Appendix E: Water Quality

E-1 INTRODUCTION

This appendix presents a summary of modeling activities and pollutant loading calculations conducted in support of the analysis of the potential impacts to water resources of the Hudson River from the construction of the Replacement Bridge Alternative. It describes the two public domain models employed in the hydrodynamic modeling, inputs to the models and includes documentation of the analyses used to develop some of these inputs as attachments in addition to other studies conducted in support of the water resources assessment. The attachments to this appendix include:

- Attachment 1—Lamont-Doherty Earth Observatory's (LDEO's) 20th century sediment deposition study.
- Attachment 2—Memorandum from Don Hayes, University of Louisiana presenting the SedFlume testing and results.
- Attachment 3—Memorandum from Don Hayes, University of Louisiana on estimating water quality impacts from construction vessel traffic.
- Attachment 4—Memorandum from Don Hayes, University of Louisiana, presenting an overview of Tappan Zee Bridge Sediment Resuspension Rate Findings.
- Attachment 5—Projected Total Suspended Sediment Concentrations During Construction of the Replacement Bridge Alternative.
- Attachment 6—Pollutant Loading Calculations Table1 and Table 2 estimating the pollutant loading from stormwater discharges to the Hudson River.

For the Hudson River, the principal water quality resources issue for the construction of the Replacement Bridge Alternative is the resuspension of river sediments during construction and removal of the existing bridge foundations, and the transport and eventual deposition of this resuspended sediment elsewhere in the Hudson River. While the sand fraction of river sediment settles out relatively quickly after being resuspended, the finer sediment fractions will remain suspended and will be transported away from the construction area.

E-2 HYDRODYNAMIC MODELING

Hydrodynamic modeling was used to project the plume of resuspended sediment that would result from sediment-disturbing construction activities and the fate and transport of this plume within the Hudson River estuary. Two public domain models were employed in the modeling:

- The EFDC model simulates three dimensional flow, sediment transport and water quality. Originally developed at the Virginia Institute of Marine Science it is currently supported by the US Environmental Protection Agency (USEPA) and has been extensively tested and documented in numerous modeling studies.
- The RMA-2 model is a widely tested model that is used extensively for bridge scour evaluations in estuaries. It was used to evaluate the results of the EFDC modeling during the periods when the Hudson River Estuary is well-mixed throughout its depth (e.g., during the spring freshet—a time of high freshwater inflows). The model was originally developed for the US Army Corps of Engineers (USACE).

EFDC is a numerically sophisticated model capable of simulating a large number of complex physical processes, including density induced circulation and sediment transport. These physical processes may also evolve over long time scales, on the order of months or years. When considering the numerical requirements of the processes and the time scales over which they occur, the EFDC model is inherently computationally intensive. These computational requirements create practical constraints on the model grid size and the resolution of near-field processes.

- The RMA-2 model simulates fewer physical processes (which typically evolve over shorter time scales) than the EFDC model and also utilizes a more flexible numerical grid. These characteristics allow for significantly more detailed numerical grids in areas of interest. Subsequently, the RMA-2 model can typically produce more detailed near-field data but may also produce progressively worse approximations of transport processes over large periods of time due to the physical processes it does not describe. Subsequently, the EFDC model was used as a far-field model, considering processes such as sediment transport, while the RMA-2 model was used as a near-field model, modeling processes which evolve over periods less than those of tidal cycles.

Inputs to the hydrodynamic models included the following:

- Results of site-specific monitoring and studies conducted for the Replacement Bridge Alternative within the study area, including a bathymetric study, grain size analysis, total suspended solids and turbidity measurements, monitoring of tide gauges installed for the project, dye study, water quality monitoring (i.e., conductivity, temperature, and turbidity), channel salinity profile mapping, and river velocity monitoring to create a cross-sectional profile of the river velocities.
- Results of SedFlume analysis of sediments within the vicinity of the area to be dredged, which indicated sediments within the study area are highly susceptible to resuspension (see Attachment 2).
- Existing information to characterize the Hudson River Estuary within the study area. Examples include bathymetry from the National Oceanic and Atmospheric Administration (NOAA) navigational charts, tidal data from US Geological Survey (USGS) and NOAA tide stations, USGS freshwater discharge, and USGS salinity and suspended sediment concentration data.
- Results of numeric models developed to estimate suspended sediment loadings that would result from dredging; pile driving, coffer dam installation, dewatering, and

removal; and vessel movement as described below and in Attachments 3 and 4. Inputs to these models are presented below.

- Suspended sediment generated by dredging—Assessment assumed the use of environmental/closed bucket with no barge overflow and a sediment loss rate of about 1 percent. This conservative loss rate of 1 percent, combined with the projected dredging rate and the sediment characteristics results in an average sediment resuspension rate for each dredge of 39 kilograms per minute (kg/min), and a maximum rate of 94 kg/min (See Attachment 4).
- Suspended sediment generated by cofferdam construction and dewatering—In the absence of existing information on sediment resuspension rates associated with cofferdam construction, resuspension of sediment during installation of sheet pile for cofferdams was developed on the basis of results of suspended sediment monitoring conducted for the San Francisco-Oakland Bay Bridge East Span Seismic Safety Project during dredging and in-water construction activities (http://biomitigation.org/bio_overview/subjects_overview.asp#water). Results of monitoring for that project indicated that installation of sheet pile for coffer dam construction resulted in average resuspension of bottom material that was about 30 percent of the average resuspension during dredging. (See Attachment 4).
- Suspended sediment generated by pile driving and dewatering—Existing information on sediment resuspension from pile driving and dewatering was similarly absent and was estimated to be approximately 40 percent of that observed during dredging on the basis of the suspended sediment monitoring for the San Francisco-Oakland Bay Bridge East Span Seismic Safety Project (See Attachment 4).
- Suspended sediment generated by vessel movement and prop scour— Since the results of the SedFlume analysis and scour modeling (see Attachment 3) indicated that the bottom sediment following dredging would be highly susceptible to resuspension due to scouring by the props on the tugs needed to move the construction barges along the dredged access channel, the project included the placement of sand/gravel armoring material within the dredged channel following dredging. Therefore, the resuspension resulting from vessel movement would be limited to sediment that has been naturally deposited in the dredged access channel which will act as a sediment trap. Using an estimated depositional rate of sediment within the dredged channel of 104 kilograms per meter per day developed on the basis of van Rijn (1986), described in Attachment 4 and below, and total suspended sediment concentrations measured during studies conducted for the Replacement Bridge Alternative, the hourly scour rate of sediment as the vessels move along the armored channel was estimated as 8.7 kg per meter per hour (kg/m/hr) (See Attachment 4).

E-3 20TH CENTURY SEDIMENT DEPOSITION

As described in Attachment 1, the main objectives of this study by LDEO were to identify the extent and thickness of sediments potentially containing elevated levels of contaminants, as well as areas where sediments were eroding or non-depositing. Locations of these sediments can be used to determine areas of recent and historical deposition. Results are based on 14 sediment cores collected in September 2001 and

15 sediment cores collected in May 2006 in the vicinity of the proposed Tappan Zee construction zone.

LDEO used the presence of lead concentrations in sediments above natural background levels (15 to 30 parts per million (ppm)) as a proxy for identifying those sediments impacted by twentieth century activities. Sediments containing elevated lead concentrations also potentially contain other contaminants of concern, while sediments containing background levels of lead represent sediments deposited prior to the onset of industrial activities and do not pose a significant contamination issue.

The majority of sediments collected were terrigenous, bioclastic, clays and sandy clays. Lead concentrations ranged from a few ppm to about 225 ppm. The majority of samples measured had concentrations lower than 25 ppm and in the range of natural background levels. The depth to which elevated lead levels penetrated the sediments varied considerably throughout the study site. The majority of penetration depths were between 0 and 20 inches, with depths exceeding 60 inches at a few sites.

Sediments collected north of the existing Tappan Zee Bridge exhibited elevated lead concentrations penetrating between 0 and 20 inches, with the majority between 0 and 8 inches, suggesting that deposition of recent sediments in this portion of the study site was limited. Depositional patterns observed south of the existing bridge were more complex. Many of the cores along the western side of the river indicated limited penetration of elevated levels of lead, which may indicate limited deposition of recent sediments. On the eastern side of the river, lead was consistently found at greater depths, suggesting that deposition of recent sediments can be localized.

E-4 SEDFLUME AND PROP SCOUR ANALYSES

The SedFlume is a straight rectangular flume designed to evaluate erosion rates using adjustable sediment heights and constant flow rate. The primary purpose of this analysis is to understand the relationship between flow velocity and sediment erosion. Water flows through the flume, and an adjustable layer of sediment rests on the bottom. Once the proper flow is established, the sediment core is raised manually until the sediment surface is even with the bottom flow surface of the SedFlume. This continues until the water becomes too turbid to see the sediment level in the flume. Sediment erosion rate is recorded in centimeters per minute as the average erosion over the testing period (Attachment 2).

To assess the potential for sediment scour, the SedFlume results were used in combination with the following two propeller-induced shear stress models (Attachment 3):

- Bottom Shear Stress: This model incorporates both propeller velocity and vessel wake velocity, and adjusts for the fact that tugs and barges associated with the construction project should be maneuvering at low speeds resulting in minimal wake effects.
- Propeller-induced Velocities at Sediment Surface: This model designates two velocity fields, or zones, located immediately behind the vessels’ propellers. The zones act independently, but eventually join to create a single flow field.

For this analysis, four 5-gallon composite samples of fine-grained depositional sediment were collected at multiple locations in two general areas along the study area for the project. SedFlume testing of bottom sediments in shallow areas of the Hudson River showed that these sediments begin to erode at shear stress of 1.14 Pa, which occurred at a velocity of 2 feet per second.

E-5 SEDIMENT RESUSPENSION RATE FROM IN-WATER CONSTRUCTION ACTIVITIES

In-water bridge construction activities have the potential to resuspend sediments. The primary construction activities of concern are sheet pile installation, dewatering of cofferdams during pier construction, and pile driving activities. The most comprehensive and applicable data set regarding resuspension rates came from the San Francisco – Oakland Bay Bridge East Span Seismic Safety Project. Thousands of water quality measurements, mostly turbidity, were taken during various aspects of the project, including dredging, sheet pile installation, cofferdam dewatering, and pile driving. As presented in Attachment 4, the results of the water quality monitoring for the San Francisco – Oakland Bay Bridge East Span Seismic Safety Project were used to project sediment resuspension rates resulting from in-water construction activities for the Replacement Bridge Alternative.

E-6 DEPOSITIONAL RATES IN ARMORED DREDGED CHANNEL

E-6-1 INTRODUCTION AND BACKGROUND

A procedure for estimating sedimentation rates in dredged channels is outlined in Sedimentation of Dredged Channels by Currents and Waves (van Rijn 1986). This procedure describes a means of determining a “trapping efficiency” (the percent of the sediment load passing over the channel that remains in the channel) based on the orientation of the channel relative to the flow, the angle of the channel side slopes, the ratio of settling velocity to shear velocity, and the ratios of the depth and width of the dredged channel relative to the upstream depth. The trapping efficiency in turn defines the rate at which a dredged channel will fill in over time.

The simplified procedure described in van Rijn (1986) uses nomographs to relate the various parameters described above for several combinations of factors, and was used to determine the sedimentation rate in the dredged channel. Because only a limited number of nomographs have been developed, it was necessary to approximate certain parameters in order to develop a “typical” condition for analysis. For example, the channel was assumed to have side slopes of 1:20 (a conservative assumption; a nomograph of the proposed 1:10 slope is not available).

Based on the available data and necessary approximations, the trapping efficiency of the proposed dredged channel was estimated at 0.05. For a typical suspended sediment concentration of 35 mg/L and an average current velocity of 1.3 ft/s, the resulting rate of sediment accumulation is estimated at approximately 1 foot per year. However, the actual rate of sedimentation at any given location within the dredged channel will vary with the changing physical conditions across the length of the channel.

Overall, it is expected that actual sedimentation rates at any given location might vary by as much as 50 percent from the "average" prediction and are likely to be greater (i.e., fill in more quickly) in areas of deeper dredging, and lesser (slower) in areas of shallower dredging.

E-6-2 DEPOSITIONAL RATES IN DREDGED CHANNEL

Quantitative estimates of sedimentation rates in dredged channels were calculated using procedures outlined in Sedimentation of Dredged Channels by Currents and Waves by Leo C. van Rijn (van Rijn, 1986). The calculation method used in this subchapter is based on the nomographs developed in that paper for simplified estimates of sedimentation rates.

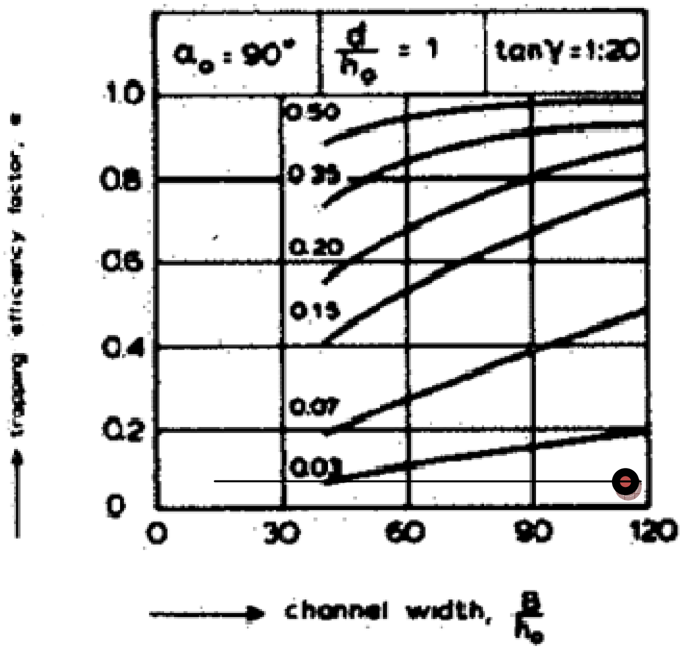
The nomographs of trapping efficiency (the percent of the sediment load passing over the channel that remains in the channel) are based on the orientation of the channel to the flow, the angle of the side slopes, and several dimensionless parameters: the ratio of settling velocity to shear velocity; the depth of the dredged channel to the upstream depth; and the width of the channel to the upstream depth.

The proposed dredged channel is perpendicular to the typical ebb and flood flow directions (α=90º). The side slopes are assumed to be 1:20 due to the low shear strength of the soil (a nomograph of the proposed 1:10 slope is not available). The settling velocity was calculated assuming 95% of the suspended material is in the silt to clay fraction based on sampling by the USGS (USGS 2006). Assuming the ambient silt to clay material is represented by a typical silt particle with a diameter of 16 microns, the settling velocity, based on relationships developed by van Rijn, is 0.00023 m/s. Shear velocity is defined as:

$$u_* = \frac{K}{-1 + \ln\left(\frac{h}{z_0}\right)} \frac{Q}{bh}$$

where K = the Von Karman constant (~0.4), h is the water depth, z_0 is $0.33k_s$, where ks is the effective roughness height, and Q/bh is the depth averaged velocity. The maximum value of either $3*D_{90}$ or 0.01 meters was used to define k_s. Using a k_s=0.01 meters, a water depth of 2 meters, and a typical velocity of 0.4 m/s, the upstream shear velocity $u_{*,0}$, was calculated as 0.03 m/s. The ratio of settling velocity to shear velocity, w_s/ $u_{*,0}$ is approximately 0.008.

A representative depth of the dredged channel is 2 meters, a representative depth of the upstream depth is also 2 meters, leading to a ratio of d/h_o=1. The width of the channel is approximately 200 meters, leading to a ratio of B/ h_o of 100. An estimate of trapping efficiency can be estimated based on the following nomograph presented by van Rijn:



Deposition Nomograph

The trapping efficiency was estimated as 0.05. Based on a typical suspended sediment concentration of 35 mg/L and velocity of 0.4 m/s, the mass of sediment passing through the channel, per meter width, over a 5 year period is (0.05)(2m)(1m)(0.4m/s)(0.035kg/m^3)(31,536,000s/yr)(5yr) = 221,000 kg. Using a dry sediment density of 900 kg/m^3, the volume is 250 m^3/m. The depth of sediment is 250 m^3/m/200m = 1.3 m, or approximately 1 foot per year.

E-7 PROJECTED TOTAL SUSPENDED SEDIMENT CONCENTRATIONS DURING CONSTRUCTION OF THE REPLACEMENT BRIDGE ALTERNATIVE

Figures 1 through 18 (Attachment 5) indicate the increase in total suspended sediment over ambient concentrations projected by the hydrodynamic modeling resulting from the anticipated schedule for in-water construction activities. These figures depict the projected suspended sediment concentrations due to dredging with other concurrent in-water construction activities for the Replacement Bridge Alternative Long Span and Short Span Options at a given point of time during these construction activities under three tidal conditions, flood, ebb and slack.

The results of the modeling of the scenarios expected to result in the greatest resuspension of sediment indicated in Attachment 5 suggest that total suspended sediment concentrations in the range of 50 to 100 mg/L above ambient conditions will only occur in the immediate vicinity of the dredges, and that a much smaller contribution would result from the other sediment disturbing construction activities (i.e., driving of piles for the cofferdams, pile driving, vessel movement, and cofferdam dewatering). On flood and ebb tides, concentrations of 10 mg/L above ambient conditions may extend in a relatively thin band approximately 1,000 to 2,000 feet from the two dredges, while concentrations of 5 mg/L may extend a greater distance.

E-8 POLLUTANT LOADING CALCULATIONS

Potential effects to Hudson River water quality due to the discharge of stormwater runoff from the project were assessed by considering the change in impervious surfaces and changes in pollutant loadings discharged to the Hudson River. Attachment 6 presents the pollutant loading calculations for total phosphorus (TP) and total suspended solids (TSS) for the landings and bridge with treatment of only the landings (Table 1 of Attachment 6) and for the landings only (Table 2 of Attachment 6).

This pollutant loading analysis was performed to evaluate the quality of the stormwater runoff in existing and proposed conditions using the pollutant coefficient method, as outlined in *Reducing the Impacts of Stormwater Runoff from New Development* published by the New York State Department of Environmental Conservation (NYSDEC) in April 1992. Pollutant coefficient values were used to best evaluate the pre- and post-development conditions based on the land use type, which was predominantly impervious surfaces. Following the pollutant coefficient method, the upland portion of the study area was broken up into three major drainage areas on the basis of topography: Rockland landing, bridge, and Westchester landing. The predominant land use within these three drainages is roadways or impervious surface. Therefore, a pollutant loading coefficient of 0.6 pounds per year (lbs/acre/year) was used for phosphorus and 833 lbs/acre/year was used for total suspended solids (TSS). The contributing drainage areas are multiplied by the pollutant loading coefficient for the associate land use resulting in the total annual pollutant load to the Hudson River.Appendix E provides the detailed pollutant loading calculations: On the basis of the New York State Stormwater Management Design Manual (SWMDM), the stormwater management practices that would be implemented to treat the stormwater runoff are capable of reducing Total Suspended Solids (TSS) by 80 percent and total phosphorus (TP) by 40 percent. These pollutant removal rates are then applied to the calculated total pollutant load to determine the final pollutant load to the Hudson River.

E-9 LITERATURE CITED

United States Geological Survey (USGS). 2006. Use of an ADCP to Compute Suspended – Sediment Discharge in the Tidal Hudson River, New York. Scientific Investigations Report 2006-5055. 16 pp.

Van Rijn, L.C. 1986. Sedimentation of Dredged Channels by Currents and Waves. Journal of Waterway, Port, Coastal, and Ocean Engineering, Vol. 112, No. 5, September, 1986.

Assessment of the deposition of sediments impacted by Twentieth Century activities in the vicinity of the Tappan Zee Bridge

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Introduction

Alternatives being considered as part of the Tappan Zee Bridge/I-287 Environmental Review include significant modification of the current bridge or construction of a new one, requiring that the existing structure be removed. With the exception of the no-build alternative, the remaining and more likely options will result in significant disturbance and/or removal of river bottom sediments. Work required for the DEIS and FEIS will include the assessment of the levels and penetration depths of a variety of contaminants in sediments residing within the proposed construction zone.

Sediment work typically entails collection of sediment cores, followed by costly and time consuming analysis for specific contaminants such as heavy metals, organic contaminants, etc. Because there is little depositional information available for the sediment cores prior to sectioning, some pre-determined increment is used regardless of the specific depositional setting of each core. Depending on the individual sedimentation regime, this results in the over-sampling of sediment cores where anthropogenic contamination is low or absent and under-sampling of sediment cores where anthropogenic contamination is present and higher-resolution sampling would provide additional and valuable information– in short, there is currently no way to optimize core sampling to obtain the highest quality information from the fewest number of samples.

As part of several sediment coring projects at LDEO, we have developed techniques to rapidly assess sediment deposition on split, wet sediment cores shortly after collection and prior to the commencement of further analyses. To identify sediments impacted by twentieth century activities, we use down-core sediment distributions of lead as a proxy to identify sediments deposited within the last ~100 years. Increases in the concentration of lead and other industrial metals have been used in numerous studies to provide constraints on deposition timing. The timing of the majority of industrial activities generally overlaps with the period of the 20^{th} century. As a result, elevated lead concentrations in sediments also allow the identification of sediments that likely contain other anthropogenic particle-reactive contaminants of concern.

Our approach entails the measurement of lead and several other elements using a hand-held x-ray fluorescence spectrometer (XRF). Measurements are made at 5-10cm increments on split, wet sediment cores. Using *in-situ* wet-bulk density estimates obtained from our core logging system, we are able to calculate water content and correct XRF measurements to a dry weight basis. We use the presence of lead concentrations in sediments above natural background levels (15-30ppm) as a proxy for identifying those sediments impacted by twentieth century activities. As mentioned above, sediments containing elevated lead concentrations will also potentially contain other contaminants of concern, while sediments containing background levels of lead represent sediments deposited prior to the onset of industrial activities and do not pose a contamination issue. Using this information, one can gain baseline information regarding sediment deposition regimes and design a more cost-effective core sectioning strategy limiting the number of analyses performed on uncontaminated sediments. For future field sampling, the results of the proposed work will aid in targeting areas where additional cores are needed as well as specific regions where longer sediment cores (vibra-cores) will be necessary to assess contaminant levels.

Main Objectives

The main objectives of this project are to identify the extent and thickness of sediments potentially containing elevated levels of contaminants as well as areas where sediments are eroding or non-depositing and contamination issues are limited. This information is based on 14 sediment cores collected in September 2001 as well as 15 sediment cores collected in May 2006 in the vicinity of the proposed Tappan Zee construction zone. This report contains the following information:

(1) Map with coring locations

(2) Lead distribution profiles for both archived and new sediment cores collected in the vicinity of the proposed study site, including data interpretation.

(3) Basic information for sediment cores, including megascopic sediment core descriptions, digital color photographs of split sediment cores, and sediment physical properties.

Note: Surface sediment grain size distributions, potentially contaminated sediment volume estimates resulting from the integration of geochemical data with geophysical results from the high-resolution acoustic mapping work are contained in the final project report.

Methods

Study site

The Tappan Zee Bridge study site is shown in Figure 1. The shaded region is a corridor running the length of the existing bridge, extending approximately 500 meters north and south. The symbols represent the core sample locations.

Sediment core collection

The sediment cores analyzed as part of this study were collected of two separate sampling expeditions (Figure 1). The LWB2 coring series (yellow squares) was collected on September 5, 2001 aboard the R/V Lionel A. Walford operated by the New Jersey Marine Science Consortium. The DPB2-06 coring series was collected on May 10 and 11, 2006 aboard the R/V Donald W. Pritchard operated by SUNY- Stony Brook. On both expeditions, sediment cores were collected using a gravity coring device fitted with 4” diameter PVC pipe. The gravity corer is equipped with a check valve, which maintains a vacuum above the collected sediments and permits the collection of samples without the use of a core catcher, which can cause disturbances. In many cases, clear PVC was used in order to assess core length and quality in the field. Table 1 contains information regarding sediment core collection.

Sediment core processing

After cores were collected, they were stored and transported upright in order to preserve the integrity of the core tops. At the end of each day, cores were transported to LDEO’s core

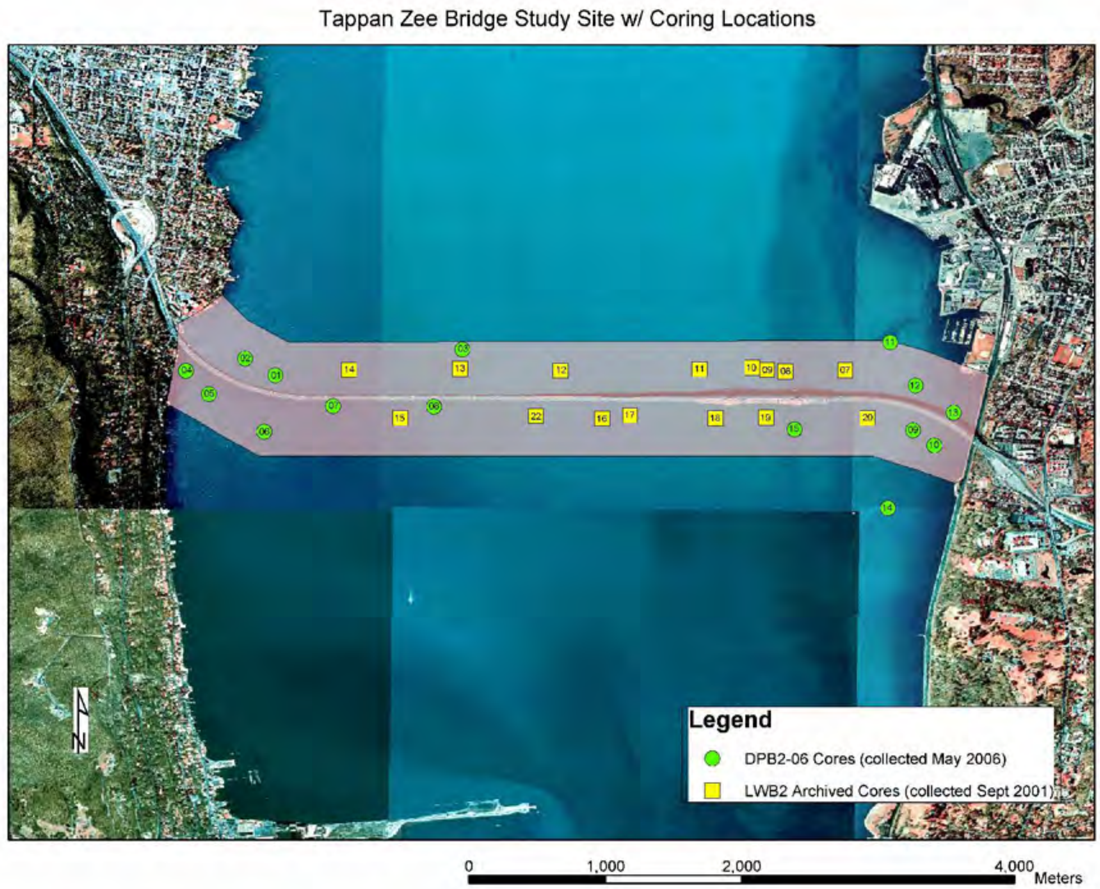


Figure 1*. Tappan Zee Bridge study site with sediment core locations. Yellow squares represent archived cores collected September 2001; green circles represent new cores collected May 2006. Numbers within symbols indicate sample number for the respective coring series. See Table 1 for additional information.*

facility and stored in a walk-in refrigerator at 4°C to before processing. Sediment cores were then carefully de-watered, excess PVC above the core top was removed and a foam plug was securely fitted to stabilized sediments. Sediment cores were then logged for physical properties, after which they were split longitudinally, archived, which includes inserting depth markers, digitally photographing both core halves, and conducting megascopic descriptons. In between various processing steps and upon completion of analysis, sediment core samples were placed in D-tubes and stored at 4°C.

Physical properties

Once dewatered and prior to splitting, sediment cores were logged for physical properties at 1cm intervals using a GEOTEK Multi-Sensor Core Logger. Properties measured included gamma ray attenuation, magnetic susceptibility, as well as P-wave velocity and amplitude.

Table 1. Sediment core locations and information

Core ID	Latitude	Longitude	Collection Date	Core length (cm)	Water Depth (m)
LWB2-07	41° 4.313' N	73° 52.532' W	09/05/01	177	5.5
LWB2-08	41° 4.308' N	73° 52.769' W	09/05/01	140.6	12.9
LWB2-09	41° 4.314' N	73° 52.841' W	09/05/01	65	14.3
LWB2-10	41° 4.323' N	73° 52.900' W	09/05/01	88	14
LWB2-11	41° 4.316' N	73° 53.108' W	09/05/01	161	9.6
LWB2-12	41° 4.311' N	73° 53.657' W	09/05/01	41.5	3.5
LWB2-13	41° 4.318' N	73° 54.055' W	09/05/01	39.5	3.1
LWB2-14	41° 4.314' N	73° 54.494' W	09/05/01	151	2.7
LWB2-16	41° 4.121' N	73° 53.493' W	09/05/01	121.6	3.4
LWB2-17	41° 4.134' N	73° 53.383' W	09/05/01	42	3.1
LWB2-18	41° 4.122' N	73° 53.045' W	09/05/01	156.3	10.8
LWB2-19	41° 4.126' N	73° 52.844' W	09/05/01	78.5	13.5
LWB2-20	41° 4.124' N	73° 52.444' W	09/05/01	165.6	2.4
LWB2-22	41° 4.131' N	73° 53.755' W	9/8/2001	39	3
DPB2-06-01	41° 4.292' N	73° 54.785' W	05/11/06	116	3.3
DPB2-06-02	41° 4.359' N	73° 54.905' W	05/11/06	151.5	3
DPB2-06-03	41° 4.395' N	73° 54.045' W	05/11/06	87	2.4
DPB2-06-04	41° 4.310' N	73° 55.139' W	05/11/06	115.5	2.3
DPB2-06-05	41° 4.218' N	73° 55.048' W	05/10/06	162.5	1.8
DPB2-06-06	41° 4.069' N	73° 54.829' W	05/10/06	164.5	2.1
DPB2-06-07	41° 4.171' N	73° 54.557' W	05/10/06	195	2.8
DPB2-06-08	41° 4.169' N	73° 54.158' W	05/10/06	135	3.7
DPB2-06-09	41° 4.075' N	73° 52.263' W	05/10/06	53	2.9
DPB2-06-10	41° 4.014' N	73° 52.179' W	05/10/06	71	2.5
DPB2-06-11	41° 4.423' N	73° 52.354' W	05/11/06	105.5	3.5
DPB2-06-12	41° 4.252' N	73° 52.253' W	05/10/06	49	3
DPB2-06-13	41° 4.145' N	73° 52.103' W	05/11/06	65.5	2.7
DPB2-06-14	41° 3.769' N	73° 52.363' W	05/10/06	103	3
DPB2-06-15	41° 4.078' N	73° 52.732' W	05/10/06	156	12.5

X-ray Fluorescence Spectrometry

Split sediment cores were analyzed for lead concentrations every 10cm using an Innov-X Alpha series 4000 handheld X-ray fluorescence (XRF) spectrometer. To prevent contamination of the instrument between measurements, the sediment surface was covered with plastic wrap during analysis. Each measurement was conducted for 120 seconds, which reduced analytical uncertainties to less than a few percent. Lead concentrations made on wet sediments were corrected for water content and are reported on a dry weight basis. Although confirmatory analyses were not conducted as part of this study, previous work on other Hudson River cores has indicated good agreement between lead concentration measurements obtained via the wet corrected XRF technique and sub-samples analyzed by total digestion ICP-MS analysis using established procedures (r^2 = 0.92; n = 24). Wet bulk density, derived from gamma ray attenuation was used to calculate water content using the following equation:

$$Water\ content = \frac{\left(\frac{(\rho_{H2O} \cdot \rho_{Sed})}{WBD} - \rho_{H2O}\right)}{(\rho_{Sed} - \rho_{H2O})} \qquad \text{(eq. 1)}$$

$where:$

$\rho_{H2O} = water\ density$

$\rho_{Sed} = dry\ grain\ density$

In this study, we assumed 1g cm^{-3} and 2.6g cm^{-3}, for water and dry grain density, respectively.

Sediment grain size analysis

Sub-samples from selected core tops were disaggregated in distilled water and washed through a 63- µm sieve to determine the coarse fraction. The <63 µm fraction was then analyzed using a Micromeritics SediGraph 5100 particle-size analyzer to obtain a continuous grain size distribution down to 0.8 µm. Sediment size fractions greater than 63 µm were dried, and sieved using an ATM sonic sifter, individual sieved fractions were weighed using a Mettler micro-balance.

Results

Lead concentrations

Lead concentrations are reported in ppm on a corrected dry weight basis. Figures 2 and 3 show down core lead distribution profiles measured for all cores in the study site. For comparison, the depth and concentrations scales are set at 0-200 cm and 0-250ppm for all profiles. Lead concentrations ranged from a few ppm to ~225ppm. The majority of samples measured were less than 25ppm and in the range of natural background levels. In several instances, lead levels elevated above natural background are observed in the upper portions of the sediment cores. The depth to which elevated lead levels penetrate the sediments varied considerably throughout the study site; the majority of penetration depths are between 0 and 50 cm, with penetration depths exceeding 150cm at a few sites. The deepest sediments recovered in all but two cores (LWB2-16 and DPB2-06-14) contain lead levels consistent with expected natural background.

Lithologies, Physical properties, and Core images

Physical properties, core images, along with megascopic descriptions are contained in Appendix A. The majority of sediments collected are terrigenous, bioclastic, clays and sandy clays. Carbonate content is generally low, and quartz is the most abundant mineral observed in the coarse fraction. Lesser amounts of observed minerals in the coarse fraction include mica,

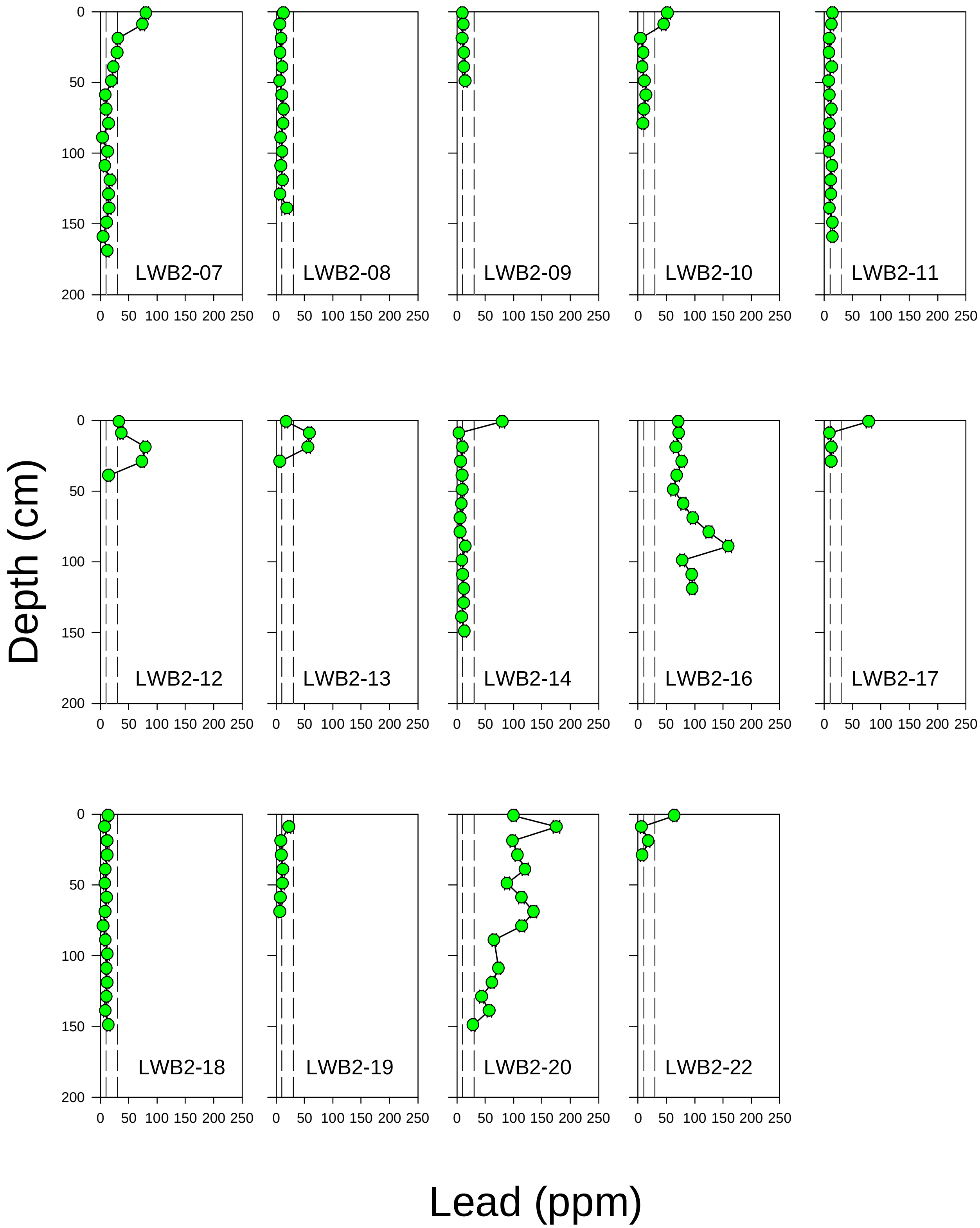


Figure 2. Down core lead distribution profiles for LWB2 series cores collected September 2001. The concentration range between the dashed lines is 10-30ppm and represents natural background lead levels.

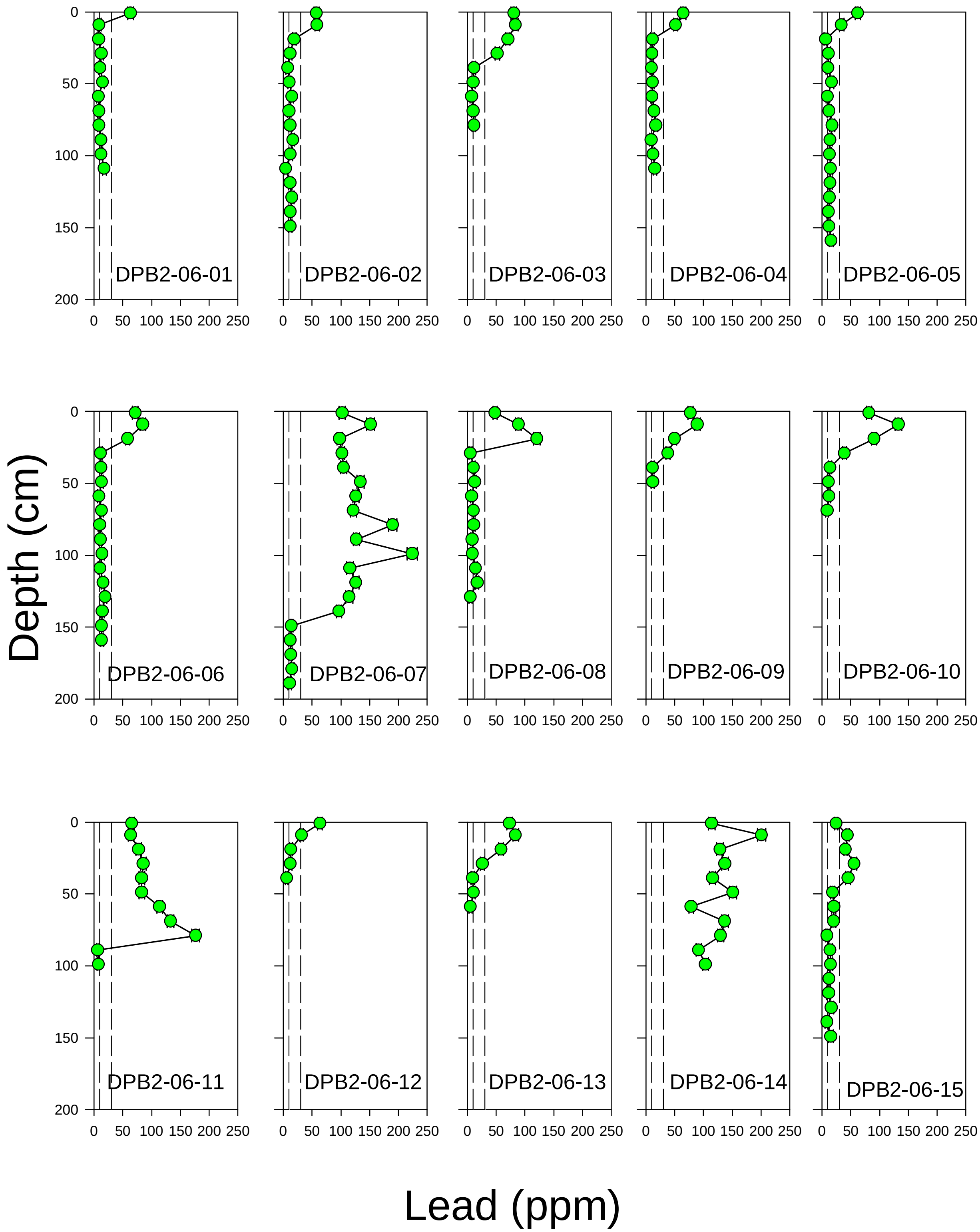


Figure 3. Down core lead distribution profiles for DPB2-06 series cores collected May 2006. The concentration range between the dashed lines is 10-30ppm and represents natural background lead levels.

iron oxide stained grains, feldspar, hornblende, framboidal pyrite, and pyroxene (see individual log sheets in Appendix A, for specific details). In general bulk densities ranged between ~1.2 and ~1.6 g/cc. In several cases, the depth at which lead concentrations decreased to expected natural background coincided with a clear increase in wet-bulk density values. In a few cases, we also observe a coincident decrease in magnetic susceptibility readings. Color images of each core also appear in Appendix A as bitmapped images. It should be noted that in several cases, the bitmapped images are stretched to match the depths of the physical property and lead data. In cases where very short cores were collected, this distortion is noticeable. In addition to these images included in Appendix A, we can provide the original high-resolution composite images with the final report. As noted above, sediment grain size analyses are not yet complete; these results will be included in the final report.

Data interpretation

We use the presence of lead concentrations in sediments above natural background levels (15-30ppm) as a proxy for identifying those sediments impacted by twentieth century activities. As mentioned above, sediments containing elevated lead concentrations will also potentially contain other contaminants of concern, while sediments containing background levels of lead represent sediments deposited prior to the onset of industrial activities and do not pose a significant contamination issue.

Figure 4 shows the study site, core locations, as well as the lead profiles obtained for each core. With the exception of DPB2-06-11, all the sediment cores collected north of the existing Tappan Zee Bridge exhibit elevated lead concentrations penetrating between 0 and 50 cm, with the majority penetrating between 0 and 20cm. These data suggest that deposition of recent sediments in this portion of the study site is limited. The deeper penetration observed in DPB2-06-11, and relatively sharp decline to background levels at ~90cm suggest a dredge boundary. This interpretation is consistent with acoustic and bathymetric data identifying the coring site as being located in the channel leading the marina in Tarrytown and subject to frequent dredging.

In contrast, the depositional patterns observed in sediment cores collected within the study site and south of the existing bridge are more complex. While many of the cores indicate limited penetration of elevated levels of lead, which can be interpreted as limited deposition of recent sediments (e.g. the western margin), there are several instances of deeper penetration, suggesting that deposition of recent sediments can be significant in specific areas. Sediment cores collected from the area south of the existing bridge along the eastern side of the river, exhibit consistently deeper lead penetration than other areas. Individual cores such as LWB2-16 and DPB2-06-07 also exhibit relatively deep lead penetration and are likely indicative of drift bodies related to bridge pilings.

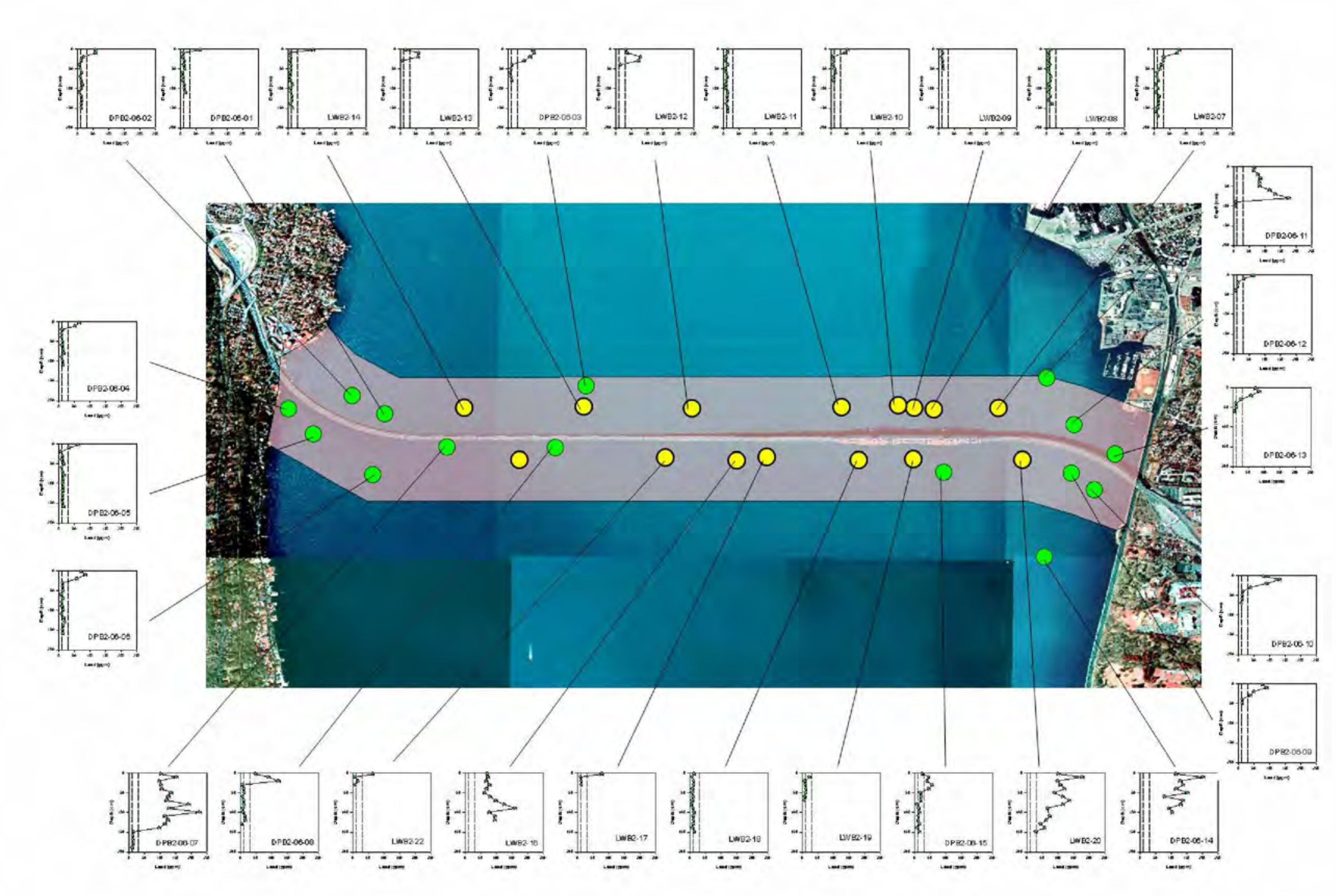


Figure 4. Tappan Zee Bridge study site with sediment core locations and lead distribution profiles. See Table 1 for additional information.

Recommendations

Interpretation of sediment core data collected at 29 locations in the vicinity of the existing Tappan Zee Bridge and within the proposed study site suggests that deposition of sediments impacted by Twentieth Century activities is limited in the portion of the study site north of the existing bridge. The collection of significantly longer cores (i.e., vibra-cores) does not appear to be necessary. For the purposes of assessing levels of other anthropogenic particle-reactive contaminants of concern in the northern portion, we also suggest higher resolution sub-sampling of cores in the upper 50cm, and lower resolution below this depth.

Although the lead penetration in cores collected from the western margin south of the bridge suggests limited deposition in this area, the variability of lead penetration observed in the remainder of the southern portion of the study site may indicate the need of additional core samples to adequately characterize the depositional patterns. The area that appears to have consistently experienced the highest deposition of recent sediments is the southeastern portion of the study site. In two cores (LWB2-16 and DPB2-06-14), the deepest sediments recovered (~120cm and ~100cm, respectively), contained lead levels elevated above natural background. Assessing the actual thickness of the impacted layer at these two sites is not possible without the acquisition of longer sediment cores.

Appendix A

Core Log Data:
Physical Properties
Core images
Lithology

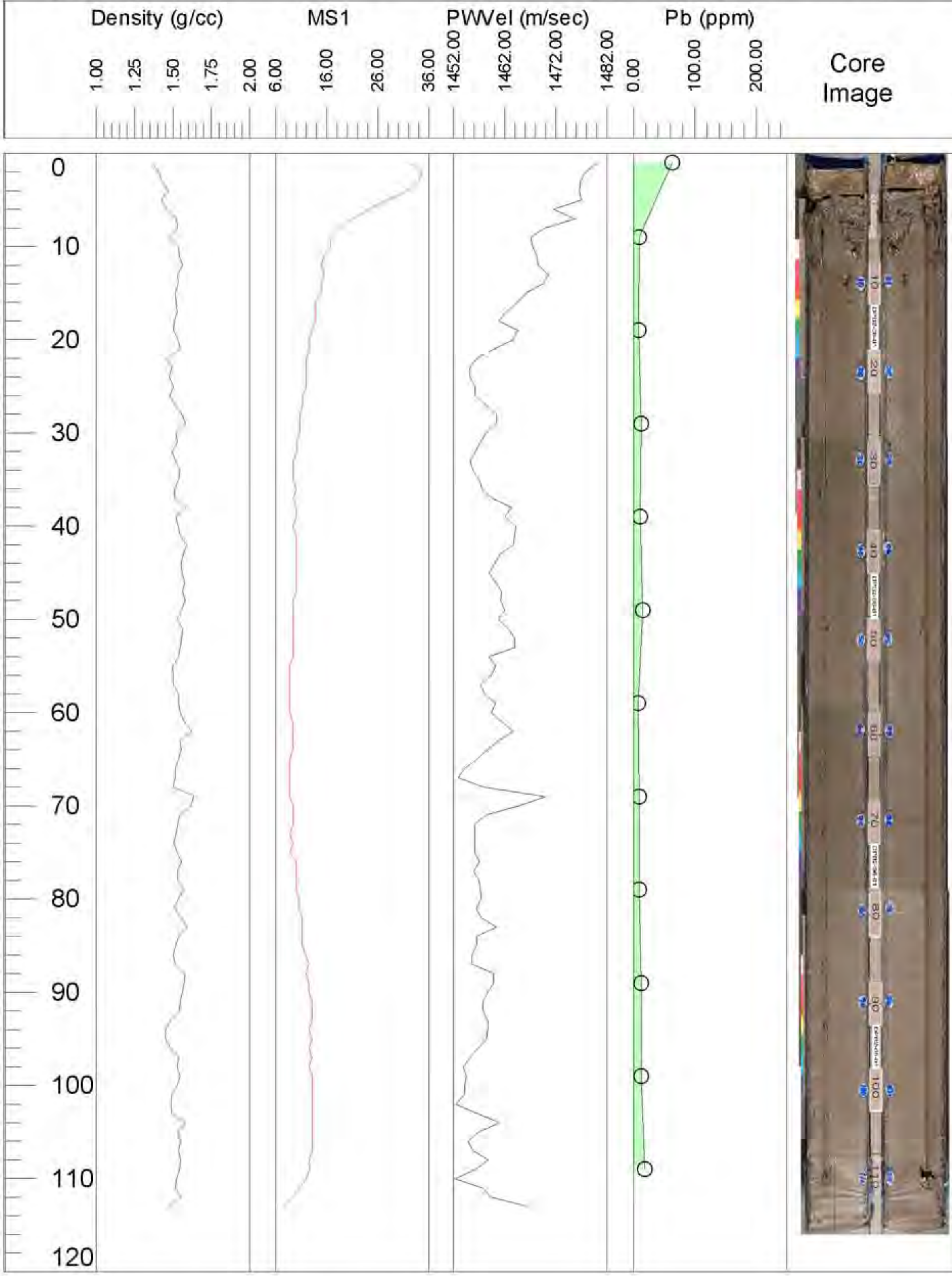
Lamont-Dohery Earth Observatory

DPB2-06-01

Project Title: Assessment of the deposition of sediments impacted by Twentieth Century activities in the vicinity of the Tappan Zee Bridge

Project No.: EARTHT D213123

Principle Investigators: Timothy C. Kenna and Frank Nitsche



Lithology

TERRIGENOUS (BIOSILICIOUS) CLAY [Sandy clay], very dark grayish brown (2.5Y3/2); wet and pliable. Carbonate content is low. Coarse fraction 17% consists of abundant quartz; rare iron oxide stained grains; trace mica, plant debris, brick fragments, opaque grains, feldspar, amphibole and diatoms. Basal contact is a distinct color change. Sampled at 2cm.

TERRIGENOUS (BIOCLASTIC) CLAY [Clay], very dark gray (5Y3/1); shell fragments at 45, 49 and (dragged from 4cm) 110cm lamina of coarser sediment at 70 cm; mottled of coarser sediment at 94-97 cm; moist and pliable. Carbonate content is low. Coarse fraction 2% consists of abundant plant debris; common mica; trace quartz, diatoms, planktonic foraminifera, framboidal pyrite, opaque grains, feldspar and sponge spicules. Sampled at 55 cm.

Core ID:	DPB2-06-01	Latitude:	41° 4.292' N
Core Length:	116 cm	Longitude:	73° 54.785' W
Collection Date:	05/11/06	PDR Depth:	3.3 m

Date Opened:	05/19/06
Date Photographed:	05/19/06
Date Described:	06/01/06
Described by:	N. Anest

Attachment 1

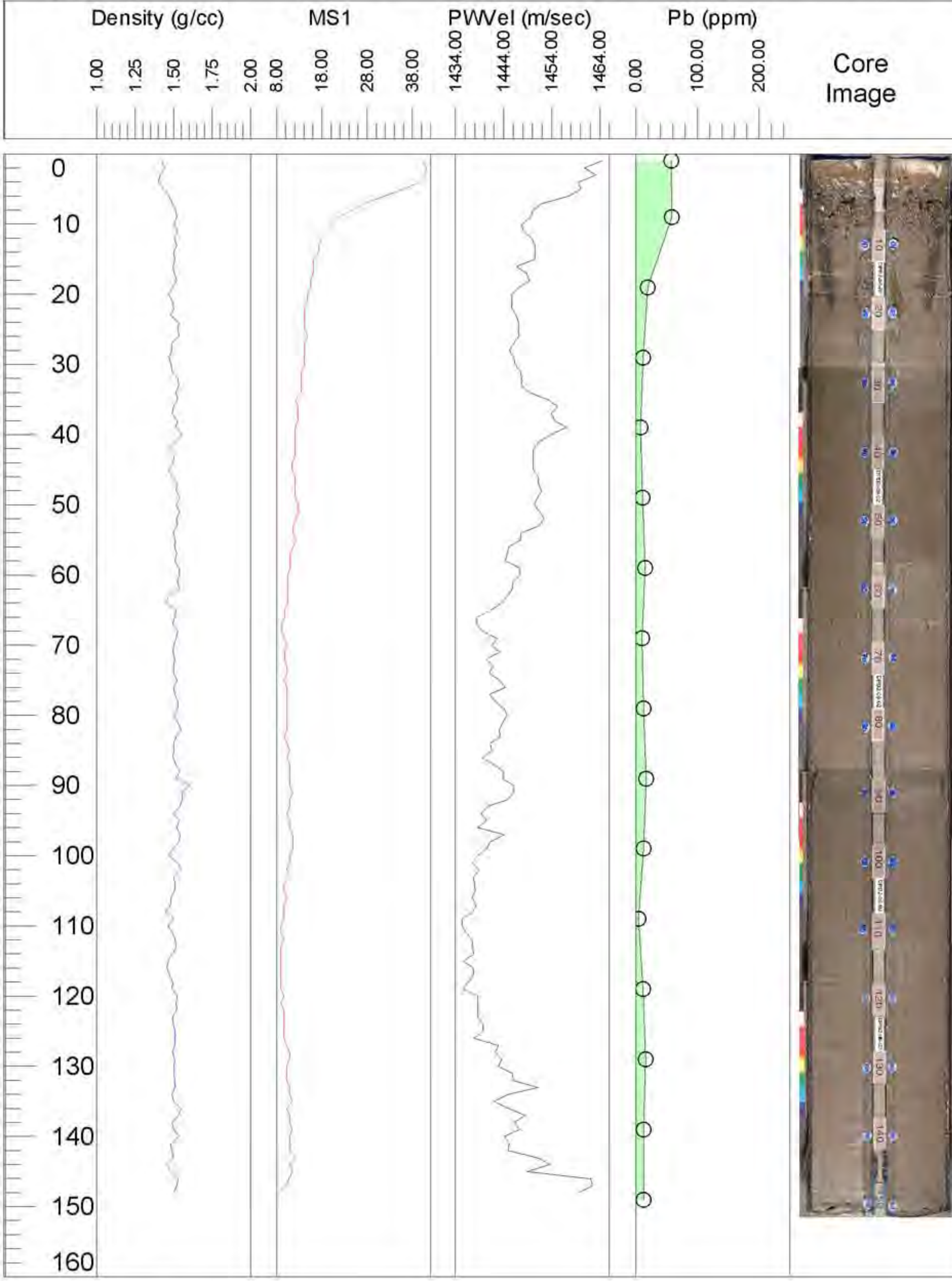
Lamont-Dohery Earth Observatory

DPB2-06-02

Project Title: Assessment of the deposition of sediments impacted by Twentieth Century activities in the vicinity of the Tappan Zee Bridge

Project No.: EARTHT D213123

Principle Investigators: Timothy C. Kenna and Frank Nitsche



Lithology

TERRIGENOUS (BIOCLASTIC) CLAY [Sandy clay], dark olive brown (2.5Y3/2.5); wet and pliable. Carbonate content is low. Coarse fraction 17% consists of abundant quartz; common iron oxide stained grains; rare plant debris; trace mica, brick fragments, planktonic foraminifera, opaque grains, feldspar, worm tubes, pyroxene and diatoms. Basal contact is a distinct color change. Sampled at 2cm

TERRIGENOUS (BIOCLASTIC) CLAY [Clay], very dark gray (5Y3/1); very dark grayish brown (2.5Y3/2) burrow at 3-21 cm; shell fragments at 7.5, 47, 64, 91, 107, 110, 135 and 148 cm; laminae of gray (2.5Y5/1) at 26-28 cm; mottle of very dark grayish brown (10YR3/2) wood at 71 cm; moist and pliable. Carbonate content is low. Coarse fraction 3% consists of abundant plant debris; common quartz; rare mica; trace diatoms, planktonic foraminifera, framboidal pyrite, iron oxide stained grains, feldspar and sponge spicules. Sampled at 75cm. (Live nematode at 6cm.)

Core ID: DPB2-06-02	Latitude: 41° 4.359' N	Date Opened:	05/17/06
Core Length: 151.5 cm	Longitude: 73° 54.905' W	Date Photographed:	05/17/06
Collection Date: 05/11/06	PDR Depth: 3.0 m	Date Described:	06/01/06
		Described by:	N. Anest

Attachment 1

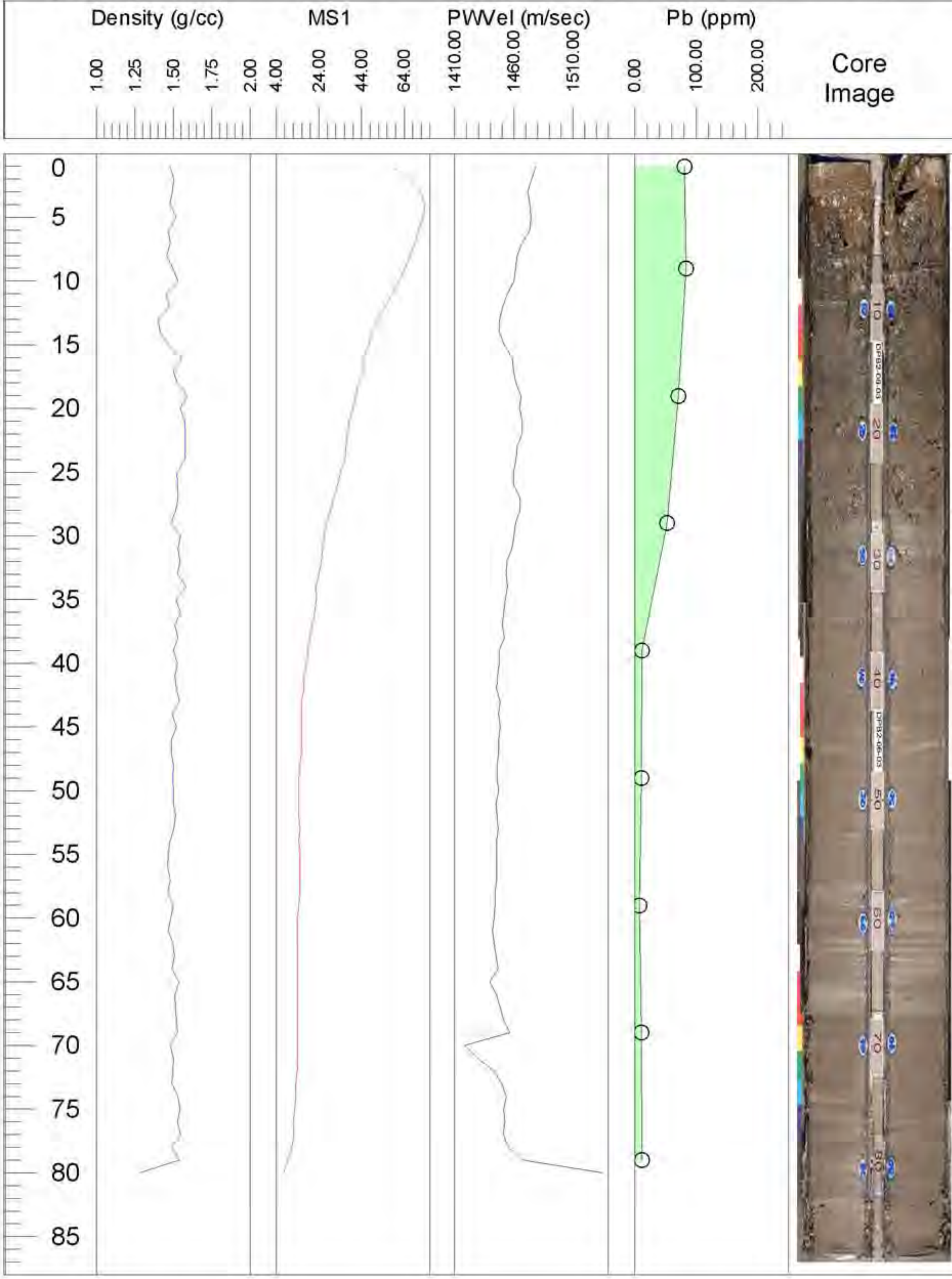
Lamont-Dohery Earth Observatory

DPB2-06-03

Project Title: Assessment of the deposition of sediments impacted by Twentieth Century activities in the vicinity of the Tappan Zee Bridge

Project No.: EARTHT D213123

Principle Investigators: Timothy C. Kenna and Frank Nitsche



Lithology

TERRIGENOUS (BIOCLASTIC) CLAY [Sandy clay], mottled dark olive gray (5Y3/2) and very dark grayish brown (2.5Y3/2); shell fragments at 20 and 30 cm; mottles of very dark grayish brown (10YR3/2) wood at 24 and 31 cm; wet and pliable. Carbonate content is low. Coarse fraction 11% consists of abundant quartz; common iron oxide stained grains; rare plant debris; trace mica, feldspar, planktonic foraminifera, opaque grains, shell fragments, framboidal pyrite and diatoms. Basal contact is a distinct color change. Sampled at 15 cm.

TERRIGENOUS (BIOCLASTIC) CLAY [Clay], very dark gray (5Y3/1); mottles of black (N2.5) (wood?) at 35-40 and 60 cm; mottles of very dark grayish brown (10YR3/2) wood at 67.5 cm; shell fragments at 40, 66, 70, 74 and 82 cm; moist and pliable. Carbonate content is low. Coarse fraction 6% consists of abundant quartz; common plant debris; rare iron oxide stained grains; trace mica, diatoms, brick fragments, feldspar, planktonic foraminifera, framboidal pyrite, opaque grains and sponge spicules. Sampled at 55 cm.

Core ID: DPB2-06-03	Latitude: 41° 4.395' N	Date Opened:	05/19/06
Core Length: 87 cm	Longitude: 73° 54.045' W	Date Photographed:	05/19/06
Collection Date: 05/11/06	PDR Depth: 2.4 m	Date Described:	06/01/06
		Described by:	N. Anest

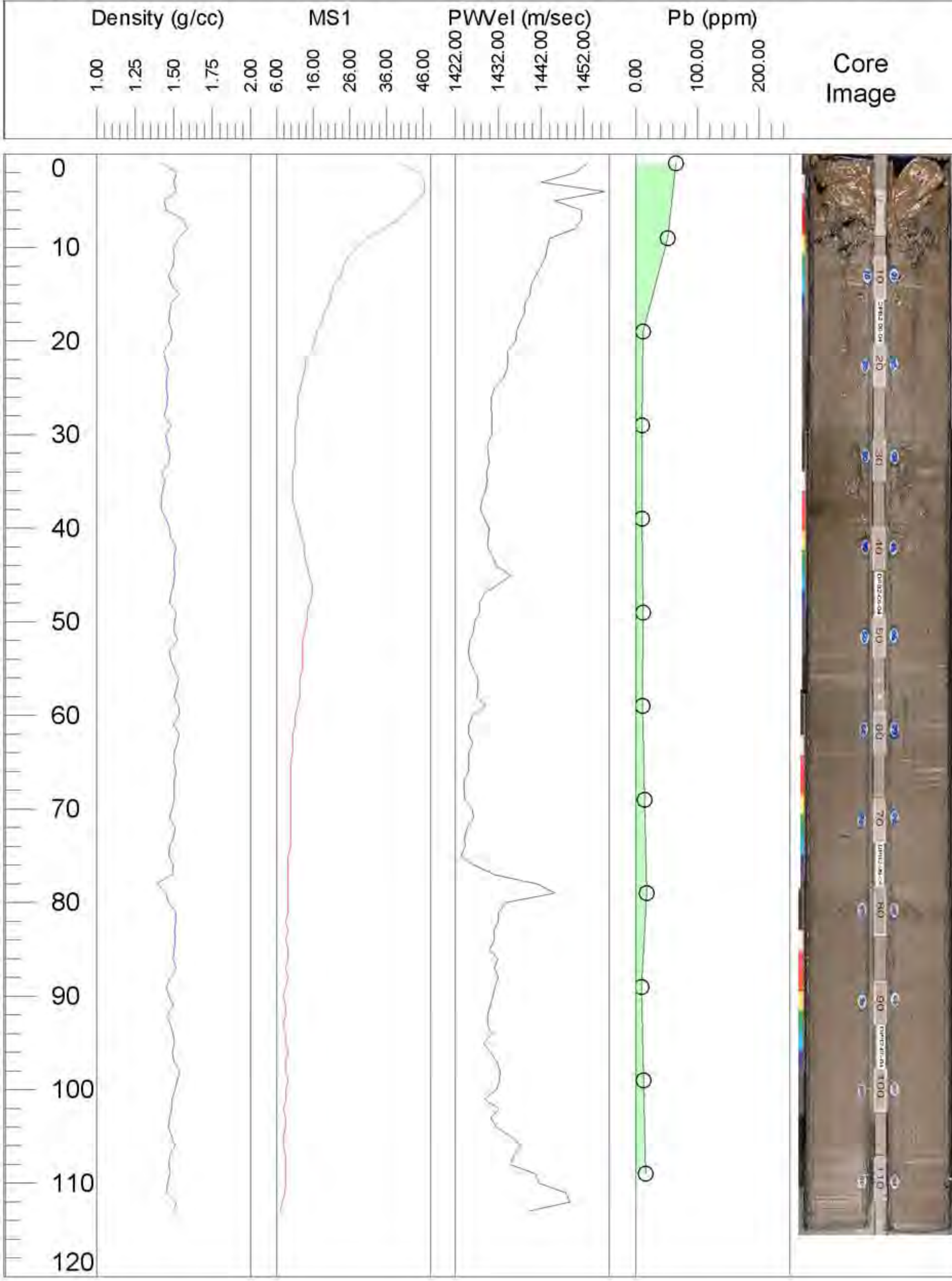
Attachment 1

Lamont-Dohery Earth Observatory

DPB2-06-04

Project Title: Assessment of the deposition of sediments impacted by Twentieth Century activities in the vicinity of the Tappan Zee Bridge

Project No.: EARTHT D213123 Principle Investigators: Timothy C. Kenna and Frank Nitsche



Lithology

TERRIGENOUS (BIOCLASTIC) CLAY [Sandy clay], very dark grayish brown (2.5Y3/2) becoming dark grayish brown (2.5Y4/2); wet and pliable. Carbonate content is low. Coarse fraction 27% consists of abundant quartz; common iron oxide stained grains; trace brick fragments, mica, plant debris, opaque grains, planktonic foraminifera, framboidal pyrite, shell fragments, feldspar, diatoms and sponge spicules. Basal contact is a bioturbated distinct color change. Sampled at 5 cm.

TERRIGENOUS (BIOCLASTIC) CLAY [Clay], black (5Y2.5/2); dark grayish brown (2.5Y4/2) burrows at 10-20 cm; shell fragments at 13, 17, 37, 49, 72, 79.5 and 99 cm; mottle of black (N2.5) (wood?) at 50 cm; mottles of very dark grayish brown (10YR3/2) wood at 80 cm; wet becoming moist and pliable. Carbonate content is low. Coarse fraction 5% consists of abundant plant debris, quartz; trace mica, planktonic foraminifera, diatoms, feldspar, opaque grains, iron oxide stained grains, framboidal pyrite and sponge spicules. Sampled at 55 cm.

Core ID:	DPB2-06-04	Latitude:	41° 4.310' N	Date Opened:	05/19/06
Core Length:	115.5 cm	Longitude:	73° 55.139' W	Date Photographed:	05/19/06
Collection Date:	05/11/06	PDR Depth:	2.3 m	Date Described:	06/01/06
				Described by:	N. Anest

Attachment 1

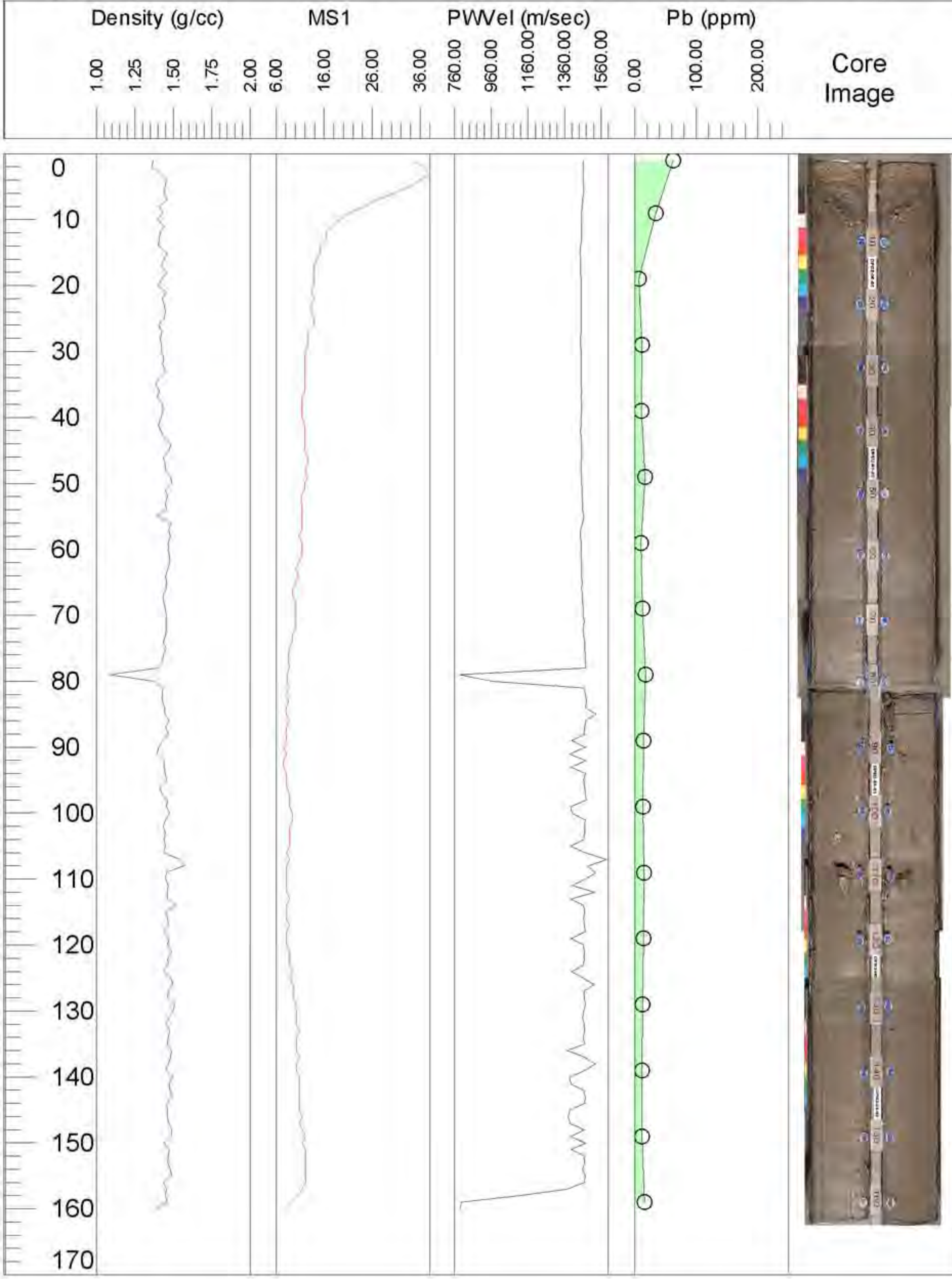
Lamont-Dohery Earth Observatory

DPB2-06-05

Project Title: Assessment of the deposition of sediments impacted by Twentieth Century activities in the vicinity of the Tappan Zee Bridge

Project No.: EARTHT D213123

Principle Investigators: Timothy C. Kenna and Frank Nitsche



Lithology

TERRIGENOUS (BIOCLASTIC) CLAY [Sandy clay], very dark grayish brown (2.5Y3/2); wet and pliable. Carbonate content is low. Coarse fraction 11% consists of abundant quartz; common iron oxide stained grains; rare plant debris; trace mica, planktonic foraminifera, opaque grains, pyroxene, diatoms and sponge spicules. Basal contact is a distinct color change. Sampled at 3cm.

TERRIGENOUS (BIOCLASTIC) CLAY [Clay], very dark gray (5Y3/1); mottles and burrows of dark gray (2.5Y4/1) at 6-22 cm; mottle of black (N2.5) (wood?) at 15 cm; mottles of very dark grayish brown (10YR3/2) wood at 54, 76 and 156 cm; shell fragments at 27.5, 47, 70, 82, 93, 104, 113 and 127 cm; mottles of very dark gray (2.5Y3/1) at 129 and 152 cm; wet becoming moist and pliable. Carbonate content is low. Coarse fraction 3% consists of abundant plant debris; common quartz; trace mica, diatoms, framboidal pyrite, planktonic foraminifera, opaque grains, amphibole and sponge spicules. Sampled at 75 cm.

Core ID:	DPB2-06-05	Latitude:	41° 4.218' N	Date Opened:	05/23/06
Core Length:	162.5 cm	Longitude:	73° 55.048' W	Date Photographed:	05/23/06
Collection Date:	05/10/06	PDR Depth:	1.8 m	Date Described:	06/02/06
				Described by:	N. Anest

Attachment 1

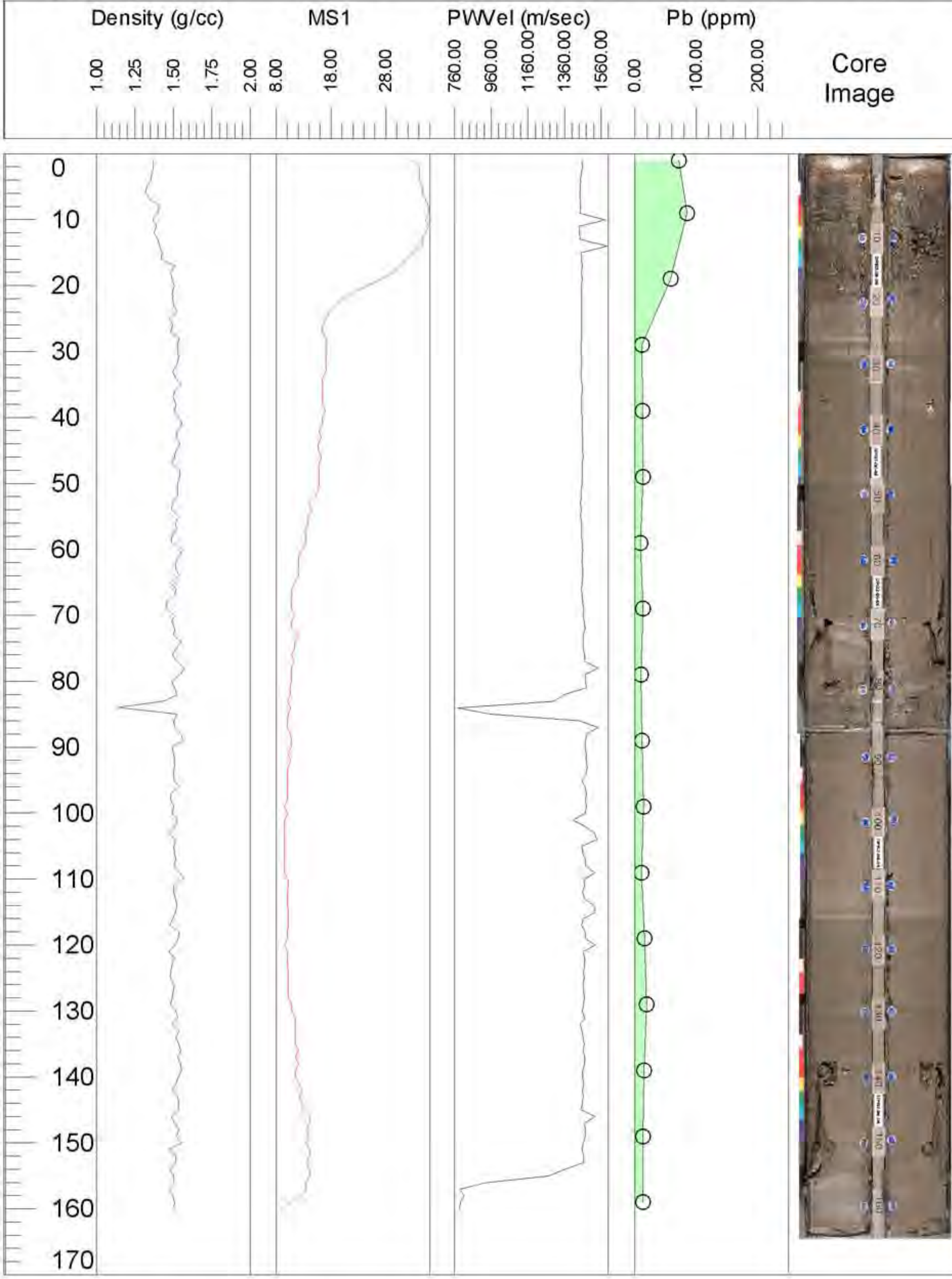
Lamont-Dohery Earth Observatory

DPB2-06-06

Project Title: Assessment of the deposition of sediments impacted by Twentieth Century activities in the vicinity of the Tappan Zee Bridge

Project No.: EARTHT D213123

Principle Investigators: Timothy C. Kenna and Frank Nitsche



Lithology

TERRIGENOUS (BIOCLASTIC) CLAY [Clay], very dark grayish brown (2.5Y3/2); wet and pliable. Carbonate content is low. Coarse fraction 9% consists of abundant quartz; common to rare plant debris, iron oxide stained grains; trace shell fragments, mica, opaque grains, clear glassy spherules, brick fragments, planktonic foraminifera, zircon and diatoms. Basal contact is an indistinct color change. Sampled at 3cm.

TERRIGENOUS (BIOCLASTIC) CLAY [Clay], very dark gray (5Y3/1); band and mottles of brown (7.5YR4/2) at 22 cm; mottles of very dark grayish brown (2.5Y3/2) at 10 and 18.5 cm; shell fragments at 20, 23, 36, 49.5, 56, 60, 69, (bagged at 75cm), 84, 106, 109, 140, 152 and 162 cm; brown (10YR4/3) wood at 73.5 cm; wet becoming moist and pliable. Carbonate content is low. Coarse fraction 4% consists of abundant quartz, plant debris; trace mica, diatoms, framboidal pyrite, pyroxene, amphibole and sponge spicules. Sampled at 75 cm.

Core ID:	DPB2-06-06	Latitude:	41° 4.069' N	Date Opened:	05/23/06
Core Length:	164.5 cm	Longitude:	73° 54.829' W	Date Photographed:	05/23/06
Collection Date:	05/10/06	PDR Depth:	2.1 m	Date Described:	06/02/06
				Described by:	N. Anest

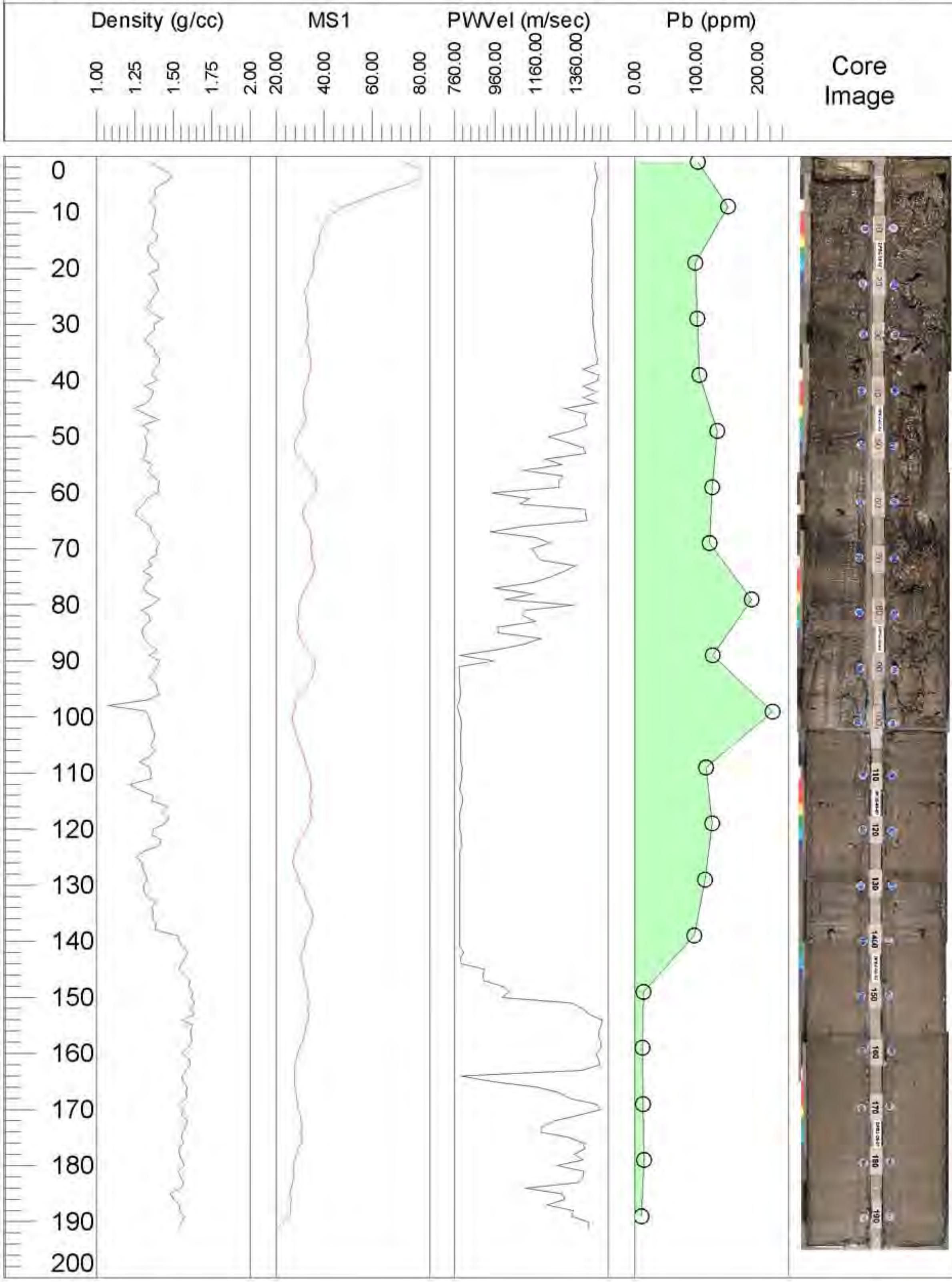
Attachment 1

Lamont-Dohery Earth Observatory

DPB2-06-07

Project Title: Assessment of the deposition of sediments impacted by Twentieth Century activities in the vicinity of the Tappan Zee Bridge

Project No.: EARTHT D213123 Principle Investigators: Timothy C. Kenna and Frank Nitsche



Lithology

TERRIGENOUS (BIOCLASTIC) CLAY [Clay], very dark gray (2.5Y3/1) with mottles of very dark grayish brown (2.5Y3/2) throughout interval; shell fragments at 2 cm; mottles of dark yellowish brown (10YR4/4) at 23.5 and 30cm; wet and pliable. Carbonate content is low. Coarse fraction 4% consists of abundant plant debris; common quartz; trace mica, shell fragments, iron oxide stained grains, opaque grains, diatoms, sponge spicules and zircon. Basal contact is an indistinct color change. Sampled at 15 cm.

TERRIGENOUS (BIOCLASTIC) CLAY [Clay], very dark gray (2.5Y3/1); shell fragments at 40, 95, 115, 142.5, 156, 162, 166, 176.5 and 180 cm; lamina of dark grayish brown (10YR4/2) at 98.5 cm; bed of very dark grayish brown (2.5Y3/2) at 128-129.5 cm; wet becoming moist and pliable. Carbonate content is low. Coarse fraction 5% consists of abundant plant debris; common to rare quartz; trace iron oxide stained grains, mica, opaque grains, framboidal pyrite, clear glassy spherules, slag, feldspar and diatoms. Sampled at 115cm.

Core ID:	DPB2-06-07	Latitude:	41° 4.171' N	Date Opened:	05/23/06
Core Length:	195 cm	Longitude:	73° 54.557' W	Date Photographed:	05/23/06
Collection Date:	05/10/06	PDR Depth:	2.8 m	Date Described:	06/02/06
				Described by:	N. Anest

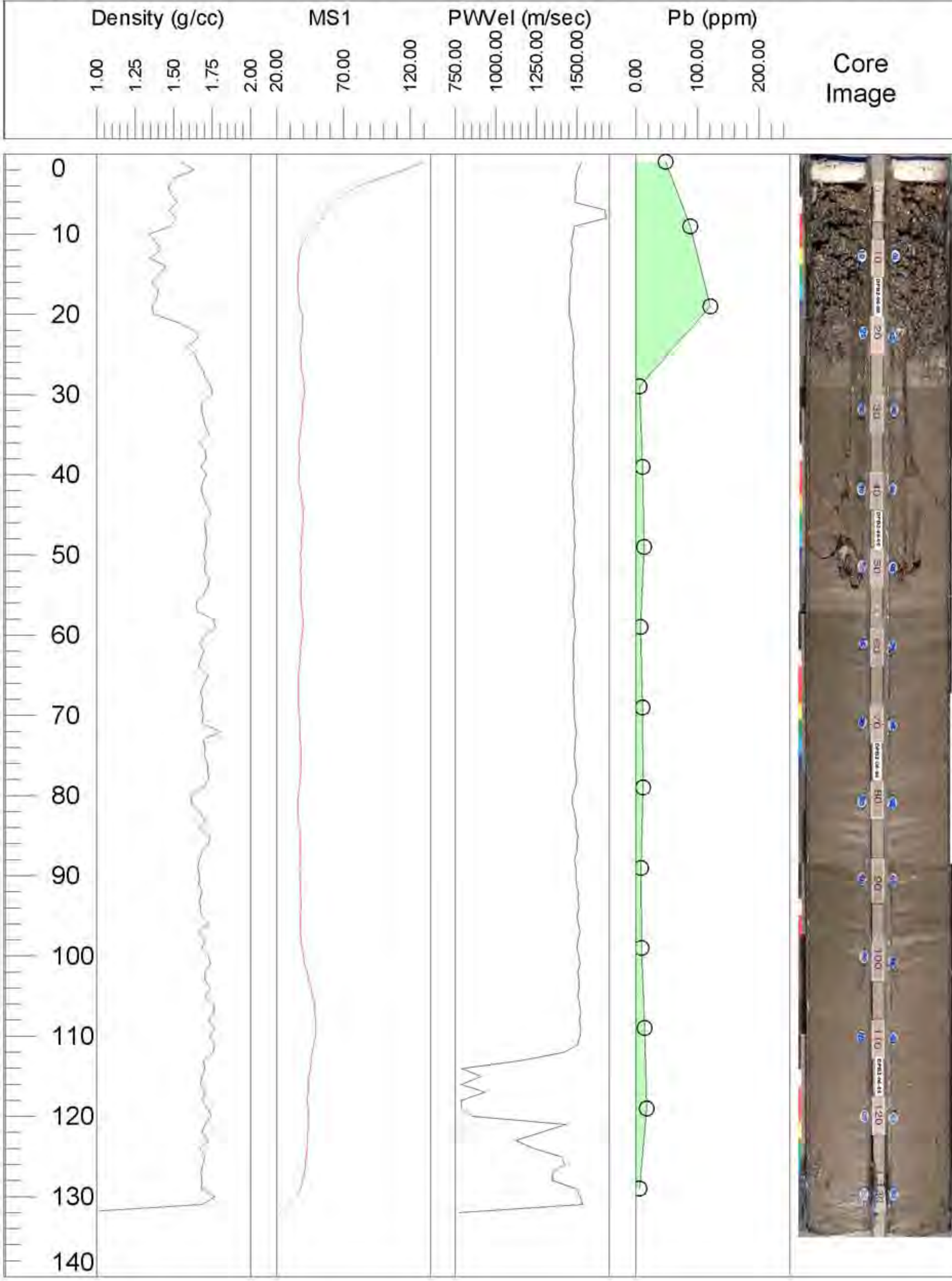
Lamont-Dohery Earth Observatory

DPB2-06-08

Project Title: Assessment of the deposition of sediments impacted by Twentieth Century activities in the vicinity of the Tappan Zee Bridge

Project No.: EARTHT D213123

Principle Investigators: Timothy C. Kenna and Frank Nitsche



Lithology

TERRIGENOUS (BIOCLASTIC) SAND [Shell hash], very dark grayish brown (2.5Y3/2) becoming dark olive gray (5Y3/2); abundant shell fragments throughout interval; wet and pliable. Carbonate content is low. Coarse fraction 56% consists of abundant shell fragments; common plant debris, quartz; rare opaque grains; trace slag, iron oxide stained grains, brick fragments, mica, clear glassy spherules, diatoms, zircon and framboidal pyrite. Basal contact is a gradual color and distinct texture change. Sampled at 6 cm.

TERRIGENOUS (BIOCLASTIC) CLAY [Clay], black (5Y2.5/2); shell fragments at 15.5-20 and 30 cm; very small mottles of coarser sediment throughout interval; moist and pliable. Carbonate content is low. Coarse fraction 6% consists of abundant quartz; rare plant debris, mica; trace iron oxide stained grains, slag, opaque grains, diatoms, amphibole, pyroxene and feldspar. Basal contact is a gradual texture change. Sampled at 31 cm.

TERRIGENOUS (BIOCLASTIC) CLAY [Clay], black (5Y2.5/2) with mottles and laminae of coarser material throughout interval and increasing in abundance down core; shell fragments at 50-60, 70, 101, 108, 115 and 135 cm; moist and pliable. Carbonate content is low. Coarse fraction 1% consists of common plant debris, mica; rare quartz; trace planktonic foraminifera, diatoms, ostracodes, opaque grains, framboidal pyrite and feldspar. Sampled at 85 cm.

Core ID:	DPB2-06-08	Latitude:	41° 4.169' N	Date Opened:	05/17/06
Core Length:	135 cm	Longitude:	73° 54.158' W	Date Photographed:	05/17/06
Collection Date:	05/10/06	PDR Depth:	3.7 m	Date Described:	06/08/06
				Described by:	N. Anest

Attachment 1

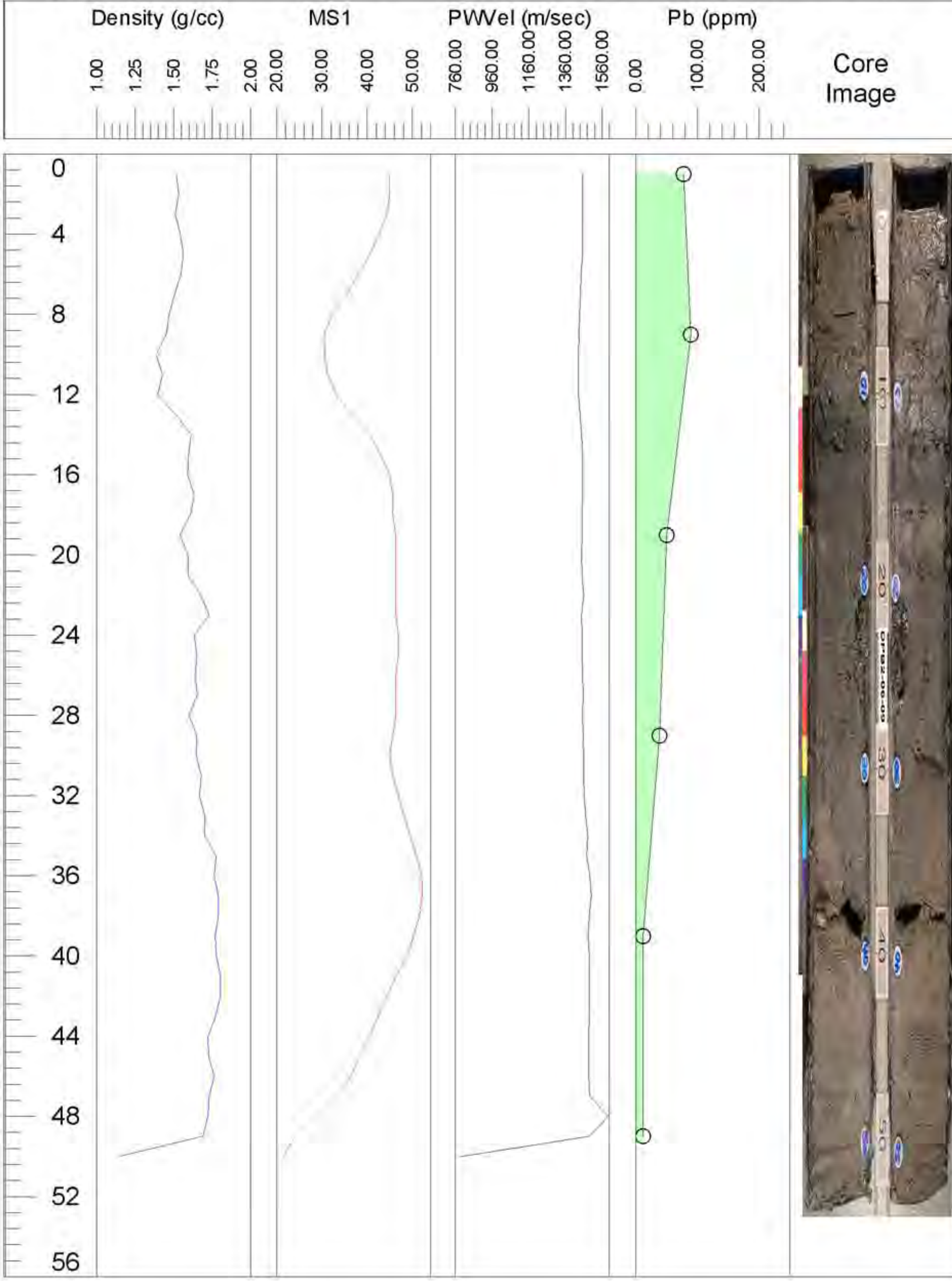
Lamont-Dohery Earth Observatory

DPB2-06-09

Project Title: Assessment of the deposition of sediments impacted by Twentieth Century activities in the vicinity of the Tappan Zee Bridge

Project No.: EARTHT D213123

Principle Investigators: Timothy C. Kenna and Frank Nitsche



Lithology

TERRIGENOUS (BIOSILICIOUS) CLAY [Sandy clay], black (5Y2.5/2); very dark grayish brown (2.5Y3/2) bed at 0-1 cm; moist and pliable. Carbonate content is low. Coarse fraction 17% consists of abundant quartz; rare metallic grains; trace mica, ferromagnesian mineral grains, plant debris, iron oxide stained grains, slag, clear glassy spherules, diatoms, feldspar, garnet and sponge spicules. Basal contact is a distinct color change. Sampled at 5 cm.

TERRIGENOUS (BIOCLASTIC) CLAY [Sandy clay], very dark grayish brown (2.5Y3/2); mottles of black (5Y2.5/2) coarser sediment at 16-20 cm; shell fragments at 21-27 and 35 cm; mottle of dark brown (7.5YR3/4) at 21 cm; moist and pliable. Carbonate content is low. Coarse fraction 16% consists of abundant quartz; trace mica, plant debris, ferromagnesian mineral grains, metallic grains, iron oxide stained grains, brick fragments, (brookite?), feldspar and diatoms. Basal contact is an uneven, gradual color change. Sampled at 25 cm.

TERRIGENOUS (BIOCLASTIC) CLAY [Sandy clay], very dark gray (5Y3/1); mottles of coarser sediment at 35-43 cm; laminae of coarser sediment at 43-53 cm; shell fragments at 35-41 cm; moist and pliable. Carbonate content is low. Coarse fraction 20% consists of abundant quartz; rare plant debris; trace mica, ferromagnesian mineral grains, iron oxide stained grains, feldspar, planktonic foraminifera, diatoms, metallic grains, framboidal pyrite, garnet and sponge spicules. Sampled at 45 cm.

Core ID:	DPB2-06-09	Latitude:	41° 4.075' N	Date Opened:	05/22/06
Core Length:	53 cm	Longitude:	73° 52.263' W	Date Photographed:	05/22/06
Collection Date:	05/10/06	PDR Depth:	2.9 m	Date Described:	06/08/06
				Described by:	N. Anest

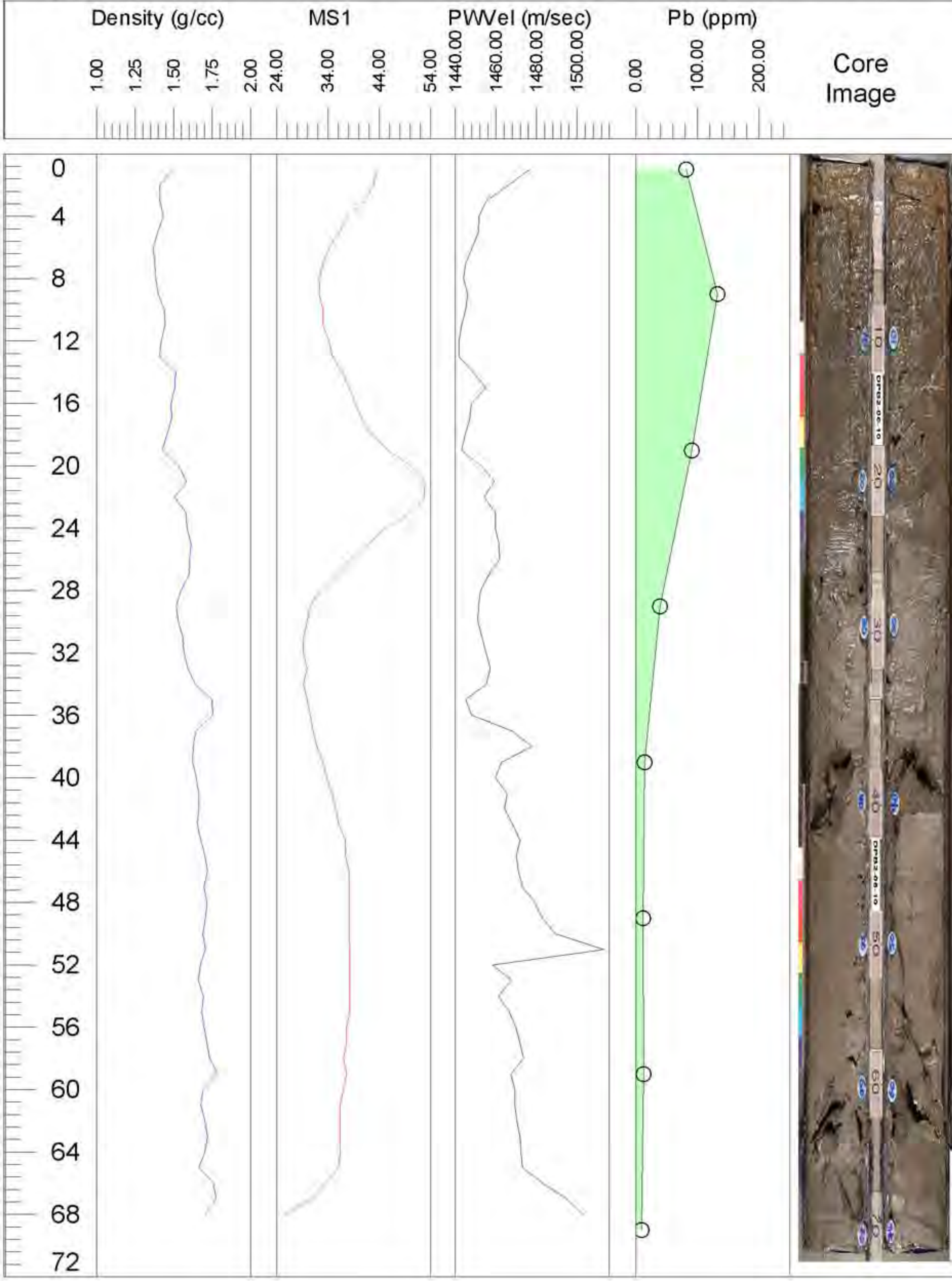
Attachment 1

Lamont-Dohery Earth Observatory

DPB2-06-10

Project Title: Assessment of the deposition of sediments impacted by Twentieth Century activities in the vicinity of the Tappan Zee Bridge

Project No.: EARTHT D213123 Principle Investigators: Timothy C. Kenna and Frank Nitsche



Lithology

TERRIGENOUS (BIOCLASTIC) CLAY [Clay], black (5Y2.5/1) with very dark grayish brown (2.5Y3.5/2) mottles throughout interval; shell fragments at 17 cm; wet and pliable. Carbonate content is low. Coarse fraction 3% consists of abundant quartz, plant debris; trace metallic grains, mica, framboidal pyrite, ostracodes, planktonic foraminifera, iron oxide stained grains, brick fragments, slag, feldspar and diatoms. Basal contact is an indistinct color and texture change. Sampled at 12 cm.

TERRIGENOUS (BIOCLASTIC) CLAY [Clay], black (5Y2.5/1); shell fragments at 32, 37, 47-64 and 68 cm; moist and pliable. Carbonate content is low. Coarse fraction 10% consists of abundant quartz, plant debris; trace mica, ferromagnesian mineral grains, garnet, ostracodes, feldspar, shell fragments, planktonic foraminifera, diatoms, framboidal pyrite and sponge spicules. Sampled at 45 cm.

Core ID:	DPB2-06-10	Latitude:	41° 4.014' N	Date Opened:	05/22/06
Core Length:	71 cm	Longitude:	73° 52.179' W	Date Photographed:	05/22/06
Collection Date:	05/10/06	PDR Depth:	2.5 m	Date Described:	06/08/06
				Described by:	N. Anest

Attachment 1

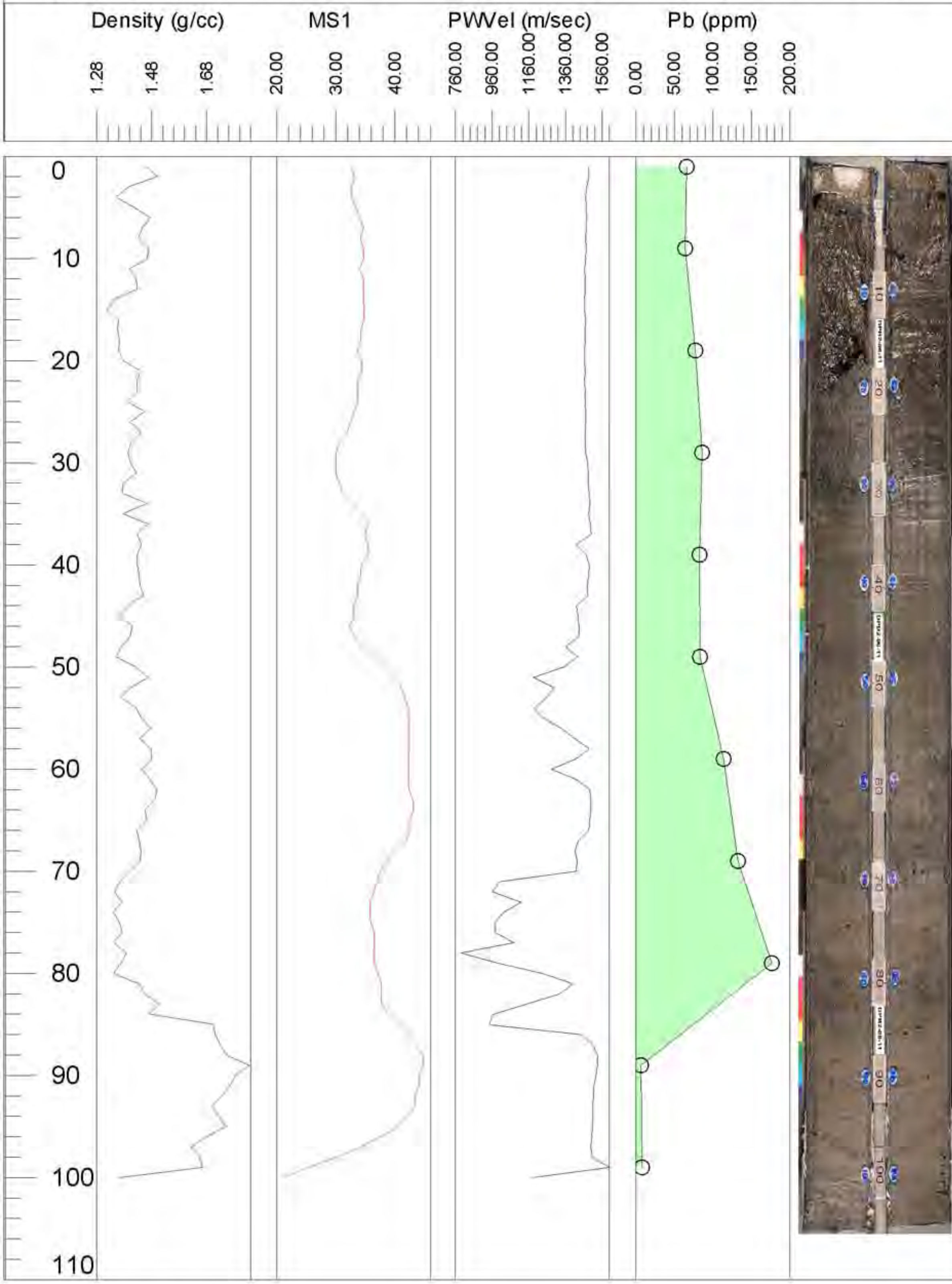
Lamont-Dohery Earth Observatory

DPB2-06-11

Project Title: Assessment of the deposition of sediments impacted by Twentieth Century activities in the vicinity of the Tappan Zee Bridge

Project No.: EARTHT D213123

Principle Investigators: Timothy C. Kenna and Frank Nitsche



Lithology

TERRIGENOUS (BIOCLASTIC) CLAY [Clay], very dark grayish brown (2.5Y3/2) with mottles and laminae of coarser material throughout interval; crustacean claw at 20 cm; shell fragments at 23 cm; wet becoming moist and pliable. Carbonate content is low. Coarse fraction 11% consists of abundant quartz, plant debris; common metallic grains; rare mica; trace iron oxide stained grains, slag, shell fragments, planktonic foraminifera, brick fragments, feldspar, ferromagnesian mineral grains, garnet, diatoms and sponge spicules. Basal contact is a distinct color change. Sampled at 27 cm.

TERRIGENOUS (BIOCLASTIC) CLAY [Sandy clay], black (5Y2.5/2) with mottles of coarser material throughout interval; shell fragments at 57, 66 and 86 cm; moist and pliable. Carbonate content is low. Coarse fraction 19% consists of abundant quartz; trace metallic grains, ferromagnesian mineral grains, mica, slag, brick fragments, iron oxide stained grains, planktonic foraminifera, plant debris, feldspar, garnet, diatoms, sponge spicules and framboidal pyrite. Basal contact is a distinct color change. Sampled at 68 cm.

TERRIGENOUS (BIOCLASTIC) CLAY [Clay], very dark gray (2.5Y3/1) with laminae of coarser sediment at 90-105.5 cm; shell fragments at 87 and 91 cm; moist and pliable. Carbonate content is low. Coarse fraction 9% consists of abundant quartz; common plant debris; trace mica, iron oxide stained grains, brick fragments, ferromagnesian mineral grains, planktonic foraminifera, diatoms, ostracodes, metallic grains, garnet, framboidal pyrite and sponge spicules. Sampled at 95 cm.

Core ID:	DPB2-06-11	Latitude:	41° 4.423' N	Date Opened:	05/19/06
Core Length:	105.5 cm	Longitude:	73° 52.354' W	Date Photographed:	05/19/06
Collection Date:	05/11/06	PDR Depth:	3.5 m	Date Described:	06/08/06
				Described by:	N. Anest

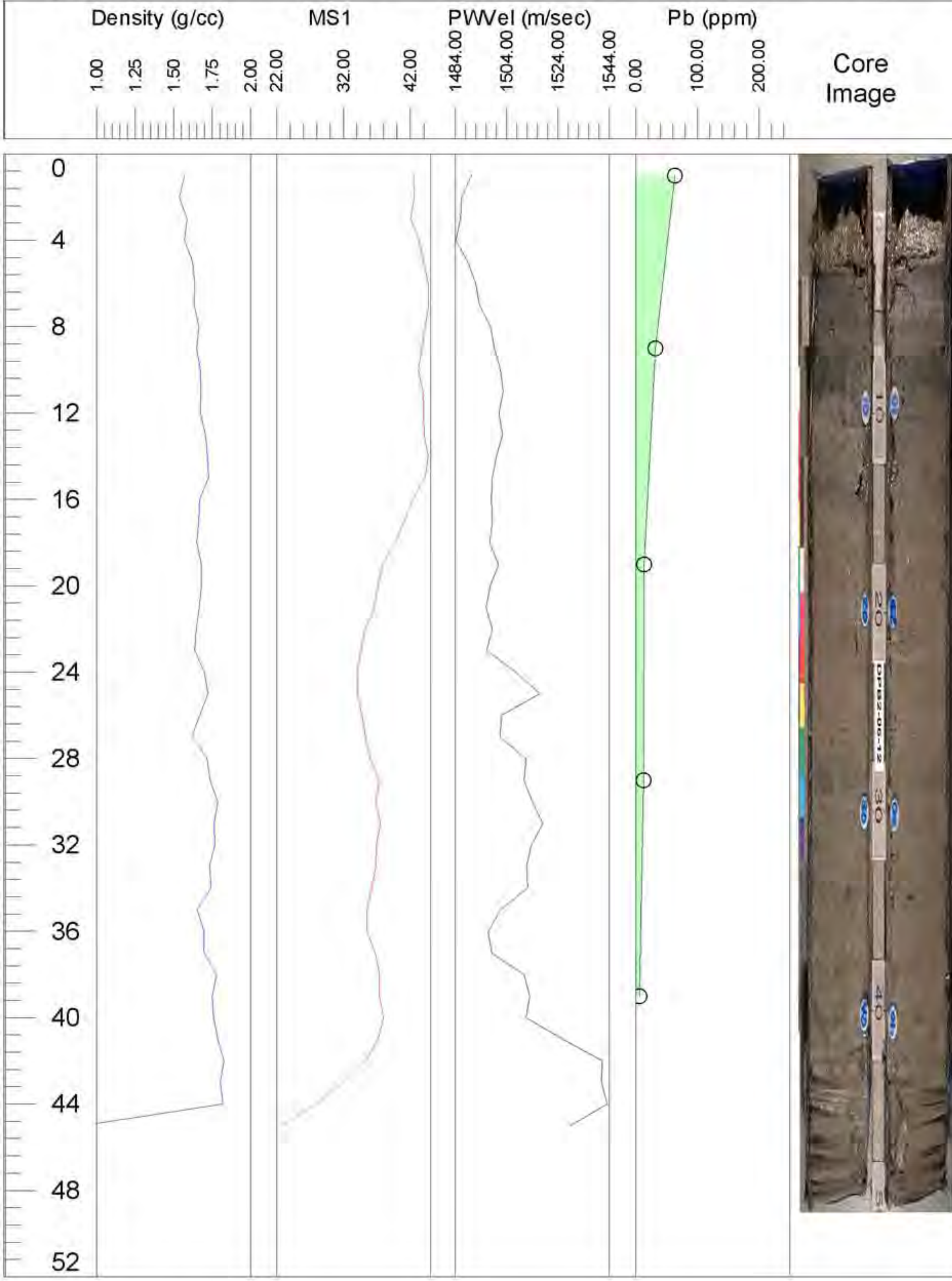
Attachment 1

Lamont-Dohery Earth Observatory

DPB2-06-12

Project Title: Assessment of the deposition of sediments impacted by Twentieth Century activities in the vicinity of the Tappan Zee Bridge

Project No.: EARTHT D213123 Principle Investigators: Timothy C. Kenna and Frank Nitsche



Lithology

TERRIGENOUS (BIOCLASTIC) CLAY [Sandy clay], very dark grayish brown (2.5Y3/2) with mottles of coarser material throughout interval; shell fragments at 5, 10 and 17 cm; moist and pliable. Carbonate content is low. Coarse fraction 14% consists of abundant quartz; rare plant debris, mica; trace iron oxide stained grains, brick fragments, ferromagnesian mineral grains, garnet, planktonic foraminifera, feldspar, diatoms, framboidal pyrite and sponge spicules. Basal contact is a gradual color change. Sampled at 15 cm.

TERRIGENOUS (BIOCLASTIC) CLAY [Sandy clay], very dark gray (5Y3/1) with mottles and laminae of coarser material throughout interval; shell fragments at 25.5, 29, 41 and 46 cm; moist and pliable. Carbonate content is low. Coarse fraction 21% consists of abundant quartz; trace plant debris, mica, iron oxide stained grains, framboidal pyrite, diatoms, planktonic foraminifera, feldspar, sponge spicules and zircon. Sampled at 35 cm.

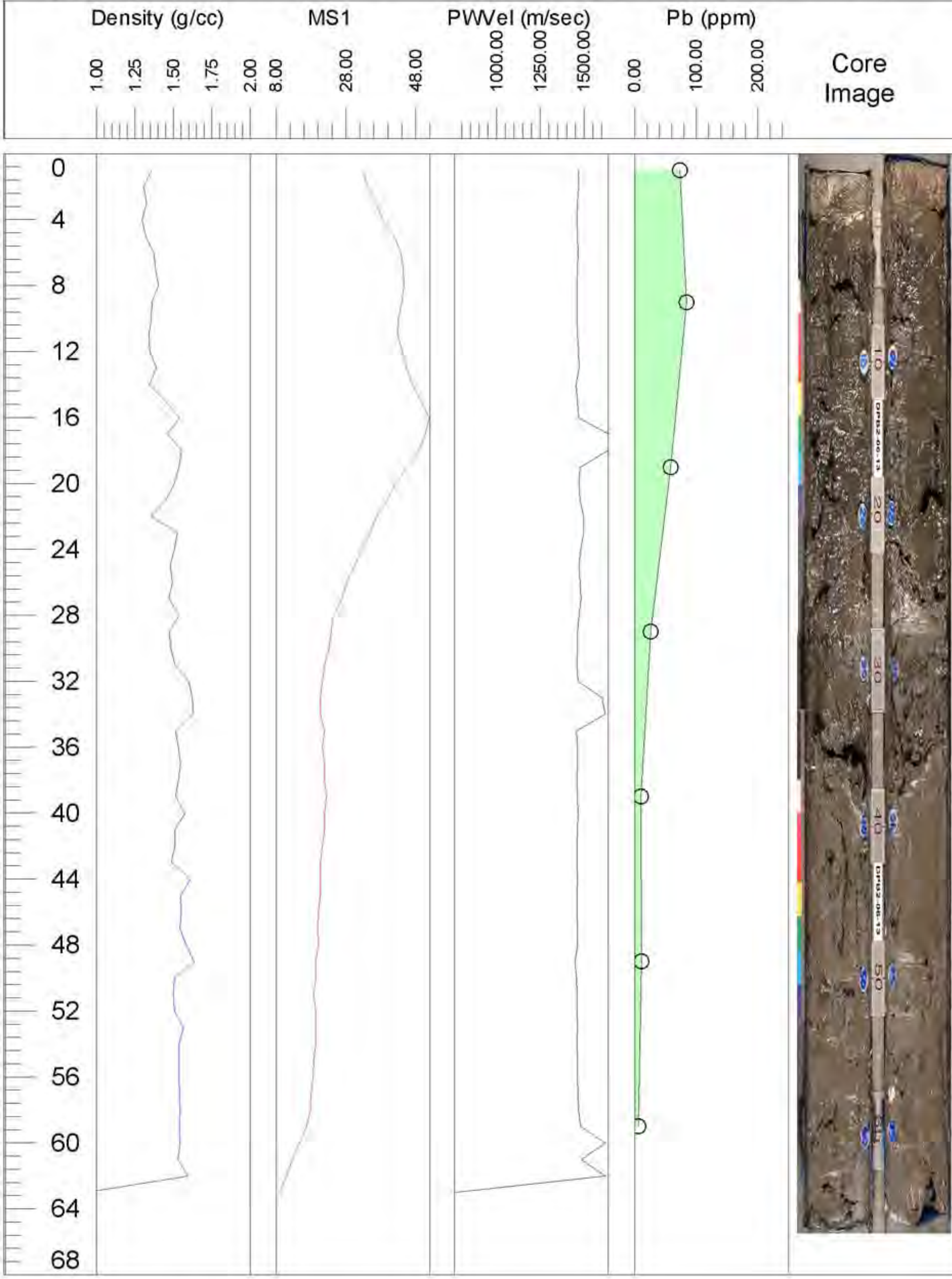
Core ID:	DPB2-06-12	Latitude:	41° 4.252' N	Date Opened:	05/22/06
Core Length:	49 cm	Longitude:	73° 52.253' W	Date Photographed:	05/22/06
Collection Date:	05/10/06	PDR Depth:	3.0 m	Date Described:	06/09/06
				Described by:	N. Anest

Lamont-Dohery Earth Observatory

DPB2-06-13

Project Title: Assessment of the deposition of sediments impacted by Twentieth Century activities in the vicinity of the Tappan Zee Bridge

Project No.: EARTHT D213123   Principle Investigators: Timothy C. Kenna and Frank Nitsche



Lithology

TERRIGENOUS (BIOCLASTIC) CLAY [Clay], very dark grayish brown (2.5Y3/2); shell fragments at 10-25 cm; very dark brown (7.5YR2.5/3) wood at 24 cm; moist and pliable. Carbonate content is low. Coarse fraction 8% consists of abundant quartz; common plant debris; trace mica, metallic grains, shell fragments, iron oxide stained grains, garnet, planktonic foraminifera, ferromagnesian mineral grains, feldspar, slag, (brookite?), framboidal pyrite, diatoms and sponge spicules. Basal contact is a distinct color change. Sampled at 12cm.

TERRIGENOUS (BIOCLASTIC) CLAY [Clay], very dark gray (5Y3/1.5); shell fragments at 25, 35, 48 and 58-65.5 cm; mottles of very dark grayish brown (2.5Y3/2) at 25-31 cm; moist and pliable. Carbonate content is low. Coarse fraction 3% consists of abundant quartz, plant debris; rare mica; trace planktonic foraminifera, framboidal pyrite, feldspar, diatoms, iron oxide stained grains, ferromagnesian mineral grains, garnet and sponge spicules. Sampled at 45 cm.

Core ID:	DPB2-06-13	Latitude:	41° 4.145' N	Date Opened:	05/22/06
Core Length:	65.5 cm	Longitude:	73° 52.103' W	Date Photographed:	05/22/06
Collection Date:	05/11/06	PDR Depth:	2.7 m	Date Described:	06/12/06
				Described by:	N. Anest

Attachment 1

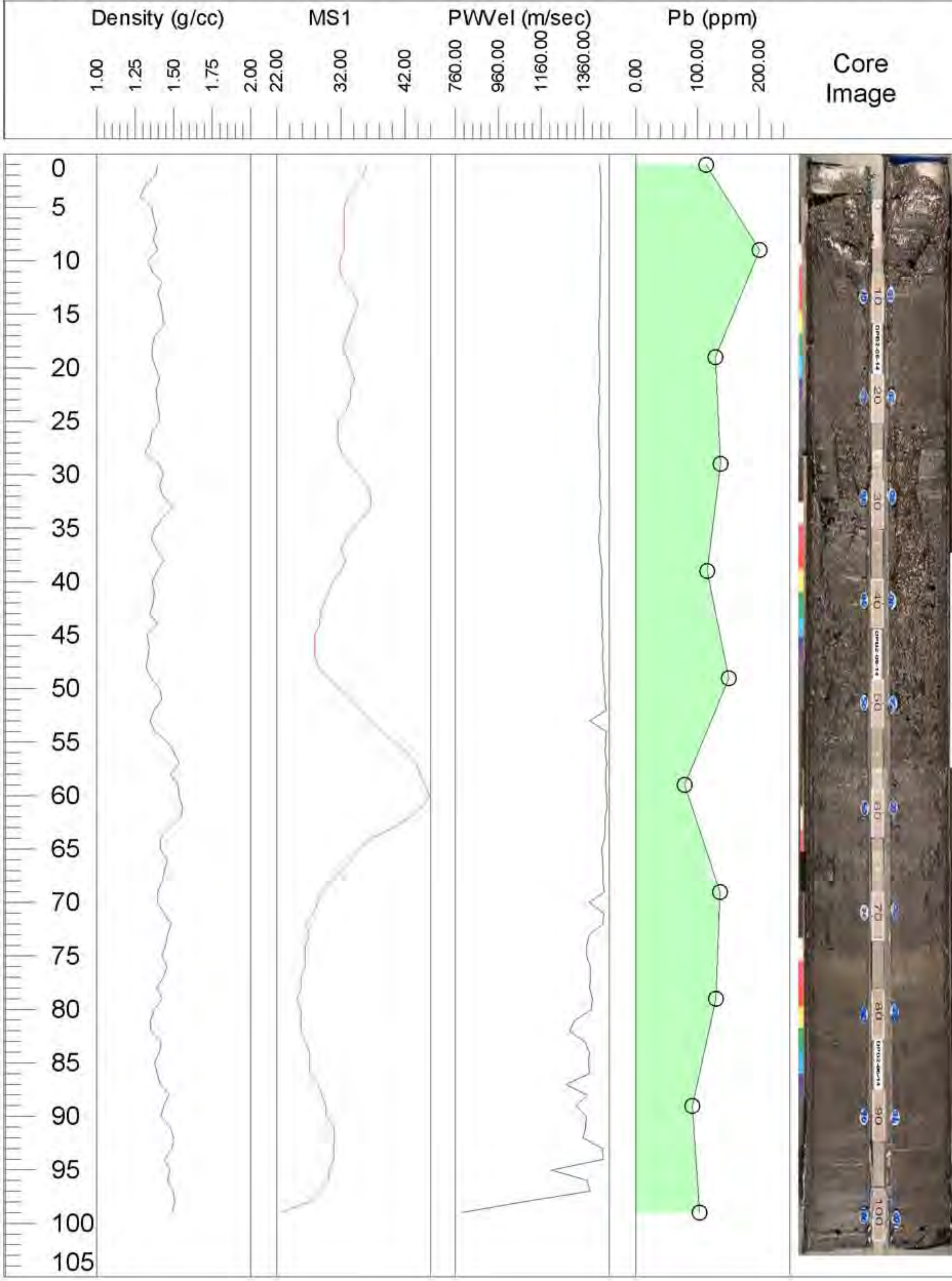
Lamont-Dohery Earth Observatory

DPB2-06-14

Project Title: Assessment of the deposition of sediments impacted by Twentieth Century activities in the vicinity of the Tappan Zee Bridge

Project No.: EARTHT D213123

Principle Investigators: Timothy C. Kenna and Frank Nitsche



Lithology

TERRIGENOUS (BIOCLASTIC) CLAY [Clay], dark olive gray (5Y3/2); mottles of dark grayish brown (10YR4/2) at 16.5 cm; lamina of olive gray (5Y3.5/2) at 46cm; laminae and mottles of coarser sediment at 57-67, 74 and 80-103 cm; moist and pliable. Carbonate content is low. Coarse fraction at 15cm, 3% consists of common plant debris, quartz; rare metallic grains; trace shell fragments, mica, diatoms, foraminifera, slag, framboidal pyrite, diatoms and garnet. Coarse fraction at 85cm, 5% consists of abundant quartz; common plant debris; rare metallic grains; trace shell fragments, mica, slag, foraminifera, opaque glassy spherule, framboidal pyrite, planktonic foraminifera, diatoms, feldspar, ferromagnesian mineral grains and sponge spicules. Sampled at 15 and 85 cm.

Core ID:	DPB2-06-14	Latitude:	41° 3.769' N	Date Opened:	05/19/06
Core Length:	103 cm	Longitude:	73° 52.363' W	Date Photographed:	05/19/06
Collection Date:	05/10/06	PDR Depth:	3.0 m	Date Described:	06/12/06
				Described by:	N. Anest

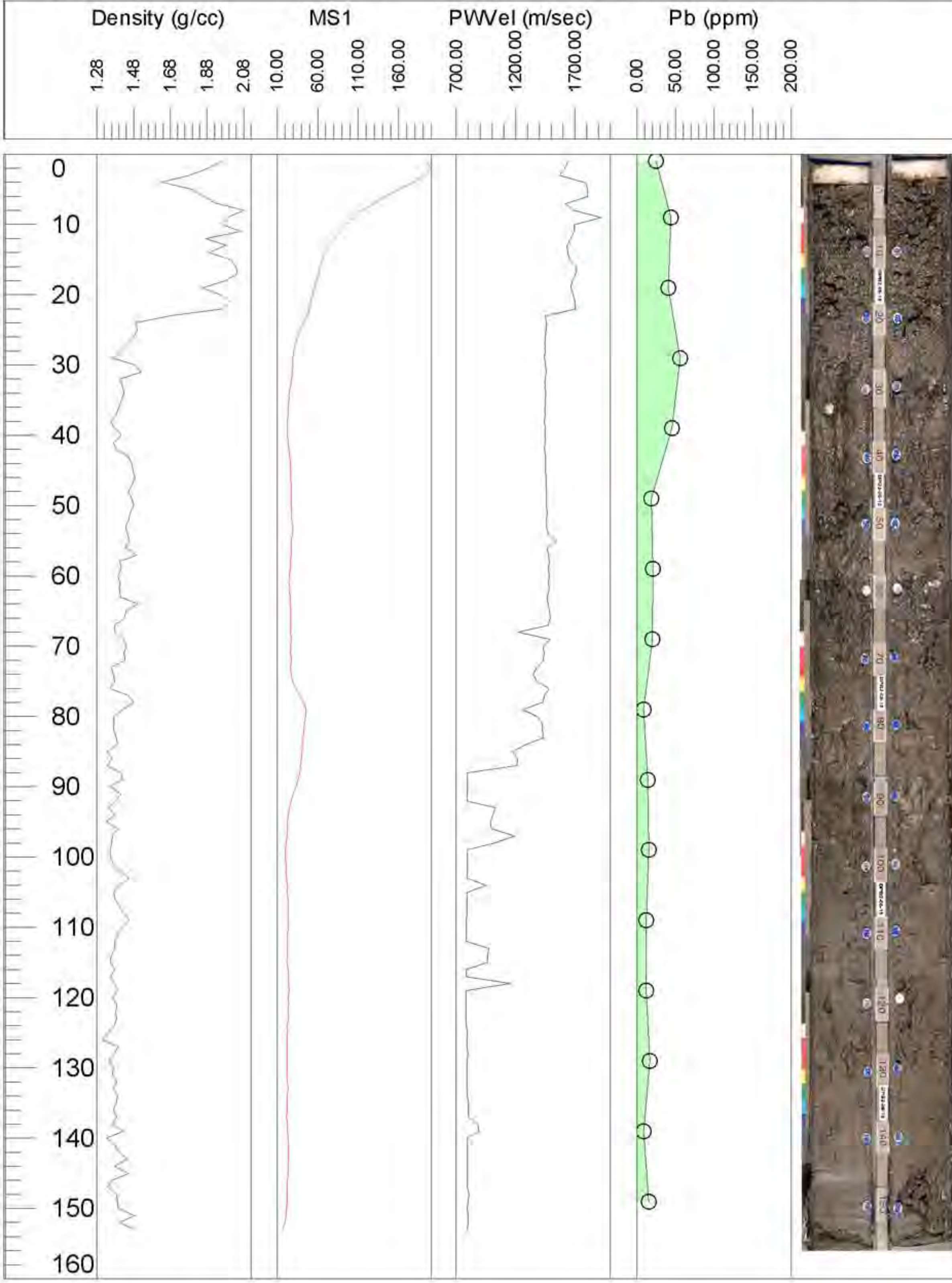
Attachment 1

Lamont-Dohery Earth Observatory

DPB2-06-15

Project Title: Assessment of the deposition of sediments impacted by Twentieth Century activities in the vicinity of the Tappan Zee Bridge

Project No.: EARTHT D213123 Principle Investigators: Timothy C. Kenna and Frank Nitsche



Lithology

TERRIGENOUS (BIOCLASTIC) SAND [Gravely quartz sand], dark olive gray (5Y3/2) and black (5Y2.5/2) with shell fragments throughout interval; moist and pliable. Carbonate content is low to moderate. Coarse fraction 89% consists of abundant quartz; rare slag; trace garnet, mica, glassy spherule containing air bubbles, shell fragments, ferromagnesian mineral grains, iron oxide stained grains, opaque grains and diatoms. Basal contact is a distinct texture change. Sampled at 12 cm.

TERRIGENOUS (BIOCLASTIC) CLAY [Clay], very dark grayish brown (2.5Y3/2); laminae of very dark gray (2.5Y3/1) at 32 and 42 cm, bed of same at 79-81 cm, mottles of same at 86, 89 and 95-99 cm; lamina of very dark grayish brown (10YR3/2) at 43 cm; shell fragments at 34, 54-60, 67 and 72.5 cm; very small mottles of coarser sediment at 47, 50, 55.5, 59, 68 and 94 cm; plant debris at 50 and 71 cm; moist and pliable. Carbonate content is low. Coarse fraction 10% consists of abundant quartz; common plant debris; trace mica, garnet, ferromagnesian mineral grains, diatoms, iron oxide stained grains, brick fragments, framboidal pyrite and sponge spicules. Basal contact is a distinct texture change. Sampled at 65 cm.

TERRIGENOUS (BIOCLASTIC) CLAY [Clay], very dark grayish brown (2.5Y3/2) with laminae of coarser material throughout interval; laminae of dark grayish brown (10YR4/2) at 110 and 111 cm; moist and pliable. Carbonate content is low. Coarse fraction 3% consists of abundant quartz, plant debris; trace mica, iron oxide stained grains, diatoms, opaque grains, ferromagnesian mineral grains, garnet, sponge spicules and benthic foraminifera. Basal contact is a distinct color change. Sampled at 107 cm.

TERRIGENOUS (BIOCLASTIC) CLAY [Clay], dark olive gray (5Y3/2) with laminae of coarser material throughout interval; plant debris at 113.5 and 128 cm; shell fragments at 128, 141 and 152 cm; moist and pliable. Carbonate content is low. Coarse fraction 1% consists of abundant plant debris; trace mica, quartz, diatoms, opaque grains, silicoflagellates, framboidal pyrite, ferromagnesian mineral grains, feldspar and sponge spicules. Sampled at 131 cm.

Core ID:	DPB2-06-15	Latitude:	41° 4.078' N	Date Opened:	05/22/06
Core Length:	156 cm	Longitude:	73° 52.732' W	Date Photographed:	05/22/06
Collection Date:	05/10/06	PDR Depth:	12.5 m	Date Described:	06/12/06
				Described by:	N. Anest

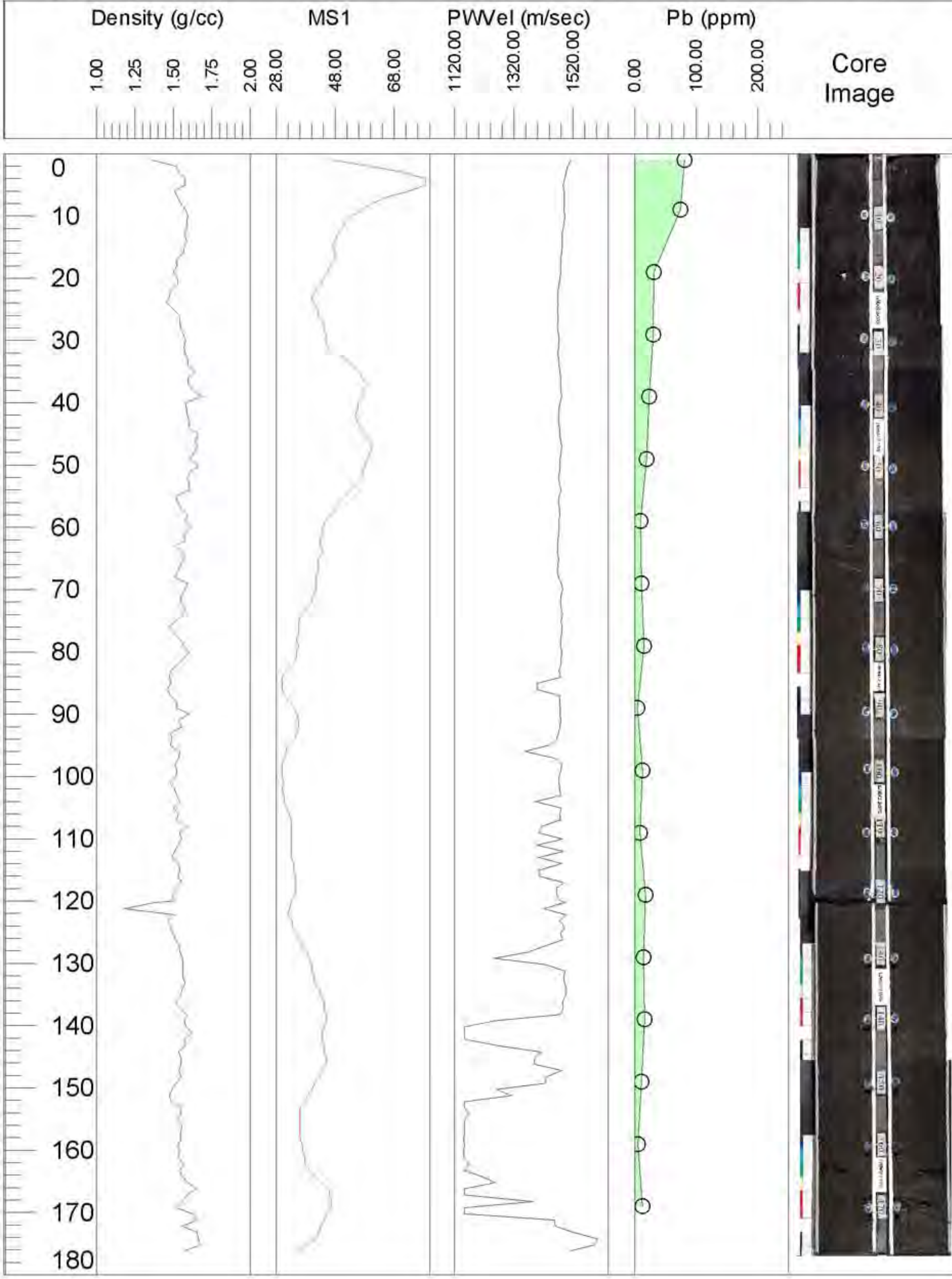
Attachment 1

Lamont-Dohery Earth Observatory

LWB2-07

Project Title: Assessment of the deposition of sediments impacted by Twentieth Century activities in the vicinity of the Tappan Zee Bridge

Project No.: EARTHT D213123 Principle Investigators: Timothy C. Kenna and Frank Nitsche



Lithology

TERRIGENOUS (BIOCLASTIC) CLAY [Clay], black (5Y2.5/1) with mottles of black (5Y2.5/2) throughout interval; mottle of very dark grayish brown (2.5Y3/2) at 0-3 cm; shell fragments at 14.5 and 20 cm; moist and pliable. Carbonate content is low. Coarse fraction 5 % consists of abundant quartz; common plant debris; trace mica, shell fragments, opaque grains, iron oxide stained grains, feldspar, hornblende, tourmaline, diatoms, framboidal pyrite, zircon and garnet. Bioturbated basal contact is a distinct color change. Sampled at 25 cm.

TERRIGENOUS (BIOCLASTIC) CLAY [Clay], black (5Y2.5/2) with laminations of coarser sediment throughout interval; bioturbations of black (5Y2.5/2) at 51-58 cm; mottle of black (5Y2.5/2) at 52-57 cm; shell fragments at 66, 78, 165 and 170 cm; mottles of black (10YR2/1) organic debris at 82 and 100 cm; mottle of black (N2.5/) at 164 cm; moist and pliable. Carbonate content is low. Coarse fraction 6 % consists of abundant quartz; common plant debris; trace iron oxide stained grains, mica, diatoms, opaque grains, garnet and sponge spicules. Sampled at 65 cm.

Core ID:	LWB2-07	Latitude:	41° 4.313' N	Date Opened:	02/13/02
Core Length:	177 cm	Longitude:	73° 52.532' W	Date Photographed:	02/13/02
Collection Date:	09/05/01	PDR Depth:	5.5 m	Date Described:	02/13/02
				Described by:	N. Anest

Attachment 1

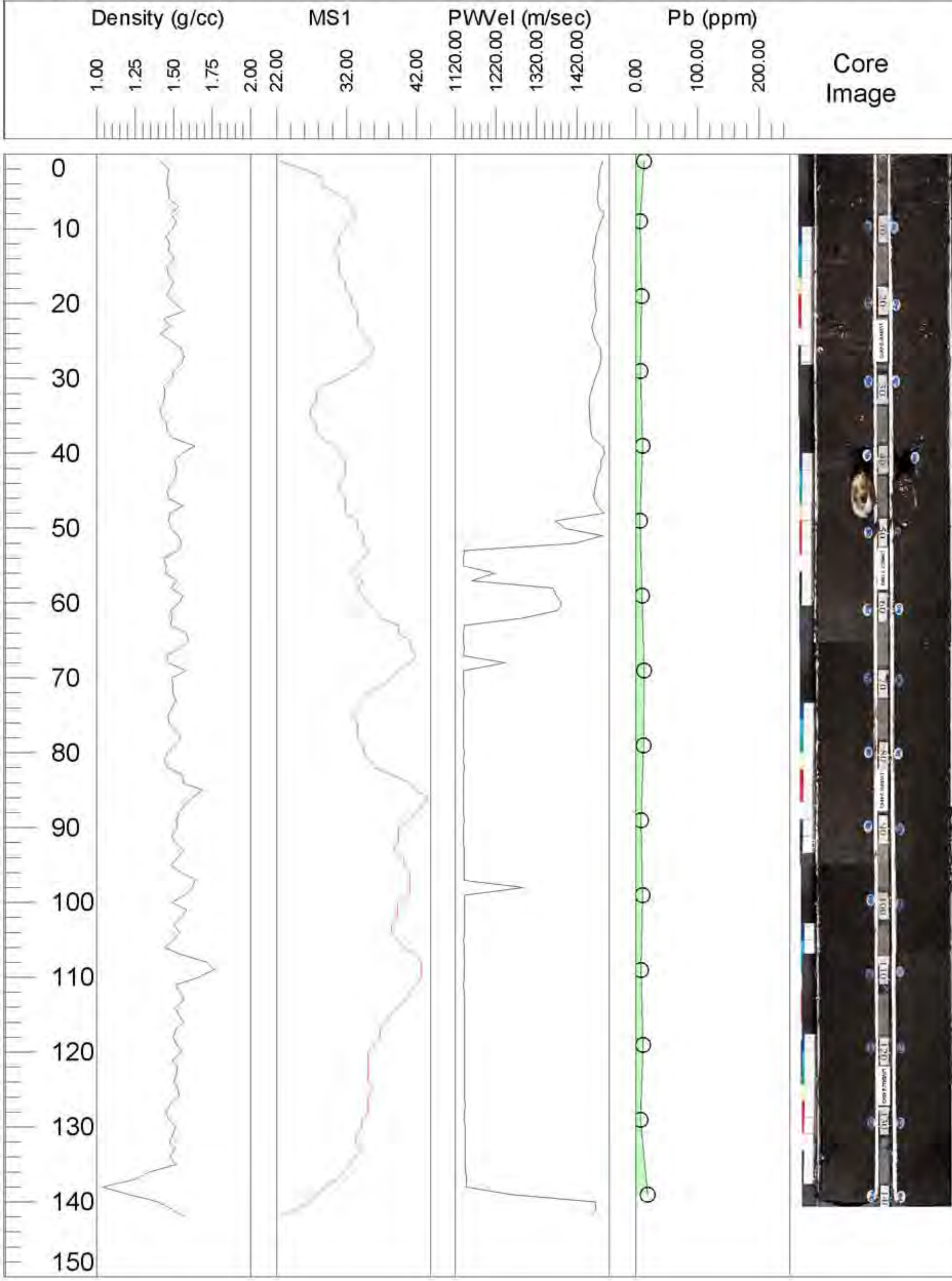
Lamont-Dohery Earth Observatory

LWB2-08

Project Title: Assessment of the deposition of sediments impacted by Twentieth Century activities in the vicinity of the Tappan Zee Bridge

Project No.: EARTHT D213123

Principle Investigators: Timothy C. Kenna and Frank Nitsche



Lithology

BIOCLASTIC (TERRIGENOUS) CLAY[Clay], black (5Y2.5/2); mottles of very dark grayish brown (2.5Y3/2) at 0-5 cm; mottles of very dark gray (5Y3/1) at 0-5 cm; shell fragments at 7, 14, 22-27 and 36 cm; wet becoming moist and pliable. Carbonate content is low. Coarse fraction 3 % consists of abundant plant debris; common mica; trace diatoms, framboidal pyrite, opaque grains, quartz, hornblende, garnet and epidote. Basal contact is a distinct, uneven color change. Sampled at 15 cm.

TERRIGENOUS (BIOCLASTIC) CLAY[Clay], black (5Y2.5/1) with laminations of coarser sediment throughout interval; shell fragments at 36-45 cm; moist and pliable. Carbonate content is low. Coarse fraction 2 % consists of abundant plant debris, quartz; common mica; trace diatoms, framboidal pyrite, hornblende, pyroxene, garnet and zircon. Sampled at 75 cm.

Core ID:	LWB2-08	Latitude:	41° 4.308' N	Date Opened:	03/13/02
Core Length:	140.6 cm	Longitude:	73° 52.769' W	Date Photographed:	03/13/02
Collection Date:	09/05/01	PDR Depth:	12.9 m	Date Described:	03/13/02
				Described by:	N. Anest

Attachment 1

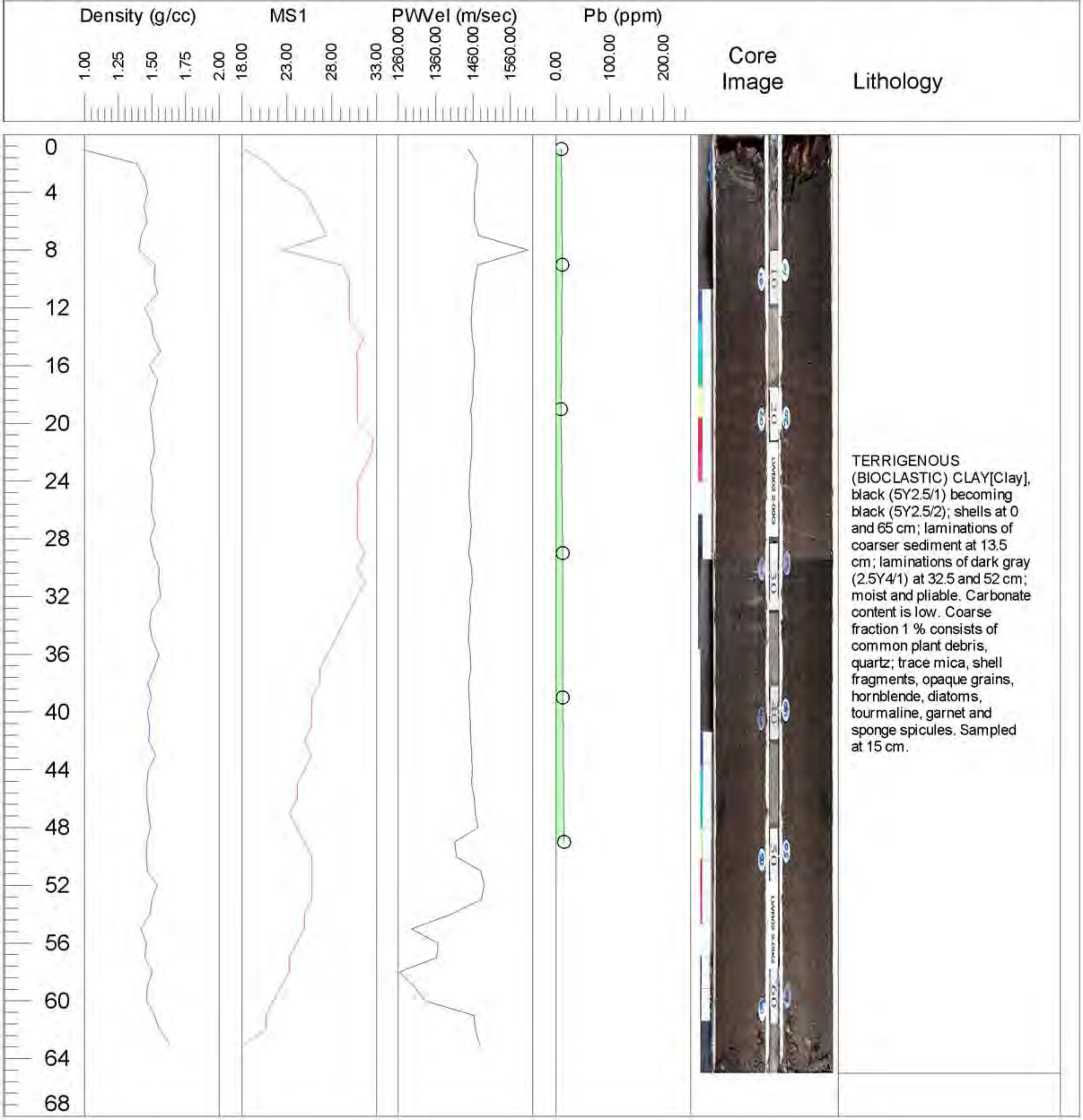
Lamont-Dohery Earth Observatory

LWB2-09

Project Title: Assessment of the deposition of sediments impacted by Twentieth Century activities in the vicinity of the Tappan Zee Bridge

Project No.: EARTHT D213123

Principle Investigators: Timothy C. Kenna and Frank Nitsche



TERRIGENOUS (BIOCLASTIC) CLAY[Clay], black (5Y2.5/1) becoming black (5Y2.5/2); shells at 0 and 65 cm; laminations of coarser sediment at 13.5 cm; laminations of dark gray (2.5Y4/1) at 32.5 and 52 cm; moist and pliable. Carbonate content is low. Coarse fraction 1 % consists of common plant debris, quartz; trace mica, shell fragments, opaque grains, hornblende, diatoms, tourmaline, garnet and sponge spicules. Sampled at 15 cm.

Core ID:	LWB2-09	Latitude:	41° 4.314' N	Date Opened:	02/19/02
Core Length:	65 cm	Longitude:	73° 52.841' W	Date Photographed:	02/19/02
Collection Date:	09/05/01	PDR Depth:	14.3 m	Date Described:	02/19/02
				Described by:	N. Anest

Attachment 1

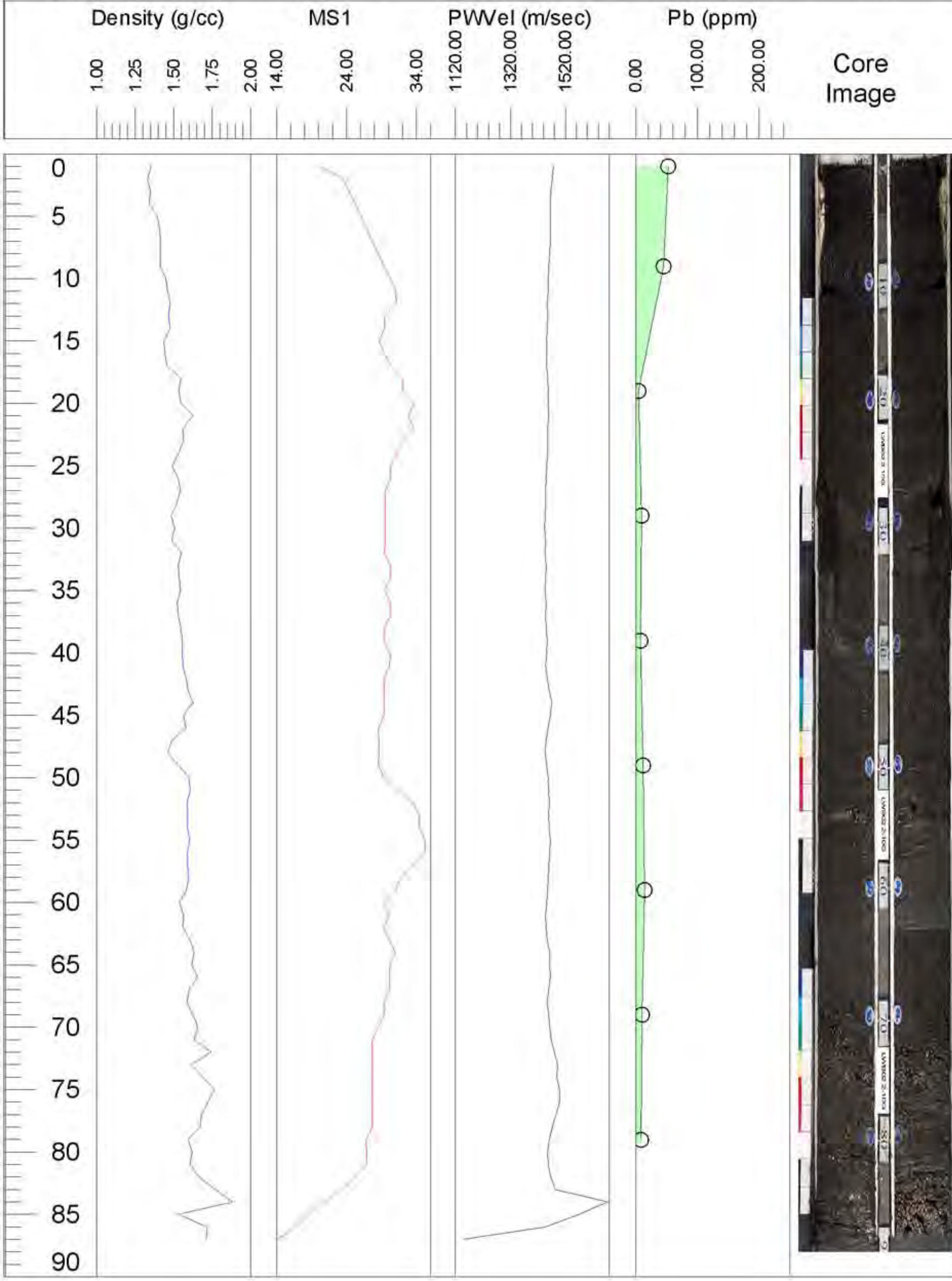
Lamont-Dohery Earth Observatory

LWB2-10

Project Title: Assessment of the deposition of sediments impacted by Twentieth Century activities in the vicinity of the Tappan Zee Bridge

Project No.: EARTHT D213123

Principle Investigators: Timothy C. Kenna and Frank Nitsche



Lithology

BIOCLASTIC (TERRIGENOUS) CLAY [Clay], black (5Y2.5/2); mottles of very dark grayish brown (2.5Y3/2) at 0-3 cm, bed of same at 6-9 cm; mottles of black (2.5Y2.5/1) at 13 and 15 cm; shell fragments at 11 and 30 cm; lamination of shell hash at 54 cm, beds of same at 71-79.5 and 84-88 cm; lamination of sand at 70.5 cm; moist and pliable. Carbonate content is low. Coarse fraction 1 % consists of common to rare plant debris; trace quartz, mica, feldspar, diatoms and opaque grains. Sampled at 25 cm.

Core ID:	LWB2-10	Latitude:	41° 4.323' N	Date Opened:	02/13/02
Core Length:	88 cm	Longitude:	73° 52.9' W	Date Photographed:	02/13/02
Collection Date:	09/05/01	PDR Depth:	14.0 m	Date Described:	02/13/02
				Described by:	N. Anest

Attachment 1

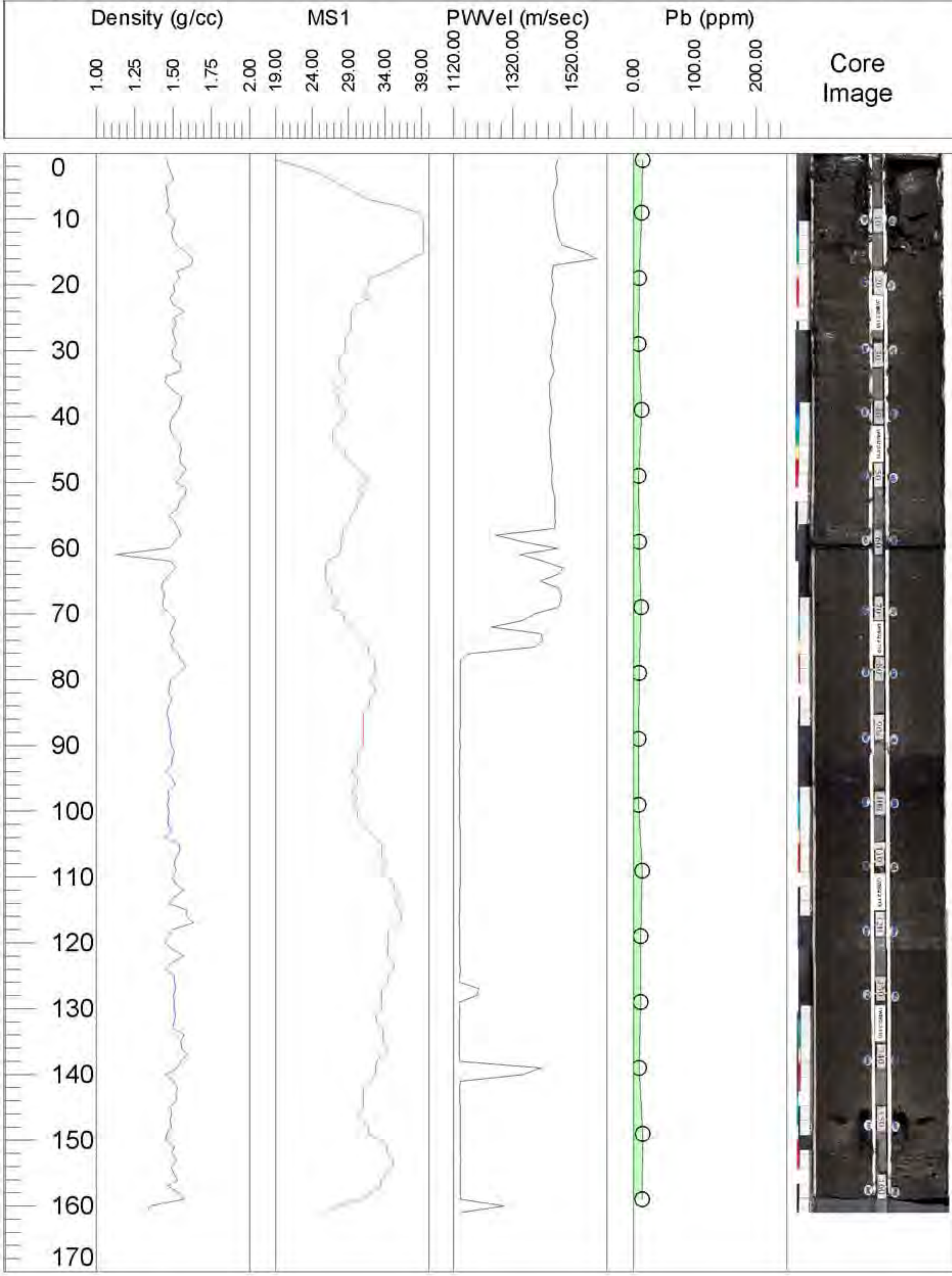
Lamont-Dohery Earth Observatory

LWB2-11

Project Title: Assessment of the deposition of sediments impacted by Twentieth Century activities in the vicinity of the Tappan Zee Bridge

Project No.: EARTHT D213123

Principle Investigators: Timothy C. Kenna and Frank Nitsche



Lithology

TERRIGENOUS (BIOCLASTIC) CLAY[Clay], dark olive gray (5Y3/2) becoming black (5Y2.5/2); mottles of black (N2.5/) at 0-16 cm; bed of black (5Y2.5/1) at 95-101 cm; mottles of very dark gray (2.5Y3/1.5) at 102-107 cm; shell fragments at 10, 15, 63, 83, 122, 127, 150 and 157 cm; black (N2.5/) organic debris at 150 cm; moist and pliable. Carbonate content is low. Coarse fraction 3 % consists of abundant quartz, plant debris; trace mica, foraminifera, iron oxide stained grains, diatoms, opaque grains and zircon. Sampled at 25 cm.

Core ID:	LWB2-11	Latitude:	41° 4.316' N	Date Opened:	02/19/02
Core Length:	161 cm	Longitude:	73° 53.108' W	Date Photographed:	02/19/02
Collection Date:	09/05/01	PDR Depth:	9.6 m	Date Described:	02/19/02
				Described by:	N. Anest

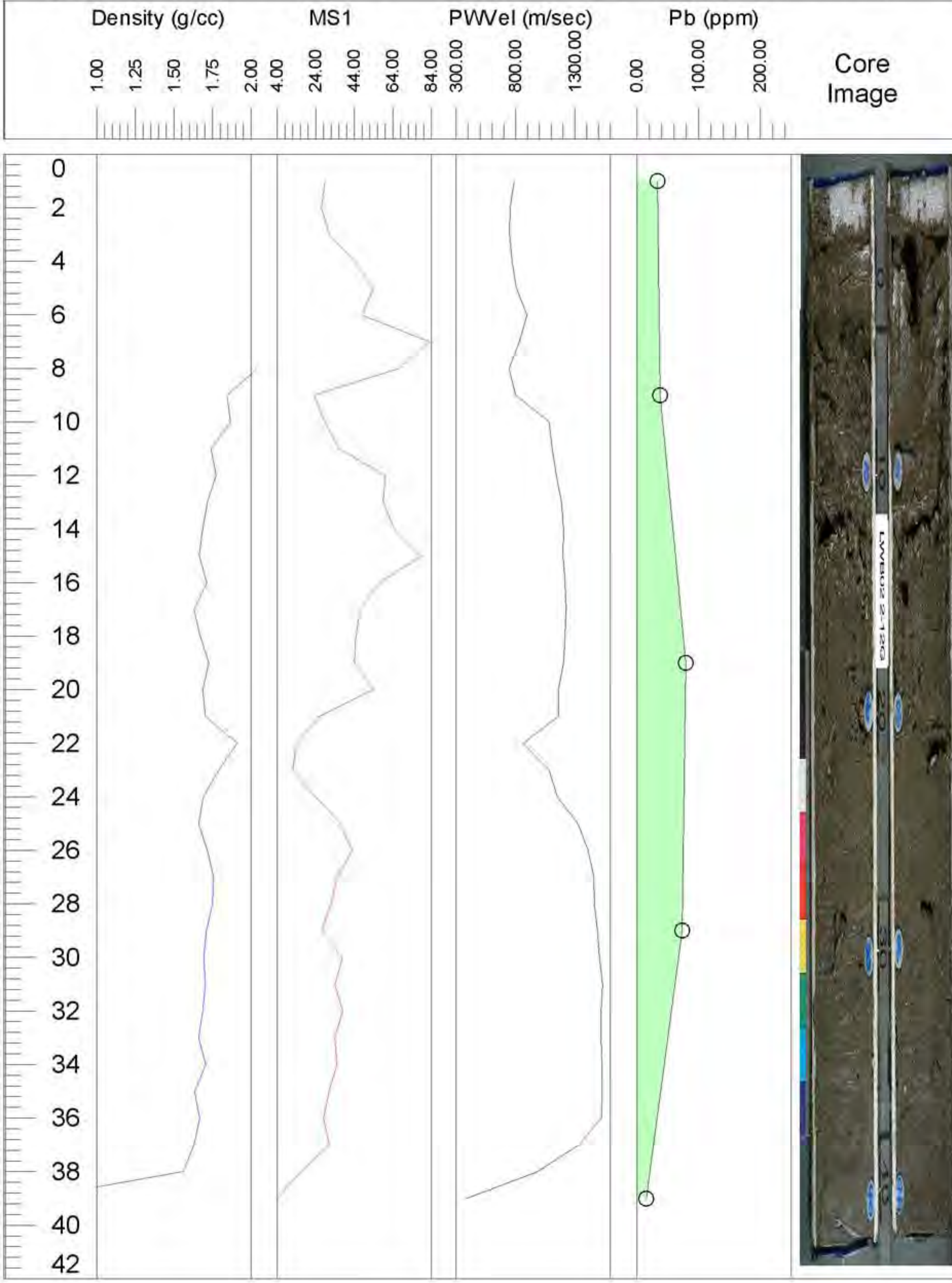
Attachment 1

Lamont-Dohery Earth Observatory

LWB2-12

Project Title: Assessment of the deposition of sediments impacted by Twentieth Century activities in the vicinity of the Tappan Zee Bridge

Project No.: EARTHT D213123 Principle Investigators: Timothy C. Kenna and Frank Nitsche



Lithology

TERRIGENOUS (BIOCLASTIC) CLAY [Clay], very dark gray (5Y3/1); mottles of very dark grayish brown (2.5Y3/2) at 0-10 cm; mottles of black (2.5Y2.5/1) at 9.5-10.5 and 17-28 cm; shell fragments at 7-23 and 36 cm; wet becoming moist and pliable. Carbonate content is low. Coarse fraction 10 % consists of abundant quartz; rare plant debris; trace iron oxide stained grains, shell fragments, foraminifera, glauconite, opaque grains, mica, hornblende, pyroxene, garnet, zircon and diatoms. Sampled at 15 cm.

Core ID:	LWB2-12	Latitude:	41° 4.311' N	Date Opened:	01/25/02
Core Length:	41.5 cm	Longitude:	73° 53.657' W	Date Photographed:	01/25/02
Collection Date:	09/05/01	PDR Depth:	3.5 m	Date Described:	01/25/02
				Described by:	N. Anest

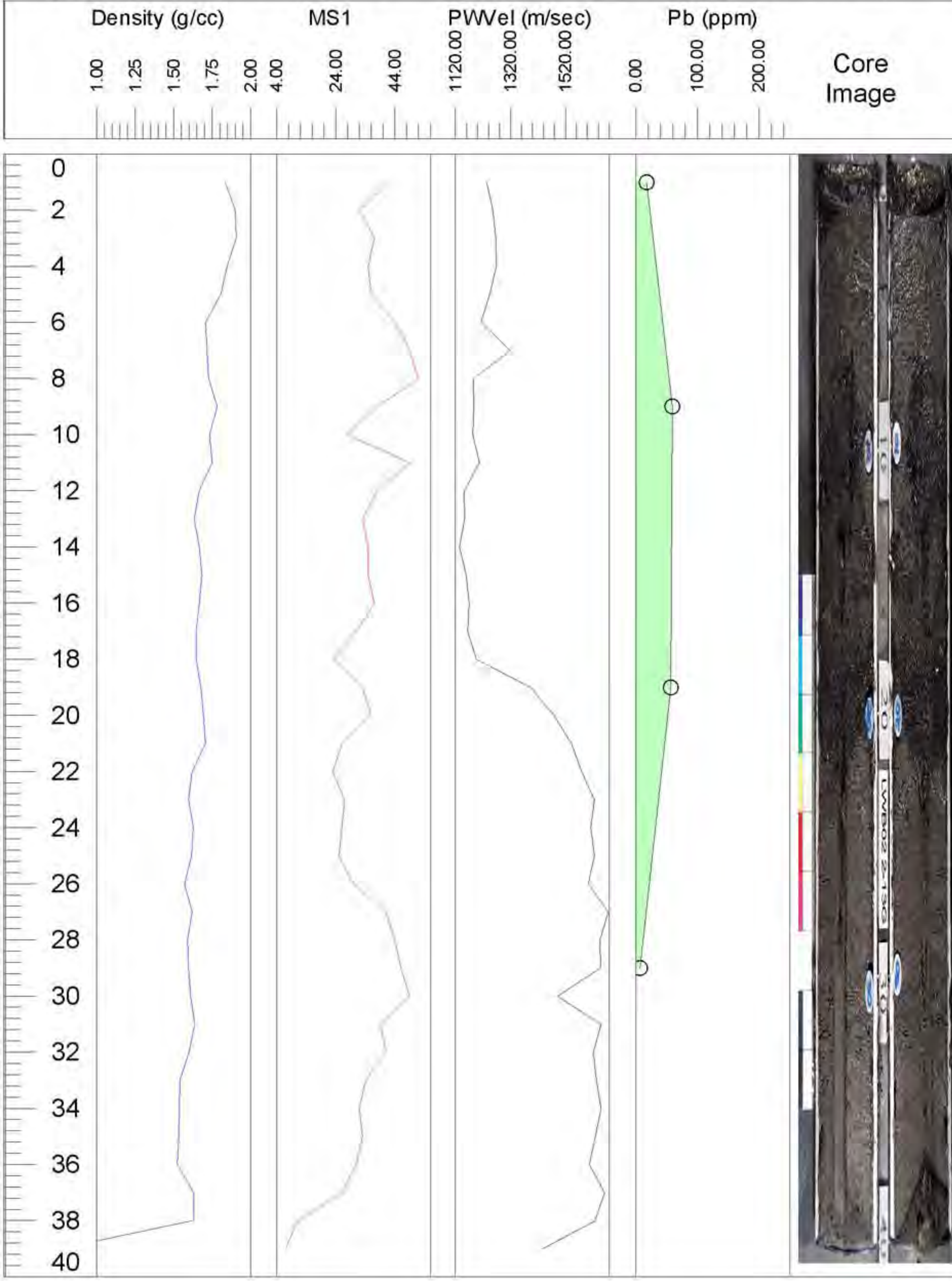
Attachment 1

Lamont-Dohery Earth Observatory

LWB2-13

Project Title: Assessment of the deposition of sediments impacted by Twentieth Century activities in the vicinity of the Tappan Zee Bridge

Project No.: EARTHT D213123 Principle Investigators: Timothy C. Kenna and Frank Nitsche



Lithology

TERRIGENOUS (BIOCLASTIC) CLAY [Clay], black (5Y2.5/2); mottles of black (N2.5/) at 0-2, 7-22 and 30 cm; mottles of very dark grayish brown (2.5Y3/2) at 0-4 and 7.5 cm; mottles of dark olive gray (5Y3/2) at 8.5 and 12-17 cm; shell fragments at 10-12, 25, 31 and 39 cm; wet becoming moist and pliable. Carbonate content is low. Coarse fraction 4 % consists of abundant quartz, plant debris; rare mica; trace shell fragments, opaque grains, iron oxide stained grains, diatoms, feldspar, hornblende, garnet, pyroxene and zircon. Sampled at 15 cm.

Core ID: LWB2-13	Latitude: 41° 4.318' N	Date Opened:	02/08/02
Core Length: 39.5 cm	Longitude: 73° 54.055' W	Date Photographed:	02/08/02
Collection Date: 09/05/01	PDR Depth: 3.1 m	Date Described:	02/08/02
		Described by:	N. Anest

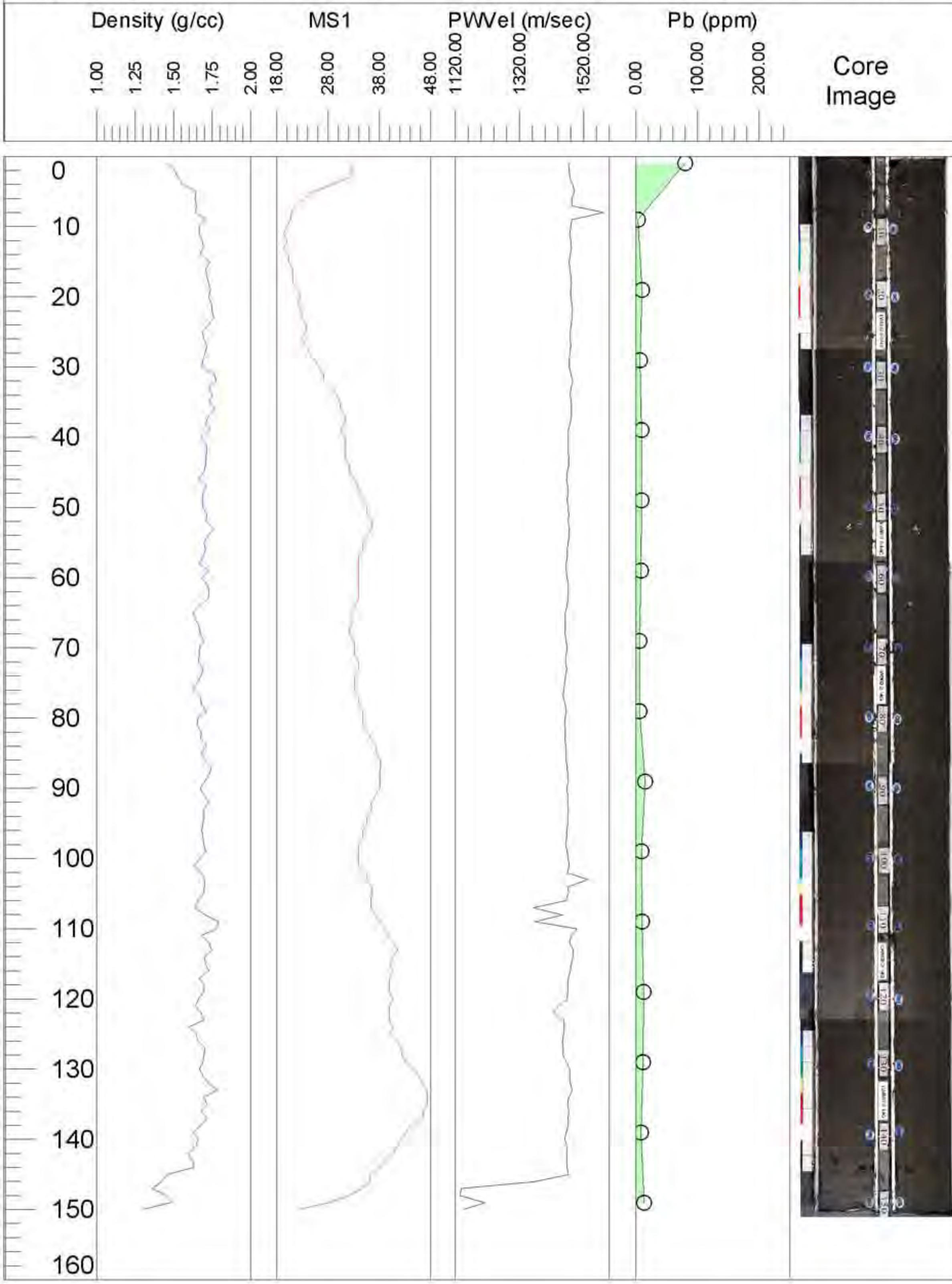
Lamont-Dohery Earth Observatory

LWB2-14

Project Title: Assessment of the deposition of sediments impacted by Twentieth Century activities in the vicinity of the Tappan Zee Bridge

Project No.: EARTHT D213123

Principle Investigators: Timothy C. Kenna and Frank Nitsche



Lithology

TERRIGENOUS (BIOCLASTIC) CLAY [Clay], very dark gray (5Y3/1); mottles of very dark grayish brown (2.5Y3/2) at 0-3 cm; mottles of black (N2.5/) at 1-12 cm; shell fragments at 4-8, 23-26, 41, 44, 53, 72, 90, 132 and 143 cm; mottle of very dark brown (10YR2/2) organic debris at 116.5 cm; moist and pliable. Carbonate content is low. Coarse fraction 2 % consists of abundant plant debris; common quartz, mica; trace foraminifera, diatoms, opaque grains, pyroxene, hornblende, garnet and sponge spicules. Sampled at 15 cm.

Core ID:	LWB2-14	Latitude:	41° 4.314' N	Date Opened:	03/14/02
Core Length:	151 cm	Longitude:	73° 54.494' W	Date Photographed:	03/14/02
Collection Date:	09/05/01	PDR Depth:		Date Described:	03/14/02
				Described by:	N. Anest

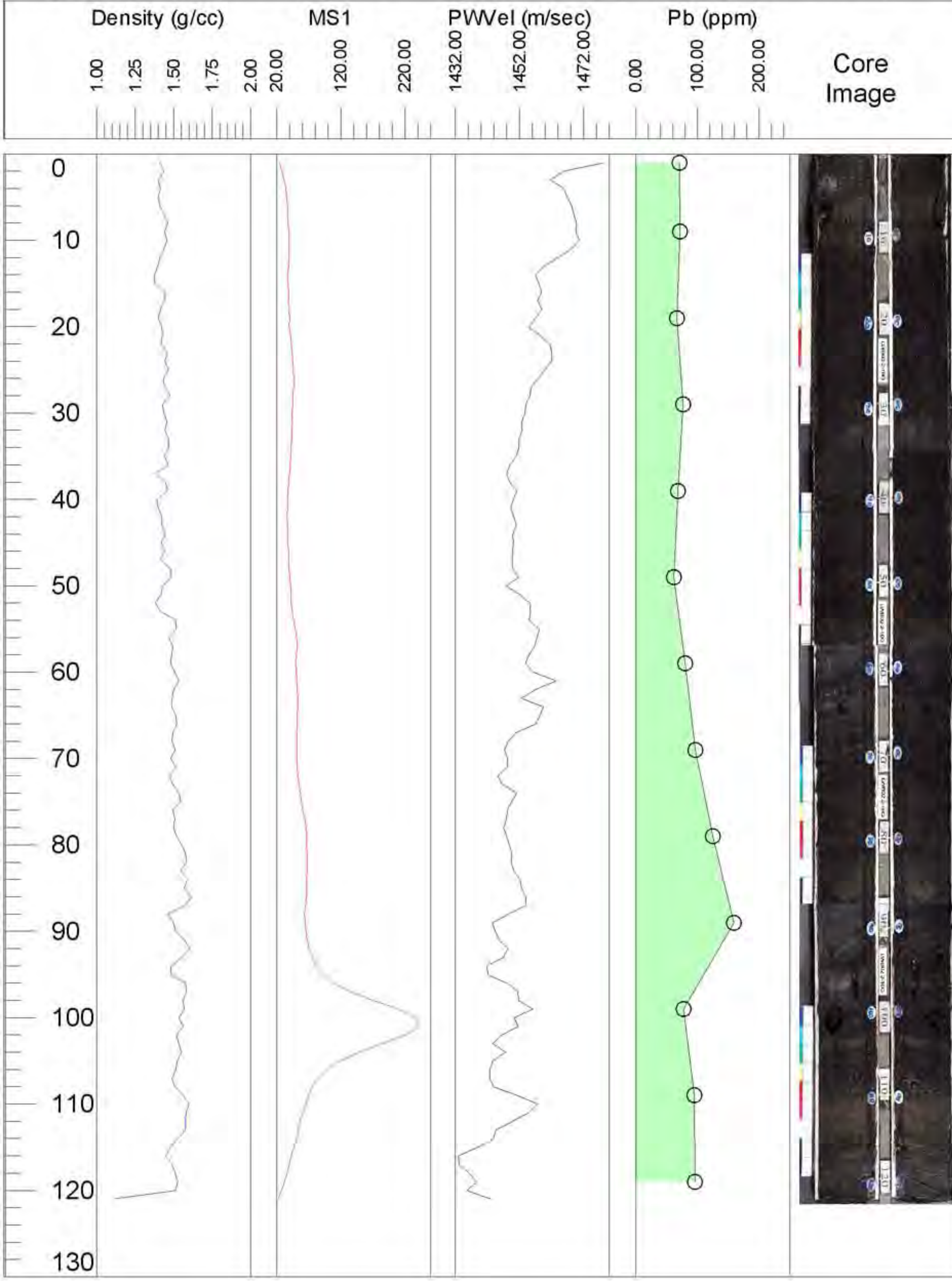
Attachment 1

Lamont-Dohery Earth Observatory

LWB2-16

Project Title: Assessment of the deposition of sediments impacted by Twentieth Century activities in the vicinity of the Tappan Zee Bridge

Project No.: EARTHT D213123 Principle Investigators: Timothy C. Kenna and Frank Nitsche



Lithology

TERRIGENOUS (BIOCLASTIC) CLAY [Clay], interbedded black (N2.5/) and black (5Y2.5/2); mottles of black (5Y2.5/2) at 20-35, 70, 76, 80, 84-94 and 116-120 cm; shell fragments at 93 and 98 cm; moist and pliable. Carbonate content is low. Coarse fraction 8 % consists of abundant quartz; rare plant debris; trace mica, iron oxide stained grains, opaque grains, diatoms, hornblende and pyroxene. Sampled at 25 cm.

Core ID:	LWB2-16	Latitude:	41° 4.121' N	Date Opened:	02/19/02
Core Length:	121.6 cm	Longitude:	73° 53.493' W	Date Photographed:	02/19/02
Collection Date:	09/05/01	PDR Depth:	3.4 m	Date Described:	02/19/02
				Described by:	N. Anest

Attachment 1

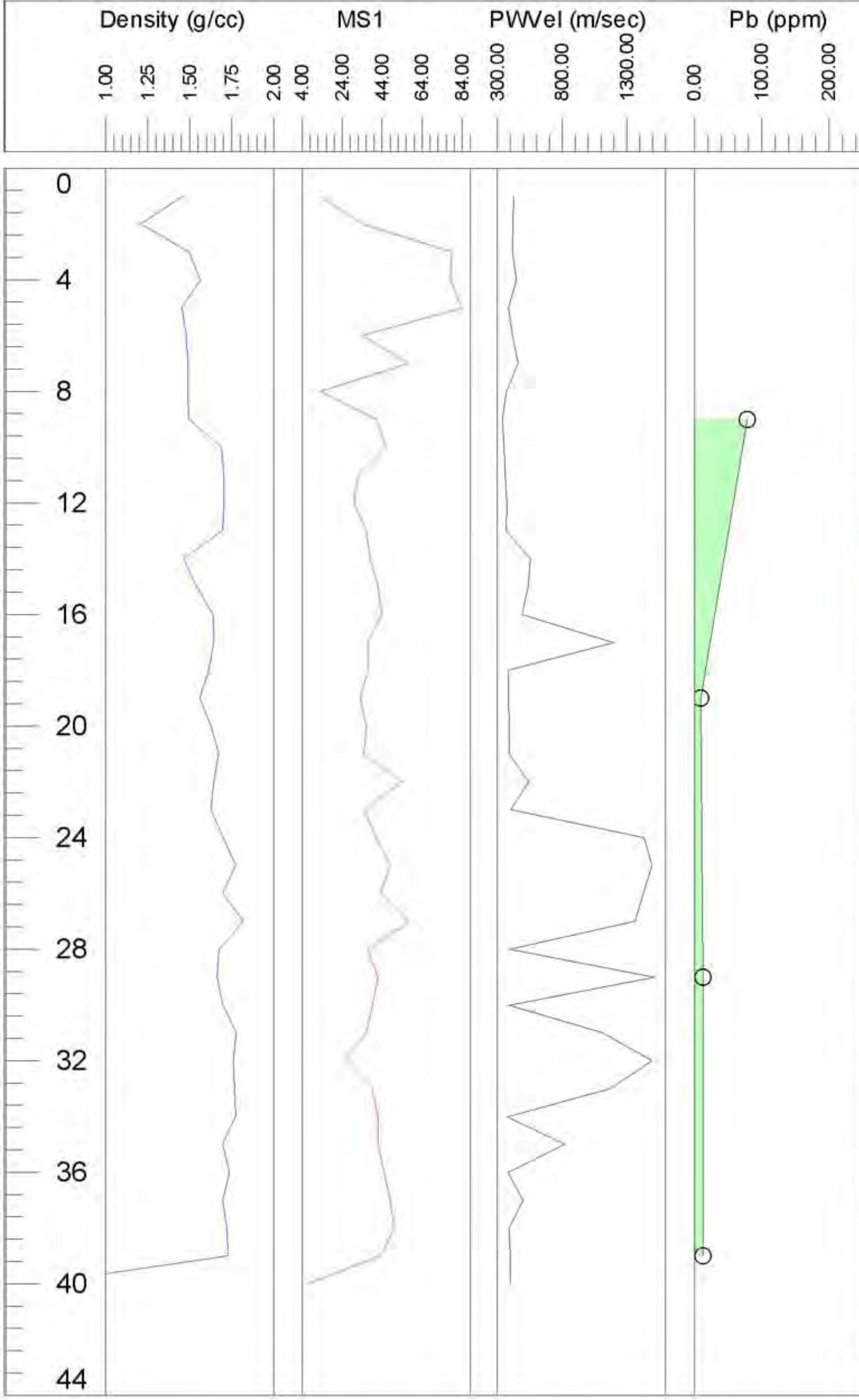
Lamont-Dohery Earth Observatory

LWB2-17

Project Title: Assessment of the deposition of sediments impacted by Twentieth Century activities in the vicinity of the Tappan Zee Bridge

Project No.: EARTHT D213123

Principle Investigators: Timothy C. Kenna and Frank Nitsche



Core Image

Lithology

TERRIGENOUS (BIOCLASTIC) CLAY [Clay], black (5Y2.5/1); mottles of very dark grayish brown (2.5Y3/2) at 0-10 cm; gravel at 0 cm; shell fragments at 0-10 and 25.5 cm; band of black (N2.5/) at 0-12.5 cm; laminations of coarser sediment at 12.5-42 cm; moist and pliable. Carbonate content is low. Coarse fraction 6 % consists of abundant quartz, plant debris; trace mica, framboidal pyrite, iron oxide stained grains, diatoms, opaque grains, garnet and hornblende. Sampled at 15 cm.

Core ID:	LWB2-17	Latitude:	41° 4.134' N	Date Opened:	01/29/02
Core Length:	42 cm	Longitude:	73° 53.383' W	Date Photographed:	01/29/02
Collection Date:	09/05/01	PDR Depth:	3.1 m	Date Described:	01/29/02
				Described by:	N. Anest

Attachment 1

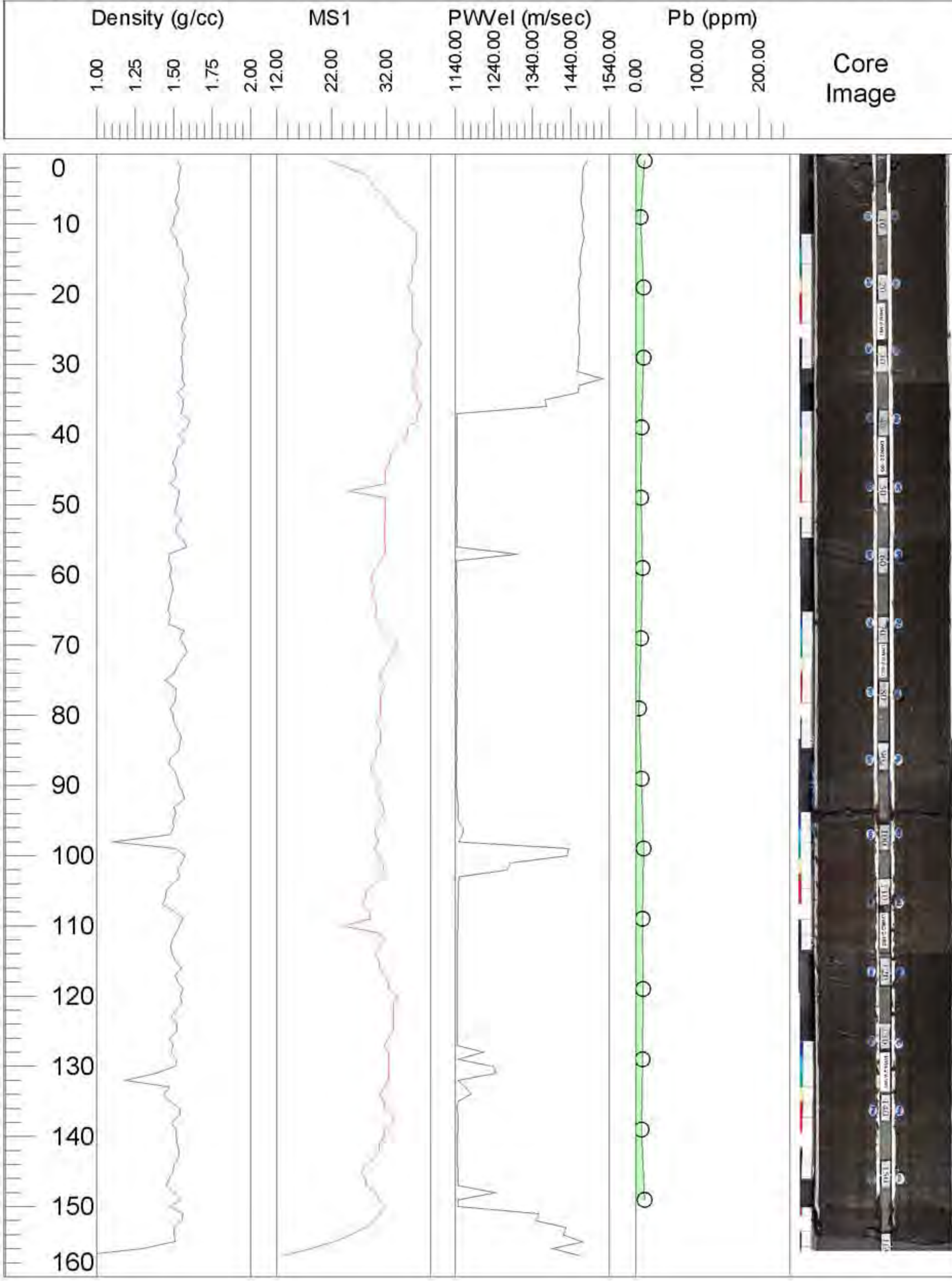
Lamont-Dohery Earth Observatory

LWB2-18

Project Title: Assessment of the deposition of sediments impacted by Twentieth Century activities in the vicinity of the Tappan Zee Bridge

Project No.: EARTHT D213123

Principle Investigators: Timothy C. Kenna and Frank Nitsche



Lithology

TERRIGENOUS (BIOCLASTIC) CLAY [Clay], very dark gray (2.5Y3/1); shell fragments at 33, 60, 82 and 101 cm; laminations of dark gray (10YR4/1) at 113 and 142 cm; mottles of very dark grayish brown (10YR3/2) organic debris at 60.5 and 75 cm; laminations of coarser sediment at 56, 68-70, 72, 82, 101.5, 123, 130, 134-142 and 146-153 cm; moist and pliable. Carbonate content is low. Coarse fraction 2 % consists of abundant quartz; trace plant debris, mica, iron oxide stained grains, opaque grains, diatoms, pyroxene, hornblende and garnet. Sampled at 15 cm.

Core ID: LWB2-18	Latitude: 41° 4.122' N	Date Opened:	02/19/02
Core Length: 156.3 cm	Longitude: 73° 53.045' W	Date Photographed:	02/19/02
Collection Date: 09/05/01	PDR Depth: 10.8 m	Date Described:	02/19/02
		Described by:	N. Anest

Attachment 1

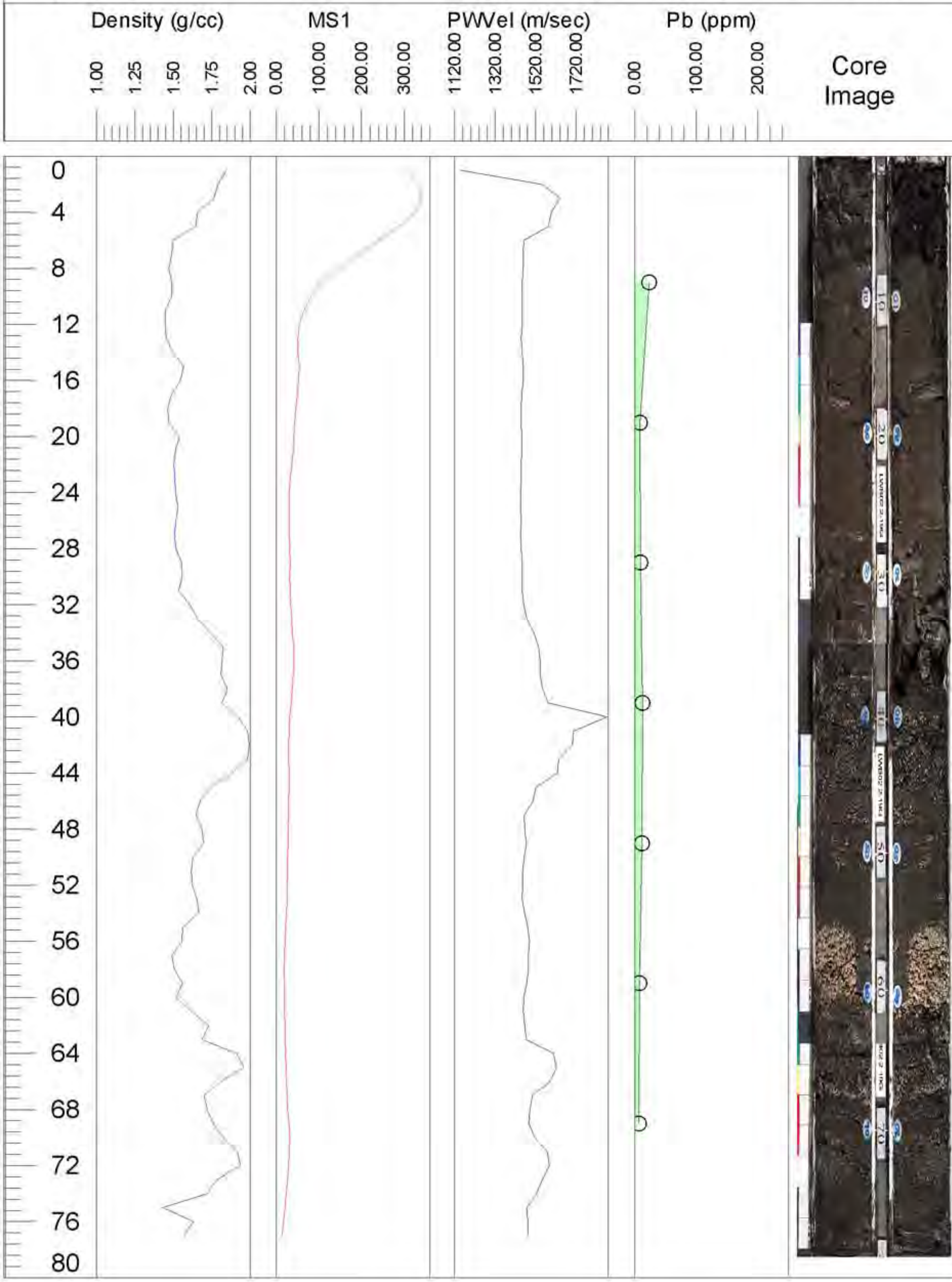
Lamont-Dohery Earth Observatory

LWB2-19

Project Title: Assessment of the deposition of sediments impacted by Twentieth Century activities in the vicinity of the Tappan Zee Bridge

Project No.: EARTHT D213123

Principle Investigators: Timothy C. Kenna and Frank Nitsche



Lithology

TERRIGENOUS (BIOCLASTIC) CLAY [Clay], black (5Y2.5/2); bed of black (N2.5/) gravely clay at 0-7 cm; mottles of very dark grayish brown (2.5Y3/2) at 0-4 cm; shell fragments at 1, 6, 29, 31 and 36 cm; beds of very dark gray (N3/) sand with numerous shells at 34-38 and 40-45.5 cm, mottles and laminations of same at 46-51.5 and 64-78 cm; laminations of very dark gray (N3/) sand at 52-54 cm; bed of shell hash at 56-62 cm; moist and pliable. Carbonate content of clay is low. Coarse fraction 2 % consists of abundant quartz; common plant debris; trace mica, opaque grains, diatoms, framboidal pyrite, feldspar, pyroxene, hornblende and garnet. Sampled at 15 cm.

Core ID:	LWB2-19	Latitude:	41° 4.126' N	Date Opened:	02/12/02
Core Length:	78.5 cm	Longitude:	73° 52.844' W	Date Photographed:	02/12/02
Collection Date:	09/05/01	PDR Depth:	13.5 m	Date Described:	02/12/02
				Described by:	N. Anest

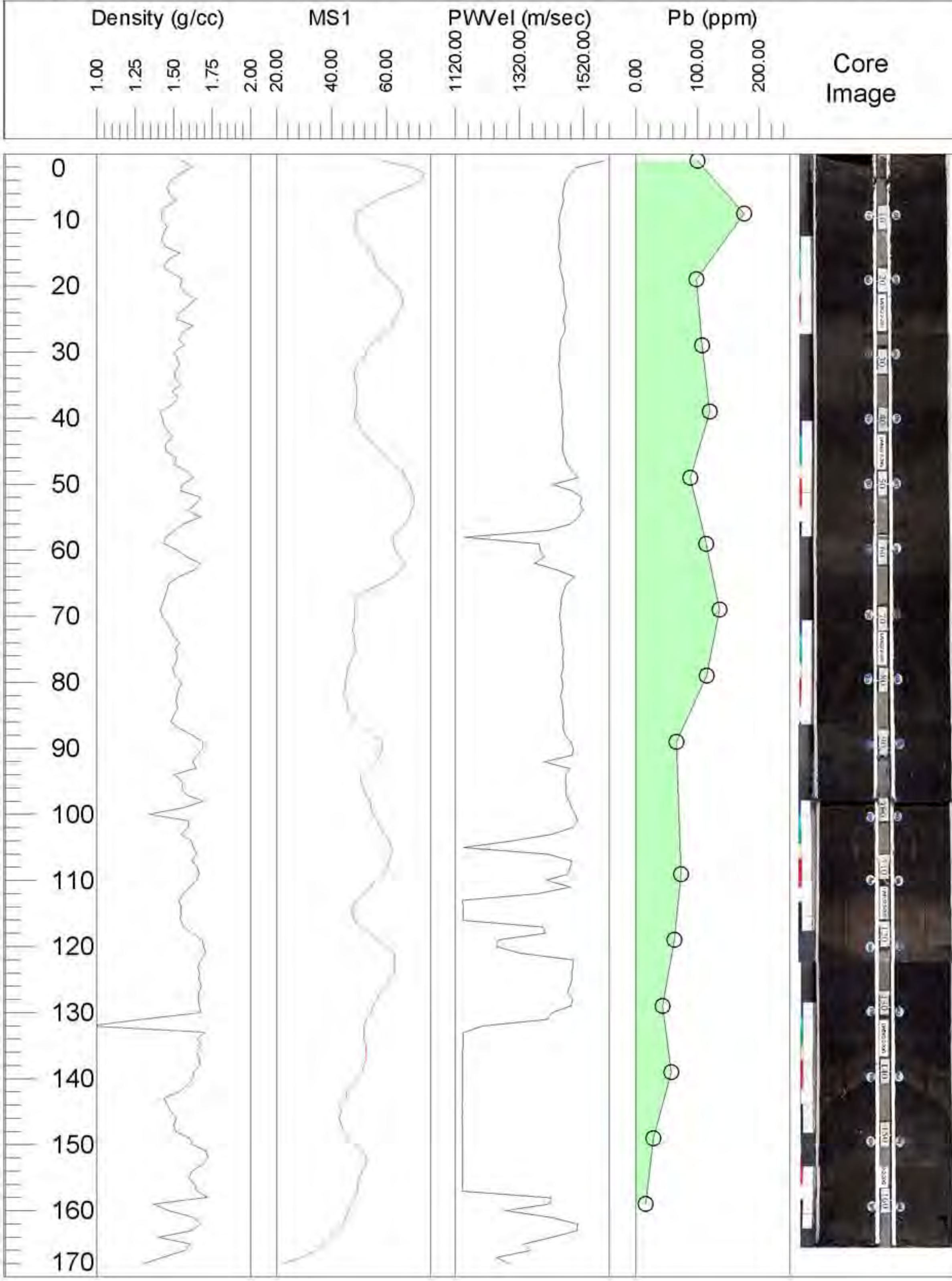
Attachment 1

Lamont-Dohery Earth Observatory

LWB2-20

Project Title: Assessment of the deposition of sediments impacted by Twentieth Century activities in the vicinity of the Tappan Zee Bridge

Project No.: EARTHT D213123 Principle Investigators: Timothy C. Kenna and Frank Nitsche



Lithology

TERRIGENOUS (BIOCLASTIC) CLAY [Clay], interbedded black (N2.5/) and black (5Y2.5/2); mottled at 70-86 and 120-165.6 cm; mottles of very dark grayish brown (2.5Y3/2) at 0-5, 98.5, 102-107, 140-146 and 158 cm; laminations of coarser sediment at 41, 49-56, 61-64, 98.5-122 and 133 cm, mottles of same throughout core; shell fragments at 93, 129, 135, 139, 142-150, 156 and 164 cm; pebbles at 89 cm; moist and pliable. Carbonate content is low. [15 cm sample] Coarse fraction 12 % consists of abundant quartz; trace opaque grains, mica, iron oxide stained grains, plant debris, framboidal pyrite, feldspar, pyroxene, hornblende, diatoms and garnet. [35 cm sample] Coarse fraction 6 % consists of abundant quartz; rare opaque grains; trace plant debris, mica, shell fragments, iron oxide stained grains, diatoms, framboidal pyrite, garnet, pyroxene, tourmaline and sponge spicules. Sampled at 15 cm [black (N2.5/)] and 35 cm [black (5Y2.5/2)].

Core ID:	LWB2-20	Latitude:	41° 4.124' N	Date Opened:	02/12/02
Core Length:	165.6 cm	Longitude:	73° 52.444' W	Date Photographed:	02/12/02
Collection Date:	09/05/01	PDR Depth:	2.4 m	Date Described:	02/12/02
				Described by:	N. Anest

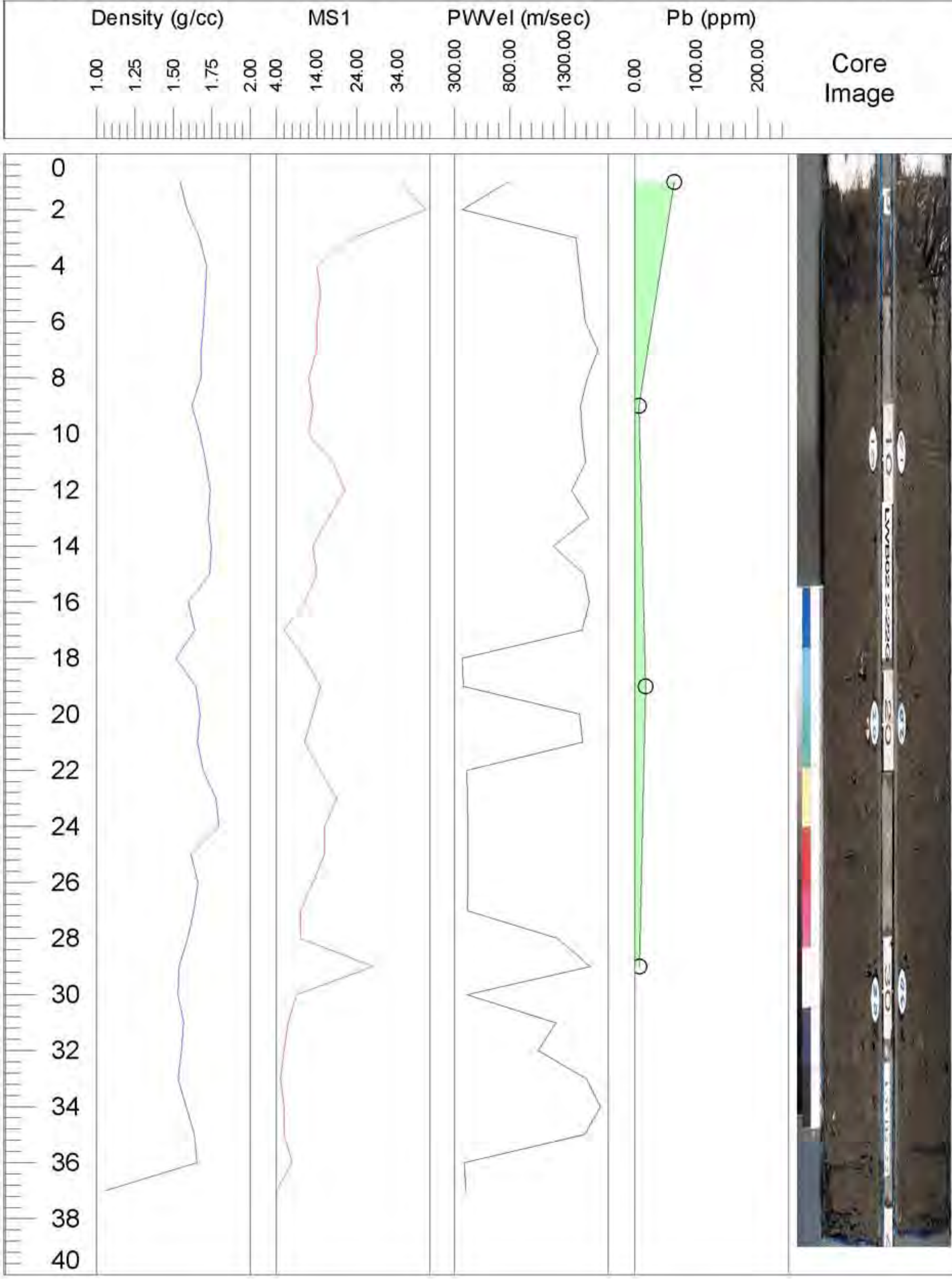
Lamont-Dohery Earth Observatory

LWB2-22

Project Title: Assessment of the deposition of sediments impacted by Twentieth Century activities in the vicinity of the Tappan Zee Bridge

Project No.: EARTHT D213123

Principle Investigators: Timothy C. Kenna and Frank Nitsche



Lithology

TERRIGENOUS (BIOCLASTIC) CLAY [Clay], very dark gray (2.5Y3/1); laminations of coarser sediment throughout core; shell fragments at 7, 17-23, 34 and 38 cm; mottle of dark gray (2.5Y4/1) at 16-23 cm; wet becoming moist and pliable. Carbonate content is low. Coarse fraction 5 % consists of abundant quartz; common plant debris; rare mica; trace feldspar, pyroxene, diatoms, glauconite, framboidal pyrite and garnet. Sampled at 15 cm.

Core ID:	LWB2-22	Latitude:	41° 4.131' N	Date Opened:	10/23/01
Core Length:	39 cm	Longitude:	73° 53.755' W	Date Photographed:	10/23/01
Collection Date:	9/8/01	PDR Depth:	3.0 m	Date Described:	12/26/01
				Described by:	N. Anest

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Université des Acadiens

MEMO

September 21, 2009

TO: EarthTech/AECOM

FROM: Don Hayes

RE: SedFlume Testing and Results

Note: A draft memo submitted on 8/31/09 included data from the SedFlume testing. Those data included a computation error in the conversion of flow rate in the SedFlume to shear stress. This memo corrects that error and should be used as the basis for all further sediment erosion discussions.

Sediment Characteristics

Four 5-gallon composite samples of fine-grained depositional sediment were collected from surface samples at multiple locations in two general areas along the Tappan Zee bridge construction site. These samples were sealed and shipped to the University of Louisiana at Lafayette in Spring 2009. Individual samples were collected from each container and their physical properties determined. The results are summarized in Table 1.

Table 1. Physical properties of Hudson River sediment samples.

Sample	Water Content (%)	Specific Gravity	Organic Content (%)	Atterberg Limits		Sieve Analysis		
				Plastic Limit	Liquid Limit	D_{10} (mm)	D_{50} (mm)	D_{90} (mm)
SF01 A	65.2	2.75	0.53%	30.2		0.11	0.17	0.25
SF01 B	61.0	2.50	3.10%	25.6		0.11	0.14	0.23
SF02 A/B	65.8	2.70	2.30%	29.3		0.11	0.14	0.25
SF02 B/C	65.1	2.70	2.29%	27.5		0.11	0.14	0.26

SedFlume Sample Preparation

Much of the written discussion on SedFlume testing describes erosion testing of core samples taken directly from the field. In these cases, the erosion rate of in situ sediment deposits is evaluated with depth. As sediment properties and densities change, erodibility changes as well. This type of testing also provides valuable information about likely scour depths for different events.

Since core samples were not available for this effort, the composite sediment samples from each general area were combined into single samples and homogenized. Sample SF01 was composed of equal volumes from SF01A and SF01B. Sample SF02 was composed of equal volumes from SF02 A/B and SF02 B/C. The water content of composite samples SF01 and SF02 were 65.4% and 60.5%, respectively. Reconstituted core samples were constructed such that the sediment characteristics and water contents were consistent throughout the core depth. Since sediments in the wide, shallow areas of the Hudson River in the vicinity of the TZB tend to be quite homogeneous with depth, the vertical variations in erodibility should be less significant.

SedFlume Testing

The SedFlume is a straight rectangular flume made from plexiglass sheets with an internal cross section of 50.8 mm in height by 106.7 mm in width; it is 244 cm in length. Water is pumped from a 140 gallon storage tank, through a two inch diameter pipe into the SedFlume. Flow is regulated by a three way valve, allowing a portion of the water to flow through the flume and the excess to return to the tank. A gradually widening inlet section straightens flow and assures uniform, turbulent flow as the water enters the SedFlume channel. The channel has a rectangular opening in its bottom located 120 cm from the entrance through which a sediment core can be inserted for testing. An outlet section and two-inch pipe carry the flow back to the tank for recirculation. The sediment core is housed in a rectangular tube with a 9.0 cm by 14.2 cm horizontal cross section and is 50 cm in length attached beneath the SedFlume. Top and cross section views of the Sedflume and sediment core tube are shown in Figure 1.

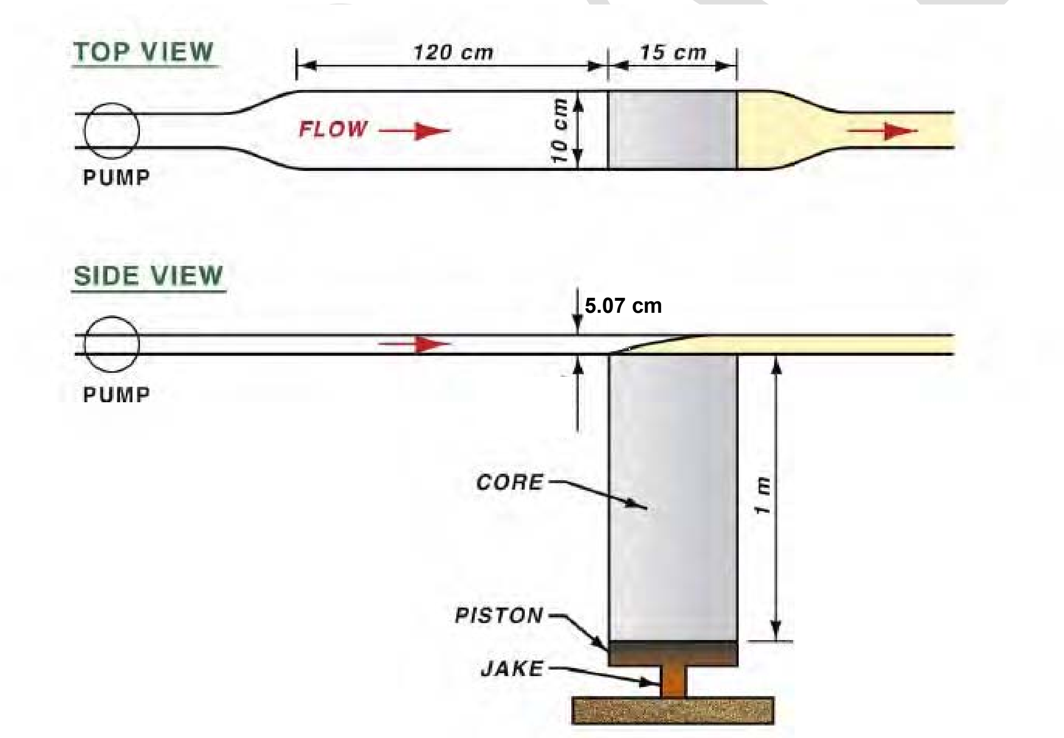


Figure 1. SedFlume schematic.

Reconstituted sediment samples from one location, either SF01 or SF02, were prepared and placed in the sediment core tube. Care was taken to ensure consistency between tests and vertically within each core sample. About 20 cm of sediment was used for each sample.

All SedFlume tests were started with the sediment core well below the flume base until the desired flow was established. Flow meters were used to estimate flow rates, but the actual flow rate was measured based upon the time to fill a 35-gallon container. The flow for incipient erosion was determined by first establishing a flow rate less than required for erosion. Then, the piston was used to raise the sediment sample so the sediment surface was even with the bottom flow surface of the SedFlume. Flow was gradually increased until incipient erosion was noted and the flow rate measured.

Erosion rate tests were conducted by first establishing the desired flow in the SedFlume with the sediment surface below flow path. Once the proper flow was established, the sediment core was raised manually using the piston until the sediment surface was even with the bottom flow surface of the SedFlume. As flow eroded sediment from the core, it was raised to maintain the sediment surface even with the bottom flow surface. This continued until the water became too turbid to see the sediment level in the flume. Most of these tests lasted about 10 minutes in an attempt to overcome any errors that might result from either raising the sediment level too fast (resulting in increased erosion rate) or too slow (resulting in less erosion). The sediment erosion rate was recorded as the average erosion over the testing period; e.g. 10 cm of erosion over a 10 minute test would yield an erosion rate of 10 cm/minute.

A few SedFlume tests were also conducted on sediment from SF01 and SF02 at two increased water contents.

Shear Stress Calculations

The primary purpose of the SedFlume tests is to understand the relationship between velocity and sediment erosion. Shear stress is the primary cause of erosion; thus, it is useful to estimate the shear stress experienced by the sediment during the SedFlume testing. This shear stress can be estimated as (Gailani 2001):

$$\tau = f\left(\frac{\rho_w U^2}{8}\right)$$

where τ = wall shear stress (N/m^2), f = friction factor (dimensionless), ρ_w = density of water (kg/m^3), and U = average velocity (m/sec). The friction factor can be computed using the Colebrook-White formula (Walski 2003):

$$\frac{1}{\sqrt{f}} = -0.86\ln\left[\frac{\varepsilon}{3.7D} + \frac{2.51}{R_e\sqrt{f}}\right]$$

where ε = roughness of SedFlume surface (m), D = hydraulic diameter (m), and R_e = Reynolds number. The SedFlume is acrylic, but its surface is similar to that of PVC pipe; Walski (2003) suggests that a reasonable value for roughness, ε, in a PVC pipe is 1.5 x 10^{-6} m. Reynolds number can be computed as:

$$R_e = \frac{UD}{\upsilon}$$

where υ = kinematic viscosity (m^2/sec). The kinematic viscosity of water at 20°C is 1.004 x 10^{-6} m^2/sec and is reasonably representative of the conditions during the testing. The hydraulic diameter of the SedFlume's rectangular cross section is defined as:

$$D = \frac{2hw}{h + w}$$

where w = flow width(m), h = wall height(m). Internal dimensions of 50.8 mm in height by 106.7 mm in width yields a hydraulic diameter of 68.8 mm. Average velocities greater than 0.06 m/sec are adequate to produce turbulent flow ($R_e > 4000$).

SEDFLUME Results

SEDFLUME tests were conducted in the UL Hydraulics Laboratory during July and August 2009 on the two composite reconstituted Hudson River sediment samples, SF01 and SF02. Using sediment samples allowed each sample to be tested over a range of flow rates and tests to be repeated as necessary. The SedFlume results are summarized in Tables 2 and 3.

Table 2. SedFlume results for Hudson River sediment sample SF 01

Measured Flow Rate (GPM)	Measured Erosion Rate (cm/min)	Flow Rate (ft^3/sec)	Flow Rate (L/sec)	Velocity (ft/sec)	Velocity (m/sec)	Friction Factor (unitless)	Shear Stress (Pa)
Water content = 65.4%							
57.4	0.00	0.128	3.62	2.19	0.669	0.0218	1.21
58.2	0.19	0.130	3.68	2.22	0.678	0.0217	1.24
59.1	0.33	0.132	3.73	2.26	0.689	0.0216	1.28
60.8	0.53	0.136	3.84	2.32	0.708	0.0215	1.34
62.9	1.07	0.140	3.97	2.40	0.733	0.0213	1.43
65.2	1.62	0.145	4.18	2.49	0.760	0.0212	1.52
67.4	4.10	0.150	4.26	2.57	0.785	0.0210	1.62
Water content = 67.1%							
62.9	2.47	0.140	3.97	2.40	0.733	0.0213	1.43
Water content = 71.0%							
62.9	3.50	0.140	3.97	2.40	0.733	0.0213	1.43

Table 3. SedFlume results for Hudson River sediment sample SF 02

Measured Flow Rate (GPM)	Measured Erosion Rate (cm/min)	Flow Rate (ft^3/sec)	Flow Rate (L/sec)	Velocity (ft/sec)	Velocity (m/sec)	Friction Factor (unitless)	Shear Stress (Pa)
Water content = 60.5%							
55.3	0.00	0.123	3.49	2.11	0.644	0.0219	1.14
57.5	0.10	0.128	3.63	2.20	0.670	0.0217	1.22
59.3	0.16	0.132	3.74	2.27	0.691	0.0216	1.29
62.0	0.46	0.138	3.92	2.37	0.722	0.0214	1.39
65.5	0.56	0.146	4.14	2.50	0.763	0.0211	1.54
67.8	0.68	0.151	4.28	2.59	0.790	0.0210	1.63
69.1	0.82	0.154	4.36	2.64	0.805	0.0209	1.69
70.8	1.08	0.158	4.47	2.70	0.825	0.0208	1.76
72.7	1.28	0.162	4.59	2.78	0.847	0.0207	1.85
73.2	1.73	0.163	4.62	2.80	0.853	0.0206	1.87
75.9	3.12	0.169	4.79	2.90	0.884	0.0205	2.00
77.7	4.07	0.173	4.91	2.97	0.905	0.0204	2.08
Water content = 63.0%							
70.8	2.14	0.1578	4.471	2.70	0.825	0.0208	1.76
Water content = 65.3%							
70.8	3.40	0.1578	4.471	2.70	0.825	0.0208	1.76

Analysis of SedFlume Results

Critical Velocity and Critical Shear Stress. SedFlume results allow direct observation of the critical velocities and critical shear stresses required to induce incipient erosion in the two samples tested. Those are:

	Sample SF01	Sample SF02
Critical Velocity, V* (m/s)	0.669	0.644
Critical Shear Stress, τ* (Pa)	1.21	1.14

Given the accuracy of the testing approach and potential variability in sediment characteristics, it seems wise to take the critical velocity of the sediments to be 0.64 m/s and the critical shear stress to be 1.1 Pa.

Erosion Rate versus Shear Stress. Most previous analyses of SedFlume results used linear regression to fit the data to a curve of the form:

$$E = a\tau^{n}$$

where E = erosion rate (cm/min); a and n are regression coefficients. Figure 2 shows the regression results for the data in Tables 2 and 3.

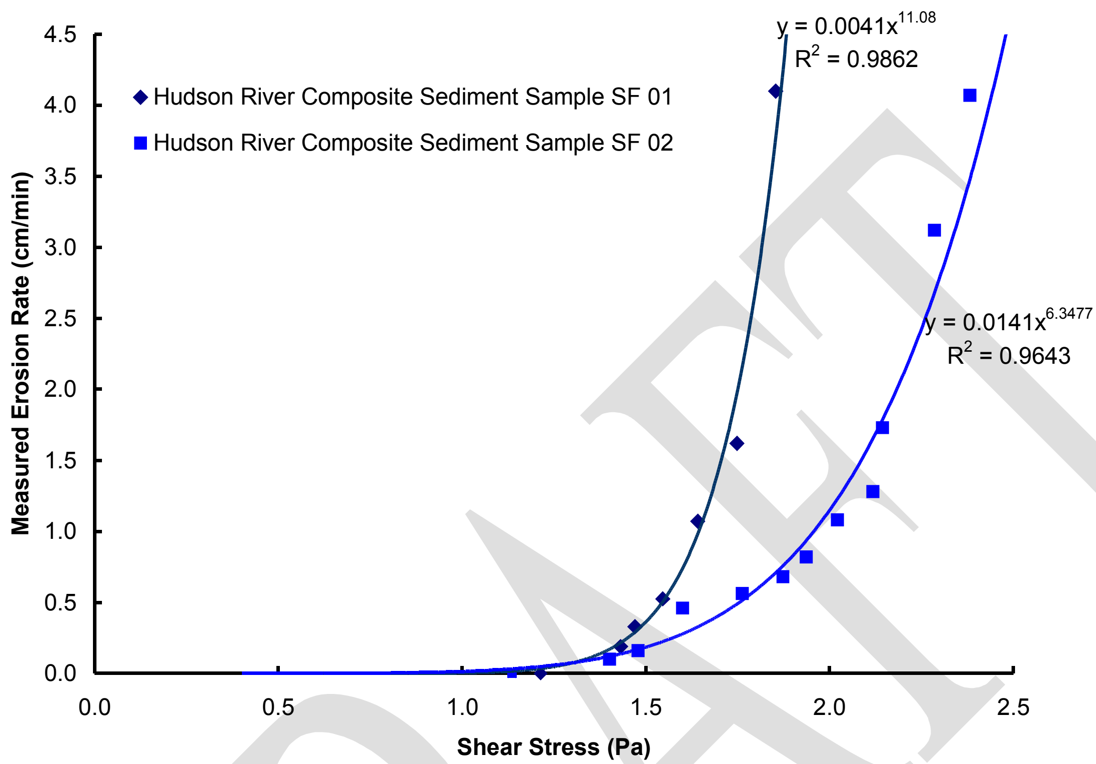


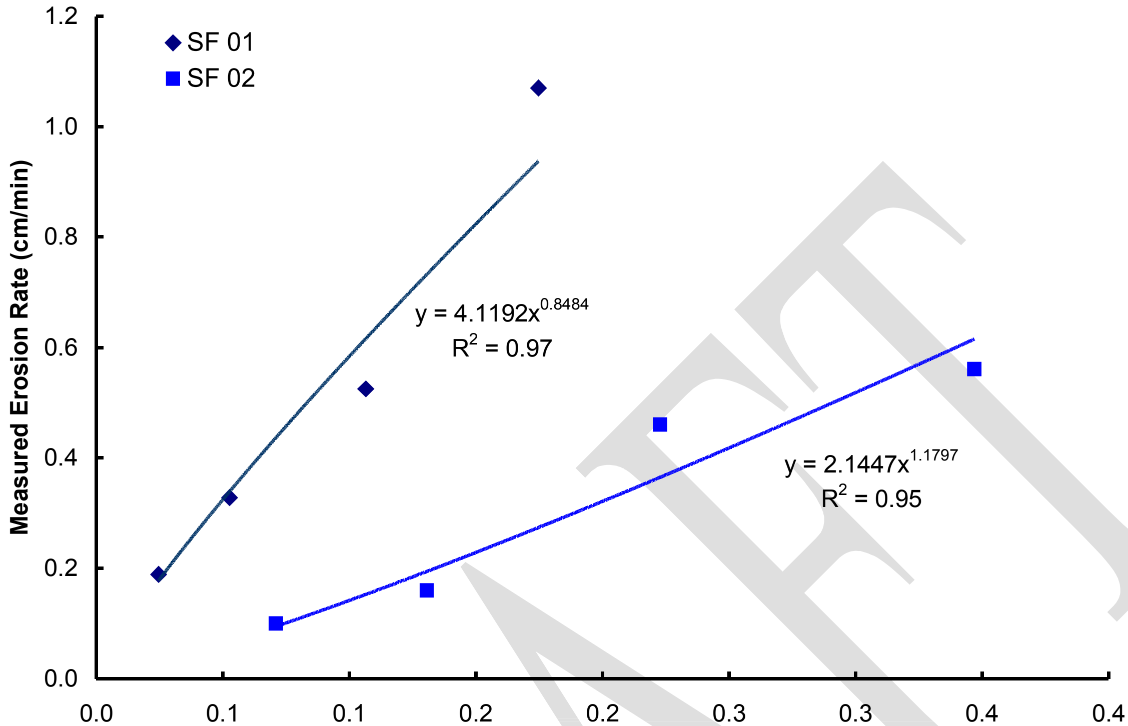
Figure 2. Measured erosion rate versus shear stress from SedFlume testing on two Hudson River sediments.

The regression results in Figure 2 show strong correlation coefficients. The resulting equations also fit the data well. However, the large exponents in the resulting equations require caution not to apply them outside of the range of available data. Care should especially be taken not to use the equations for shear stresses less than the critical shear stress since the equations will errantly give a small amount of erosion at any shear stress.

Gailani (2001) indicated that it is also possible to fit data for moderate shear stresses (< 1.5 Pa) to the equation:

$$E = a\left(\frac{\tau - \tau^*}{\tau^*}\right)^n$$

Figure 3 shows the data that fit the criteria and the resulting regression results.



$$\frac{\tau - \tau^*}{\tau^*}$$

Figure 3. Erosion rate versus relative shear stress.

References

Borrowman, T.D.; Smith, E.R.; Gailani, J.Z., and Caviness, L. 2006. "Erodibility Study Of Passaic River Sediments Using USACE Sedflume," US Army Engineer Research and Development Center, Vicksburg, MS, June 2006.

Gailani, J. Z., Kiehl, A., McNeil, J., Jin, L. and Lick, W. (2001). "Erosion rates and bulk properties of dredged sediments from Mobile, Alabama," *DOER Technical Notes Collection* (ERDC TN-DOER-N10), U.S. Army Engineer Research and Development Center, Vicksburg, MS. *www.wes.army.mil/el/dots/doer*

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MEMO

September 28, 2009

TO: EarthTech/AECOM

FROM: Don Hayes

RE: Estimating water quality impacts from construction vessel traffic

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A draft memo was submitted on 8/31/09 that discussed water quality impacts from prop wash and dredging operations. This memo supersedes that discussion on prop wash; the prior draft memo should no longer be used.

Previous bridge construction projects have noted construction vessel traffic as a contributor to water quality impacts. This is a concern since a new Tappan Zee Bridge (TZB) will involve extensive on-water construction activity. Personnel, equipment, and materials will be moved using barges and tugs from shoreline docks and the navigation channel side to construction locations along the bridge alignment. The construction schedule will result in extensive waterborne vessel traffic.

The Hudson River bathymetry is relatively shallow outside of the navigation channel, gradually rising from about 12 to 14 ft near the banks of the navigation channel to 2 to 3 feet at the shoreline, with most of the area west of the channel being 10 to 12 ft deep. The bottom sediments in these areas are soft silts. SedFlume testing of these sediments showed they begin to erode at shear stress of 1.14 Pa which occurred at a velocity of 0.64 m/s.

This memo combines the SedFlume results with models of propeller-induced shear stress to assess the potential for sediment scour and resulting water quality impacts.

Prop-wash Models

Bottom Shear Stress. Maynord (2000) indicated that the bed shear stress (t) should be calculated as:

$$\tau = 0.5\rho_w C_{fs} V_{prop}^2$$

where
τ = bed shear stress (Pa)
ρ_w = density of water (kg/m^3)
C_{fs} = bottom friction factor for propeller wash (dimensionless)

V_{prop} = bottom velocity due to propeller wash, as calculated previously.

Shear stress and bottom friction factor should consider both propeller velocity and vessel wake velocity. However, tugs and barges associated with the construction project should be maneuvering at low speeds resulting in minimal wake affects. Thus, the bottom friction factor for propeller wash should be computed as (Maynord 2000):

$$C_{fs} = 0.01\left(\frac{D_p}{H_p}\right)$$

where
D_p = propeller diameter (m)
H_p = distance from propeller centerline to the sediment surface (m)

Propeller-induced Velocities at Sediment Surface. While other models of propeller induced velocities exist, those presented in Maynord (2000) seem most applicable to the TZB project. Many tugs have two engines and propellers, located equidistant on either side of the tug centerline. The velocity fields immediately behind the propellers act independently, but eventually join to create a single flow field.

Maynord designated the region nearest the propeller where each engine creates its own velocity field as Zone 1. The empirical equation for spatial velocity distribution in Zone 1 is provided in Figure 1. Maynord indicated that this equation is applicable from just beyond the propeller to a distance of about ten propeller diameters ($Xp \leq 10\ D_p$).

Somewhere beyond Zone 1, the independent velocity fields of the two propellers begin to merge. Maynord (2000) presents the model shown in Figure 2 for this region, denoting it as Zone 2. Maynord notes that the models are the weakest in the vicinity of the transition which occurs at about $Xp = 10\ D_p$.

Model Application

The models were applied using the basic physical characteristics of Weeks Marine's tug Elizabeth and SedFlume data on composite sediment samples collected from the Hudson River in the vicinity of the TZB construction. The Elizabeth is one of the tugs provided by ARUP as an example of what might be used during the TZB project. Although smaller tugs may end up being used in the actual vicinity of the construction, the Elizabeth will serve to illustrate the model application.

Figure 3 shows maximum propeller-induced velocities along the sediment surface at a range of applied powers and depth between the propeller shaft and sediment surface (H_p). The resulting curves show that the maximum induced velocity along the sediment surface in Zone 1 varies little with Hp, but reduce significantly as the applied power reduces.

$$^{Z1}V(X_p, Y_{cl}) = 1.45 V_2 \left(\frac{X_p}{D_p}\right)^{-0.524} \left(\exp\left(-15.4\frac{R_1^2}{X_p^2}\right) + \exp\left(-15.4\frac{R_2^2}{X_p^2}\right)\right)$$

where

$$V_2 = \frac{1.13}{D_0}\sqrt{\frac{T}{\rho_w}}$$

$$R_1^2 = \left(Y_{cl} - 0.5W_p\right)^2 + \left(H_p - C_j\right)^2$$

$$R_2^2 = \left(Y_{cl} + 0.5W_p\right)^2 + \left(H_p - C_j\right)^2$$

$$C_j = -\left[0.213 - 1.05\left(\frac{C_p g}{V_2^2}\right)\left(X_p - 0.5L_{set}\right)\right]\left(X_p - 0.5L_{set}\right)$$

Kort Nozzle Propeller	**Open Nozzle Propeller**
$C_p = 0.04$	$C_p = 0.12\left(\frac{D_p}{H_p}\right)^{0.67}$
$D_0 = D_p$	$D_0 = 0.71D_p$
$EP = 31.82P_{hp}^{0.974} - 5.4V_w^2 P_{hp}^{0.5}$	$EP = 23.57P_{hp}^{0.974} - 2.3V_w^2 P_{hp}^{0.5}$

X_p= Distance behind the propeller (m)
D_p= Propeller diameter (m)
W_p= Distance between propellers (m)
L_{set}= Distance from ship stern to propeller (m)
H_p = Distance from center of propeller axis to channel bottom (m)
Y_{cl} = Lateral distance from ship centerline (m)
C_j = vertical distance from propeller shaft to location of maximum velocity within the jet (m)
g = acceleration of gravity (m/s^2)
T = Thrust (N)
ρ_w=Density of water (kg/m^3)
EP= Effective Push (equivalent to thrust) from both propellers (N)
P_{hp}= Total ship power (hp)
V_w= Ship speed relative to water, 0 for stationary vessels (m/s)

Figure 1. Maynord (2000) model for propeller-induced flow at the sediment surface within Zone 1 (≤ 10 D_p) of the propeller.

$$^{Z1}V\left(X_p, Y_{cl}\right) = 0.34V_2\left(\frac{D_p}{H_p}\right)^{0.93}\left(\frac{X_p}{D_p}\right)^{0.24} C_1 \exp\left[-0.0178\frac{X_p}{D_p} - \frac{Y_{cl}^2}{2C_{z2}^2 X_p^2}\right]$$

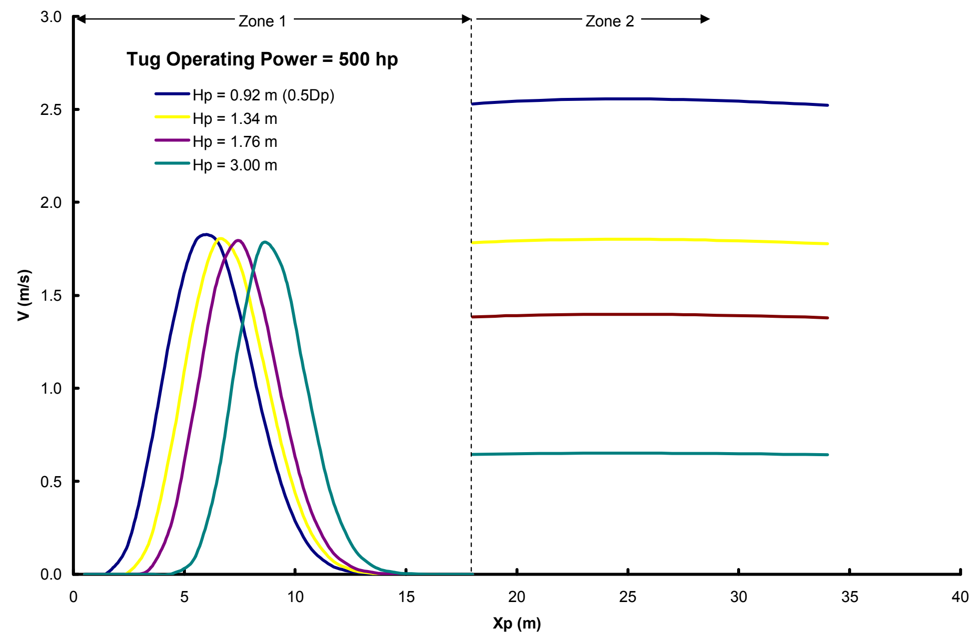
Where:
C_1 = 0.66 for open-wheeled propeller; 0.85 for Kort nozzle propeller
$C_{Z2} = 0.84\,(X_p/D_p)^{-0.62}$

Figure 2. Maynord (2000) model for propeller-induced flow at the sediment surface within Zone 2 ($\geq 10\ D_p$) of the propeller.

Table 1. Properties of assumed tug operations, taken primarily from Weeks Marine's tug Elizabeth

Description	Notation	Value	Comment
Available specifications			
Tugboat Length	**L_{tb} (m)**	23.50	
Engines		2	
Engine Power (per engine)	**HP (horsepower)**	900	
Diameter of Propellers	**D_p (m)**	1.83	
Propeller Type	**Open/Kort**	Kort	
Tug Draft Depth	**H_d (m)**	3.23	
Boat Width/Beam	**W_b (m)**	7.93	
Assumed or calculated specifications			
Propeller Axis Depth	**Z_p (m)**	4.15	Estimated as ($H_d + 0.5D_p$)
Distance Between Propellers	**W_p (m)**	2.64	Estimated as $W_b/3$
Distance From Stern to Propeller	**L_{set} (m)**	2.35	Assumed
Boat Speed	**V_w (m/s)**	1.00	Assumed

Zone 2 velocities vary less with distance and a similar variation with power. However, they also show a significant variation with variations in H_p. This variation seems to be in contradiction to the Zone 1 model.



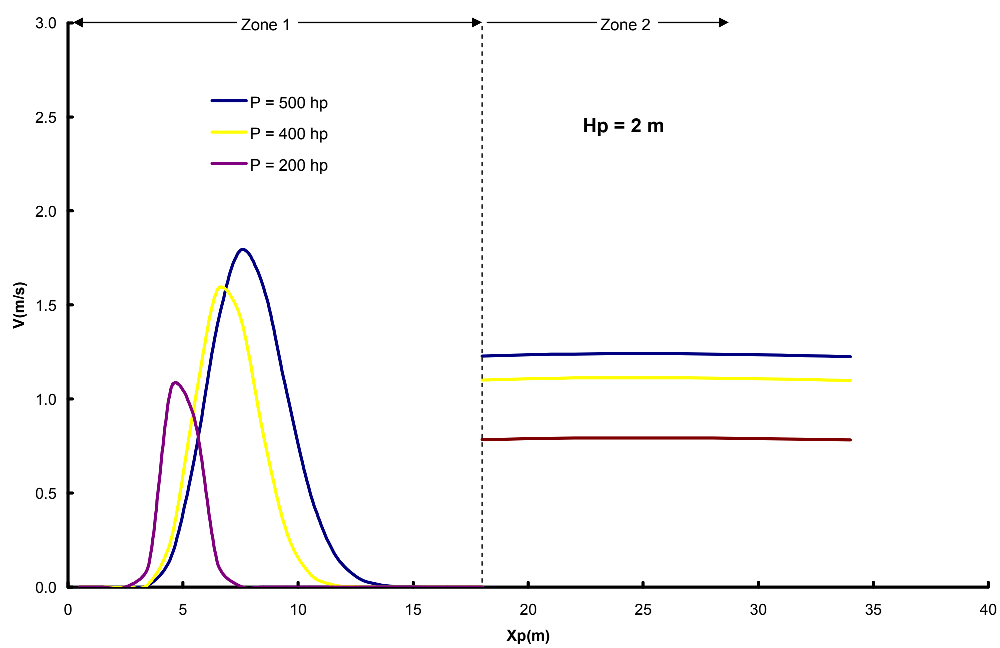


Figure 3. Maximum propeller-induced velocities along the sediment surface as they vary with applied power and height of the propeller shaft above the sediment (H_d).

$$\frac{\partial V_1}{\partial X_p} = -0.524 A X_P^{-1.524}\left(e^{\frac{-15.4R_1^2}{X_P^2}} + e^{\frac{-15.4R_2^2}{X_P^2}}\right) +$$

$$\left(AX_P^{-0.524}\right)\left(\frac{-15.4(\frac{\partial R_1^2}{\partial X_p}X_p - 2R_1^2)}{X_P^3}e^{\frac{-15.4R_1^2}{X_P^2}} + \frac{-15.4(\frac{\partial R_2^2}{\partial X_p}X_p - 2R_2^2)}{X_P^3}e^{\frac{-15.4R_2^2}{X_P^2}}\right)$$

where

$$A = 1.45V_2D_p^{0.524}$$

$$\frac{\partial R_i^2}{\partial X_p} = -2\left(H_p - C_i\right)\left[\frac{8.1\rho_w D_o^2 C_p}{T}\left(X_p - 0.5L_{set}\right) - \left(0.213 - \frac{8.1\rho_w D_o^2 C_p}{T}\left(X_p - 0.5L_{set}\right)\right)\right]$$

$$\frac{\partial C_i}{\partial X_p} = \left(\frac{8.1\rho_w D_o^2 C_p}{T}\right)\left(X_p - 0.5L_{set}\right) - \left(0.213 - 8.1\frac{\rho_w D_o^2 C_p\left(X_p - 0.5L_{set}\right)}{T}\right)$$

Figure 4. First derivative of the velocity equation with respect to X_p used to compute X_p*.

Model Application

Erosion begins when sediment experiences the critical shear stress, τ_c, at the surface due to water movement at the interface. Keeping the shear stress associated with the peak velocity (see Figure 3) less than the critical shear stress will ensure that erosion does not occur. Thus, the application of the models described above should focus on determining minimum water depth and maximum applied power necessary to maintain peak velocities below that associated with the critical shear stress. This section describes the approach to generate a simple graphical representation of this relationship.

The downstream location of the peak velocity, X_p*, can be determined by solving for X_p at

$$\frac{\partial V}{\partial X_p} = 0$$

The resulting equations are shown in Figure 4. Although these equations are somewhat cumbersome, they are easily solvable with EXCEL or other computational software for known values of T and H_b.

In this case, we are interested in the velocity that will generate the critical shear at the sediment surface. The equation presented previously can be rearranged to yield that velocity:

$$V_c = \sqrt{\frac{\tau_c}{0.5\rho_w C_{fs}}}$$

For this velocity, unique combinations of applied power and H_p that satisfy the equations for V (provided in Figure 1) and $\partial V/\partial X_p = 0$ represent operational conditions that produce the critical shear stress. Thus, any values above this function represent scour conditions while values beneath the function represent acceptable operational conditions. Figure 5 shows the results of this analysis in the form of minimum water depth versus applied horsepower necessary.

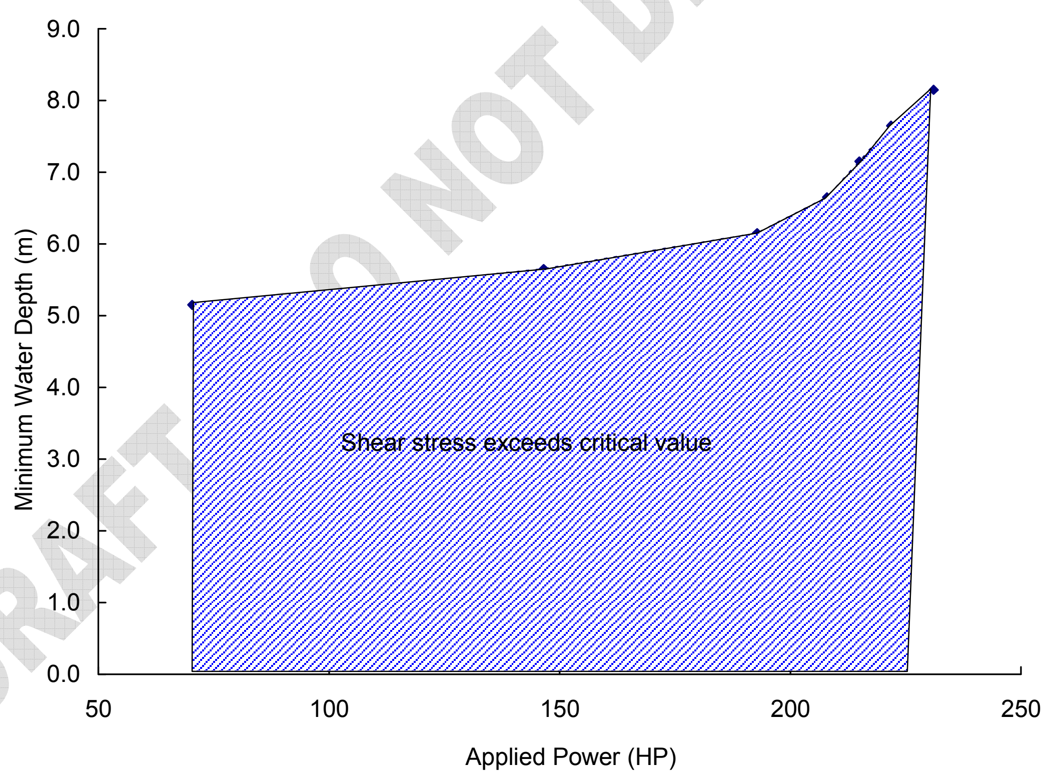


Figure 5. Minimum water depth versus horsepower to avoid sediment erosion. NOT CURRENTLY FOR DISTRIBUTION.

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MEMO

September 27, 2010

TO: Kevin Koning, AECOM

FROM: Don Hayes, Institute for Coastal Ecology and Engineering

RE: Overview of Tappan Zee Bridge Sediment Resuspension Rate Findings

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This memo provides preliminary estimates of water quality impacts associated with reconstruction of the Tappan Zee Bridge for use in the Environmental Impact Statement (EIS) Analyses. The primary water quality concerns are anticipated to result from suspending bottom sediments during dredging, driving piles, sheet pile installation, vessel movement, and cofferdam dewatering for pier construction. This document summarizes our best estimates of sediment suspension rates associated with these activities.

Bottom Sediment Characteristics

Hudson River bottom sediments in the vicinity of the Tappan Zee Bridge are mostly clayey silts. Soil tests showed an average water content of 64%, specific gravity of 2.66, and 2% organic content. SedFlume tests showed the sediments are highly erodible and most areas do not have a distinguishable bedrock layer near the sediment surface.

Resuspension Due to Dredging

Bridge construction and demolition will involve an array of vessels with drafts significantly greater than available water depth. Anticipated characteristics of the access channel are stated in *Replacement Bridge: Hudson River Construction* include:

- Construction access channel will be dredged to an elevation of -17.89 feet NAVD88.
- Demolition access channel will be dredged to an elevation of -14.89 feet NAVD88.
- Sediment volume to be dredged is approximately 1.77 million cubic yard
- Clamshell dredges will be used with environmental (closed) buckets.
- Each dredged will remove an average of 7,500 cubic yards/day.

- Two dredges will operate concurrently during portions of the operation to expedite construction yielding a typical daily sediment removal rate of 15,000 cubic yards.

Sediment resuspension during dredging has been a topic of substantial interest. Hayes and Wu (2001) summarized loss rates from environmental clamshell buckets. Based upon that data, loss rates for clamshell bucket dredges have been observed to range between 0.16% and 0.88%. The highest values are associated with open clamshell buckets with substantial overflow from adjacent barges. This suggests that the resuspension for this project should be on the lower side since environmental clamshell buckets will be used and barge overflow will not be allowed. However, SedFlume results of these sediments in the channel areas showed that they are more susceptible to resuspension than most. Synthesizing all of these factors, an estimate of 1% sediment resuspension loss is recommended to provide an adequate degree of conservatism in estimated impacts. Thus, the average sediment resuspension rate for each dredge is estimated as:

$(g_d)_{avg}$ = (7,500 yd^3/day) (1 m^3/1.3 yd^3)(980 kg/m^3)(0.01)(1 d/1440 min) = 39 kg/min

Short-term production rate estimate:

Assuming a 25 cy bucket @ 2 minute cycle times = 12.5 cy/min

$(g_d)_{max}$ = (12.5 cy/min) (1 m^3/1.3 yd^3)(980 kg/m^3)(0.01) = 94 kg/min

<u>Vessel Movement</u>

Bridge construction and demolition activities will require frequent tug operations and barge movements along the dredged channels throughout the construction period. Larger tugs than usual are being planned for because of potential safety concerns working upstream of the existing bridge. Weeks Marine recommended tugs similar to their 1,400 HP Virginia tug and the 1,800 HP Shelby tug for prop scour analyses. Scour modeling results for these vessels showed the potential for substantial sediment scour while operating over the soft bed sediments of the site. Thus, the channel design was modified to accommodate armoring of the channel bed and the side slopes. This armor will prevent bottom sediments scour during vessel operations. Thus, the only sediment available for scour will be freshly deposited from upstream currents.

Current sediment accumulation in the area is very limited, i.e. the streambed is near equilibrium depth. However, the dredged channel will act as a sediment trap increasing the deposition rate. Several water sampling efforts were undertaken in 2007 and 2008 in the construction area. Grab samples ranged in TSS from 13 mg/L to 111 mg/L with an average of 30 mg/L.

A trap efficiency of 5% is recommended based upon an analysis using the work of van Rijn (1986). Since the channel lays normal to the flow and resuspension is expected along the length of the channel, the source rate per unit length can be estimated as:

$g_{scour} = \varepsilon V_{avg} h_0 c_{avg} = 0.05(0.4 \text{ m/s})(2 \text{ m})(30 \text{ g/m}^3)(1 \text{ kg}/1000 \text{ g})(86400 \text{ s/d}) = 104 \text{ kg/m/d}$

where g = sediment resuspension rate, kg/m/sec; ε = trap efficiency, dimensionless; V_{avg} = depth averaged velocity upstream of the channel, m/sec; h_0 = upstream water depth , m; and c_{avg} = depth-averaged TSS concentration upstream of the channel.

Since the rate of scour is based upon daily sedimentation rate, it should be proportioned according to anticipated work day. For example, if vessel movement is anticipated only over a 12 hour work day, the hourly scour rate would be:

$g_{scour} = 104 \text{ kg/m/d } (1 \text{ d}/12 \text{ hr}) = 8.7 \text{ kg/hr}$

Similar proportions should be used for other workday schedules.

Bridge Construction Activities

In-water specific bridge construction activities also have the potential to resuspend sediments and impair water quality. The primary construction activities of concern are sheet pile installation, dewatering of cofferdams during pier construction, and pile driving activities. An extensive literature search was undertaken to identify previous estimates for sediment resuspension rates associated with these activities or available data to develop estimates. No previous estimates were identified, but data from several bridge construction projects were found. The most comprehensive and applicable data set was from the San Francisco-Oakland Bay Bridge East Span Seismic Safety Project. Thousands of water quality measurements – mostly turbidity – were taken during various aspects of this project including dredging, sheet pile installation, cofferdam dewatering, and pile driving. These were reported in routine water quality monitoring reports[1]. Unfortunately, velocity data were not collected in conjunction with these measurements, so they cannot be immediately converted to resuspension rates.

After a number of approaches were considered, the best approach is thought to be a comparison of these activities to dredging. The average suspended sediment concentrations above ambient observed were:

Activity	**Avg TSS, mg/L**	**Relative to Dredging**
Dredging	5.1 mg/L	1.0
Sheet Pile Installation	1.3 mg/L	0.3

[1] San Francisco-Oakland Bay Bridge, 2002-2008 Water Quality Report, found online at (http://biomitigation.org/reports/default.asp?page_size=10&page_no=2&sort_field=@publishdate&sort_order=descending&date=&subject=&location=&type=OTD Westbound Water Quality November 2008.pdf)

Pier Installation (pile driving and dewatering)	2.0 mg/L	0.4

Since these are based upon average values of numerous water quality observations, it is most appropriate to apply these values to the average daily dredged production rate. The resulting estimates are:

g_{sp} = 39 kg/min (0.3) = 12 kg/min

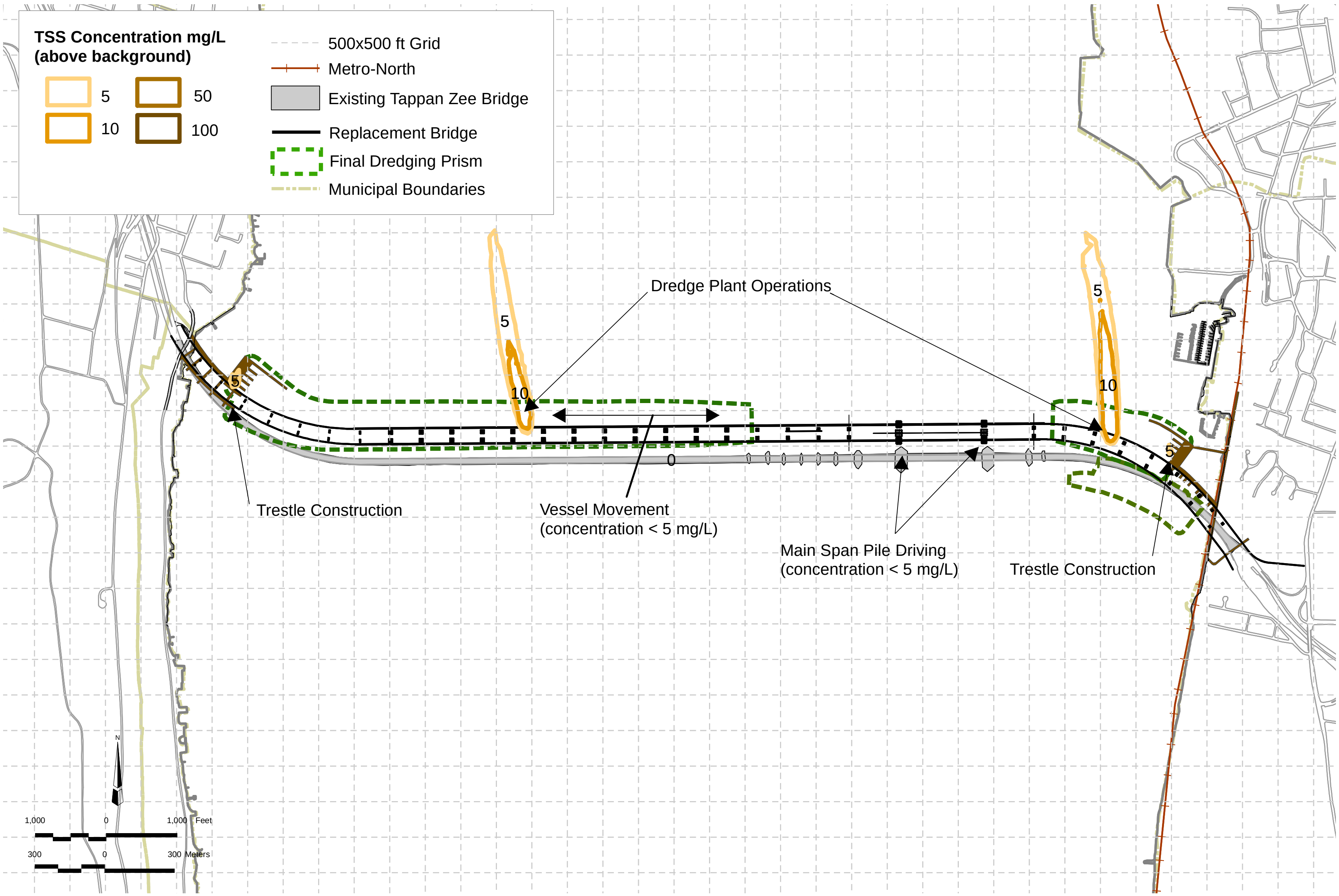
g_{pier} = 39 kg/min (0.4) = 16 kg/min

References

Hayes, Donald and Wu, Pei-Yao (2001). "Simple Approach to TSS Source Strength Estimates," *Proceedings of the WEDA XXI Conference*, Houston, TX, June 25-27, 2001.

van Rijn, Leo C. 1986. "Sedimentation of Dredged Channels by Currents and Waves," *Journal of Waterway, Port, Coastal, and Ocean Engineering*, Vol. 112, No. 5, September, 1986.

Attachment 5



TAPPAN ZEE HUDSON RIVER CROSSING
Environmental Impact Statement

Figure 1

Projected Total Suspended Sediment Concentration for the Long Span Replacement Bridge Option During Stage 1 Dredging -- Flood Tide

Attachment 5

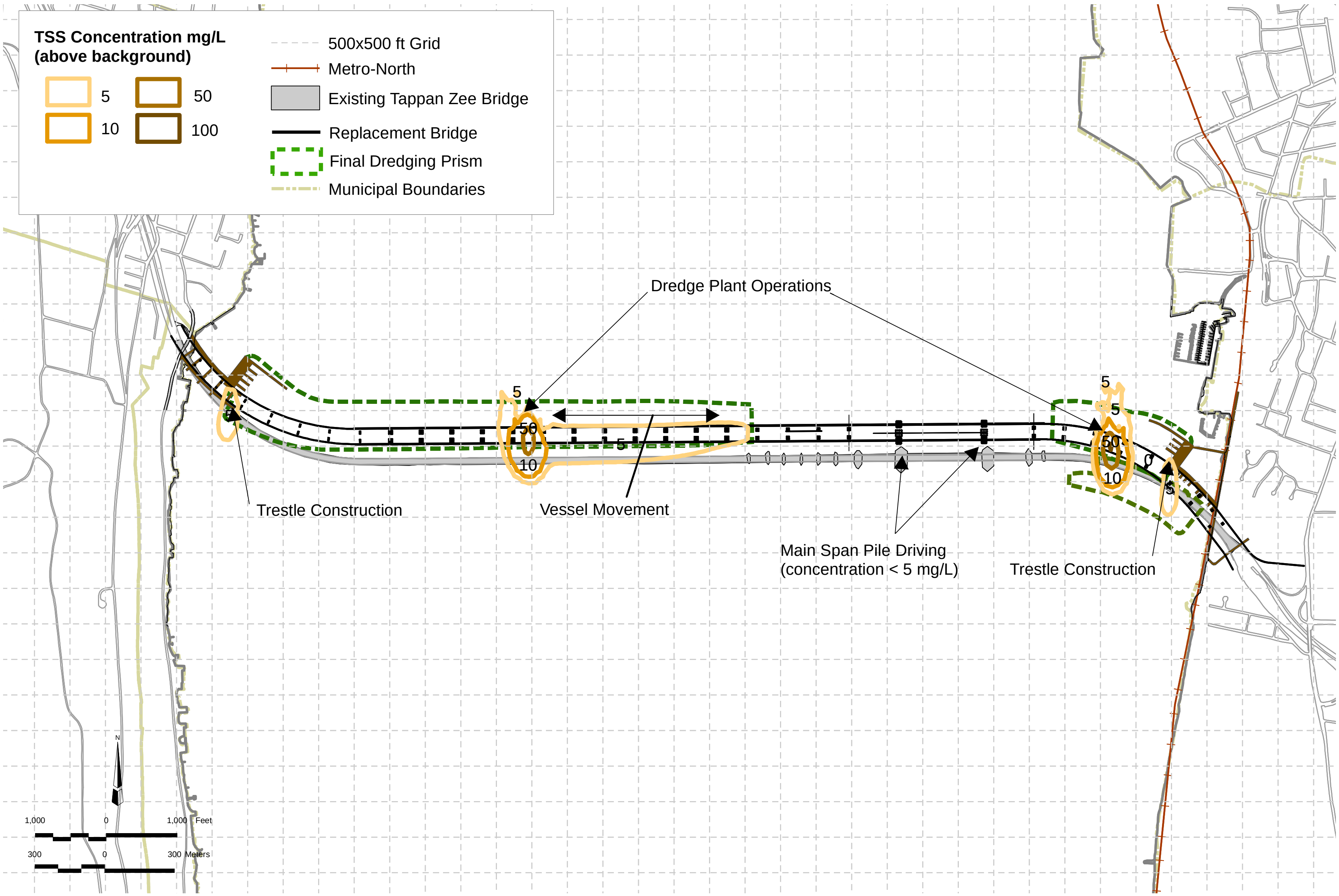


Figure 2

TAPPAN ZEE HUDSON RIVER CROSSING
Environmental Impact Statement

Projected Total Suspended Sediment Concentration for the Long Span Replacement Bridge Option During Stage 1 Dredging -- Near Slack Tide

Attachment 5

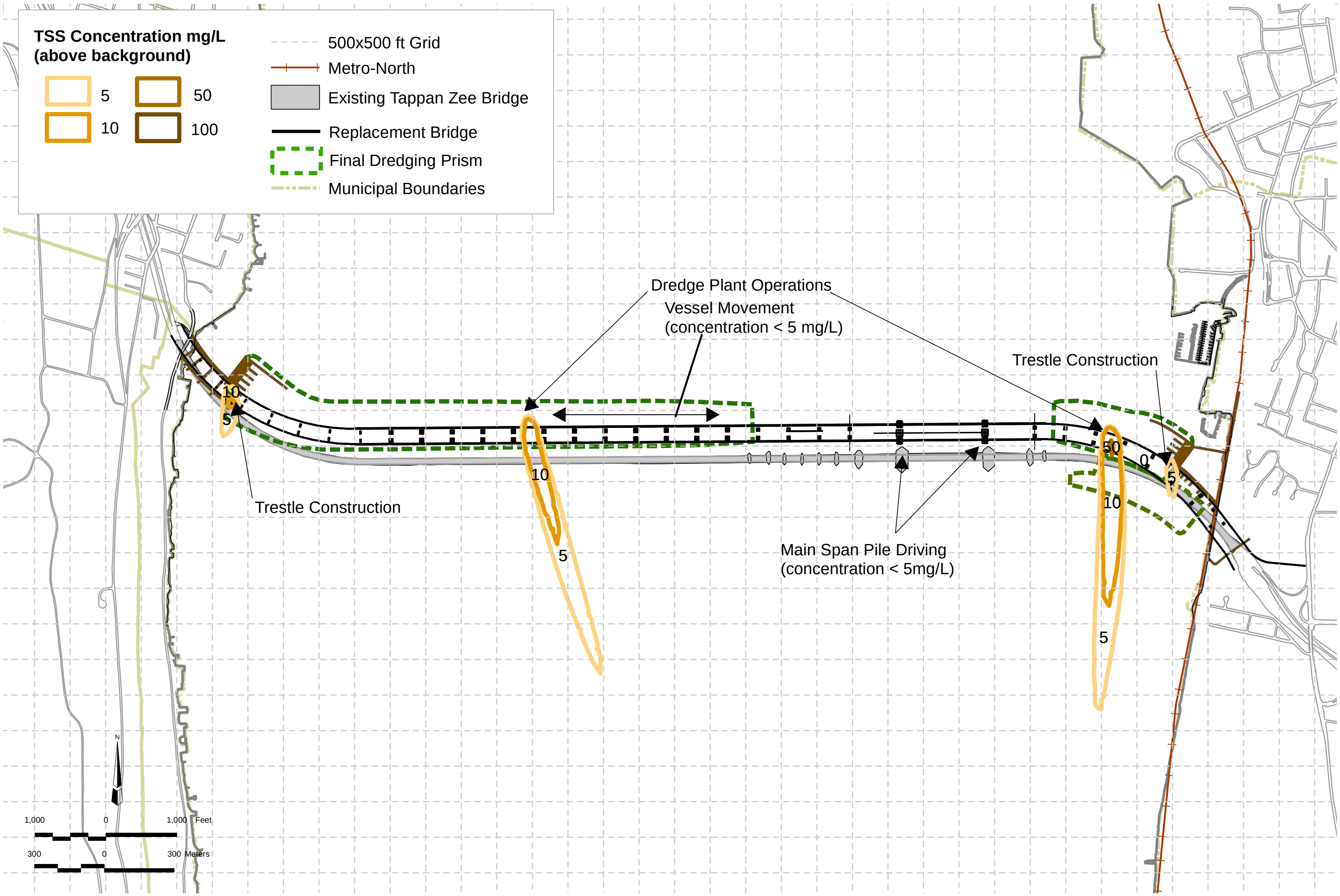


Figure 3

TAPPAN ZEE HUDSON RIVER CROSSING
Environmental Impact Statement

Projected Total Suspended Sediment Concentration for the Long Span Replacement Bridge Option During Stage 1 Dredging -- Ebb Tide

Attachment 5

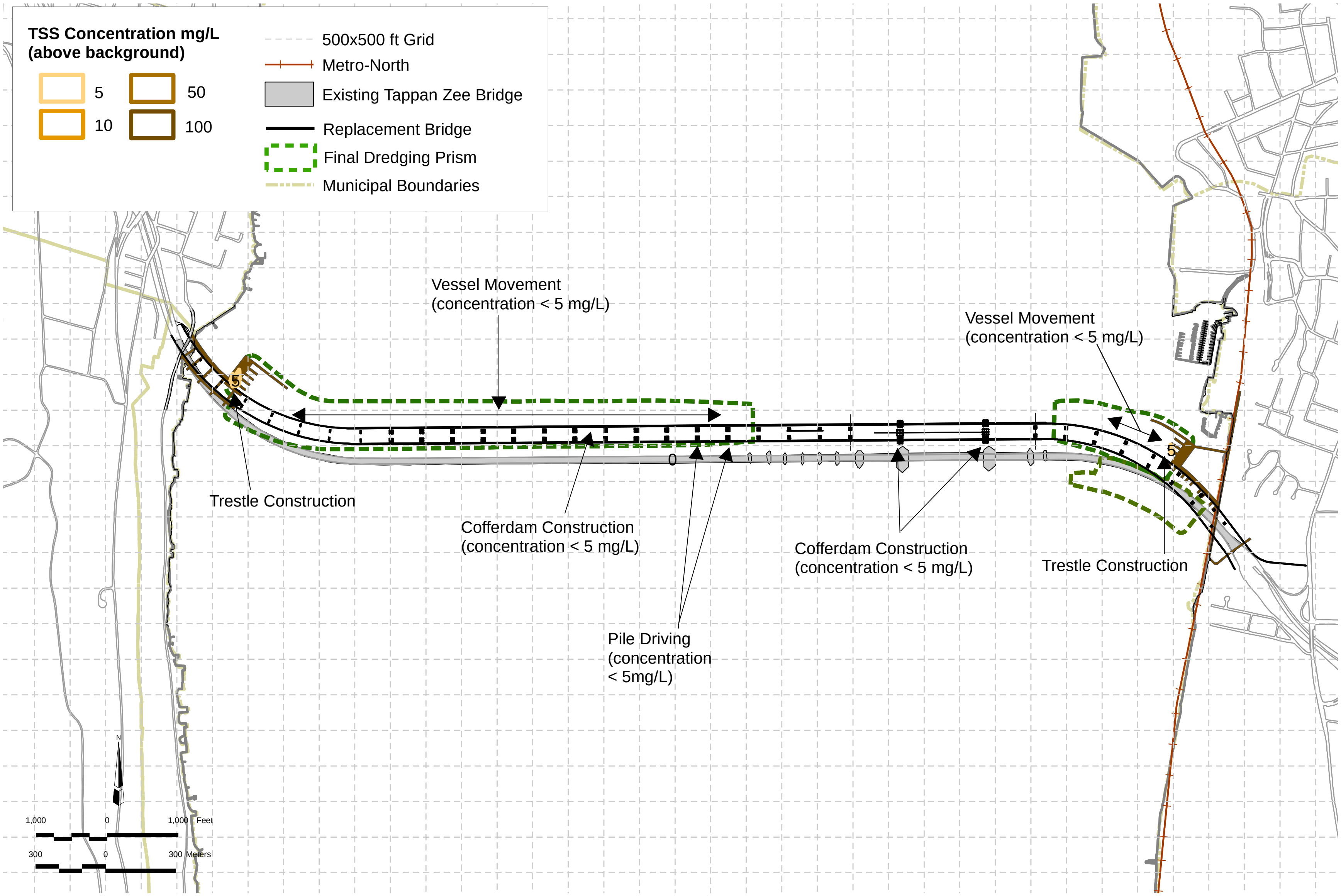


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Figure 4

Projected Total Suspended Sediment Concentration for the Long Span Replacement Bridge Option Zones C and B Construction After Dredging and Armoring -- Flood Tide

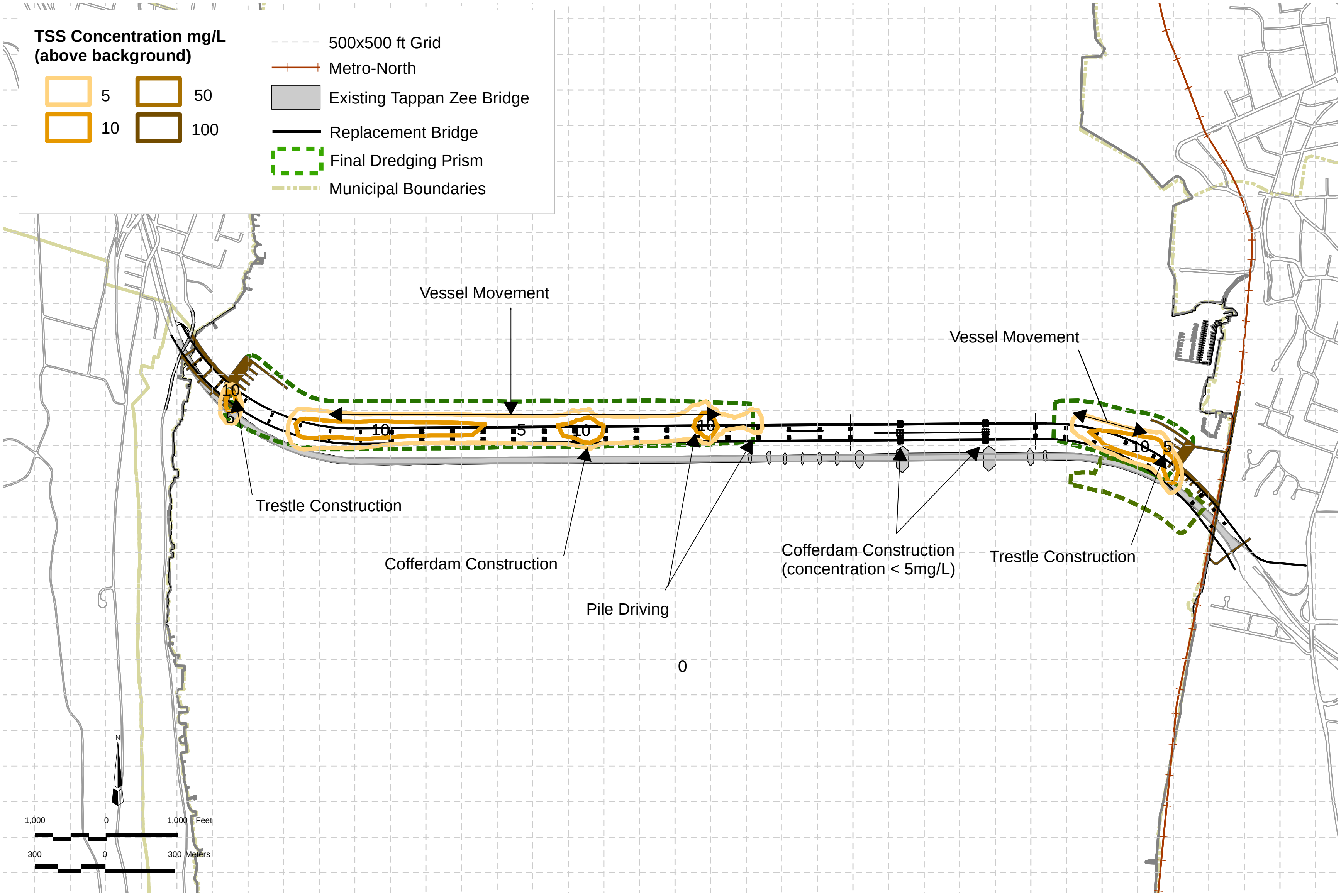


Figure 5

Projected Total Suspended Sediment Concentration for the Long Span Replacement Bridge Option Zones C and B Construction After Dredging and Armoring -- Near Slack Tide

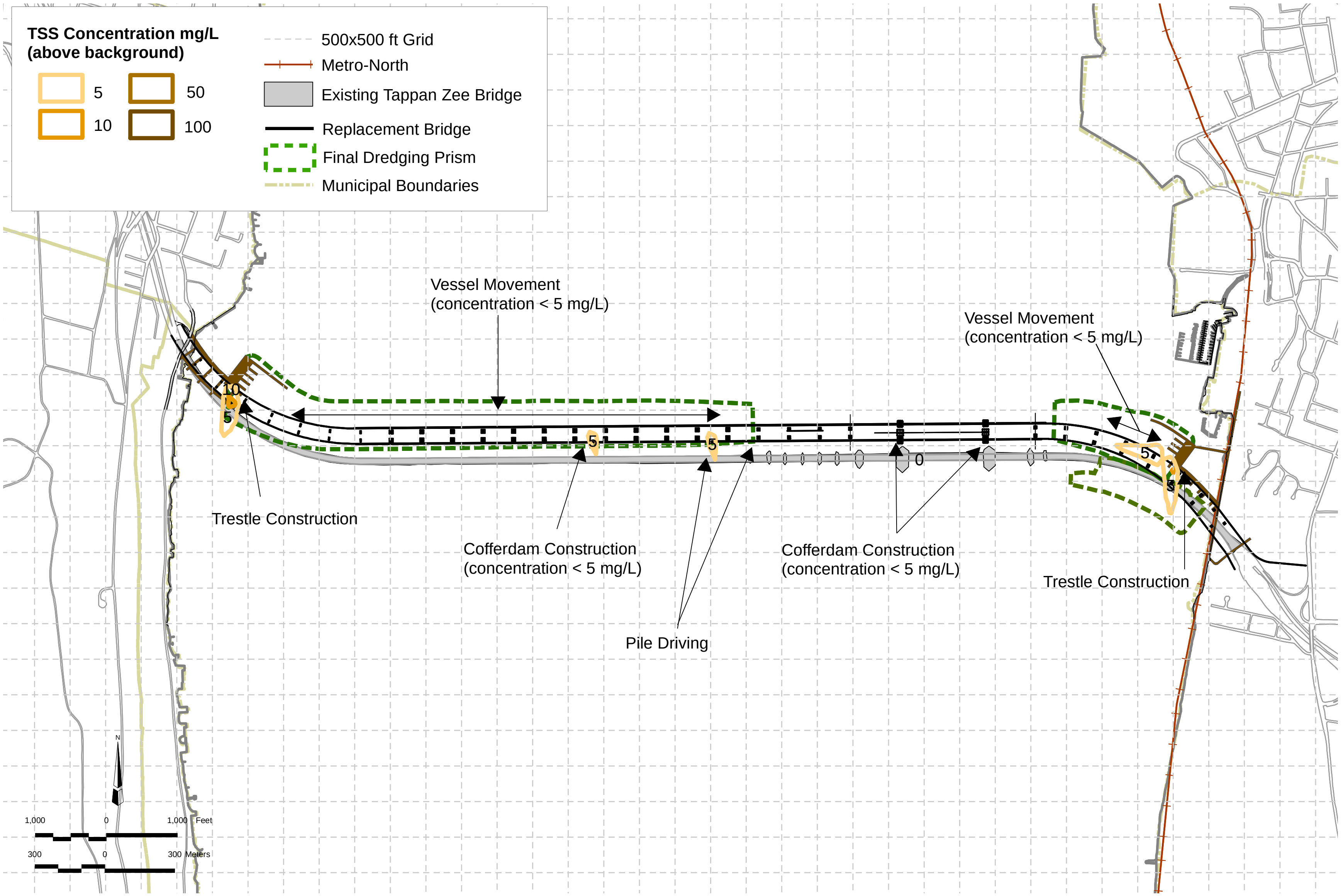


Figure 6

TAPPAN ZEE HUDSON RIVER CROSSING
Environmental Impact Statement

Projected Total Suspended Sediment Concentration for the Long Span Replacement Bridge Option Zones C and B Construction After Dredging and Armoring -- Ebb Tide

Attachment 5

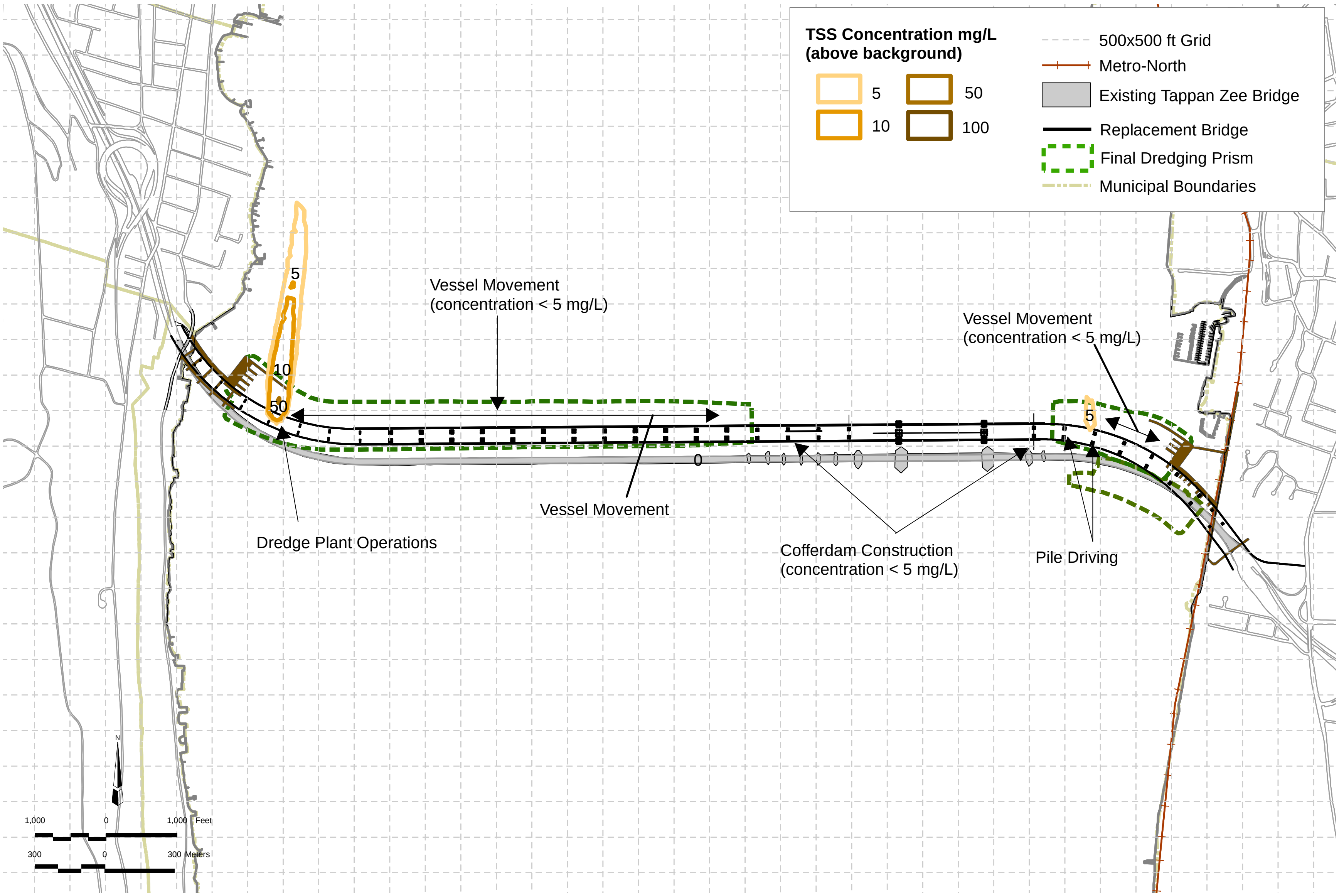


Figure 7

TAPPAN ZEE HUDSON RIVER CROSSING
Environmental Impact Statement

Projected Total Suspended Sediment Concentration for the Long Span Replacement Bridge Option During Stage 2 Dredging and Zones C and B Construction -- Flood Tide

Attachment 5

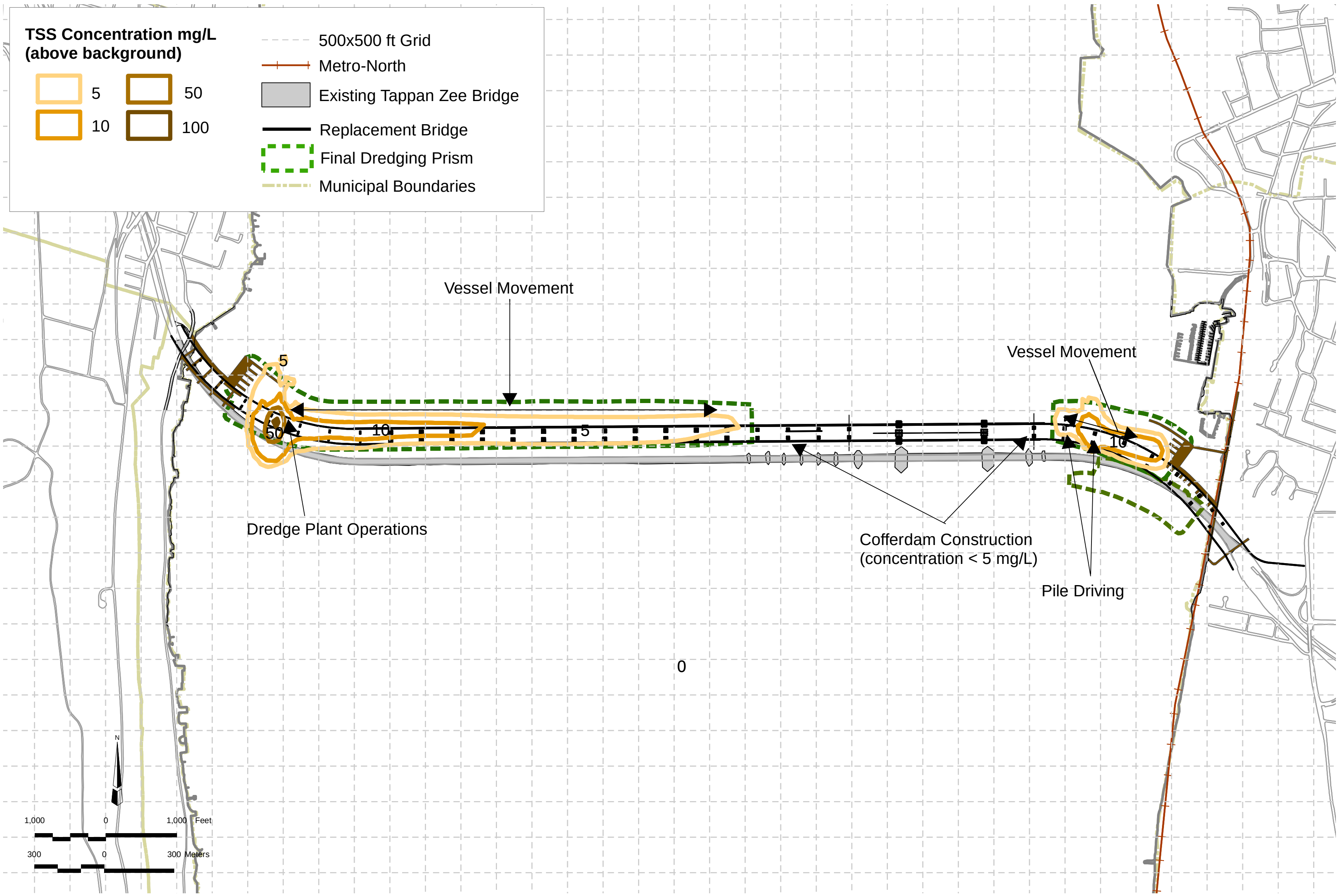


Figure 8

Projected Total Suspended Sediment Concentration for the Long Span Replacement Bridge Option During Stage 2 Dredging and Zones C and B Construction -- Near Slack Tide

TAPPAN ZEE HUDSON RIVER CROSSING
Environmental Impact Statement

Attachment 5

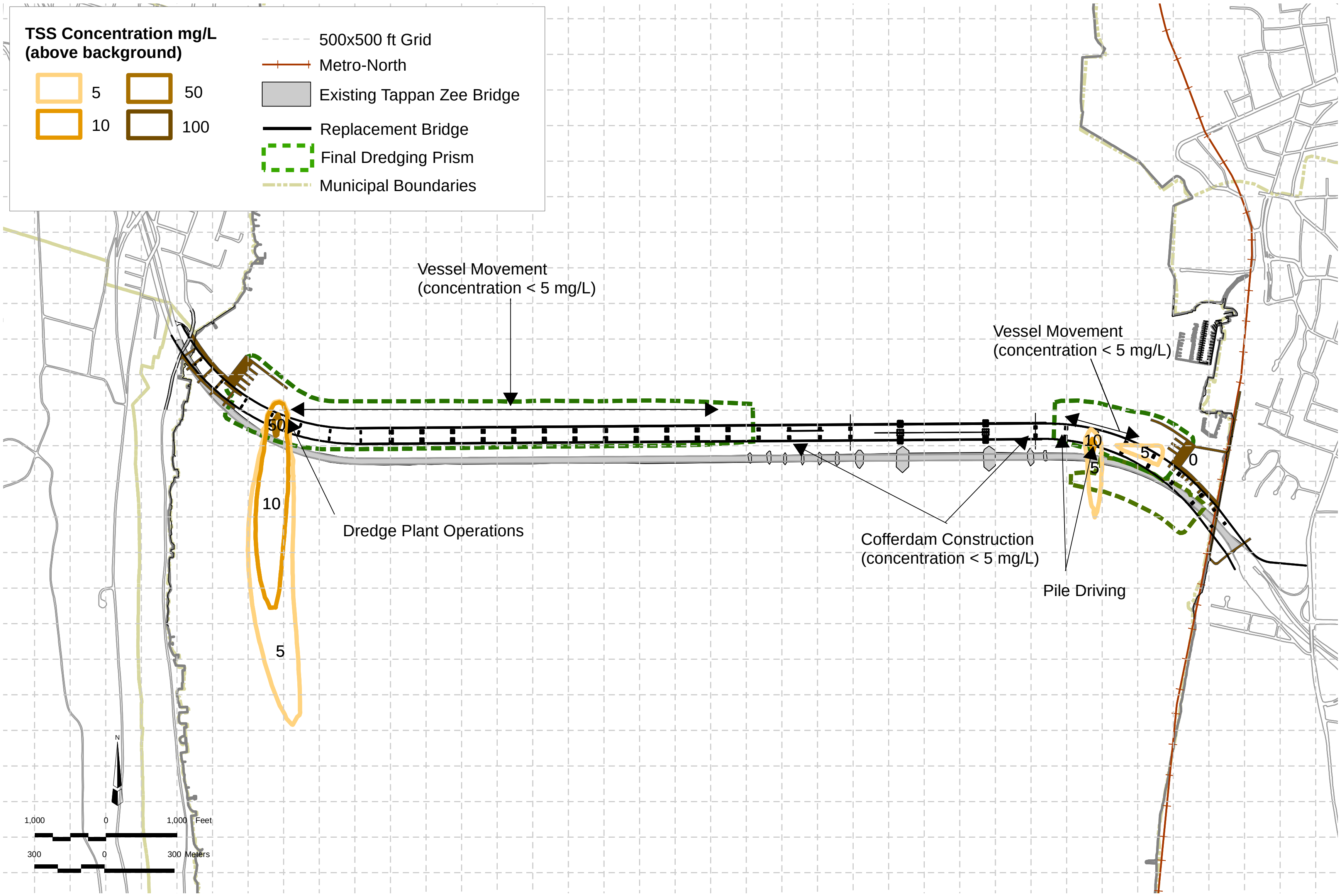


Figure 9

TAPPAN ZEE HUDSON RIVER CROSSING
Environmental Impact Statement

Projected Total Suspended Sediment Concentration for the Long Span Replacement Bridge Option During Stage 2 Dredging and Zones C and B Construction -- Ebb Tide

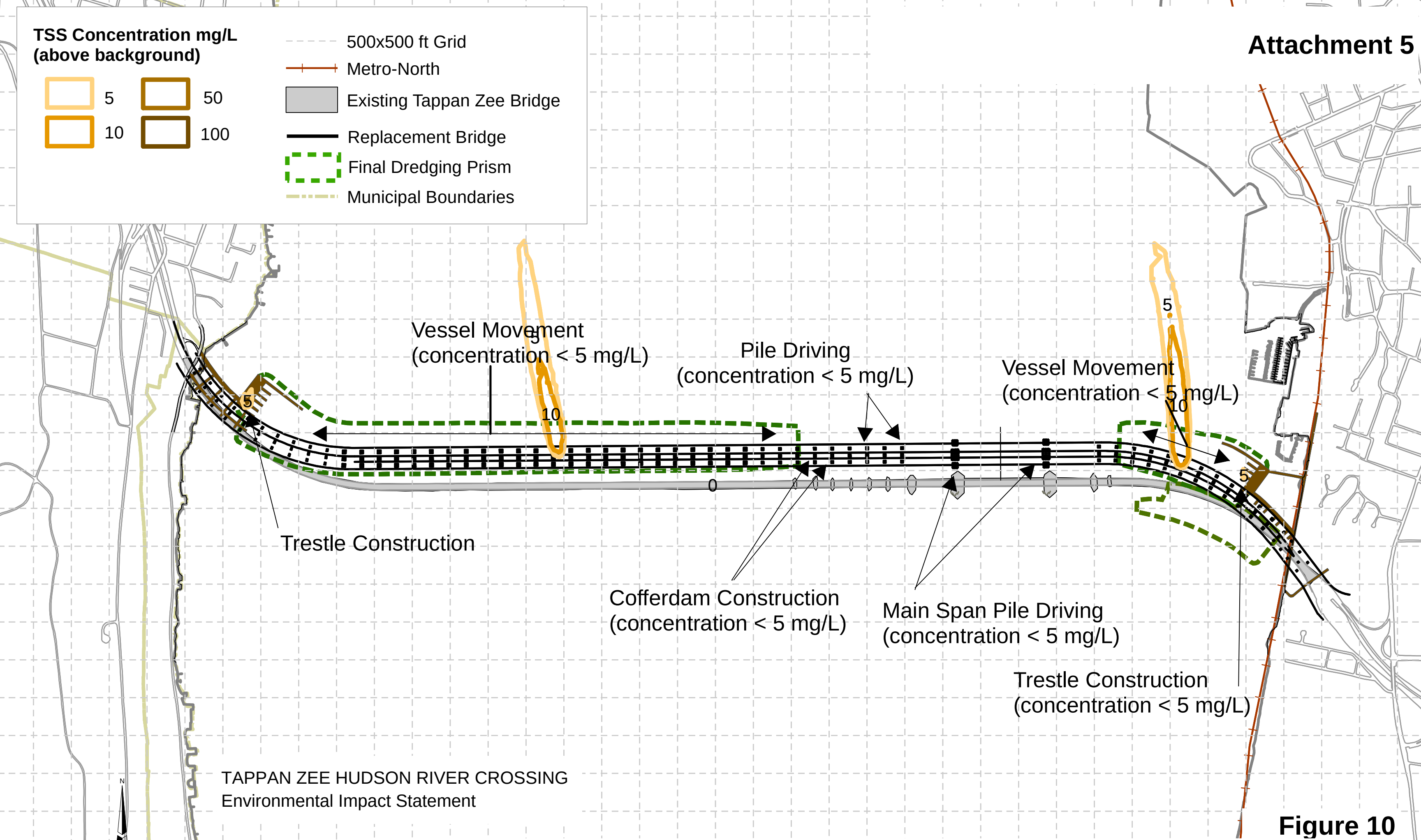


Figure 10

Projected Total Suspended Sediment Concentration for the Short Span Replacement Bridge Option During Stage 1 Dredging -- Flood Tide

Attachment 5

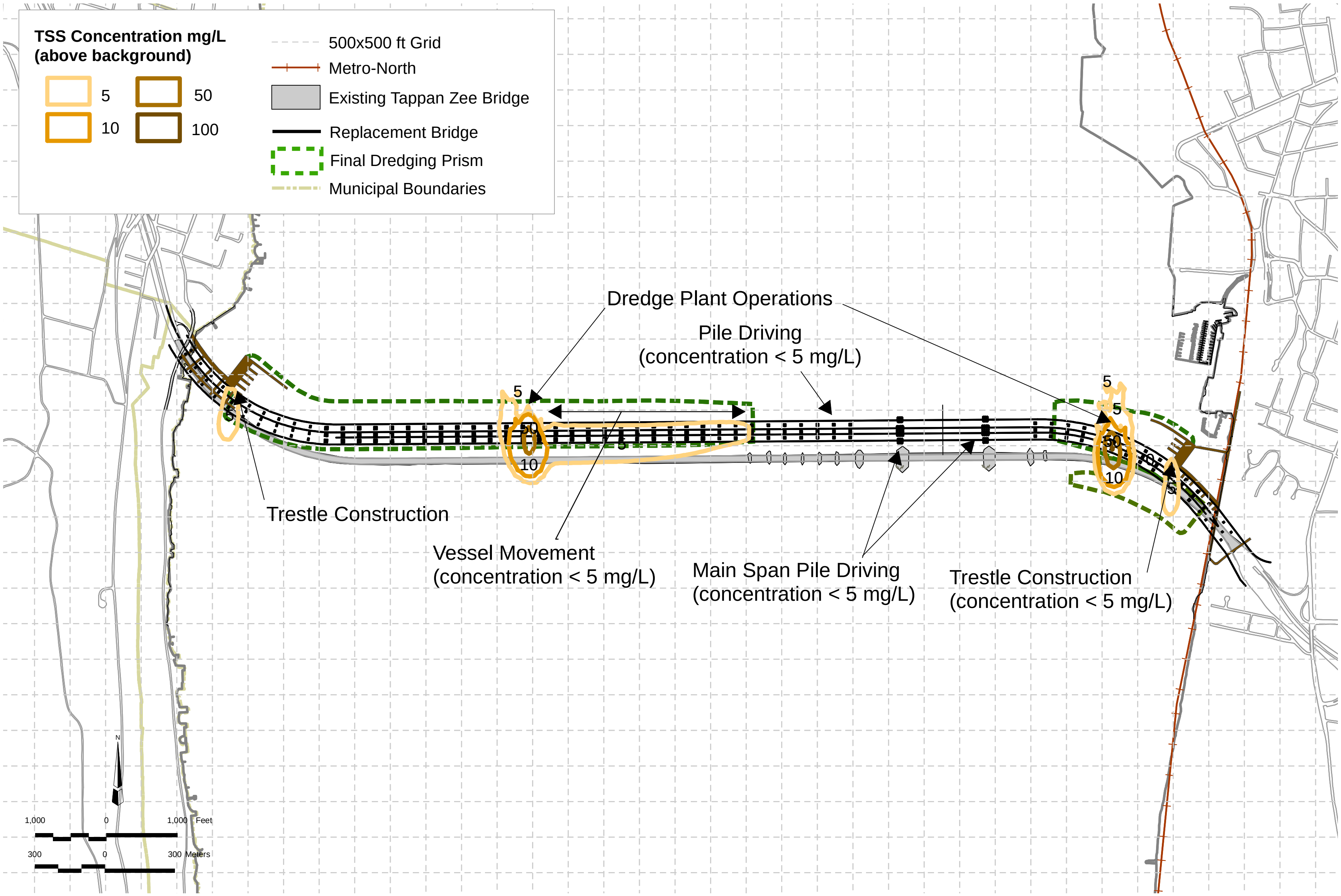


Figure 11

Projected Total Suspended Sediment Concentration for the Short Span Replacement Bridge Option During Stage 1 Dredging -- Near Slack Tide

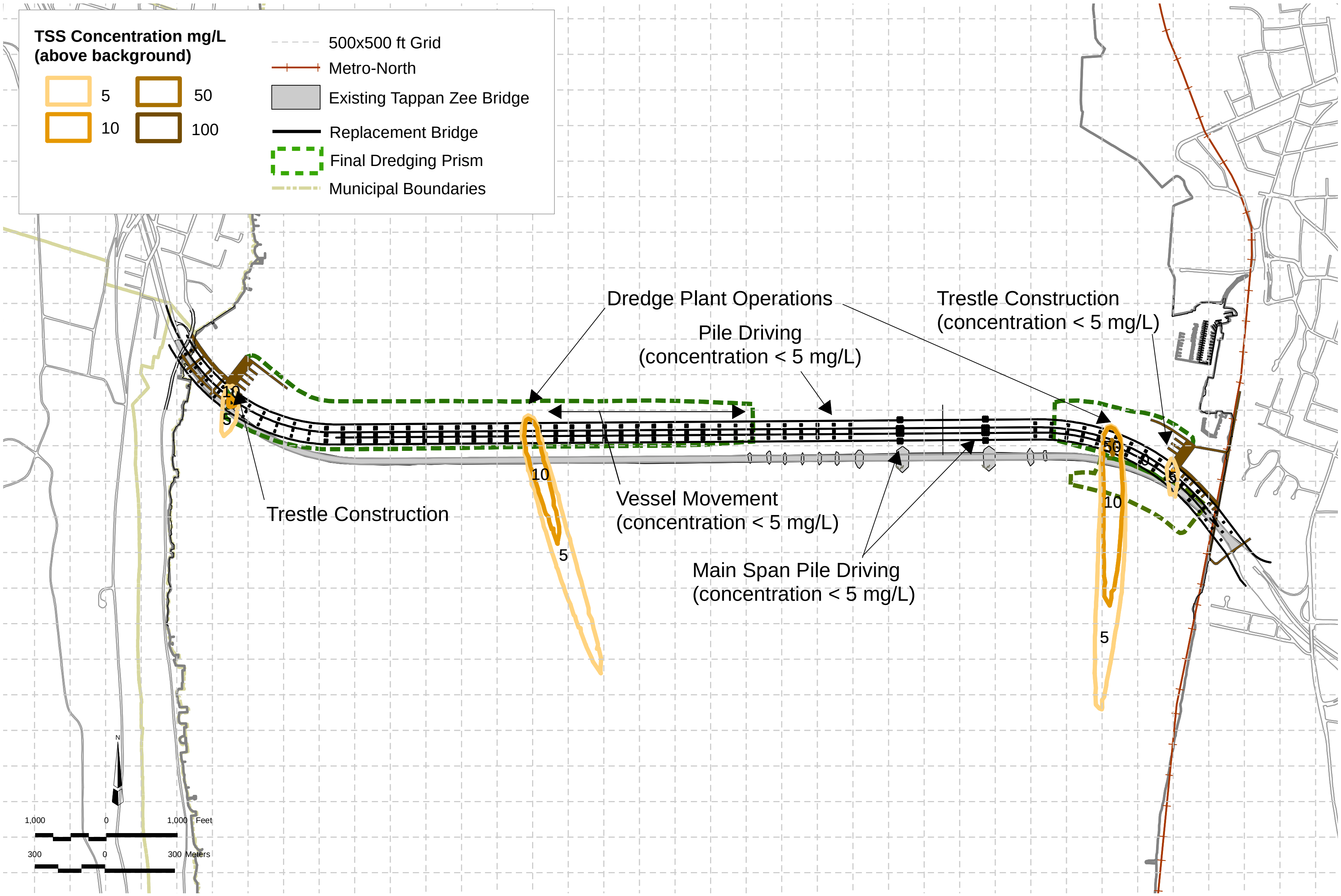


Figure 12

TAPPAN ZEE HUDSON RIVER CROSSING
Environmental Impact Statement

Projected Total Suspended Sediment Concentration for the Short Span Replacement Bridge Option During Stage 1 Dredging -- Ebb Tide

Attachment 5

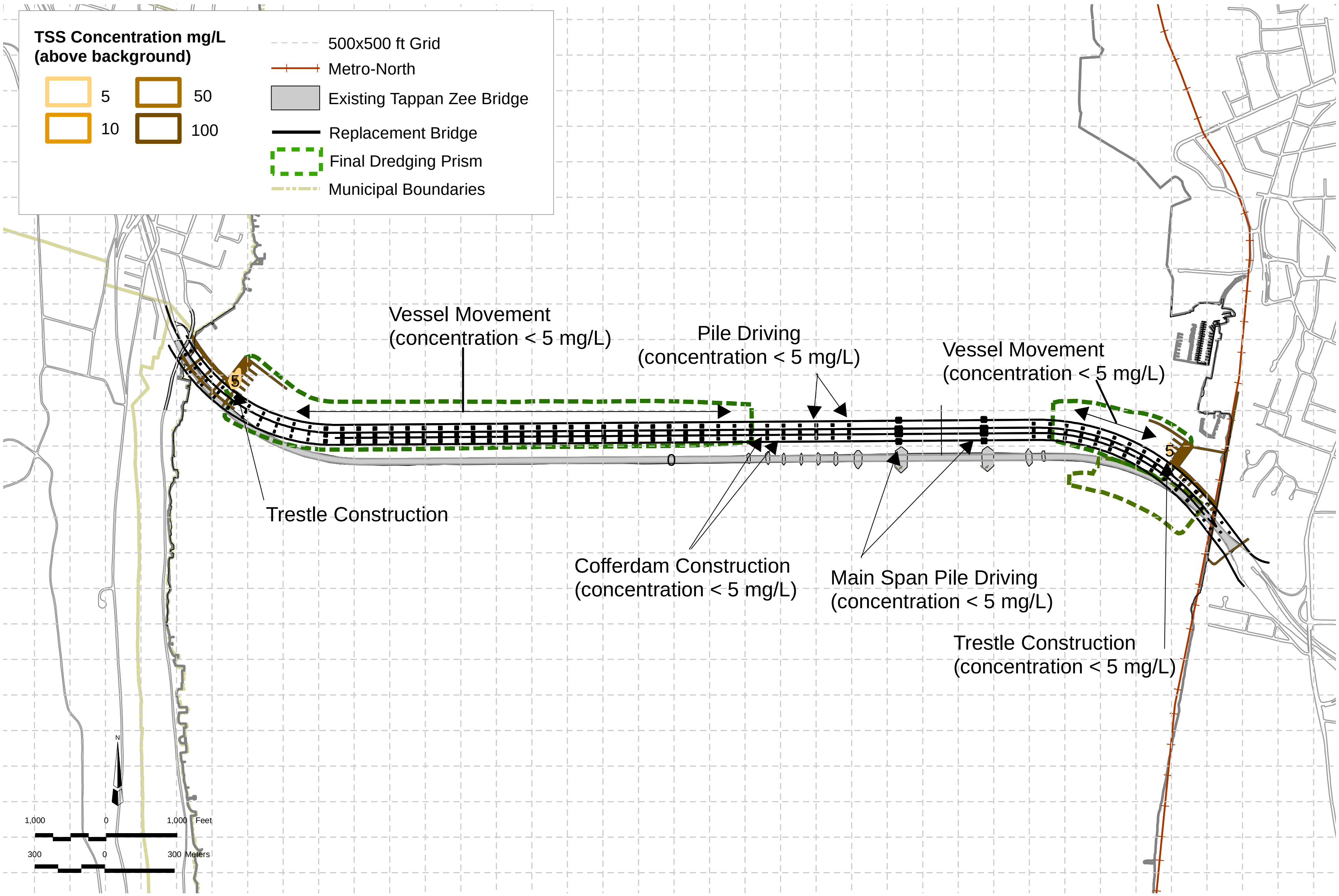


Figure 13

TAPPAN ZEE HUDSON RIVER CROSSING
Environmental Impact Statement

Projected Total Suspended Sediment Concentration for the Short Span Replacement Bridge Option Zones C and B Construction After Dredging and Armoring -- Flood Tide

Attachment 5

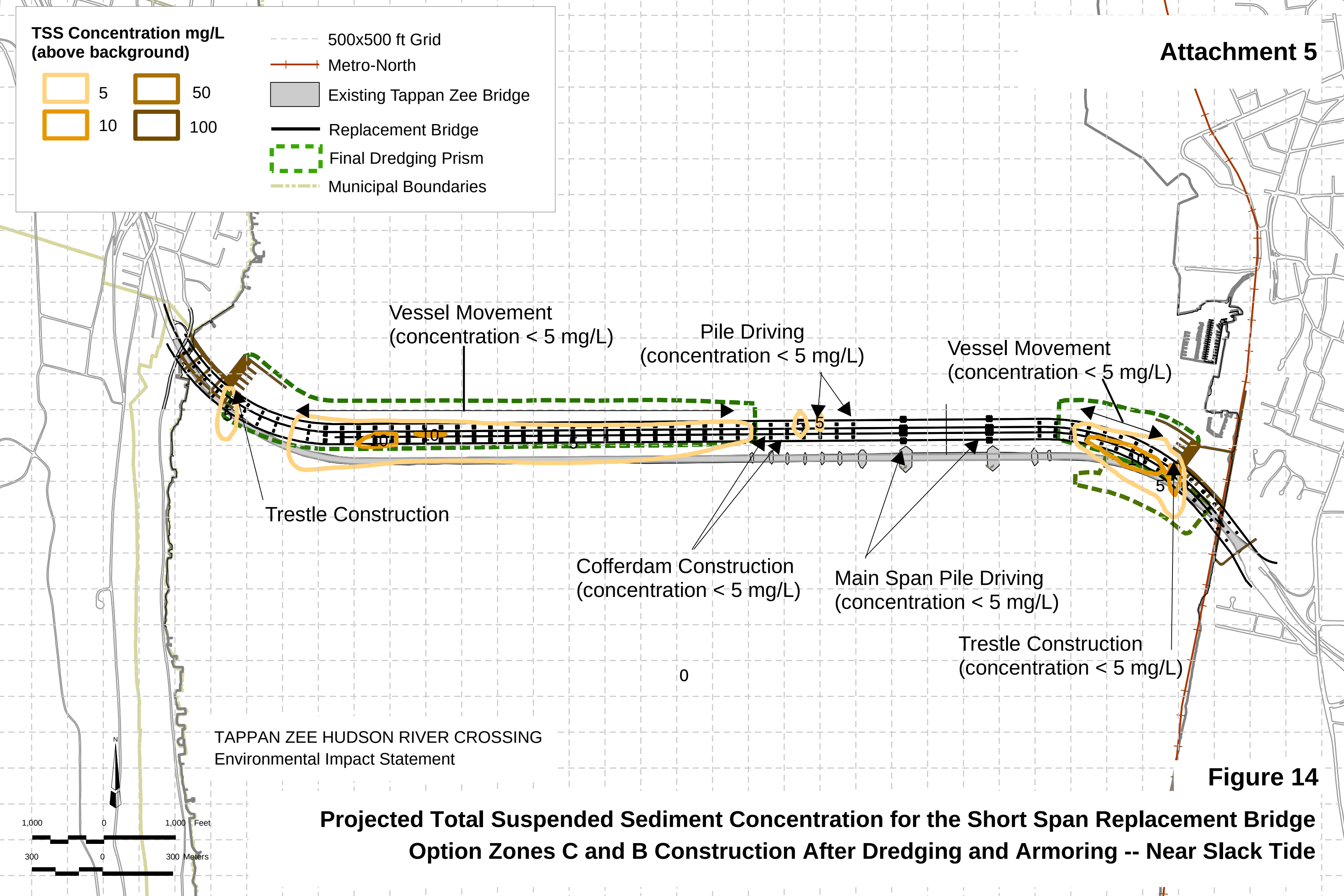


Figure 14

Projected Total Suspended Sediment Concentration for the Short Span Replacement Bridge Option Zones C and B Construction After Dredging and Armoring -- Near Slack Tide

Attachment 5

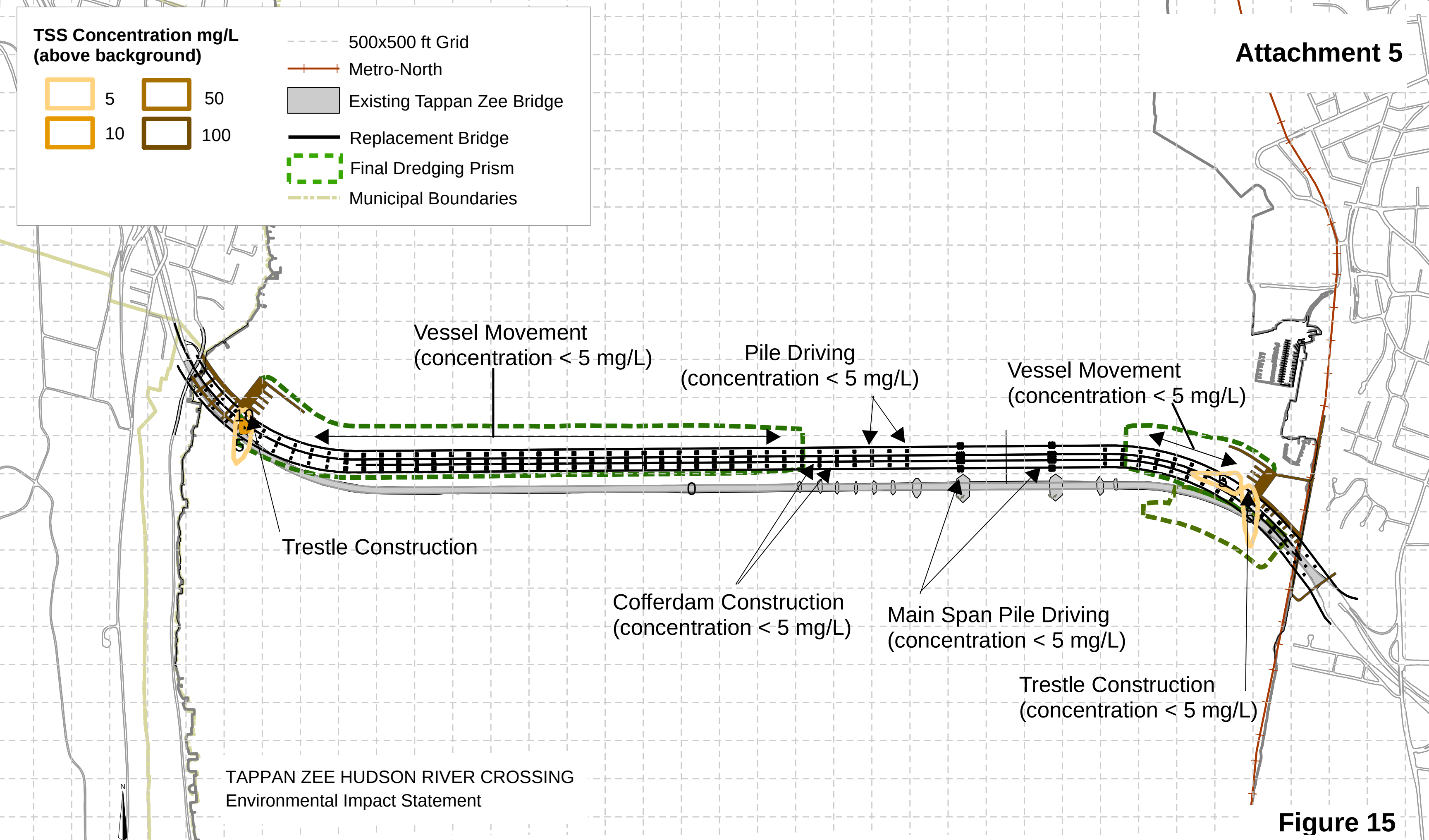
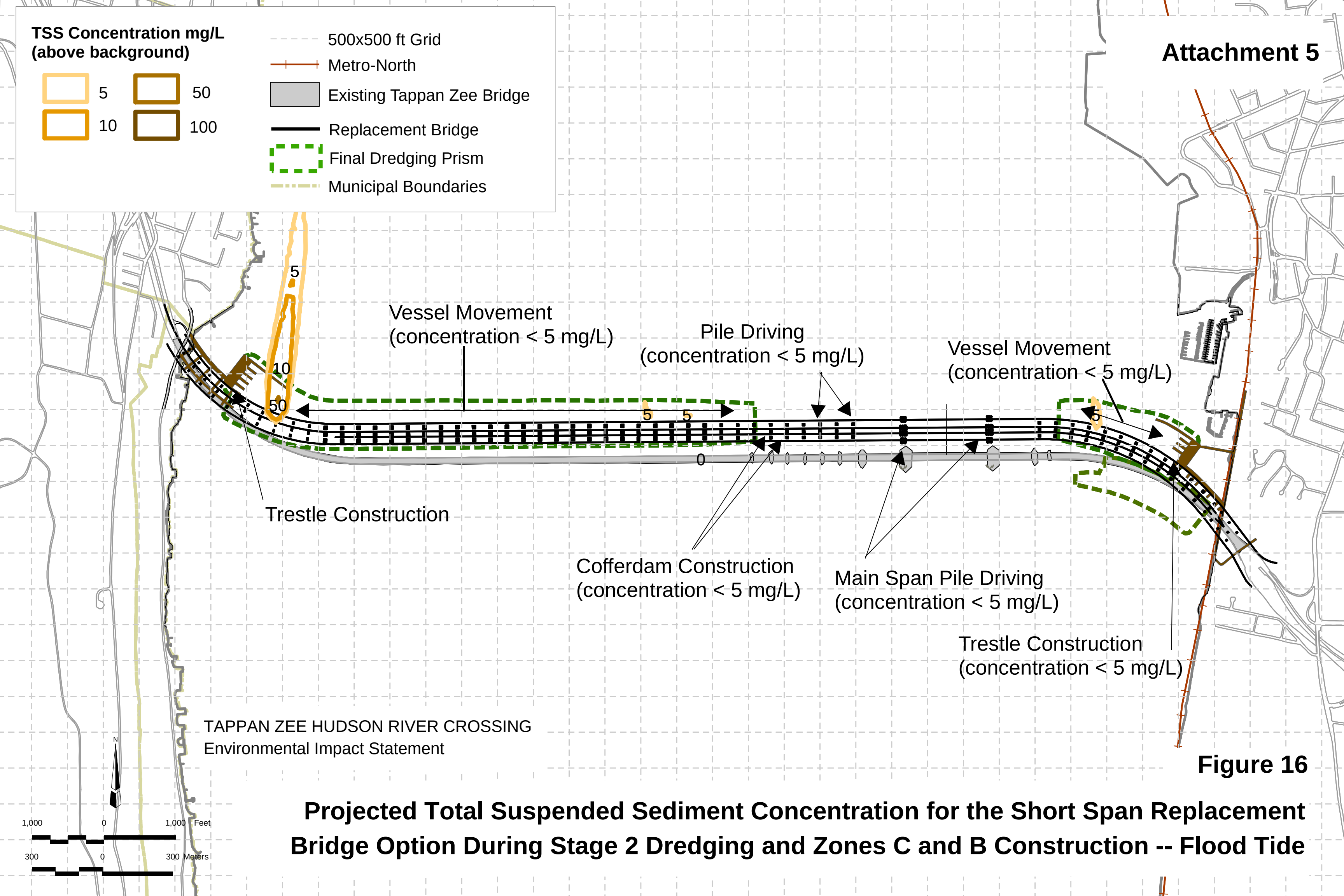


Figure 15

Projected Total Suspended Sediment Concentration for the Short Span Replacement Bridge Option Zones C and B Construction Dredging and Armoring -- Ebb Tide



TAPPAN ZEE HUDSON RIVER CROSSING
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Figure 16

Projected Total Suspended Sediment Concentration for the Short Span Replacement Bridge Option During Stage 2 Dredging and Zones C and B Construction -- Flood Tide

Attachment 5

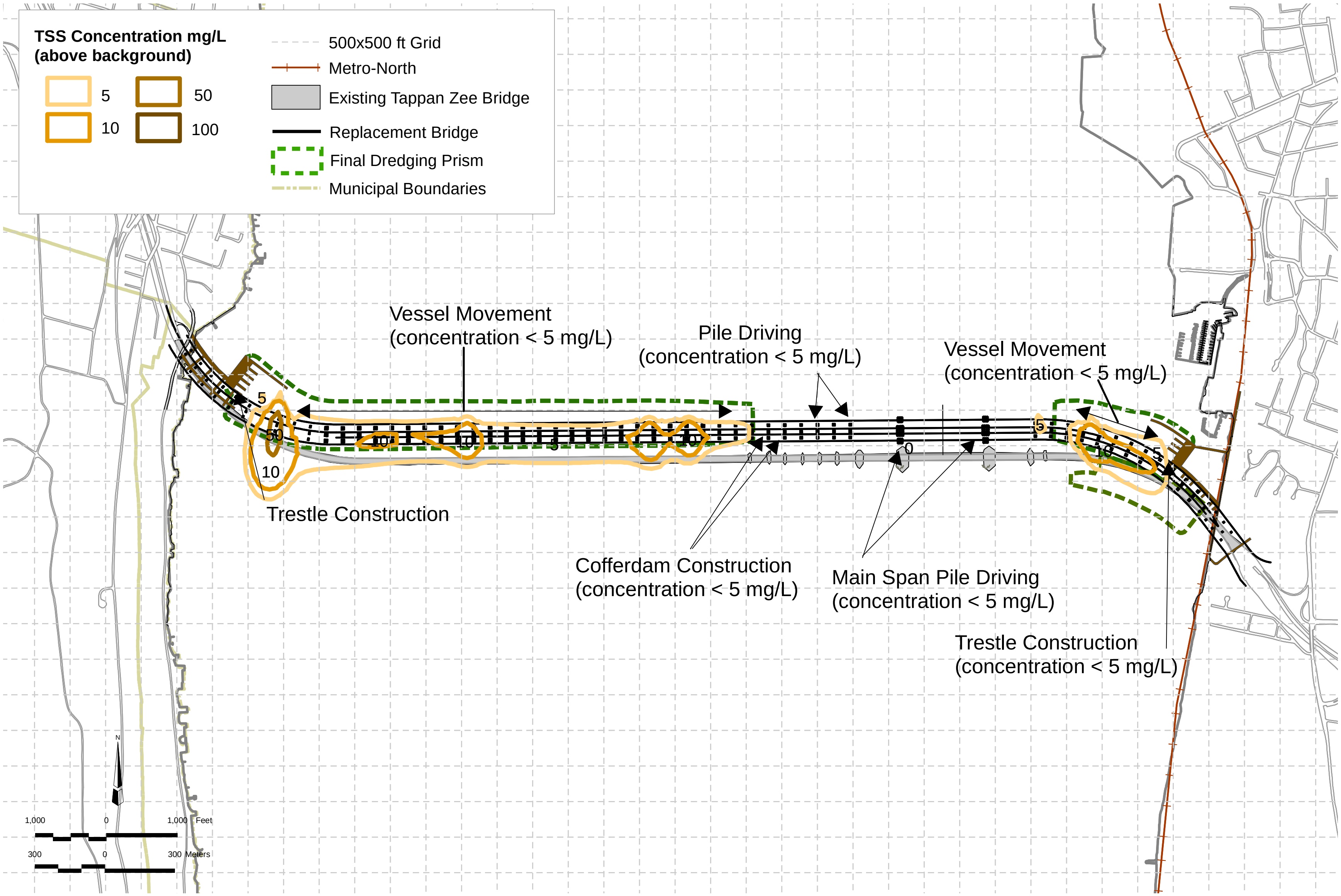

Figure 17

TAPPAN ZEE HUDSON RIVER CROSSING
Environmental Impact Statement

Projected Total Suspended Sediment Concentration for the Short Span Replacement Bridge Option During Stage 2 Dredging and Zones C and B Construction -- Near Slack Tide

Attachment 5

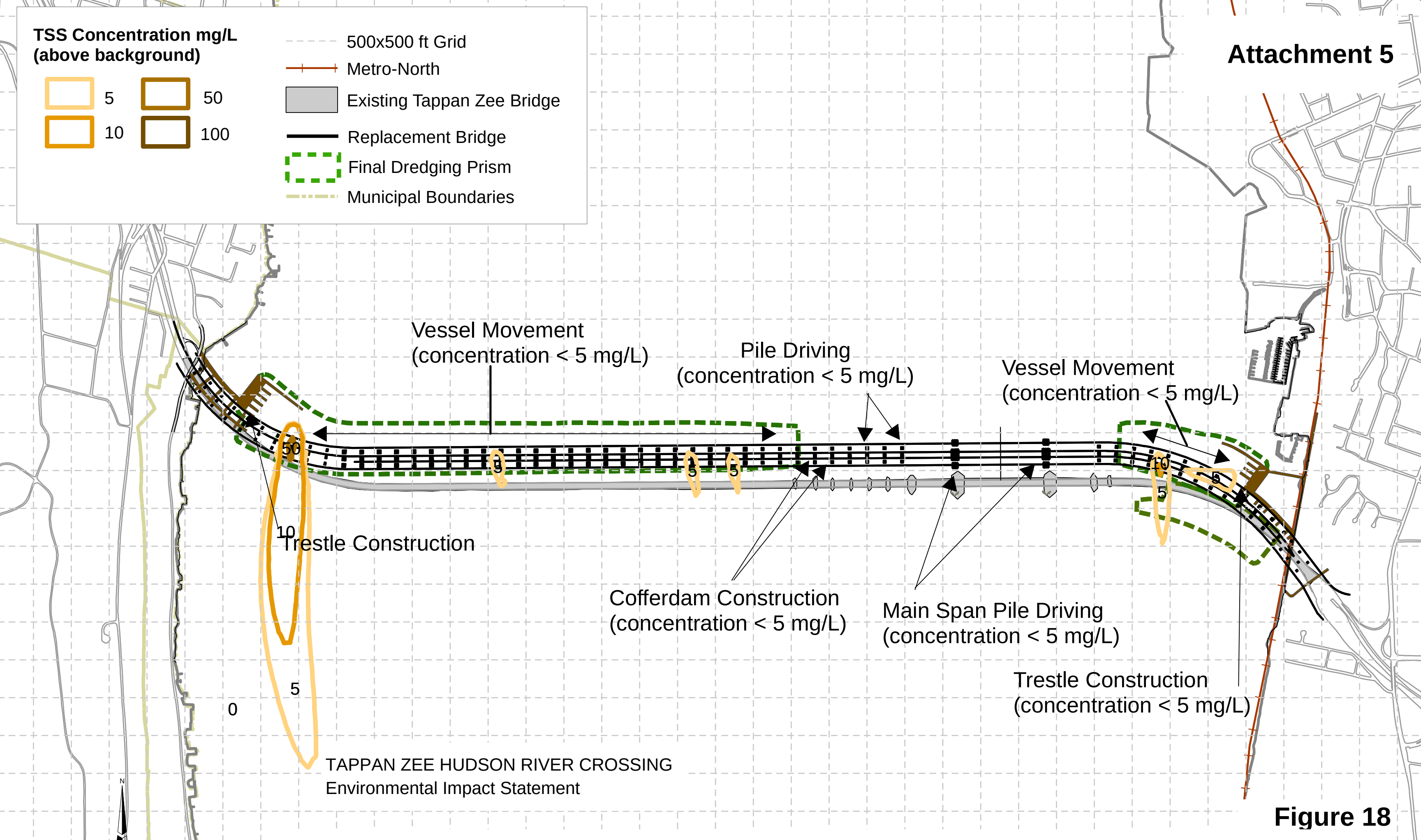

Figure 18

Projected Total Suspended Sediment Concentration for the Short Span Replacement Bridge Option During Stage 2 Dredging and Zones C and B Construction -- Ebb Tide

Attachment 6, Table 1

Pollutant Loading Calculations for Landings and Bridge with Treatment of Only the Landings

	Rockland Side		Bridge		Westchester Side				Pollutant Loading Rates		Pollutant Loading		Pollutant Loading Rate with Treatment*		Percent Change	
Description	**Area**		**Area**		**Area**		**Total Area**		**Total Phosphorus (TP)**	**Total Suspended Solids (TSS)**	**TP**	**TSS**	**TP**	**TSS**	**TP**	**TSS**
Existing Condition	**SF**	**Acres**	**SF**	**Acres**	**SF**	**Acres**	**SF**	**Acres**	**lbs/acre/year**	**lbs/acre/year**	**lbs/year**	**lbs/year**	**lbs/year**	**lbs/year**	**%**	**%**
Total Area	1,183,118	27	1,511,630	35	751,169	17	3,445,917	79.1	0.6	883	47.5	69,852	N/A	N/A		
Grass Area	324,879	7	0	0	77,855	2	402,734	9.2	0.6	883	5.5	8,164	-	-		
Impervious Area	858,239	20	1,511,630	35	673,314	15	3,043,183	69.9	0.6	883	41.9	61,688	-	-		
Proposed Condition																
Total Area	1,183,118	27	2,618,327	60	751,169	17	4,552,614	104.5	0.6	883	62.7	92,286	52.1	60,918	10%	(0)
Grass Area	265,274	6	0	0	0	0	265,274	6.1	0.6	883	3.7	5,377	-	-		
Impervious Area	917,844	21	2,618,327	60	751,169	17	4,287,340	98.4	0.6	883	59.1	86,908	-	-		

Notes

SF - square feet

lbs/year - pounds per year

Bridge area was assumed proposed abutment to proposed abutment.

The area on the east side between east and west traffic at the toll plaza is assumed paved.

The proposed maintenance facility is assumed fully paved.

Source of TSS and TP loading rates are Wanielista, MP and Yousef, YA 1992.

* Assumes 80% reduction of TSS and 40% reduction of TP for landing areas. Excludes treatment of bridge surfaces.

Attachment 6, Table 2
Pollutant Loading Calculations for Landings Only

	Rockland Side				Westchester Side				TOTAL					
											Pollutant Loading		Pollutant Loading with Treatment*	
	Area		TP	TSS	Area		TP	TSS	Total Area without Bridge		TP	TSS	TP	TSS
Description	**SF**	**Acres**	**lbs/year**	**lbs/year**	**SF**	**Acres**	**lbs/year**	**lbs/year**	**SF**	**Acres**	**lbs/year**	**lbs/year**	**lbs/year**	**lbs/year**
Existing Total Area	1,183,118	27	16	23,983	751,169	17	10	15,227	1,934,287	44.4	26.6	39,210	N/A	N/A
Grass Area	324,879	7	4	6,586	77,855	2	1	1578.19	402,734	9.2	5.5	8,164	-	-
Impervious	858,239	20	12	17,397	673,314	15	9	13648.67	1,531,553	35.2	21.1	31,046	-	-
Long Span Total Area	1,183,118	27	16	23,983	751,169	17	10	15226.86	1,934,287	44.4	26.6	39,210	16.0	7,842
Grass Area	265,274	6	4	5,377	0	0	0	0	265,274	6.1	3.7	5,377	2.2	1,075
Impervious	917,844	21	13	18,606	751,169	17	10	15226.86	1,669,013	38.3	23.0	33,832	13.8	6,766

Notes
SF - square feet
lbs/year - pound per year
Bridge area was assumed proposed abutment to proposed abutment.
The area on the east side between east and west traffic at the toll plaza is assumed paved.
The proposed maintenance facility is assumed fully paved.
TSS loading rate used was 833 lbs/acre/year; TP loading rate used was 0.6 lbs/acre/year.
Source of TSS and TP loading rates are Wanielista, MP and Yousef, YA 1992.
* Assumes 80% reduction of TSS and 40% reduction of TP.