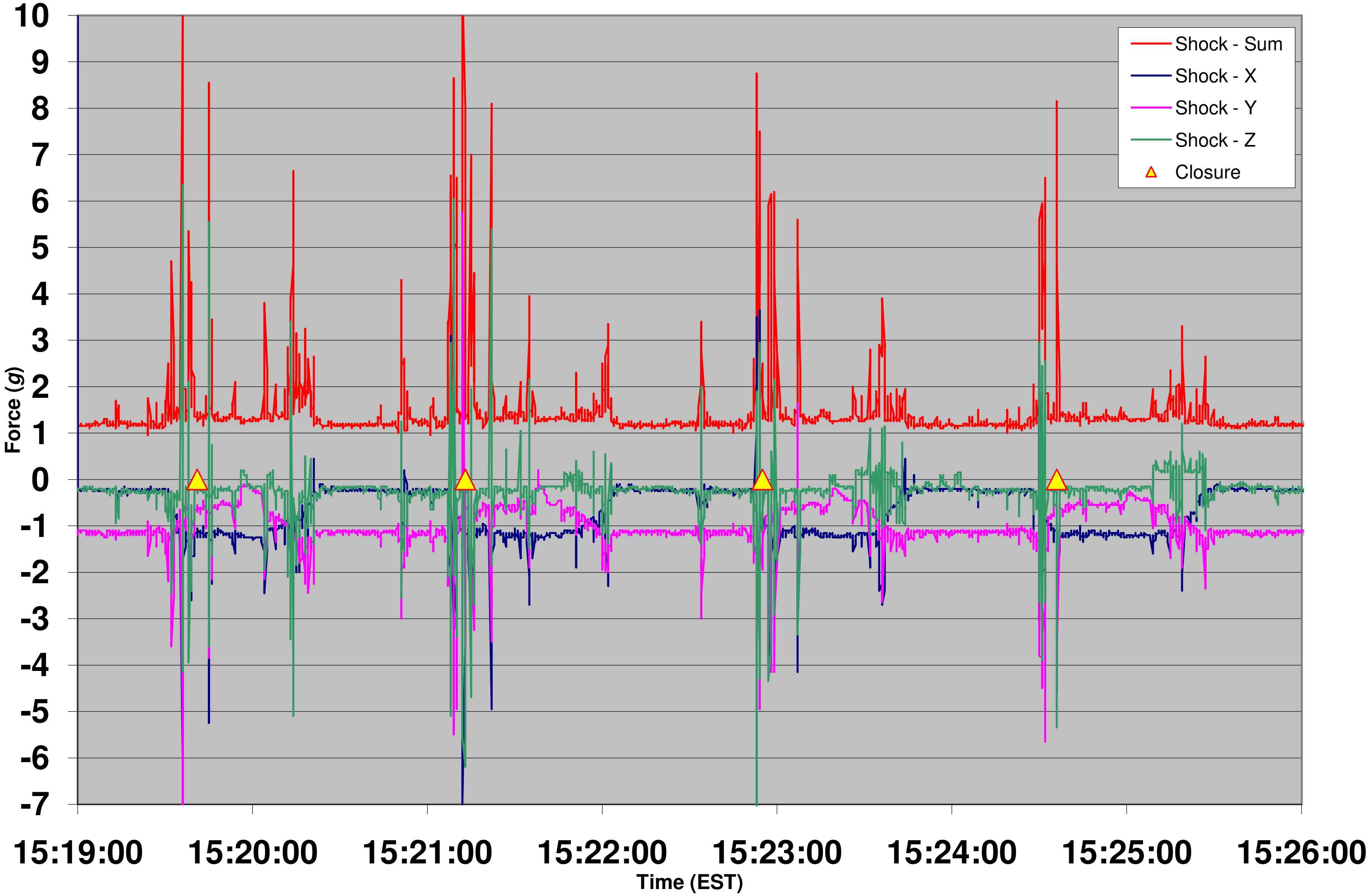

Figure 53. Accelerometer data recorded during long-duration testing on January 31, 2008.

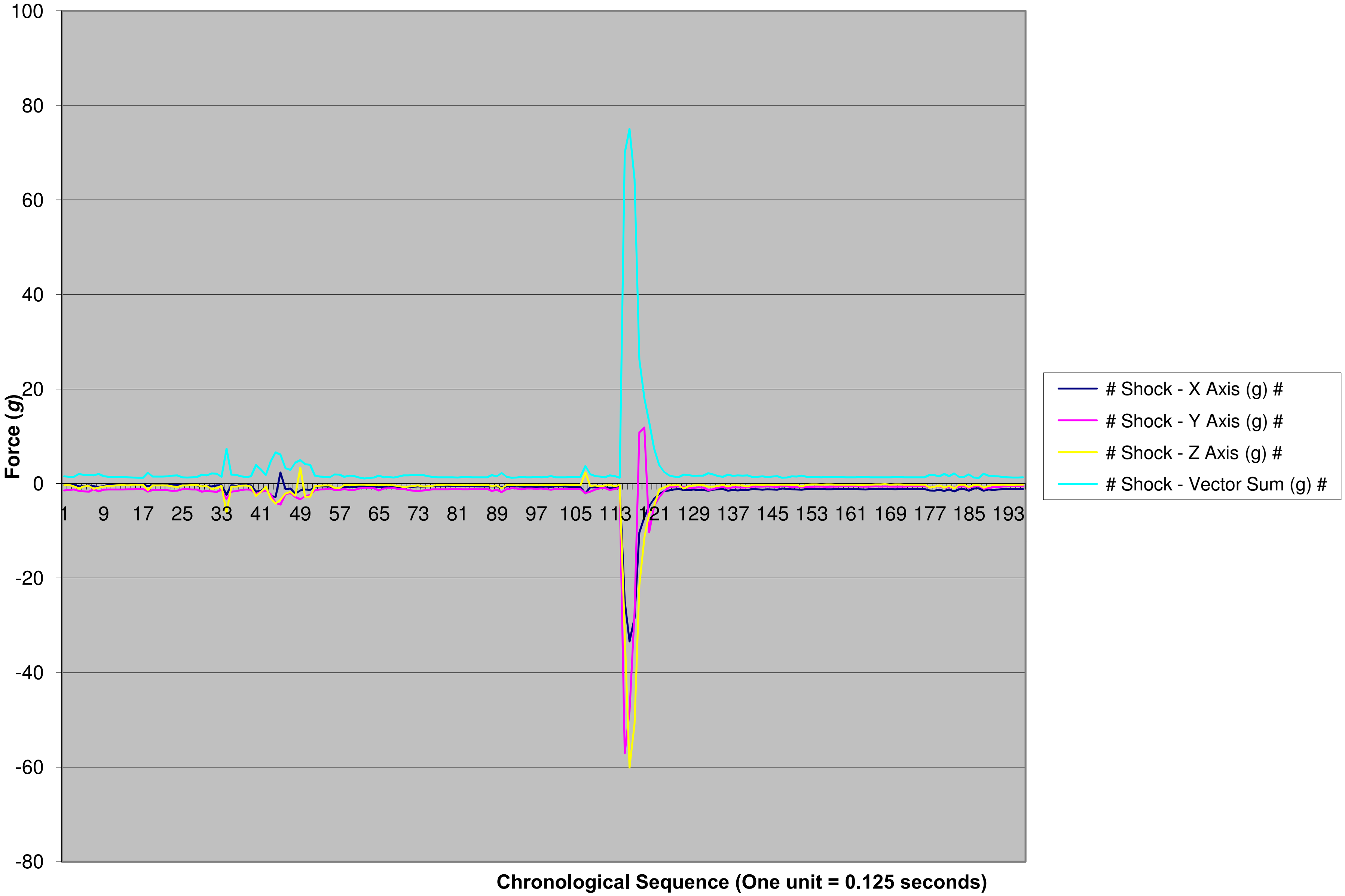

Figure 54. Accelerometer data recorded during long-duration testing on February 1, 2008 showing maximum impact forces observed.

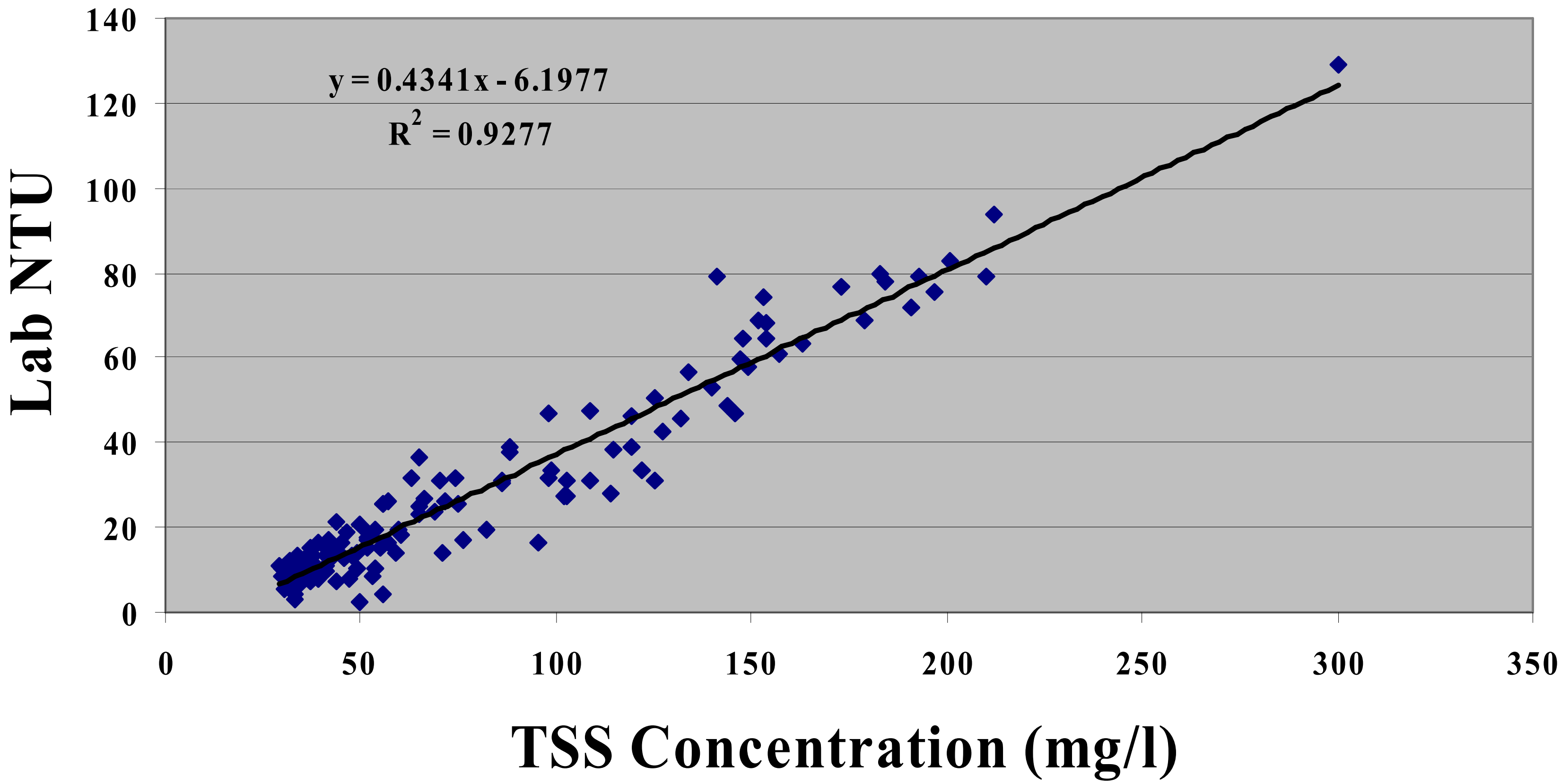

Figure 55. Relationship between turbidity and suspended sediment concentration determined from gravimetric analysis of water samples collected at the study site. Water samples were collected during active dregding on February 8 , 2008 and February 13, 2008.

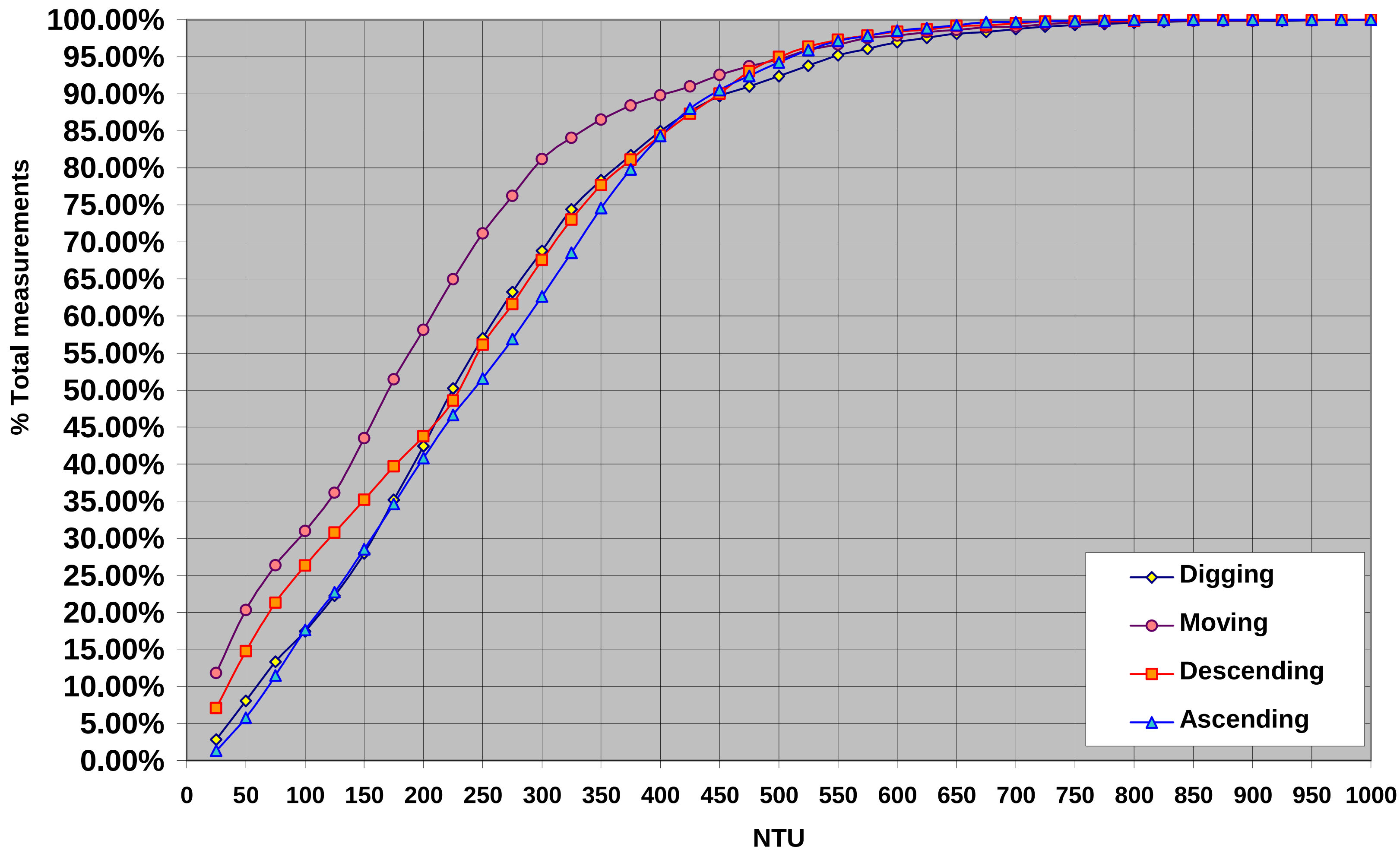

Figure 56. Cumulative percent plots of bucket-mounted turbidity measurements during components of the bucket cycle.

APPENDIX A : Stipulation & Order of Settlement & Dismissal with Appendix A

ORIGINAL

UNITED STATES DISTRICT COURT
SOUTHERN DISTRICT OF NEW YORK

NATURAL RESOURCES DEFENSE COUNCIL, INC.; RARITAN BAYKEEPER, INC.; ANDREW WILLNER; and GREENFAITH, Plaintiffs,	ECF CASE
-against-	05 Civ. 762 (SAS)
UNITED STATES ARMY CORPS OF ENGINEERS; and COL. ANIELLO L. TORTORA,[1] in his official capacity as Commander and District Engineer, United States Army Corps of Engineers, New York District, Defendants,	**STIPULATION AND ORDER OF SETTLEMENT AND DISMISSAL**
and DONJON MARINE INC., and NEW YORK CONTAINER TERMINAL, Intervenors.	

WHEREAS, Congress has authorized the United States Army Corps of Engineers ("Army Corps" or "Corps") to deepen the navigational channels of the New York/New Jersey Harbor ("Harbor Deepening Project" or "HDP"); and

WHEREAS, the Army Corps issued environmental reviews and impact statements pursuant to the National Environmental Policy Act, ("NEPA"), 42 U.S.C. § 4321 et seq., addressing the environmental effects of the HDP, between 1986 and January 2004; and

WHEREAS, on February 13, 2004, the United States Environmental Protection

[1] Colonel Aniello L. Tortora has replaced Colonel Richard J. Polo, Jr. as Commander an District Engineer, United States Army Corps of Engineers, New York District.

Agency ("USEPA") entered into an Administrative Order on Consent ("AOC") under the Comprehensive Environmental Response, Compensation, and Liability Act, 42 U.S.C. § 9601 et seq. ("CERCLA"), that ordered a Remedial Investigation/Feasibility Study ("RI/FS") in the portion of the New York/New Jersey Harbor lying within the Newark Bay Study Area of the Diamond Alkali Superfund Site ("NBSA"); and

WHEREAS, the AOC states that "conditions in the Newark Bay Study Area may present an imminent and substantial endangerment to public health, welfare or the environment," due to the "presence of hazardous substances in the sediment at the Newark Bay Study Area, the subsequent migration of hazardous substances within the Newark Bay Study Area, and the potential migration of all such substances outside of the boundaries of the Newark Bay Study Area"; and

WHEREAS, the AOC states that the "actions required by this Order are necessary to protect the public health or welfare or the environment, are in the public interest, . . . are consistent with CERCLA and the [National Contingency Plan, 40 C.F.R. Part 300 et seq.], . . . and will expedite remedial action and minimize litigation" concerning the NBSA; and

WHEREAS, the purpose of the RI/FS in the NBSA is to "determine the nature and extent of contamination within the Newark Bay Study Area of the Diamond Alkali Superfund Site and to develop and evaluate remedial alternatives"; and

WHEREAS, pursuant to CERCLA, and following completion of the RI/FS, USEPA intends to propose and adopt a Record of Decision ("ROD") and to select one of the alternative remedies evaluated in the RI/FS, which remedy shall be implemented pursuant to CERCLA; and

WHEREAS, Plaintiffs commenced this action on January 21, 2005, pursuant to NEPA and the Administrative Procedure Act, 5 U.S.C. § 706 ("APA"); and

WHEREAS, in their complaint, Plaintiffs alleged that Defendants violated NEPA and the APA by failing to prepare a supplemental Environmental Impact Statement to address the potential detrimental effects of the HDP dredging upon the effort to study, contain, and remediate the risk from contaminated sediments in the NBSA that USEPA instituted with the February 2004 AOC; and

WHEREAS, on August 5, 2005, the Court issued an Opinion and Order that, inter alia, remanded the matter to Defendants for further NEPA review; and

WHEREAS, on January 6, 2006, Defendants issued a revised Environmental Assessment; and

WHEREAS, on March 8, 2006, the Court issued an Opinion and Order that considered the January 6, 2006 Environmental Assessment and, inter alia, remanded the matter to Defendants for further NEPA review; and

WHEREAS, prior to the start of the HDP, the New Jersey Department of Environmental Protection ("NJDEP") and the New York State Department of Environmental Conservation ("NYSDEC") each issued to the Corps "umbrella" Federal Consistency Determination/Water Quality Certificates ("FCD/WQCs") for the HDP, which require the Corps to apply for and obtain additional contract-specific FCD/WQCs before proceeding with each contract area of the HDP; and

WHEREAS, on September 8, 2006, NJDEP issued a FCD/WQC to the Corps for the S-NB-1 contract area of the HDP, which includes certain conditions and reservations, including a requirement to apply for and obtain a supplemental FCD/WQC before proceeding to dredge in the side slopes of the S-NB-1 contract area; and

WHEREAS, on September 22, 2006, the Corps issued an Invitation for Bids for the S-NB-1 contract area of the HDP, which defines work in the outer side slopes as an option that may be exercised at the Corps' discretion within a set period of time following award of the contract, but within which work shall not proceed absent the Corps' exercise of that option; and

WHEREAS, the Corps published a draft Environmental Assessment (the "Draft EA") on April 4, 2007, for the purpose of addressing the issues raised by the March 8, 2006 Opinion and Order, and received comments on the Draft EA; and

WHEREAS, on or about June 21, 2007, the Corps published a Final Environmental Assessment (the "Final EA") and Finding of No Significant Impact ("FONSI"), which had been signed on June 19, 2007, for the purpose of addressing the issues raised by the March 8, 2006 Opinion and Order, as well as comments received on the Draft EA; and

WHEREAS, on or about June 21, 2007, the Corps made a formal award of the contract to dredge the S-NB-1 contract area of the HDP, but has not yet exercised the option under that contract to dredge the side slopes; and

WHEREAS, following the Court's Opinion and Order of March 8, 2006, the Parties have engaged in extensive negotiations concerning a resolution of this matter; and

WHEREAS, without any admission or adjudication of fact or law, other than as stated herein, the Parties have agreed and stipulated to a resolution of the claims in the action that they consider to be a just, fair, adequate, and equitable resolution thereof, given the unique circumstances presented, and which is in the public interest and in the interests of justice; and

NOW, THEREFORE, IT IS HEREBY STIPULATED AND AGREED by and between Plaintiffs and Defendants, by and through their counsel, as follows:

I. DEFINITIONS

1. Whenever the terms set forth below are used in this Stipulation and Order, the following definitions shall apply:

a. "Complaint" shall mean the complaint filed by the Plaintiffs in this action on January 21, 2005;

b. "Day" shall mean a calendar day unless expressly stated to be a working day. In computing any period of time under this Stipulation and Order, where the last day would fall on a Saturday, Sunday, or federal holiday, the period shall run until the close of business of the next working day;

c. "Defendants" shall mean the United States Army Corps of Engineers, and Colonel Aniello L. Tortora, in his official capacity as Commander and District Engineer, New York District;

d. "Effective Date" shall mean the date this Stipulation and Order is signed by the Court;

e. "Federal Natural Resource Trustee Agencies" shall mean the United States Fish and Wildlife Service, the National Oceanographic and Atmospheric Administration, as well as other agencies that may subsequently exercise their federal Natural Resource Trustee authority pursuant to Executive Order 12580, as amended by Executive Order 13016;

f. "Final EA" shall mean the Final Environmental Assessment published by the Defendants on or about June 21, 2007;

g. "Harbor Deepening Project" ("HDP") shall mean the project to deepen the federal navigation channels of the New York/New Jersey Harbor to 50 feet as authorized by Congress in 2000, including the contract areas: KVK-5, S-E-1, S-NB-1, S-NB-2, S-AK-1, S-AK-2, S-AK-3, S-KVK-1, S-KVK-2, S-AN-1a, S-AN-1b, S-AN-2, S-AM-1, S-AM-2, S-PJ-3, S-BR-1, as well as any modifications to these contract areas, but shall not include maintenance dredging;

h. "Month" shall mean a calendar month, such that "one month from April 15, 2007" shall mean "May 15, 2007";

i. "Newark Bay Study Area" ("NBSA") shall mean the portion of the New York/New Jersey Harbor lying within the Newark Bay Study Area of the Diamond Alkali Superfund Site that is the subject of the AOC ordered by USEPA;

j. "Paragraph" shall mean a portion of this Stipulation and Order identified by an arabic numeral;

k. "Party" or "Parties" shall mean the Plaintiffs and/or Defendants;

l. "Plaintiffs" shall mean Natural Resources Defense Council, Inc., Raritan Baykeeper, Inc., Andrew Willner, and Greenfaith;

m. "Section" shall mean a portion of this Stipulation and Order identified by a roman numeral;

n. "Stipulation and Order" shall mean this document and all appendices and exhibits attached hereto; and

o. "USEPA" shall mean the United States Environmental Protection Agency and any successor departments or agencies of the United States.

II. DISMISSAL WITH PREJUDICE

2. This action is hereby dismissed with prejudice subject to the conditions set forth in the remainder of this Stipulation and Order.

3. In order to allow Plaintiffs a reasonable period of time to prepare an application for attorneys' fees, and notwithstanding paragraph 2, this Court shall not enter a final judgment pursuant to Rule 58(a)(1) of the Federal Rules of Civil Procedure until sixty (60) days after the Court signs this Stipulation and Order.

4. Nothing in this Stipulation and Order shall constitute an admission of liability or fault on the part of Defendants, or their agents, servants or employees, and this Stipulation and Order is entered into by the Parties for the sole purpose of compromising disputed claims and avoiding the expenses and risks of further litigation.

III. COMPLIANCE REQUIREMENTS

A. Compliance Requirements Applicable to the HDP in the NBSA

5. With respect to HDP dredging in the S-NB-1 contract area, Defendants shall comply with the following best management practices ("BMPs"):

a. conditions 2 through 14 as they appear in the September 8, 2006 FCD/WQC (attached hereto as Exhibit A); and

b. Section 2900 of specifications accompanying Invitation for Bids for Contract Area S-NB-1, sub-sections 4, 6.3.c, and 6.3.e (attached hereto as Exhibit B).

6. When applying for FCD/WQCs for any HDP contract within the NBSA subsequent to the Effective Date of this Stipulation and Order, Defendants shall inform the relevant state regulatory agency (or agencies) that they consent to the inclusion of the following

BMPs:

a. conditions 2 through 14 as they appear in the September 8, 2006 FCD/WQC, except as provided by paragraph 7, below; and

b. Section 2900 of specifications accompanying Invitation for Bids for Contract Area S-NB-1, sub-sections 4, 6.3.c, and 6.3.e ; except that: (i) if condition 3 from the September 8, 2006 FCD/WQC is omitted for any future contract, Defendants are not obligated to apply to such contract the requirements of Section 02900, ¶ 6.3.e of the Invitation for Bids for Contract Area S-NB-1; and (ii) if condition 4 from the September 8, 2006 FCD/WQC is omitted for any future contract, Defendants are not obligated to apply to such contract the requirements of Section 02900, ¶ 6.3.c of the Invitation for Bids for Contract Area S-NB-1.

7. When applying for WQCs for HDP contracts within the NBSA, Defendants shall not ask NJDEP to alter conditions 2 through 14 as they appear in the September 8, 2006 WQC unless: (a) such a request is accompanied by new data or information that demonstrates that a comparable level of environmental protection can be achieved without the application of one or more of those conditions, or that the level of protection is inappropriate for that area, or (b) such a request is made for the purpose of obtaining scientific data and/or information that would assist the Corps in evaluating whether a greater or equal level of environmental protection could be achieved through alternative BMPs.

8. When issuing Invitations for Bids for contract areas S-NB-2, AK-1, AK-2 and AK-3 of the HDP as defined in the Final EA, the Corps shall define work in:

a. the side slopes of an existing channel;

b. locations outside an existing channel into which such channel shall be widened; and

c. those portions of the S-NB-2 contract area that are identified as area #10 in Figure 78 of the report titled "Geomorphological/Geophysical Characterization of the Nature and Dynamics of Sedimentation and Sediment Transport in Newark Bay Focusing on the Effects Related to the Continued and Future Federal Navigation Channel Deepening and Maintenance," which is referred to in the April 4, 2007 Draft EA as "USACE 2007" (hereinafter "Geomorphological Report") (attached hereto as Exhibit C);

as one or more options that may be exercised at the Corps' discretion within a set period of time following award of the contract, but within which work shall not proceed absent the Corps' exercise of that/those option(s), and absent an area-specific amended FCD/WQC that covers that/those option area(s). These areas for which a separate contract option is required are hereinafter referred to as the "Contract Option Areas." However, if Defendants have completed the Reports described in paragraphs 14 and 15 and Appendices A and B of this Stipulation and Order prior to issuing an Invitation for Bids for contract area S-NB-2, AK-1, AK-2 or AK-3 of the HDP as defined in the Final EA, Defendants are not required to define work in the areas described in paragraph 8.a-c as separate options for that contract.

9. When applying for an FCD/WQC for contract areas S-NB-2, AK-1, AK-2 and AK-3 of the HDP as defined in the Final EA, the Corps shall notify NJDEP that it consents to the inclusion of a requirement to apply for and obtain an amended FCD/WQC before proceeding to dredge in the Contract Option Areas. However, if Defendants have completed the

Reports described in paragraphs 14 and 15 and Appendices A and B of this Stipulation and Order prior to applying for an FCD/WQC for contract area S-NB-2, AK-1, AK-2 or AK-3 of the HDP as defined in the Final EA, Defendants are not required to apply for an amended FCD/WQC before proceeding to dredge in the areas described in paragraph 8.a-c for that contract.

B. South Elizabeth Channel Silt Curtain Study and Report

10. Defendants shall, consistent with United States Army Corps of Engineers Safety and Health Regulations EM 385-1-1, and subject to any necessary approval by NJDEP, deploy a silt curtain in a portion of the South Elizabeth Channel (an element of the S-NB-2 contract area), subject to appropriate hydrodynamic conditions (i.e., at a minimum, a flow regime that is reasonably steady and is of sufficient velocity to disperse sediments), such that environmental protection, safety, and navigation are not compromised. While the Silt Curtain is deployed, Defendants shall monitor its effectiveness at limiting the transport of any dredging-induced resuspended sediment and evaluate the feasibility of its use in future HDP dredging within the NBSA.

11. Defendants shall document in a written report ("Silt Curtain Pilot Study Report") their monitoring of the silt curtain's effectiveness at reducing the transport of any dredging-induced resuspended sediment, and their assessment of the feasibility of its use for that purpose in future HDP dredging within the NBSA.

12. Defendants shall complete the final Silt Curtain Pilot Study Report within fifteen (15) months after the exercise of the side slope/channel widening option(s) within the S-NB-2 contract. Promptly upon completion, Defendants shall provide the final Silt Curtain Pilot Study Report to Plaintiffs, USEPA, NJDEP and NYSDEC, and shall publish a notice of

availability of the final Silt Curtain Pilot Study Report on its website.

13. Prior to finalizing the Silt Curtain Report, Defendants shall circulate a draft to Plaintiffs, NJDEP and NYSDEC for comment. Defendants shall consider in good faith any comments on the draft Silt Curtain Pilot Study Report that Plaintiffs, NJDEP and/or NYSDEC submit to Defendants, provided that such comments were received by Defendants within twenty-one (21) days of the commenter's receipt of the draft Silt Curtain Pilot Study Report (or within a longer period at the discretion of Defendants). Defendants shall retain ultimate discretion as to incorporation of any specific revisions proposed by the commenters into the final Silt Curtain Pilot Study Report. No later than two (2) months after completing the final Silt Curtain Pilot Study Report, Defendants shall provide a written response to any comments timely submitted by Plaintiffs on the draft Silt Curtain Pilot Study Report.

C. Pilot Project

14. Defendants shall perform a Near Field Turbidity/Total Suspended Sediments Pilot Study ("NFTTSS") Pilot Study in the "narrow channel" contract area of the S-NB-1 contract area (the "NFTTSS Pilot Study") as set forth in Appendix A.

D. Stratified Sampling

15. Defendants shall perform a Stratified Sampling Project for HDP contract areas in the NBSA subsequent to S-NB-1 ("Stratified Sampling"), as set forth in Appendix B.

IV. COORDINATION WITH OTHER AGENCIES

16. Defendants shall continue to coordinate their HDP dredging activities in the NBSA with USEPA, NJDEP, NYSDEC, and the Federal Natural Resource Trustee agencies, and shall solicit the advice of those agencies on any such activities that may have an effect upon

the effort to study, contain and remediate the risk from contaminated sediments in the NBSA. Such coordination shall be conducted through the existing, regular inter-agency meetings identified in the Newark Bay Study Area Coordination Plan, dated December 21, 2005 (attached hereto as Exhibit D). Except as expressly provided in this Stipulation and Order, nothing in this Stipulation and Order shall abrogate or enlarge the Defendants' obligations pursuant to the Newark Bay Study Area Coordination Plan.

17. Defendants shall provide members of the public an opportunity to meet with them to offer questions or comments on their inter-agency coordination pursuant to paragraph 16 on at least a quarterly basis. Such meetings shall be scheduled to occur immediately following the end of a regularly scheduled inter-agency coordination meeting held pursuant to paragraph 16, except that if no such inter-agency coordination meeting is scheduled within a given quarter, upon the request of one or more Plaintiffs, Defendants shall provide members of the public with an equivalent opportunity to meet with them to offer questions or comments, at a time mutually convenient to Plaintiffs and Defendants. Any meeting pursuant to this paragraph may be conducted in-person or by conference call. The time and date of such meetings, as well as a call-in number, shall be posted on the Corps' website, at www.nan.usace.army.mil. Defendants shall notify USEPA, NJDEP, NYSDEC, and the Federal Natural Resource Trustee agencies of the time and date of such meetings, and shall offer them the opportunity to participate. To the extent practicable, Defendants shall also provide Plaintiffs with other relevant written materials, including Memoranda for Record of any prior coordination meetings held pursuant to paragraph 16, before any meeting pursuant to this paragraph.

18. Defendants shall prepare Memoranda for Record ("MFRs") of the

coordination meetings held pursuant to paragraph 16, and shall post the MFRs, or a notice of availability, on the Corps' website, at www.nan.usace.army.mil.

19. The foregoing coordination obligations shall terminate upon completion of construction of the final HDP contract reach within the NBSA.

V. RELEASE AND COVENANT NOT TO SUE

20. Plaintiffs release and covenant not to sue or bring any action against the Defendants, the United States, or any department or agency or official thereof concerning the adequacy of the June 2007 Final EA or FONSI. Plaintiffs further release and covenant not to sue or bring any action against the Defendants, the United States, or any department or agency or official thereof, or any of the Defendants' funding partners for the HDP, for any claim that concerns any HDP contracts and/or activities and that:

a. accrued on or before the date on which Plaintiffs sign this Stipulation and Order; or

b. arises from any data or information resulting from Defendants' performance of the South Elizabeth Channel Silt Curtain Study, the NFTTSS Pilot Study, and/or Stratified Sampling required by this Stipulation and Order.

21. In the event of a future dispute regarding the HDP activities within the NBSA, the Parties shall undertake in good faith to resolve such dispute without resort to formal litigation.

VI. MODIFICATION

22. This Stipulation and Order may be modified by (a) a written stipulation signed by all Parties, or (b) the Court, pursuant to a motion on notice by any Party, for good

cause shown; provided, however, that this Stipulation and Order may not be modified to add new obligations for any Party or to accelerate any deadlines faster than the deadlines set forth above in this Stipulation and Order, except by written stipulation signed by all Parties.

23. If the modification is by written stipulation signed by all Parties, the modification will take effect upon the entry of the written stipulation by the Court.

24. Prior to bringing any motion to modify this Stipulation and Order, the Party seeking the modification shall first seek the other Parties' consent to the proposed modification.

25. If the modification is sought by motion and concerns a deadline set forth in this Stipulation and Order, the following procedures shall apply:

a. The motion shall be filed and served at least sixty (60) days before the applicable deadline; however, failure to meet that deadline shall not, standing alone, be cause to deny the motion. In the event the 60-day deadline is missed, the motion shall state the reasons why.

b. The motion shall be accompanied by a request for expedited consideration by the Court at the option of the movant, including (i) a request that the Court decide the motion no later than twenty (20) days prior to the applicable deadline; and (ii) a request for a briefing schedule that would afford the Court sufficient time to render such an expedited decision. All Parties to this Stipulation and Order shall join in any such request for expedited consideration regardless of whether they oppose the motion on the merits.

VII. RETENTION OF JURISDICTION, REMEDIES FOR BREACH, AND TERMINATION

26. Notwithstanding the dismissal of this action as set forth in paragraph 2,

this Court shall retain jurisdiction to determine, upon motion on notice by any Party, whether any other Party has materially violated the terms of this Stipulation and Order, and has not cured such violation promptly after receiving notice from the moving Party pursuant to the procedures regarding notice set forth in paragraph 27. In any motion pursuant to the terms of this paragraph and paragraph 27, the moving Party shall bear the burden of establishing a violation, and the non-moving Party shall bear the burden of establishing that any violation did not materially affect compliance with the terms and conditions of this Stipulation and Order. If this Court determines that any Party has materially violated this Stipulation and Order, and has not promptly cured such violation after receiving notice of such violation from the moving Party, this action shall be reinstated. Reinstatement of this action pursuant to this paragraph shall be the sole remedy under the Stipulation and Order, and no other remedies, including but not limited to contempt sanctions, may be requested by any Party or ordered by the Court for any alleged breach of this Stipulation and Order. If this action is reinstated, this Stipulation and Order shall be rendered null and void, all pending obligations pursuant to this Stipulation and Order are immediately suspended, and the Parties' legal claims and defenses shall be preserved in full as if the action had not previously been dismissed.

27. In the event there is a dispute over compliance with any term or provision of this Stipulation and Order, the Parties shall engage in informal dispute resolution procedures as set forth in this paragraph, prior to seeking judicial relief. The disputing Party shall notify the other Parties in writing, setting forth (a) the nature of the dispute, (b) the disputing Party's position with respect to the dispute, and (c) the information that the disputing Party is relying on to support its position. The Parties shall then meet and/or confer in good faith to attempt to

resolve the dispute. If the Parties are unable to resolve the dispute within thirty (30) days after the disputing Party has provided written notice of dispute to the other Parties, the disputing Party may file a motion before this Court under paragraph 26 of this Stipulation and Order for a determination that a Party has materially violated this Stipulation and Order and has not promptly cured such violation after receiving notice of such violation. The thirty (30) day dispute resolution period may be shortened by agreement of the Parties, or upon emergency motion by the disputing Party demonstrating by a preponderance of the evidence that the disputing Party will be irreparably injured unless the dispute resolution period is shortened. At least one (1) business day prior to bringing any such emergency motion, the disputing Party shall provide written notice of the dispute to other Parties. Any such emergency motion shall be on notice to all Parties.

28. This Court shall retain jurisdiction to hear any application for attorneys' and expert fees and/or costs. The fact that the Court retains jurisdiction over an application for fees and/or costs shall not indicate in any way that Plaintiffs are eligible for or entitled to recover any fees or costs. Defendants reserve and will assert any and all arguments and defenses in opposition to any application by Plaintiffs for fees and/or costs.

29. Defendants shall notify Plaintiffs in writing when they believe that they have completed all of their obligations pursuant to Sections III and IV of this Stipulation and Order, and that this Stipulation and Order should be terminated ("Notice of Completion"). If Plaintiffs disagree as to whether Defendants have completed all such obligations, Plaintiffs must invoke the dispute resolution procedures set forth in paragraph 27 within fifteen (15) days of receiving the Notice of Completion from Defendants. If the dispute resolution procedures cannot

resolve the dispute, Plaintiffs must file a motion pursuant to paragraph 26 alleging material noncompliance with the terms of this Stipulation and Order no later than fifteen (15) days after the conclusion of the dispute resolution period. This Stipulation and Order shall be terminated if (a) Plaintiffs do not invoke the dispute resolution procedures within fifteen (15) days after receiving the Notice of Completion from the Defendants; (b) Plaintiffs do not file a motion pursuant to paragraph 26 of this Stipulation and Order within fifteen (15) days after the conclusion of the dispute resolution period as set forth in paragraph 27; or (c) Plaintiffs file such a motion and it is denied by the Court.

VIII. ENTIRE AGREEMENT

30. This Stipulation and Order contains the entire agreement between the Parties, and no statements, representations, promises, agreements, or negotiations, oral or otherwise, between the Parties or their counsel that are not included herein shall be of any force or effect.

IX. NO CHANGE IN OTHER LEGAL REQUIREMENTS AND OBLIGATIONS

31. Nothing in this Stipulation and Order shall be interpreted as or constitute a commitment that the Defendants take action in contravention of the APA, the NEPA, or any other law or regulation, substantive or procedural.

32. Nothing in this Stipulation and Order shall be construed to require any of the Defendants to obligate or pay funds or in any other way take action in violation of the Anti-Deficiency Act, 31 U.S.C. § 1341, or any other applicable appropriation law.

33. Nothing in this Stipulation and Order shall be construed to restrict or modify any discretion Defendants may have under law, including without limitation, NEPA, or

any other matter not addressed by this Stipulation and Order.

34. Nothing in this Stipulation and Order shall be construed to create rights in, or grant any cause of action to, any person or entity not party to this Stipulation and Order.

X. NOTICES

35. Any notices required to be served under this Stipulation and Order shall be in writing and sent by (a) electronic mail or facsimile and (b) a form of mail or other delivery that includes confirmation of delivery. All notices shall be addressed to each Party at the address specified below, or to any address a Party subsequently designates by notice to all other Parties given in accordance with this paragraph.

36. Notices submitted pursuant to this Section shall be deemed submitted upon receipt, unless otherwise provided in a modification to this Stipulation and Order or by mutual agreement of the Parties in writing.

For Raritan Baykeeper, Inc. (d/b/a NY/NJ Baykeeper) and Andrew J. Willner:

Richard Webster, Esq.
Eastern Environmental Law Center/Rutgers Environmental Law Clinic
123 Washington Street
Newark, New Jersey 07102
Tel. 973-353-5695
Fax. 973-353-5537
rwebster@kinoy.rutgers.edu

and:

Andrew J. Willner
NY/NJ Baykeeper
52 West Front Street
Keyport, New Jersey 07735
Tel. 732-888-9870
Fax. 732-888-9873
andy@nynjbaykeeper.org

For Natural Resources Defense Council, Inc. and GreenFaith:

Lawrence M. Levine
Natural Resources Defense Council
40 W 20th Street
New York, NY 10011
Tel. 212-727-2700
Fax. 212-727-1773
llevine@nrdc.org

and:

Rev. Fletcher Harper
Executive Director
Green Faith
46 Bayard St., #401
New Brunswick, NJ 08901
Tel. 732-565-7740
Fax. 732-565-7790
revharper@greenfaith.org

For the Defendants United States Army Corps and Col. Tortora:

Sarah E. Light
Assistant United States Attorney
U.S. Attorney's Office
Southern District of New York
86 Chambers Street, 3rd Floor
New York, NY 10007
Tel. 212-637-2774
Fax. 212-637-2686
sarah.light@usdoj.gov

and:

Ellen B. Simon
Assistant District Counsel
U.S. Army Corps of Engineers, New York District
26 Federal Plaza, Rm 1837 (CENAN-OC)
New York, NY 10278
Tel. 917-790-8158
Fax. 212-264-8171
Ellen.B.Simon@nan02.usace.army.mil

and:

Martin R. Cohen
Assistant Chief Counsel
U. S. Army Corps of Engineers
Room 3E-29
441 G Street N.W.
Washington, D. C. 20314-1000
Tel. 202-761-8545
Fax. 202-761-1113
Martin.R.Cohen@hq02.usace.army.mil

XI. EXECUTION BY THE PARTIES

37. The undersigned representatives of each Party certify that they are authorized by the Party to consent to the entry of this Stipulation and Order. This Stipulation and Order may be executed in counterparts.

XII. EFFECTIVE DATE

38. This Stipulation and Order shall become effective upon signature by the Court.

XIII. EXHIBITS

Exhibit A: September 8, 2006 FCD/WQC

Exhibit B: Section 2900 of specifications accompanying Invitation for Bids for Contract Area S-NB-1

Exhibit C: Geomorphological/Geophysical Characterization of the Nature and Dynamics of Sedimentation and Sediment Transport in Newark Bay Focusing on the Effects Related to the Continued and Future Federal Navigation Channel Deepening and Maintenance, Figure 78

Exhibit D: Newark Bay Study Area Coordination Plan, dated December 21, 2005

XIV. APPENDICES

Appendix A: Near Field Turbidity/Total Suspended Sediments Pilot Study

Appendix B: Stratified Sampling Project

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FOR PLAINTIFFS
NRDC and GREENFAITH:

Date: Oct. 16, 2007

LAWRENCE M. LEVINE
Natural Resources Defense Council
Attorneys for Plaintiffs
40 West 20th Street
New York, NY 10011
Tel. 212-727-2700
Fax. 212-727-1773

FOR PLAINTIFFS
RARITAN BAYKEEPER, INC. and
ANDREW WILLNER:

Date: Oct 17, 2007

Richard Webster

RICHARD WEBSTER
Eastern Environmental Law Center/
Rutgers Environmental Law Clinic
Attorneys for Plaintiffs
123 Washington Street
Newark, NJ 07102
Tel. 973-353-5695
Fax. 973-353-5537

FOR DEFENDANTS:

MICHAEL J. GARCIA
United States Attorney for the
Southern District of New York
Attorney for the Defendants

Date: 10/17, 2007

By: Sarah E. Light

SARAH E. LIGHT
Assistant United States Attorney
86 Chambers Street, 3rd Floor
New York, New York 10007
Tel. 212-637-2774
Fax. 212-637-2686

SO ORDERED:

UNITED STATES DISTRICT JUDGE

Shira A. Scheindlin, USDJ

Date: Oct. 19, 2007

Appendix A: Near Field Turbidity/Total Suspended Sediments Pilot Study

1. The Defendants shall, consistent with United States Army Corps of Engineers Safety and Health Regulations EM 385-1-1, conduct a Near Field Turbidity/Total Suspended Sediments Pilot Study ("NFTTSS Pilot Study") within the S-NB-1 "narrow channel" contract area as set forth below.

2. The NFTTSS Pilot Study will test the near-field use of both optical (OBS) and acoustic (ADCP) sensors to collect near-field optical and acoustic backscatter measurements, which will then be converted into Total Suspended Sediments ("TSS") levels, by deploying OBS sensors mounted to the bucket, and OBS and ADCP sensors to the dredge platform. Specifically, the study will attempt to determine:

    a. whether either type of sensor, mounted as set forth above, is sufficiently reliable and resilient to continuously record and/or transmit data from which quantitative backscatter measurements can be obtained continuously and in real time, within a turbulent near-field environment, over a time span routinely involved in navigational dredging; and

    b. if either type of sensor were found to demand repair, maintenance, and/or recalibration, on a frequency that made continuous monitoring impractical, whether the sensor could be hardened to avoid the need for such repair, maintenance, and/or recalibration.

3. Defendants shall prepare and provide to Plaintiffs, NJDEP and NYSDEC a draft Scope of Work prior to commencing the NFTTSS Pilot Study. Prior to issuing a final Scope of

Work, Defendants shall consider in good faith any comments on the draft Scope of Work that Plaintiffs, NJDEP and/or NYSDEC submit to Defendants, provided such comments are submitted within fourteen (14) days of the commenter's receipt of the draft Scope of Work (or within a longer period of time at the discretion of Defendants). Defendants shall retain ultimate discretion as to incorporation of any specific revisions proposed by the commenters into the final Scope of Work. Defendants shall provide a copy of the final Scope of Work to Plaintiffs, NJDEP and NYSDEC prior to initiating the NFTTSS Pilot Study. No later than two (2) months after approving the final Scope of Work, Defendants shall provide to Plaintiffs a written response to any comments that Plaintiffs, NJDEP and/or NYSDEC timely submitted on the draft Scope of Work.

4. Defendants shall provide access to at least one qualified technical expert, as designated by Plaintiffs, to observe the field work for the NFTTSS Pilot Study. The number of additional personnel permitted to observe field work may be limited in the discretion of the Defendants due to health and safety conditions.

5. The NFTTSS Pilot Study shall take place during dredging of non-HARS suitable materials from an area within the S-NB-1 "narrow channel" contract area that is subject to moderate to high current velocities characteristic of tidal flows in the main Newark Bay channel reaches. Measurements shall be taken at a range of conditions in the tidal cycle.

6. Defendants shall request any FCD/WQCs from appropriate State regulatory agencies that may be necessary to conduct the NFTTSS Pilot Study.

7. Following the completion of the field work described in paragraphs 1 and 2 of this

Appendix, Defendants shall prepare a technical report (the "NFTTSS Pilot Study Report") that:

a. addresses each of the issues set forth in paragraphs 2.a and 2.b of this Appendix;

b. analyzes the feasibility of applying the pilot-tested configuration of optical and acoustic backscatter instrumentation and data collection capability or a refinement thereof to future HDP activities within the NBSA and the anticipated efficacy of such pilot-tested measures to assist in minimizing dredging-induced sediment resuspension during such dredging activities;

c. presents all measured optical and acoustic backscatter levels, with corresponding information describing, for each measurement, the location in the NBSA where it was taken, the date and time when it was taken, and the type of instrument used; and

d. presents all gravimetric water sample calibration data collected to generate the data set used to establish a relationship among optical backscatter measurements, acoustic backscatter measurements, and TSS concentrations. These calibration data are distinct from instrumentation calibration that are performed by the manufacturer.

8. Defendants shall complete the NFTTSS Pilot Study Report prior to submitting a request for an amendment to an FCD/WQC to support exercising of any of the Contract Option Areas defined in paragraph 8 of this Stipulation and Order. If Defendants complete the NFTTSS Pilot Study Report prior to applying for an FCD/WQC for contract area S-NB-2,

AK-1, AK-2 or AK-3 of the HDP as defined in the Final EA, then Defendants shall not be required to apply for an amendment to the FCD/WQC for that contract, as set forth in paragraphs 8 and 9 of this Stipulation and Order.

9. Prior to finalizing the NFTTSS Pilot Study Report, Defendants shall circulate a draft NFTTSS Pilot Study Report to Plaintiffs, NJDEP and NYSDEC for comment. Defendants shall consider in good faith any comments on the draft submitted by Plaintiffs, NJDEP and/or NYSDEC, provided that such comments are submitted within twenty-one (21) days of the commenter's receipt of the draft NFTTSS Pilot Study Report (or within a longer period of time at the discretion of Defendants). Defendants shall retain ultimate discretion as to incorporation of any specific revisions proposed by the commenters into the final NFTTSS Pilot Study Report.

10. Defendants shall in good faith consider the results of the NFTTSS Pilot Study Report in the preparation of any specifications for and any determination to proceed with any HDP dredging contract or contract option for work within the NBSA that is awarded subsequent to completion of that Report.

11. Promptly upon completion of the final NFTTSS Pilot Study Report, Defendants shall provide a copy of that Report to Plaintiffs, NJDEP, NYSDEC, and USEPA, and shall make the Report available to members of the public upon request. No later than two months after completing the final NFTTSS Pilot Study Report, Defendants shall provide to Plaintiffs a written response to any comments that Plaintiffs, NJDEP and/or NYSDEC had timely submitted to Defendants on the draft NFTTSS Pilot Study Report.

APPENDIX B : TECHNICAL TEAM

USACE-NYD

Jenine Gallo - Chief, Estuary Section, Environmental Analysis Branch, Planning Division
Catherine Mulvey – Technical Team Co-Lead
Ronald Pinzon – Technical Team Co-Lead
Bryce Wisemiller – Technical Team Member

U.S. Army Engineer Research and Development Center Dredging Operations Technical Support Program

Dr. Douglas Clarke – Technical Team Lead
Kevin Reine – Technical Team
Chuck Dickerson – Technical Team

Consultant Technical Team

HDR
Sarah Zappala – Project Manager
David Davis – Technical Team Lead
Jaak Van den Sype - Technical Team

Battelle
Betsy Barrows – Project Manager
Amanda Maxemchuk – Technical Team

A special thanks to John Downing, technical advisor/OBS manufacturer, and Dr. Frank Bohlen, the Plaintiffs technical observer, for participating in this study.