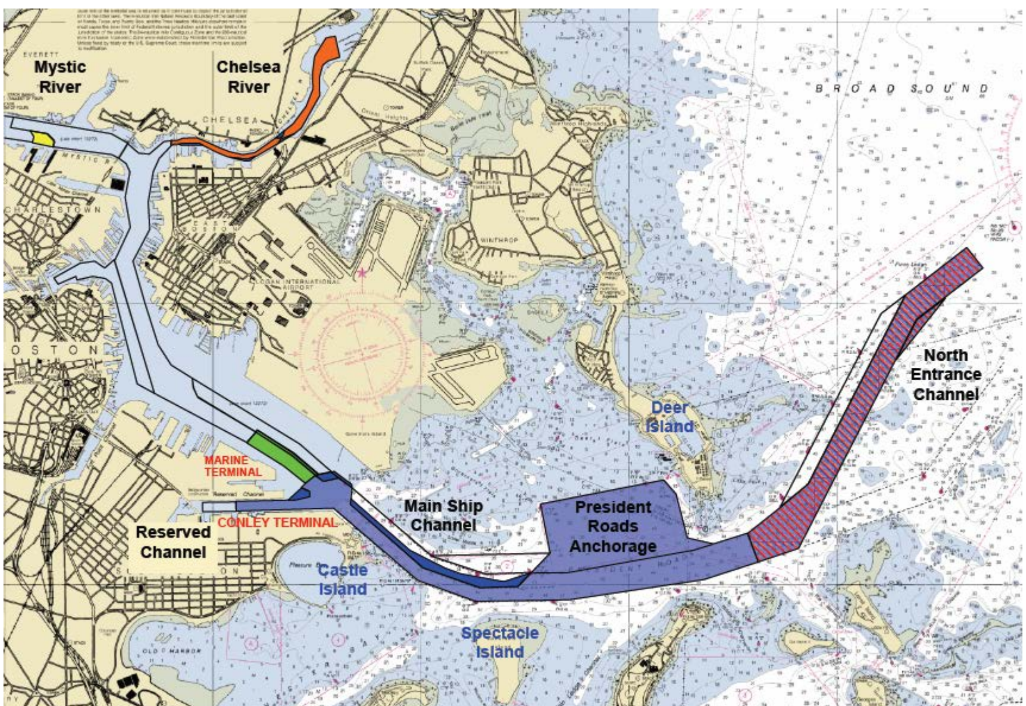
Feasibility Report and Supplemental Environmental Impact Statement/ (Massachusetts Environmental Impact Report) for Deep Draft Navigation Improvement (EOEEA #12958)

Volume 2 – Supplemental Technical Appendices F to Y

Boston Harbor
Boston, Chelsea and Revere Massachusetts



MASSACHUSETTS PORT AUTHORITY

US ARMY CORPS OF ENGINEERS
New England District

April 2013

DEPARTMENT OF THE ARMY
NEW ENGLAND DISTRICT
696 VIRGINIA ROAD
CONCORD, MASSACHUSETTS 01742-2751

REPLY TO
ATTENTION OF

BOSTON HARBOR, MASSACHUSETTS NAVIGATION IMPROVEMENT PROJECT

FEASIBILITY REPORT AND SUPPLEMENTAL ENVIRONMENTAL IMPACT STATEMENT AND MASSACHUSETTS ENVIRONMENTAL IMPACT REPORT (EOEA #12958)

VOLUME 2
SUPPLEMENTAL TECHNICAL APPENDICES - F TO Y

APRIL 2013

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Final Feasibility Report

INCLUDED IN VOLUME 1 WITH THE FEASIBILITY REPORT

SUPPLEMENTAL TECHNICAL APPENDICES F TO Y – VOLUME 2

BOSTON HARBOR
MASSACHUSETTS

NAVIGATION IMPROVEMENT STUDY

FINAL FEASIBILITY REPORT
AND FINAL SUPPLEMENTAL
ENVIRONMENTAL IMPACT STATEMENT
AND MASSACHUSETTS FINAL
ENVIRONMENTAL IMPACT REPORT

APPENDIX F

HYDRODYNAMIC FIELD DATA
COLLECTION REPORT

(This Appendix Not Revised Since 2008 Draft)

U.S. ARMY CORPS OF ENGINEERS
ENGINEERING RESEARCH AND
DEVELOPMENT CENTER
VICKSBURG, MISSISSIPPI

ERDC/CHL TR-07-3

Coastal and Hydraulics Laboratory

APPENDIX F

HYDRODYNAMIC FIELD DATA COLLECTION REPORT

US Army Corps of Engineers®
Engineer Research and Development Center

Boston Harbor Navigation Channel Improvement Project

Field Data Collection Program Final Report

Michael W. Tubman

June 2007

ERDC/CHL TR-07-3
June 2007

Boston Harbor Navigation Channel Improvement Project

Field Data Collection Program Final Report

Michael W. Tubman

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Final report

Approved for public release; distribution is unlimited.

Prepared for U.S. Army Engineer District, New England
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Abstract: A field data collection program in Boston Harbor, MA, was conducted for the U.S. Army Engineer District, New England, during the late fall and winter of 2004/2005. The purpose of the program was to obtain data needed to validate a numerical hydrodynamic model (ADvanced CIRCulation (ADCIRC) model) of Boston Harbor and adjacent areas. The currents calculated by the verified model were input to a ship simulator used to assess the design of the Boston Harbor navigation improvement project.

A total of four water-level recorders and two acoustic profiling current meters were deployed on 10 November 2004. The water-level recorders were located adjacent to a bridge between Chelsea and East Boston in Boston's inner harbor, at the seaward end of Boston North Channel, at Gallops Island, and at the Hull Yacht Club in Allerton Harbor. The current meters were located at the seaward end of Boston North Channel and near the location where Boston's main navigation channel enters the inner harbor. Data from these instruments were supplemented by tide data from a National Oceanic and Atmospheric Administration (NOAA) tide gage in the inner harbor, and NOAA wind measurements at Logan Airport. In addition, daylight current transect surveys using a downward looking acoustic profiling current meter attached to a survey vessel were conducted on 11 November 2004 and 8 February 2005. Five transect survey lines across the main navigation channel were surveyed. All instrumentation was recovered on 7 and 8 February 2005.

Maximum-measured ebb tidal currents in the harbor were 0.9 to 3.84 ft/sec. Maximum-measured flood currents were 0.77 to 3.61 ft/sec. In general, the ebb currents were stronger than the flood currents. The data from the current meter deployed at the seaward end of Boston North Channel were analyzed to evaluate the importance of the wind-driven and tide-induced residual currents. The results of the analysis were that combined, these currents are small (5 to 22 percent of the ebb currents and 6 to 26 percent of the flood currents) compared to the maximum-measured tidal currents within the harbor. The tide-induced residual current at the seaward end of the navigation channel was estimated to be 0.07 ft/sec. The technical literature shows that tide-induced residual currents within the harbor, in the vicinity of the navigation channel, are stronger than they are at that location, with speeds of about 0.33 ft/sec.

The largest currents at the seaward end of the navigation channel resulting from the action of the wind during major storms were associated with outflow of the storm surge from within the harbor. The analyses showed that during a major storm in December 2004, the currents were 0.54 ft/sec toward 70 deg, and during one of the worst storms (in terms of wind speed) in recent history, which occurred in January 2005, they were 0.56 ft/sec toward 69 deg (both speeds include an estimated tide-induced residual vector of 0.07 ft/sec toward 90 deg).

The maximum water-level range is defined as the largest change in elevation from high-water to the low-water immediately following, that was recorded at a gage location. The maximum water-level range includes wind effects, as well as the astronomical tide. The range was 13.9 ft at the bridge between Chelsea and East Boston, 13.5 ft at Gallops Island, 14.1 ft at the Hull Yacht Club, and 13.9 ft at the NOAA gage.

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Preface

The field data collection program of Boston Harbor, MA, documented in this report was performed for the U.S. Army Engineer District, New England (CENAE). John H. Winkelman was the CENAE liaison during the study.

The program was conducted by the U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL), from November 2004 to June 2005, under the direct supervision of Thomas W. Richardson, Director, CHL, Bruce A. Ebersole, Chief, Flood and Storm Protection Division, and William Birkemeier, Chief, Field Data Collection and Analysis Branch. The work was performed by John R. Bull, Christopher J. Callegan, John M. Kirklin, Thad C. Pratt, and Michael W. Tubman. This report was written by Mr. Tubman.

At the time of the study, COL Richard B. Jenkins was Commander and Executive Director of ERDC. Dr. James R. Houston was Director.

1 Introduction

Purpose

A field data collection program in Boston Harbor, MA, was conducted for the U.S. Army Engineer District, New England (hereafter New England District), during the late fall and winter of 2004/2005. The purpose of the program was to obtain data needed to validate a numerical hydrodynamic model (ADvanced CIRCulation (ADCIRC) model) of Boston Harbor and adjacent areas. The currents calculated by the verified model were input to a ship simulator used to assess the design of the Boston Harbor navigation improvement project. The proposed effort (see the original Scope of Work (SOW) in Appendix A) was for water-level measurements at two locations, current and wind measurements, each at one location, for a 1- to 2-month period. In addition, transects of current measurements across the navigation channel were proposed for two spring tidal cycles.

During planning of the first field effort, it was realized that the field program could be improved. It was found that wind data are available from a meteorological station at Logan International Airport, and the proposed wind-measurement station was eliminated from the program. This made it possible to collect additional current and water-level data without exceeding the proposed budget. Two additional water-level recorders (for a total of four), and two current-meter moorings, instead of the one proposed, were deployed.

As specified in the SOW, the deliverables of the field data collection program are:

- Time series of water-level measurements and interpolation at all benchmarked locations in the harbor.
- Vectorized current velocity data from the transect data entered into a GIS database.
- Time series of currents at the current-meter mooring.
- Correlations between mooring and transect current data.
- Correlations between wind data and filtered mooring current data.
- Summary of wind statistics for the deployment period.
- Correlations between current and water-level data.

Funding for the program was provided by the New England District of the U.S. Army Corps of Engineers (Point of Contact (POC): John H. Winkelman, CENAE-EP-EW, telephone: 978-318-8615) to the U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL). Two previous reports on the field data collection program have been sent to the New England District. One report was submitted after the instruments were deployed and the first transect current survey was conducted on 10 and 11 November 2004, and the second was submitted after the instruments were recovered and the second current survey was conducted on 7 and 8 February 2005. This is the final report for the project. The work was conducted by ERDC personnel Thad C. Pratt (POC: ERDC-CHL-HF-HM, telephone: 601-634-2959), John Bull, Chris Callegan, John Kirklin, and Michael W. Tubman.

Study Area

Boston Harbor and adjacent areas, and the areas of the navigation channel improvement project are shown in Figure 1. Typical navigationally significant currents in the harbor are primarily the result of tidal forcing. The semi-diurnal M_2 tidal component, which has a 12.42-hr period, is the most navigationally significant current. However, the M_2 tidal currents are modulated by the S_2 and N_2 components, resulting in spring tidal currents that are 33 percent stronger than average currents. The spring tidal currents occur every 15 days. There is relatively little freshwater input to the harbor, and density-driven currents are not significant in terms of their effect on ship navigation. Water-level differences over the harbor (at any one time) are small in the absence of wind. Without wind-driven effects, water levels in the harbor are controlled by the astronomical tides, and the magnitudes and timing of their variations are nearly the same over the entire harbor.

The instrument mooring locations and the location of the wind station at Logan Airport are shown in Figure 2.

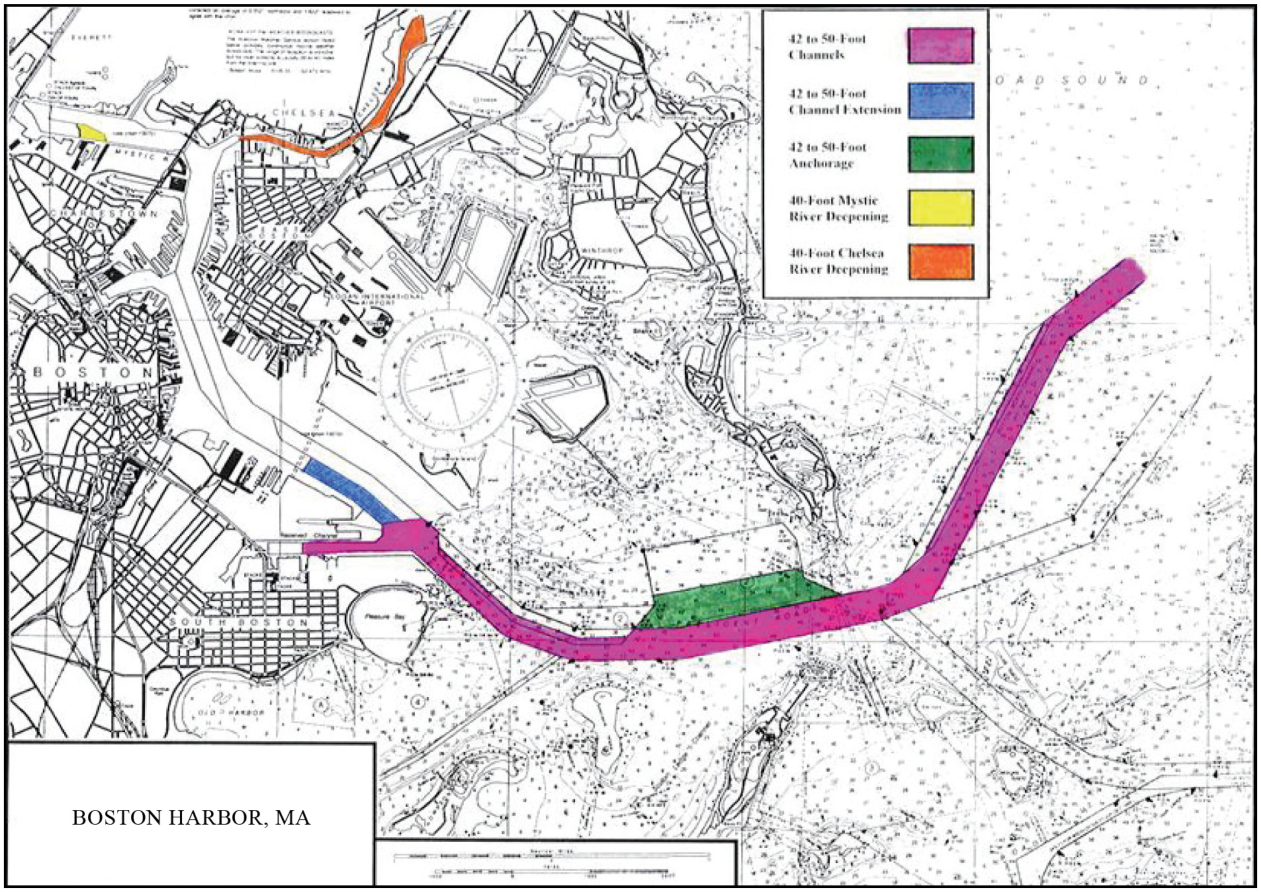


Figure 1. Boston Harbor and adjacent areas, and proposed channel deepening project.

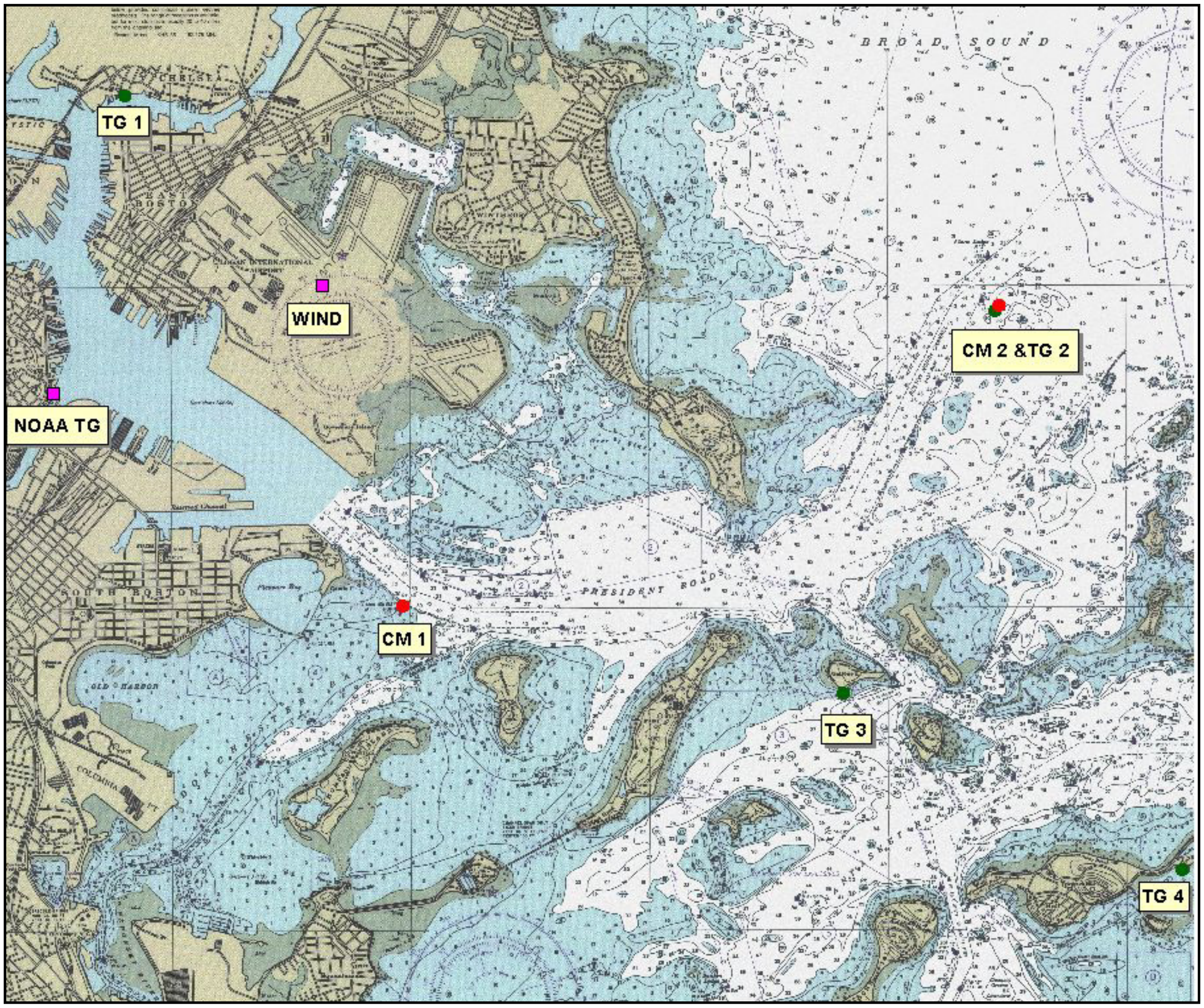


Figure 2. Locations of ERDC instrumentation (water-level recorders TG 1, TG 2, TG 3, TG 4 and current meters CM 1 and CM 2), NOAA tide gage (NOAA TG), and NOAA wind station (WIND).

2 Approach

Design of Data Collection Program

The National Oceanographic and Atmospheric Administration (NOAA) maintains a tide-measuring station in Boston's inner harbor. This station is referenced to a vertical datum. To verify ADCIRC, time series water elevation changes referenced to the record mean, as opposed to a verified datum, are adequate. Thus, the approach was to supplement the data from the NOAA station with water-level data from the four ERDC gages that were not surveyed to an established vertical datum.

Current information for the ship simulator studies was needed along the navigation channel. Producing this information was ADCIRC's primary role, and the focus of the field data collection program was to obtain current data for verification of the model along the channel. Therefore, two current transect surveys were undertaken at different locations along the navigation channel over two tidal cycles. For the purposes of the study, the strongest currents were thought to be the most significant, and the program plan was to make these surveys during spring tides. The importance of wind-driven currents was expected to be greatest near the seaward end of the navigation channel, which is basically in open-ocean waters. To record wind-driven currents, a mooring was deployed in this area. Wind measurements needed to correlate the wind-driven currents with the wind velocity were to come from the NOAA station at Logan Airport. Tidal asymmetry in the harbor can potentially result in residual tidal currents. To measure tidal currents in the vicinity of the navigation channel, a second current meter mooring was deployed near the entrance to the inner harbor.

Instrumentation

Water-level measurements were made using Coastal Leasing Microtides systems. The Microtides is a self-contained, internally recording, microprocessor controlled system (Figure 3). The instrument determines the elevation of the water column above it by measuring the pressure. A Foxboro Pressure Sensor having an accuracy of 0.1 percent of full scale is used to make these measurements. The 30-psia systems that were deployed have an elevation accuracy of approximately 0.07 ft of seawater.

Before deployment, the water-level gages were programmed to record a measurement every second for 1 min, and record the average pressure over the 1-min interval. These water-level (pressure) measurements were repeated every 6 min. A short bench-test run was made, and the measured pressures were compared to atmospheric pressure.

Figure 3. Microtides self-contained, internally recording, microprocessor controlled, water-level gage.

The water-level recorders are well suited to the Boston Harbor environment. They were deployed well below the surface (approximately 6 ft) so that they were not visible from the surface, even at low tide. This helped avoid interference with them in this heavily populated area, and it kept them below a level where ice could damage them. The pressure sensors recorded water-level changes even during times when extensive ice cover was present in the harbor.

The two current meters that were placed in bottom moorings (Figures 4 and 5), and the current meter used to perform the tidal-current survey, are acoustic profiling systems. An acoustic profiling current meter transmits sound bursts into the water column that are scattered back to the instrument by particulate matter suspended in the flowing water. The current meter "listens" for the returning signals and assigns depths to the received signals based on speed of sound and the time-after-transmit that the signals are received. The current speeds at those depths are determined on the basis of the change in frequency caused by the moving particles. This change in frequency is called Doppler shift. The bottom-moored current meters transmit their signals up toward the surface, whereas the survey current meter is mounted to the side of a survey vessel (Figure 6) and transmits its signals down toward the bottom as the vessel navigates along the survey line.

Figure 4. RDI ADCP and water-level gage mounted in mooring frame that was deployed near seaward end of navigation channel.

The survey acoustic current meter was a 1,200 kHz broadband Acoustic Doppler Current Profiler (ADCP) manufactured by RD Instruments, Inc. (RDI). During data collection, the ADCP is capable of measuring vessel velocity, water velocity, water temperature, and bottom bathymetry. The measurement of the velocity of the vessel over the bottom allows the current velocity data to be corrected for the movement of the survey vessel. The current meter near the seaward end of the navigation channel (the Boston North Channel) was also an RDI 1,200 kHz ADCP. For that instrument when in a mooring, the manufacture specifies accuracies of

+/- 0.00656 ft/sec (0.2 cm/sec) for current speed and +/- 2 deg for current direction. The current meter deployed near the inner harbor was a 1,500 kHz Acoustic Doppler Profiler (ADP) manufactured by SonTek. For that instrument SonTek specifies accuracies of +/- 0.0164 ft/sec (0.5 cm/sec) for speed and +/- 2 deg for direction when the current meter is in a mooring.

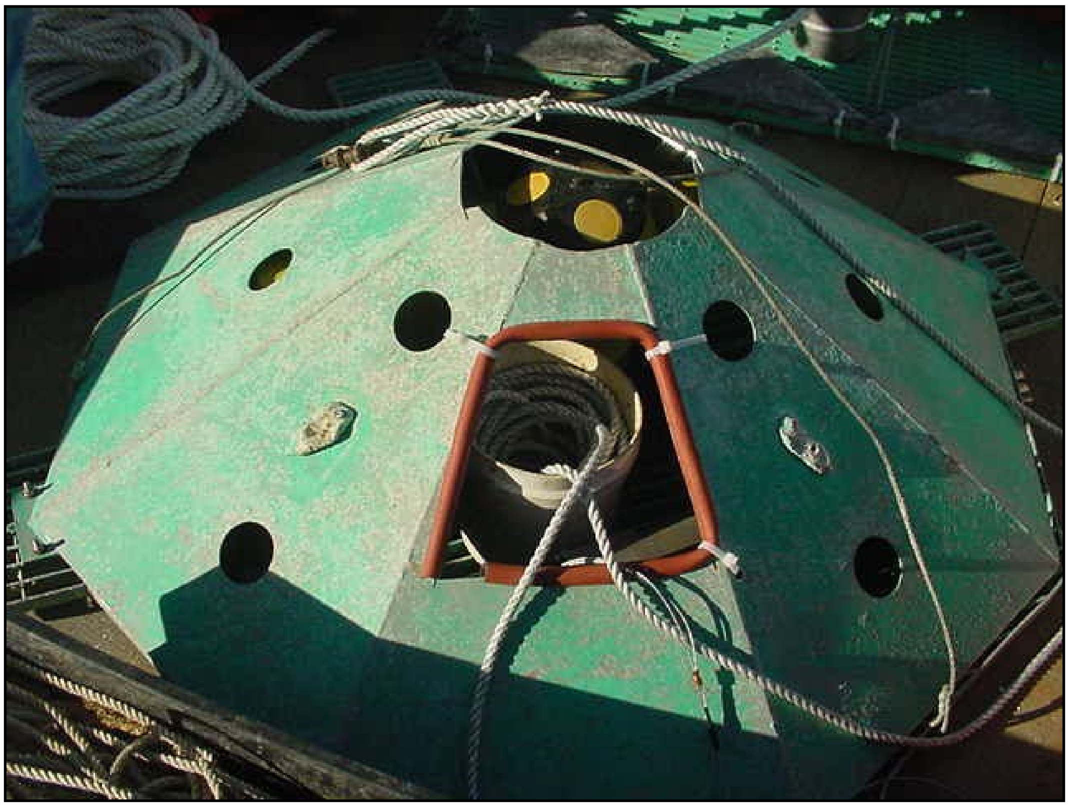


Figure 5. SonTek ADP mounted in mooring frame that was deployed near entrance to inner harbor.

The moored instruments were powered by batteries and recorded data internally. The survey instrument was externally powered and transmitted data over a cable to a computer onboard the survey vessel.

Before deployment, a program called BBTEST was run on a computer connected to the RDI current meter that was to be placed in the mooring. The program runs a series of diagnostic tests that establish that the ADCP is working properly and within specifications. To set the ADCP for deployment, the internally stored commands that the ADCP would use when started were displayed, reviewed, and changed where needed. The ADCP was set to average 170 pings, transmitted at the rate of approximately one every 0.7 sec, every 15 min, and recorded data in

1.641 ft (50 cm) vertical bins. According to RDI, this reduces the short-term random error of the acoustic measurements to near the long-term system bias of 0.007 ft/sec (standard deviation). A 120-sec averaging period was adopted to average out the wave-induced velocities.

Figure 6. Typical mounting for current transect ADCP on side of survey vessel.

The SonTek ADP used for the mooring near the entrance to the inner harbor does not have a diagnostic program. However, the compass operation was checked as recommended by SonTek, and a short bench-test run was made to verify operation of the system. As with the RDI current meter, the internal commands were displayed, reviewed, and changed where needed. The ADP transmitted nine pings per second, and was set to average the measurements from the pings over a 120-sec interval (again, to average out the wave-induced velocities) every 15 min. Data were recorded in 0.984 ft (30 cm) vertical bins. According to SonTek, this results in a standard deviation in the random error of the acoustic measurements of about 0.05 ft/sec.

The fact that the acoustic current meters can be mounted on the bottom, out of the way of vessel traffic, and can record the vertical current profile from that position means they are particularly well suited for harbor deployments. Care was taken not to deploy these meters at locations where large ships might be able to damage them in high sea states; locations were selected so that water was deep enough that boat traffic could not affect them.

Just prior to beginning the transect current surveys, a magnetic deviation correction was made by navigating pairs of back-and-forth lines along fixed headings and determining the differences between the bottom-track output headings (determined by the system compass) and the headings from GPS (true direction). The compass calibrations were verified by driving the survey vessel in a circle, starting and ending at the same spot. The bottom-track data also showed that the vessel had completed the circle and returned to the same point.

Mooring and Instrument Deployments

With the exception of the water-level gage that was mounted on the current meter mooring frame deployed near the seaward end of the navigation channel (Figures 2 and 4), each gage was placed on a horizontal pedestal that was welded at a 90-deg angle to one end of an 8-ft-long aluminum angle iron (Figure 7). The gage was then strapped to the angle iron. Each gage was deployed by bolting the end of the angle iron opposite the gage to a wooden piling. A water-level recorder dedicated to recording atmospheric pressure was placed on land in Hull, MA. The atmospheric pressure measurements were made so that atmospheric effects on changing the water level could be removed from the water-level data.

The current meter deployed near the entrance to the inner harbor was placed next to a navigation channel marker (Figure 8) at a depth of approximately 15 ft mean low water (MLW). The other current meter was deployed near the seaward end of Boston North Channel at a depth of approximately 35 ft mean sea level (MSL). The exact location for this mooring deployment was selected primarily based on markers in the vicinity that showed fishing trawling lanes, as it was crucial to avoid trawling activity that could damage the instrumentation. Both moorings had sloped metal structures around them to help deflect anchors and other objects that might snag them. They also both had pop-up buoys (Figure 9) that released following activation by an acoustic signal from the surface. The buoys were held close to the bottom during the deployment. When released, they brought lines to the surface that were used to recover the moorings.

Figure 7. Water-level gage mounted on angle iron.

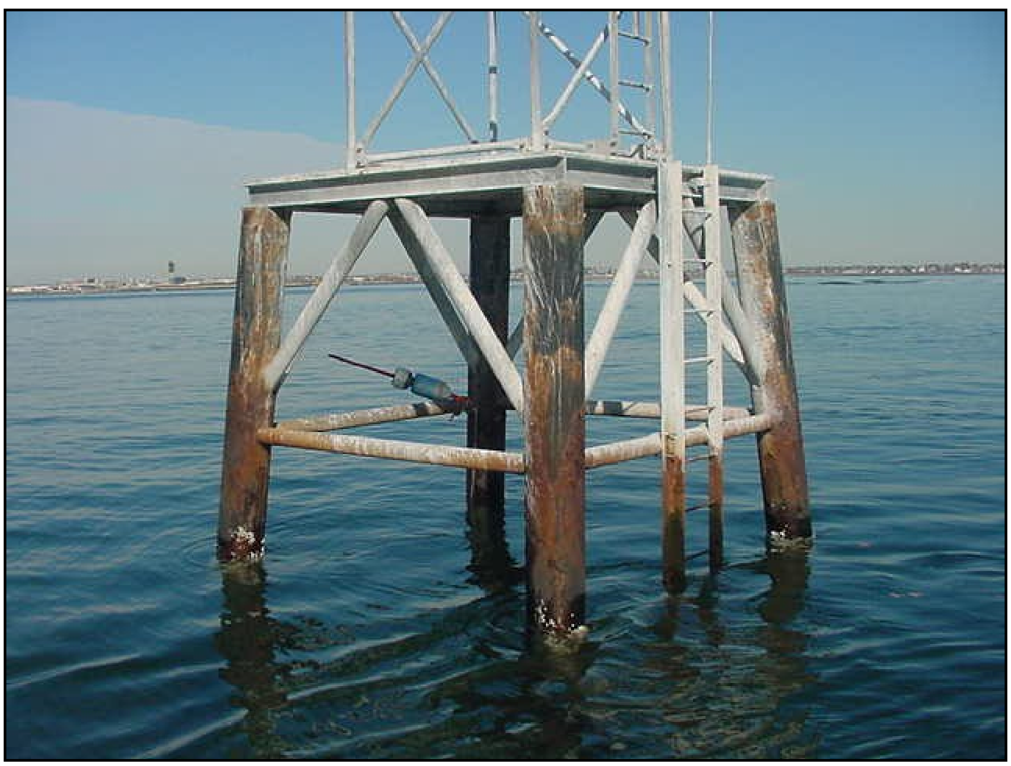


Figure 8. Navigation channel marker next to current meter deployed near entrance to inner harbor.

Figure 9. Deployment of pop-up buoy attached to mooring near seaward end of navigation channel.

The instrument deployments and recoveries were accomplished using the 35-ft fiberglass research vessel *Sakonnet,* based in Hull, MA (Figure 10). The *Sakonnet* has a 2,000-lb, 12-ft-high hydraulic A-frame that was used for deployment and recovery operations (Figure 11).

The *Sakonnet* was also used to conduct the current transect surveys. Waves were a problem for the surveys. In rough conditions, the movement of the ADCP can be such that it will lose track of the bottom and be unable to determine the speed of the survey vessel over the bottom. Vessel speed is an important measurement essential to obtaining good quality data. Certain transect lines that were planned to be run, were not, because the waves along them were too high. The waves that were encountered also required deviating from the ideal survey direction (which is perpendicular to the flow) for some lines, to more oblique angles. The survey lines are shown in Figure 12.

Figure 10. Research vessel *Sakonnet* based in Hull, MA, used for all operations.

Figure 11. A-frame on *Sakonnet* used to deploy current-meter moorings.

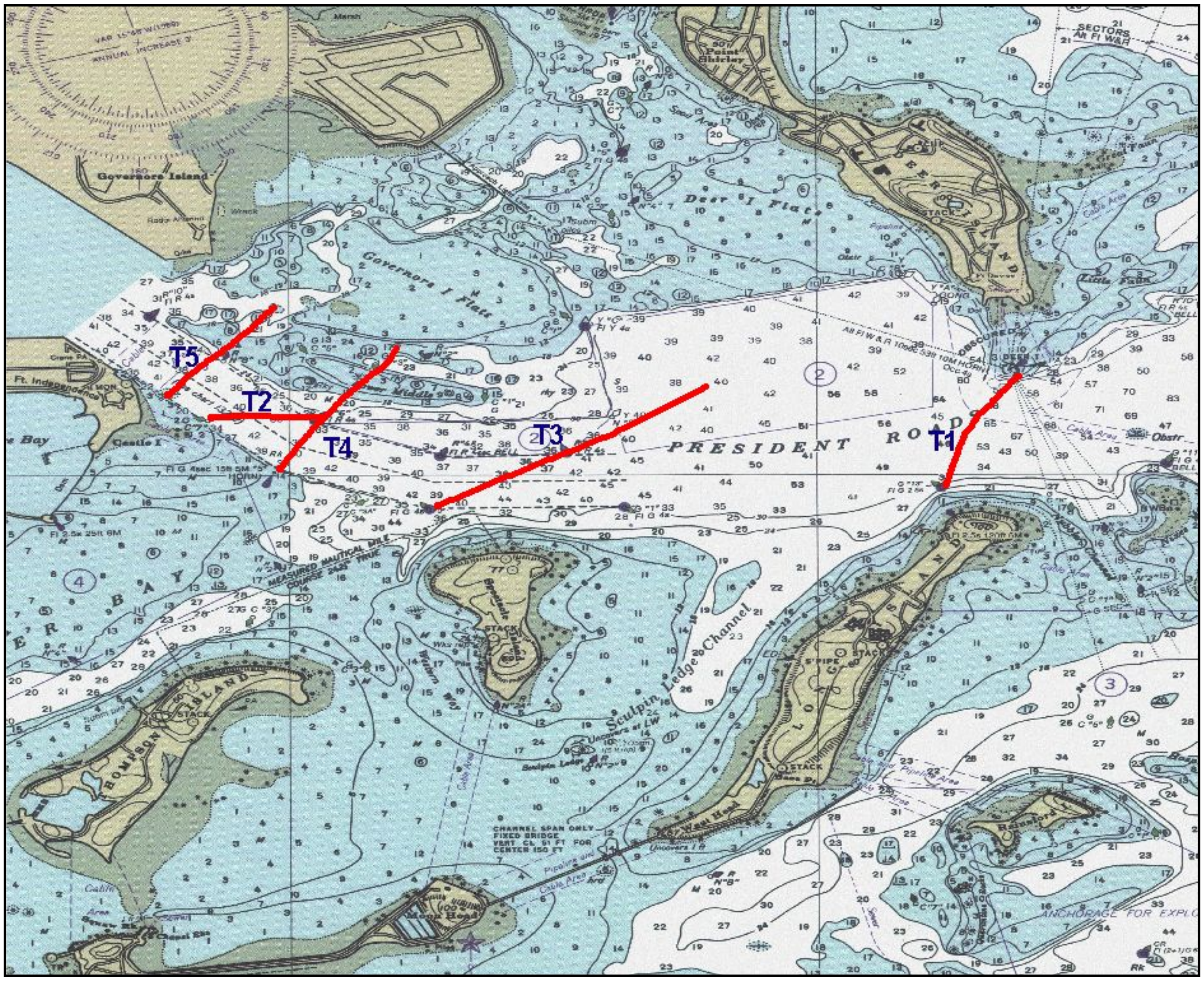


Figure 12. Current transect survey lines.

3 Chronology of Events

Preparations, Field and Post-Retrieval Activities

The first field effort was conducted from 8 to 12 November 2004. Instruments were deployed and the first current transect survey was conducted. The instruments were recovered and the second current transect survey was conducted during the 6 to 9 February 2005 effort. Detailed chronologies of the program during these times are listed in Tables 1 and 2.

Discussion

CHL responded quickly after receiving funding to begin the program on 5 November 2004. All instrumentation was deployed 5 days later on 10 November. The SOW called for 1 to 2 months of data collection. However, 3 months of data were collected, primarily because one of the worst storms in the area in 50 years occurred on 23 January 2005. The winter storm resulted in the harbor freezing and made operations impossible until the week beginning 8 February when there were both favorable wave conditions and an open passage to the survey area.

After returning from the instrument deployment and first current transect survey on 12 November 2004, a report of the field activities and a preliminary analysis of the current transect data was prepared and transmitted to the New England District approximately 2 weeks later. The recovered instrumentation at the end of the project was returned to CHL on 10 February 2005 and processing of the data from the moored instrumentation was completed by the middle of April. The ADCIRC modeling effort was preformed by the New England District with assistance from CHL personnel, and the requested data from the field collection program were provided for the modeling effort in May. A report on the second current transect survey and instrument retrieval was sent to the New England District in June 2005.

Table 1. Summary of activities for first field effort, 3-12 November 2004.

Date	Time (local)	Activities
11/3-11/5	Day	Planning, arranging logistics, instrument preparation, packing equipment.
11/7-11/8	Day	Kirklin and Bull transported equipment to Boston in truck. Pratt and Tubman flew to Boston, MA, on 11/8.
11/9	Day	Mobilized survey vessel, started tide gages and current meters, purchased supplies, prepared ADCP mount for *Sakonnet*.
	1445	Deployed TG4 on pier at Hull Yacht Club.
11/10	1015	Deployed TG2 and CM2.
	1055	Deployed CM1.
	1245	Deployed TG1.
	1351	Deployed TG3.
	1430-1645	Mounted ADCP on survey vessel and attempted calibration (ferrous metal in mount prevented calibration).
	Night	Replaced ferrous metal in ADCP mount.
11/11	0430	Kirklin and Bull started back to Vicksburg, MS, in truck.
	0600	Calibrated ADCP.
	0630-1600	Current transect survey along T3, T4, and T5.
	1630-1830	Demobilized survey vessel.
11/12	Day	Pratt and Tubman returned to Vicksburg, MS, by plane, Kirklin and Bull arrived in Vicksburg in truck.

Table 2. Summary of activities for second field effort, 5-10 February 2005.

Date	Time (local)	Activities
2/5-2/6	Day	Kirklin, Bull, and Callegan transported equipment to Boston, MA, in truck.
2/7	Morning	Mounted ADCP on survey vessel and calibrated it.
	1355	Recovered TG1.
	1527	Recovered CM1.
	1646	Recovered CM2.
2/8	0800-1500	Current transect survey along T1, T2, and T3.
	1616	Recovered TG3.
	1645	Recovered TG4.
	Evening	Demobilized survey vessel.
2/9-2/10	Day	Returned equipment to Vicksburg, MS, in truck.

An unknown problem with the current meter deployed near the entrance to the inner harbor (CM1) resulted in it not recording data. The current meter deployed at the seaward end of the navigation channel (CM2) recorded data during the entire deployment period, which included the time of the winter storm on 23 January 2005.

All of ERDC's water-level gages functioned throughout the storm and through the period where large areas of the harbor were ice covered. As a result of the requirement to stay out of trawling lanes, the water depth where the water-level recorder attached to the mooring on the seaward end of the navigation channel was deployed (TG2) ended up being approximately 5 ft deeper at high tide than the maximum range of the water-level gage. Thus, the tidal variations in water level were accurately recorded over about 60 percent of the total tidal range (missing a portion of high tide).

The NOAA tide gage in Boston's inner harbor failed at the beginning of the 23 January 2005 storm, and did not become operational again until near the beginning of 5 February 2005. The NOAA anemometer at Logan Airport provided data for the entire program with only a few invalid measurements.

4 Data Processing and Analysis

Processing Steps

Verified NOAA wind data from Logan Airport were downloaded from their Web site (*http://cdo.ncdc.noaa.gov/CDO/dataproduct*) as an ASCII file, and time series plots were made using in-house software. The data from the Microtides water-level recorders were down-loaded from the systems using software supplied by the manufacturer. The data were checked to verify that the atmospheric pressures recorded before and after deployment were correct. Using the atmospheric pressure, values recorded by the water-level recorder kept on land in Hull, MA, the atmospheric pressures were subtracted from the field data, and the pressures were converted to water-level values using a representative density of sea water (1.025 times the density of fresh water). The depths recorded just after deployment, and just prior to recovery, were then checked to verify that they agreed with the field observations at those times. The water levels were then referenced to the record means and stored in ASCII files.

The acoustic current meter that did not record data was manufactured by SonTek and there was no need to process data from it. The other moored current meter was the RDI ADCP deployed near the seaward end of the navigation channel (CM2). RDI supplies utility software for recovering and processing data. Newer versions of the software allow Windows®-based use of the software. However, the original DOS software supplied with the moored instrument was used for processing the recorded data. The RDI program BBSC was used to download the binary data file from the ADCP's memory and store it on the computer in binary form. An RDI program called BBLIST was used to convert the binary data into ASCII files. Three data-quality parameters were recorded by the current meter: correlation magnitude, percentage of good pings, and backscatter intensity. Correlation magnitude is a measure of the pulse-to-pulse correlation in a ping for each depth cell. Percentage of good pings is a data qualifier representing the percentage of pings having good data based on the signal-to-noise threshold. Backscatter intensity is a measure of the strength of the acoustic signal that is returned to the current meter in each depth cell. A low value can indicate an electronic failure or depth cells at the furthest ranges that are too far away from the instrument. At the approximately 35-ft deployment depth, all depth cells were well within range. However, the recorded backscatter intensity plays an important role in determining were the sea surface is. The acoustic signal transmitted by the ADCP will be reflected by the surface and make it appear that the instrument is still measuring valid velocities at greater ranges than the actual depth. However, the backscatter strength from the surface is relatively strong, and indicates the range at which to terminate the velocity measurements in the data processing.

The correlation magnitudes and the percentage of good pings were reviewed for each ADCP measurement. An in-house extraction program was used to create files with only the parameters needed for further processing. These parameters are the time of the measurement, the vertical orientation and heading of the instrument, the water temperature, and the backscatter intensity. The current-meter orientation and heading, at this stage in the processing, are data-quality indicators. If the current meter is tilted more than 20 deg from the vertical, it will not operate correctly. The orientation and heading can also show if the mooring was snagged by an anchor or trawl, and, if it was, when it happened.

Using an in-house analysis program, the inflection point in the backscatter intensity within the depth range of 29 to 45 ft was located in each ADCP vertical profile. The depth was calculated for the depth cell that was one cell above the one in which the inflection occurred, and new files were produced that kept all the depth cells up to one cell less than the inflection cell. The calculated depth was plotted and compared to the time series record of the water-level recorder attached to the mooring. An in-house program used these files of processed vertical current profiles to calculate vertical vector averages of the current from the first cell, at a depth of approximately 3 ft above the sea floor, to the last cell in the processed profile. These vector averages were stored in an ASCII file and plotted in time series plots.

The first step in processing the current transect survey data was to compare the survey field notes with the ASCII files of GPS navigation data recorded for each transect. There were two objectives in the process. The first was to verify that the field notes matched the file numbers to the correct survey transect lines. The times and locations in the GPS navigation files provided this information. The second objective was to determine the exact time when each survey line was acquired and started by the survey vessel, and when the line was complete. By matching these times to the times of the measurements recorded in the ADCP data files, data not along the transect line were eliminated from further processing.

The Windows®-based software package supplied by RDI used to acquire the current transect data (WinRiver) was used for the next step in processing the transect data. WinRiver converted the binary data recorded by the ADCP to ASCII output files. Two data-quality indicators are given in these files. They are percentage of good pings and backscatter intensity. These two parameters were reviewed for data quality. Correlation magnitudes are not shown in these files, as they are for the moored current meter, because unacceptable correlation magnitudes during the survey would have been shown on the transect survey output computer display, and the survey would have been stopped until the problem was corrected. In addition to the current speeds and directions in the depth cells, the WinRiver ASCII output files also contain the times of measurements, total depths, latitudes and longitudes at the locations of the measurements (from the GPS), and the total volume transport across the transect line from the current. From these files, an in-house program created files that contained the times, latitudes and longitudes, and depths for the measurements, and the current speeds and directions in the cells down to a level equal to 94 percent of the total depth. In the final 6 percent of the depth, acoustic side-lobe interference adversely affects the measurements. Using these files, an in-house program calculated the vector current average over the water column from the first depth cell, at a depth of approximately 3 ft below the surface, to the last depth cell in the processed profile. These vector averages were stored in ASCII files and plotted in time series plots.

Data Return and Assessment of Data Quality

NOAA tide data were available from the station in Boston's inner harbor for the deployment period, except from 22 January to 4 February 2005. There is no information on the NOAA Web site that explains why the data are missing for this period. However, the NOAA gage measures the distance to the sea surface inside a stilling well with an acoustic sensor positioned above the sea surface, and it may be affected by ice in the stilling well. Based on information supplied by the owner of the survey vessel (the *Sakonnet*) about conditions during this period, there is a good chance that the data loss was due to ice. At all other times during the field deployment period, NOAA has verified their data as being good.

Unlike the NOAA gage, the ERDC gages measure the water pressure above the gages without a stilling well. The effect of ice on these measurements is difficult to determine, especially without specific knowledge of the ice conditions right at the sensors. However, there are no obvious differences in the data from these gages during times when it was known that there was no ice, and during times when there may have been ice present. All indications are that at three of the gage locations, 100 percent good-data were obtained for the entire deployment period. As already noted, the fourth gage (TG2), on the current-meter mooring near the seaward end of the navigation channel, recorded water level during the entire deployment period, but the data are good only about 60 percent of the time.

As discussed earlier, the moored current meter near the entrance to the inner harbor recorded no data. For the other moored current meter (CM2), all data-quality indicators showed that it acquired 100 percent good-data for the entire deployment period and that the current meter was not disturbed at any time.

During the first transect current survey, the data quality indicators show that all the data are good. However, the wind and rough sea state on 11 November 2004 were such that the transect lines had to be confined to the western extent of the navigation channel between Spectacle and Castle Islands (lines T3, T4, and T5 in Figure 12). A failure of the shipboard generator during this survey ended the survey after 9.5 hr, instead of the planned 12 hr.

During the second transect current survey in February, the eastern extent of the navigation channel was surveyed out to a line from Deer Island to Long Island (line T1 in Figure 12). The data-quality indicators for the second survey show that on two of the lines surveyed, all the recorded data are good. As a result of the slower sound speed in the colder winter waters, the ADCP was unable to measure currents at all depths on the deepest transect line (i.e., T1 between Deer Island and Long Island). Failure to record data began at a depth of about 60 ft, and in the deepest places along this line, there are no data for the near-bottom portion of the water column. During this survey, the survey vessel had to return to the dock during daylight to avoid ice present in the harbor. As a result, the survey lasted 7.5 hr instead of the planned 12 hr.

There are verified NOAA wind data for all of the deployment period, with 3.9 percent observations labeled invalid. The longest period of invalid data is 11 hr, and the second longest is 5 hr.

The extent of the good-data coverage is shown in Figure 13. In reference to the original SOW, water elevation data were obtained for 3 months at four sites, instead of the 1 to 2 months of data at two sites, as originally proposed. Moored current data were obtained at one site for 3 months, instead of the 1 to 2 months at one site that was in the original SOW. Two transect current surveys were performed, as proposed. Wind data were obtained for nearly the entire deployment period, as proposed.

Analysis

The NOAA anemometer at Logan Airport is placed at an obstruction-free location near the center of the runway area. The sensor is 20 ft above the ground. The wind speeds and directions from the measurements at this location during the deployment period, with the gaps for invalid data filled by linear interpolations, were sorted into 30-degree direction categories. The directions are the directions the wind is blowing from in degrees true north. The speeds in each direction category were sorted into 5-ft/sec speed categories. Table 3 shows the percentage of the total number of observations in each category. There were two major storms during the 10 November 2004 to 8 February 2005 deployment period. One occurred on 27 December 2004, when a maximum wind speed of 47 ft/sec from 50 deg was measured at Logan Airport. The other one, on 23 January 2005, had a maximum wind speed and direction at Logan Airport of 57 ft/sec from 60 deg. The wind speed during the January storm is the maximum value observed during the deployment period. Table 3 is a statistical summary of the wind observations from Logan Airport; it shows that the strongest winds were from 345 to 15 deg and 45 to 75 deg. A majority of the winds were from the northwest quadrant, and almost half (47.71 percent) were 10 to 20 ft/sec. Overall, the statistics show a sustained period of strong winds, with two major storms.

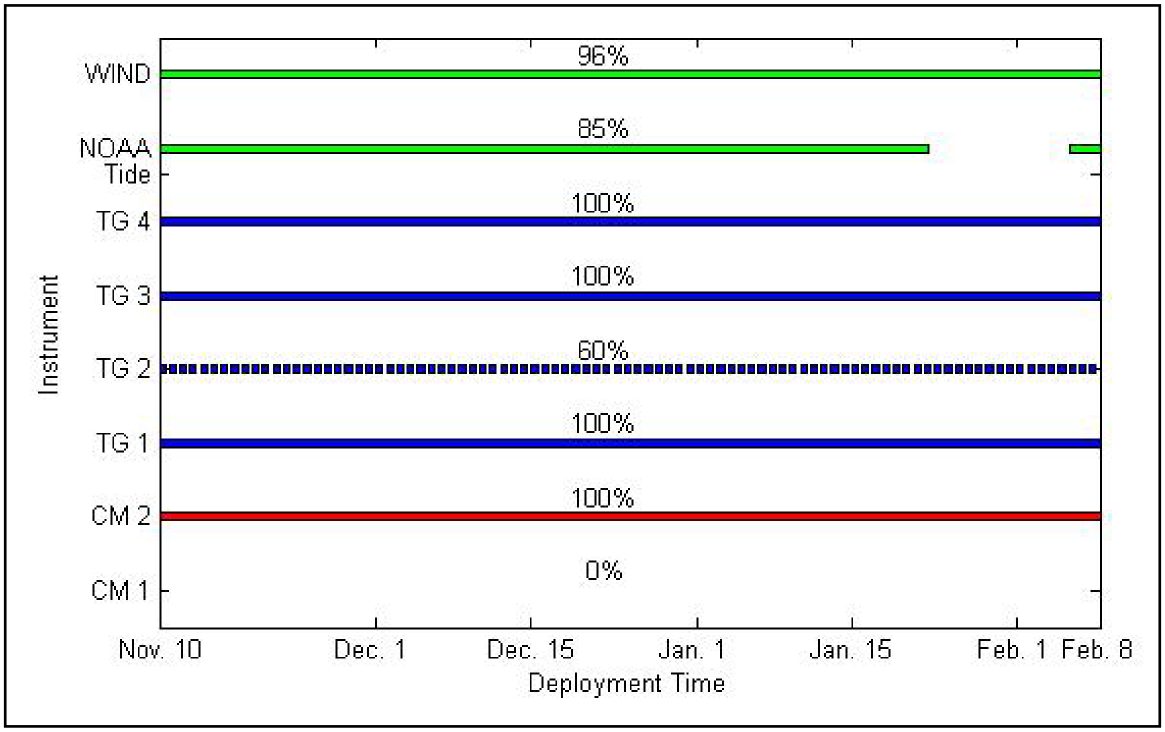


Figure 13. Summary of data return for deployment period. TG's are water-level recorders and CM's are moored current meters (see Figure 2 for instrument locations).

Table 3. Summary of wind observations made at Logan Airport during the deployment period (10 November 2004 – 8 February 2005).

		Wind Direction (deg T)												Total %
		345-015	015-045	045-075	075-105	105-135	135-165	165-195	195-225	225-255	255-285	285-315	315-345	
Wind Speed (ft/sec)	0-5	0.46	0.27	0.27	0.23	0.32	0.69	0.41	0.32	0.18	0.14	0.18	0.27	3.75
	5-10	2.61	0.96	0.46	0.91	1.37	1.37	1.01	1.74	0.78	0.73	1.23	1.37	14.53
	10-15	3.98	1.01	0.37	0.96	0.91	1.23	2.51	1.69	1.65	2.61	3.56	5.16	25.64
	15-20	3.02	1.65	0.27	0.46	0.69	0.59	0.55	2.24	2.33	3.24	3.06	3.98	22.07
	20-25	1.51	0.64	0.18	0.41	0.50	0.37	0.37	1.87	1.69	2.19	2.74	3.11	15.59
	25-30	1.42	0.18	0.14	1.10	0.27	0.14	0.14	1.10	0.96	1.28	1.92	1.23	9.87
	30-35	0.69	0.09	0.41	0.64	0.27	0.05	0.18	0.37	0.23	0.69	1.51	0.91	6.03
	35-40	0.09	0.00	0.09	0.05	0.05	0.00	0.09	0.18	0.00	0.32	0.18	0.00	1.05
	40-45	0.23	0.05	0.00	0.00	0.05	0.00	0.09	0.05	0.00	0.09	0.00	0.00	0.55
	45-50	0.23	0.00	0.18	0.05	0.00	0.00	0.05	0.09	0.05	0.05	0.00	0.00	0.69
	50-55	0.05	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14
	>55	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09
Total %		14.26	4.84	2.56	4.80	4.43	4.43	5.39	9.64	7.86	11.33	14.40	16.04	100.00

To evaluate the wind-driven currents generated near the seaward end of the navigation channel, the depth-averaged (east-west and north-south) components of the current velocities measured by the moored ADCP were put through a low-pass Butterworth filter with a cutoff frequency (0.7) of 1/26 hr^{-1} to remove the tidal signal. During the 23 January 2005 storm, the winds increased from above 32 ft/sec at 2354 (GMT) on 22 January, when they were blowing from 90 deg, to a maximum speed of 57 ft/sec (GMT) from 60 deg at 0554 (GMT) on 23 January. The wind direction then (later on 23 January) moved toward blowing from the north, and dropped below 32 ft/sec at 2100 (GMT) on the same day. During this time, the water-level records show the mean tide level in the harbor increased as the wind drove water into the harbor. The 26-hr (period) low-pass filter catches the contribution of the storm surge outflow from the harbor to the currents as a residual 0.56 ft/sec current toward 69 deg that enhanced the ebb currents near the end of the day on 23 January when the wind stress relaxed. The events during the 27 December 2004 storm repeated this pattern. The wind speed increased from 18.7 ft/sec to 45.6 ft/sec from 60 deg at 2254 (GMT) on 26 December, reached the maximum of 47.2 ft/sec from 50 deg on 27 December, and decreased below 18.7 ft/sec at 0554 (GMT) on 28 December. The filtered residual current showed a 0.54 ft/sec current toward 70 deg that enhanced the ebb currents near the end of the day on 27 December.

Other than during these two storms, the maximum current speeds after filtering were all less then 0.36 ft/sec, and there are nine periods in the record where the residual current speeds were greater than 0.30 ft/sec. During these periods, there is no obvious consistent pattern to their occurrence and wind speed and directions. Since there is very little freshwater input into Boston Harbor, density-driven currents are not likely to be contributing to the residual currents after filtering. Two other possible contributors are tide-induced residual currents and wind-driven currents.

To see if some statistical relationship between the winds and the currents might exist, power spectral estimates of the filtered velocity components were made using an in-house MATLAB program. The program uses a Fast Fourier Transform (FFT), with trend removal and a Blackman-Harris window. The resulting spectra are shown in Figure 14. The east-west filtered current components have a peak at a period of 3.489 days. The hourly wind speed and direction data from Logan Airport were broken into their east-west and north-south components and power spectra were made. The resulting spectra are shown in Figure 15. The east-west components of the wind also have a peak at a period of 3.489 days. The north-south components of the wind have a smaller peak at 3.012 days. Cross spectra between the wind components and the current components were made and correlations between the current and wind components were performed. It was found that at a period of 3.012 days, the correlation coefficient between the north-south component of the wind and the north-south component of the current was 0.92. However, there is insignificant energy in the current band centered on that period. At a period of 3.489 ft/sec, the correlation between the north-south component of the wind and the east-west component of the current is only 0.65. At that period, the correlation between the east-west component of the wind and the east-west component of the current is 0.93. These results indicate that east-west wind-driven currents from east-west winds are likely contributing to the residual currents after filtering. The tide-induced residual current is expected to persist throughout the record, and its strength at the CM2 location can be estimated by taking the mean of the filtered record. The tide-induced residual current was calculated to be 0.07 ft/sec toward 19 deg.

Two of the correlation analyses in the SOW were specifically designed to evaluate the importance of the residual tidal currents in the harbor. The analyses are the correlations between the mooring and transect current data, and the correlations between the current and water-level data. These analyses were to utilize current data from the mooring near the entrance to the inner harbor (CM1) where wind-driven currents were expected to be very small in comparison to the tide-induced residual currents. The analyses were not performed because there were no data from this mooring. According to Signell and Butman (1992)[1] the tide-induced residual circulation inside the harbor near the navigation channel has maximum speeds of about 0.33 ft/sec. In the vicinity of CM2, Signell and Butman reported tidal-induced residuals of 0.11 to 0.19 ft/sec toward 90 deg. Considering that their observations are only somewhere in the vicinity of CM2 (the paper does not give exact locations), the comparison of the analysis of the CM2 observations and their observations is reasonably good.

[1] Signell, R. P., and B. Butman. 1992. Modeling tidal exchange and dispersion in Boston Harbor. *Journal of Geophysical Research* 97:15,592-16,606.

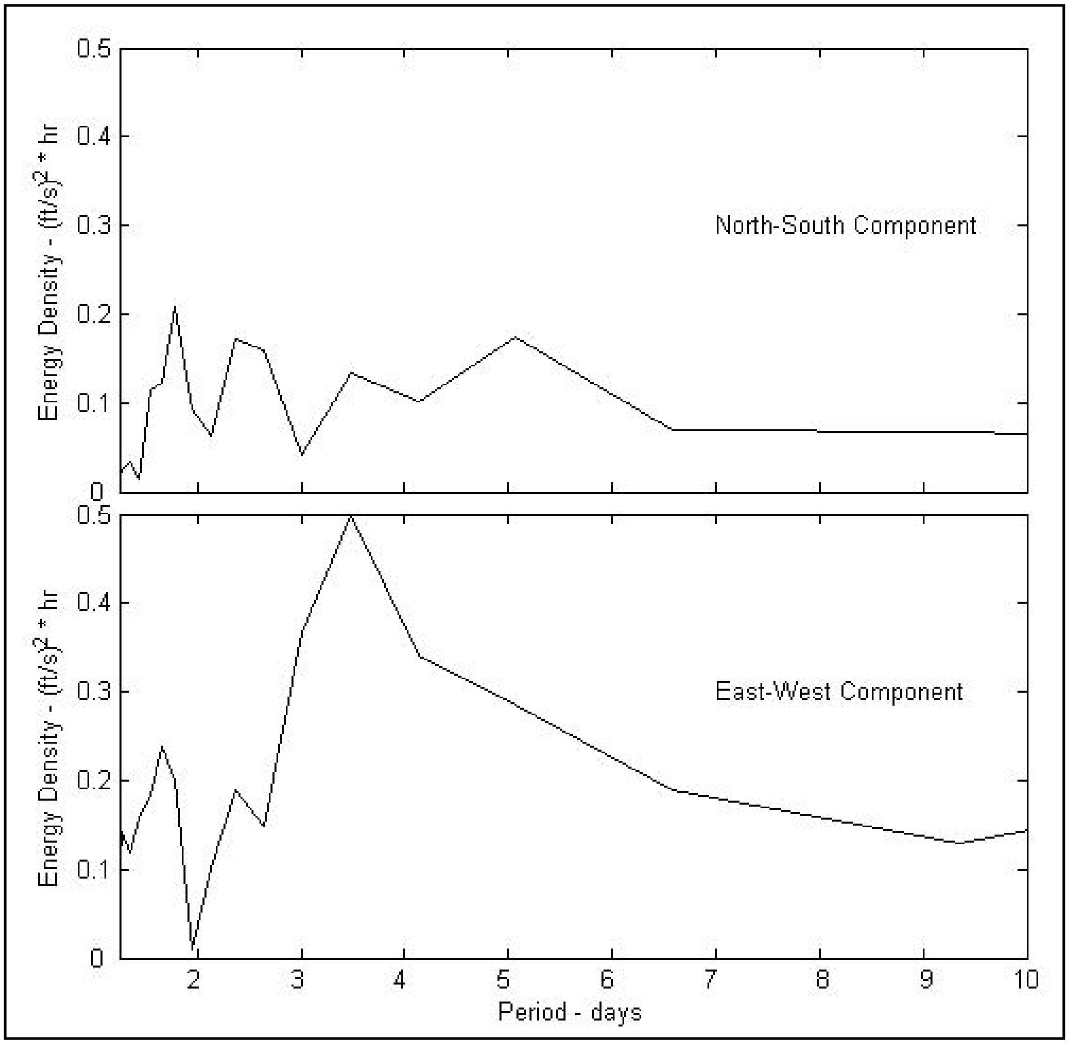


Figure 14. Power spectra of low-pass filtered (26-hr cutoff) current components of currents measured by ADCP mooring located near seaward end of navigation channel.

During the first transect current survey on 11 November 2004, the filtered residual currents at CM2 were about 0.2 ft/sec toward the west. Transects were surveyed at different times, when the survey vessel could get to them, so measurements were made at various stages in the tidal cycle. During that day, the maximum-measured tidal currents along the transects were 1.82 ft/sec along T3, 0.9 ft/sec along T4, and 1.37 ft/sec along T5 (all at ebb tide), therefore the filtered residual was 11 to 22 percent of the maximum-measured ebb speeds in November. The maximum-measured flood speeds on 11 November were 1.42 ft/sec along T3, 0.86 ft/sec along T4, and 0.77 ft/sec along T5, so the filtered residual was 14 to 26 percent of the maximum-measured flood speeds. Current meter CM2 was recovered before the second transect current survey on 8 February 2005. The maximum-measured currents at that time were 3.84 ft/sec along T1, and 1.72 ft/sec along T3 (both at ebb). Transect T2 was not sampled at any time near peak ebb. During flood tide, the maximum-measured currents were 3.61 ft/sec along T1, 0.98 ft/sec along T2, and 1.27 ft/sec along T3. Using the same residual current speed, it was 5 to 12 percent of the measured-maximum ebb currents, and 6 to 20 percent of the measured-maximum flood currents.

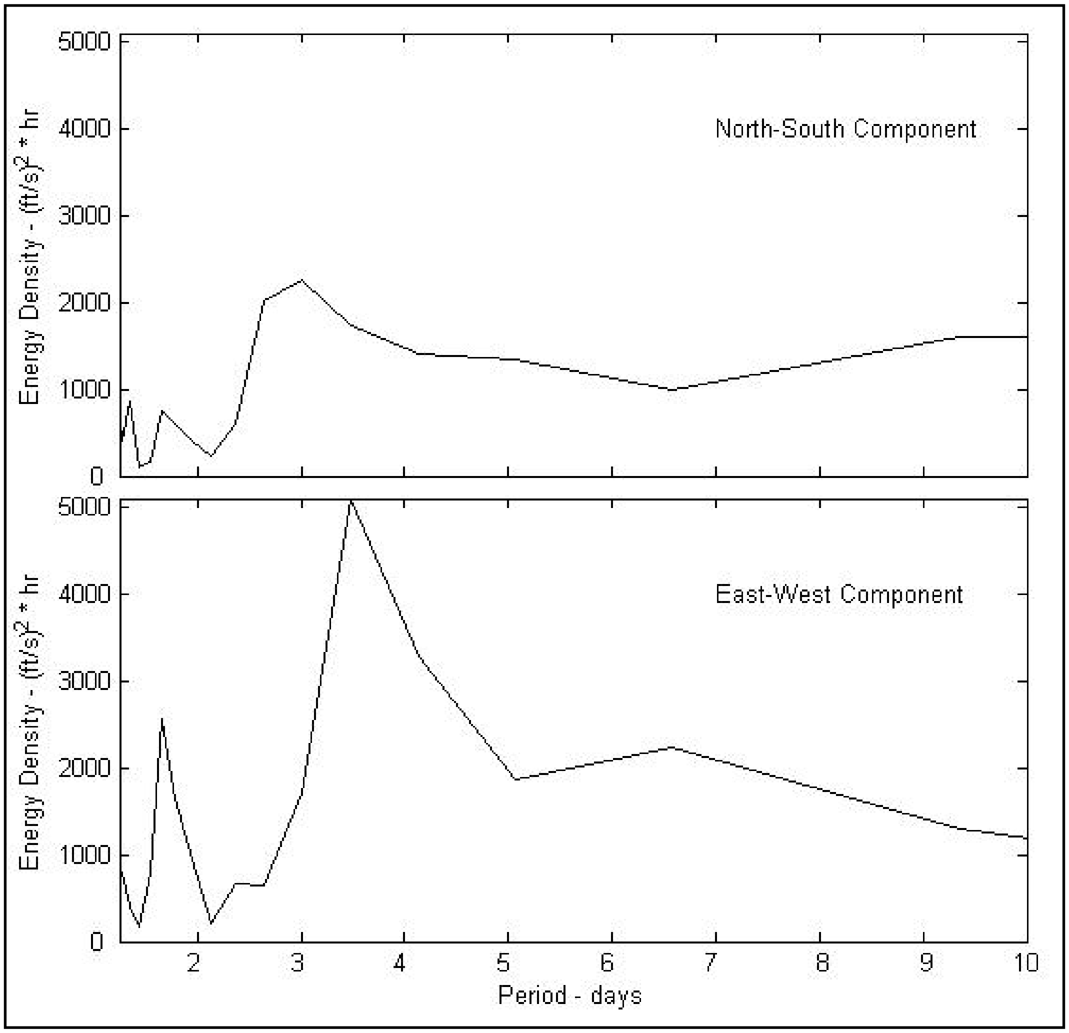


Figure 15. Power spectra of components of wind measured at Logan Airport over same period of time that currents were measured.

The maximum water-level range is defined as the largest change in elevation from high water to the low water immediately following, that was recorded at a gage location. The maximum water-level range includes wind effects, as well as the astronomical tide. Excluding TG2, which hit full scale at high tide, the range was 13.9 ft at TG1, 13.5 ft at TG3, 14.1 ft at TG4, and 13.9 ft at the NOAA gage.

Deliverables

Plots of all data in Appendices B, C, D, E, and F are in electronic form on the project DVD as ".jpeg" files. They include:

1. Water levels referenced to the record mean levels at four locations (TG1, TG 2, TG3, TG4) and tide data referenced to established mean lower low water (MLLW) at the NOAA gage in the inner harbor (Appendix B).
2. Depth-averaged current velocities from the CM2 (Appendix C).
3. Depth-averaged currents for the transect current surveys (Appendix D).
4. Horizontal cross sections of current velocities from the transect current surveys (Appendix E).
5. NOAA wind data from Logan Airport (Appendix F).

The data are on the project DVD which was sent to the New England District as ASCII text files. The folder structure of the project DVD is in Appendix G. The formats for ASCII data files are in Appendix H and are explained in "readme" files on the project DVD.

Transect current data were put in vectorized form. This makes it possible to display the current vectors in a GIS system on the transect lines along with the bathymetry and shoreline position. An ArcView project was built to make these displays. The ArcView project and the necessary files to run it are on the project DVD.

The statistical summaries and correlations are present in this report. An electronic copy of this report is on the project DVD as a "Word" document.

5 Summary and Conclusions

A field data collection program in Boston Harbor, MA, was conducted from 10 November 2004 to 8 February 2005. Four water-level gages and two moored current meters were deployed for this period. In addition, daylight current transect surveys were conducted on 11 November and 8 February. One of the moored current meters failed to collect data. The other recorded good quality data for the entire deployment period. The four tide gages recorded data for the entire deployment period; however, one gage recorded full scale readings around high tide, and thus, recorded accurate water levels for approximately 60 percent of the tidal cycle. The other three gages recorded 100 percent good data. NOAA tide and wind data were obtained for the study. Probably due to ice in the harbor, there are no NOAA tide gage data 15 percent of the time. There are some minor gaps in the NOAA wind data from Logan airport that total 3.9 percent of the deployment period.

Maximum-measured ebb tidal currents in the harbor were 0.9 to 3.84 ft/sec. Maximum-measured flood currents were 0.77 to 3.61 ft/sec. In general the ebb currents were stronger than the flood currents. The data at CM2 were analyzed to evaluate the importance of the wind-driven and tide-induced residual currents. The results of the analysis were that combined, these currents are small (5 to 22 percent of the ebb currents and 6 to 26 percent of the flood currents) compared to the maximum-measured tidal currents within the harbor. The tide-induced residual current at CM2 was estimated to be 0.07 ft/sec. The technical literature shows that tide-induced residual currents within the harbor, in the vicinity of the navigation channel, are stronger then they are at CM2, with speeds of about 0.33 ft/sec.

The strongest currents at CM2 resulting from the action of the wind during major storms were associated with outflow of the storm surge from within the harbor. The analyses showed that during a major storm in December 2004, the currents were 0.54 ft/sec toward 70 deg, and during one of the worst storms (in terms of wind speed) in recent history, which occurred in January, they were 0.56 ft/sec toward 69 deg (both speeds include an estimated tide-induced residual vector of 0.07 ft/sec toward 90 deg).

Appendix A: Scope of Work (SOW)

Field Data Collection to Validate Hydrodynamic Model Supporting Ship Simulator Studies, Boston Harbor, MA

Purpose

The purpose of the field data collection program is to obtain data needed to validate a hydrodynamic model of Boston Harbor and adjacent areas (Figure A1). The currents calculated by the verified model will be input to a ship simulator, which will be used to access the design of a navigation channel improvement project for Boston. The hydrodynamic model requires simultaneous measurements of water elevations, currents, and wind speed and direction for verification of model driving forces and calculated results.

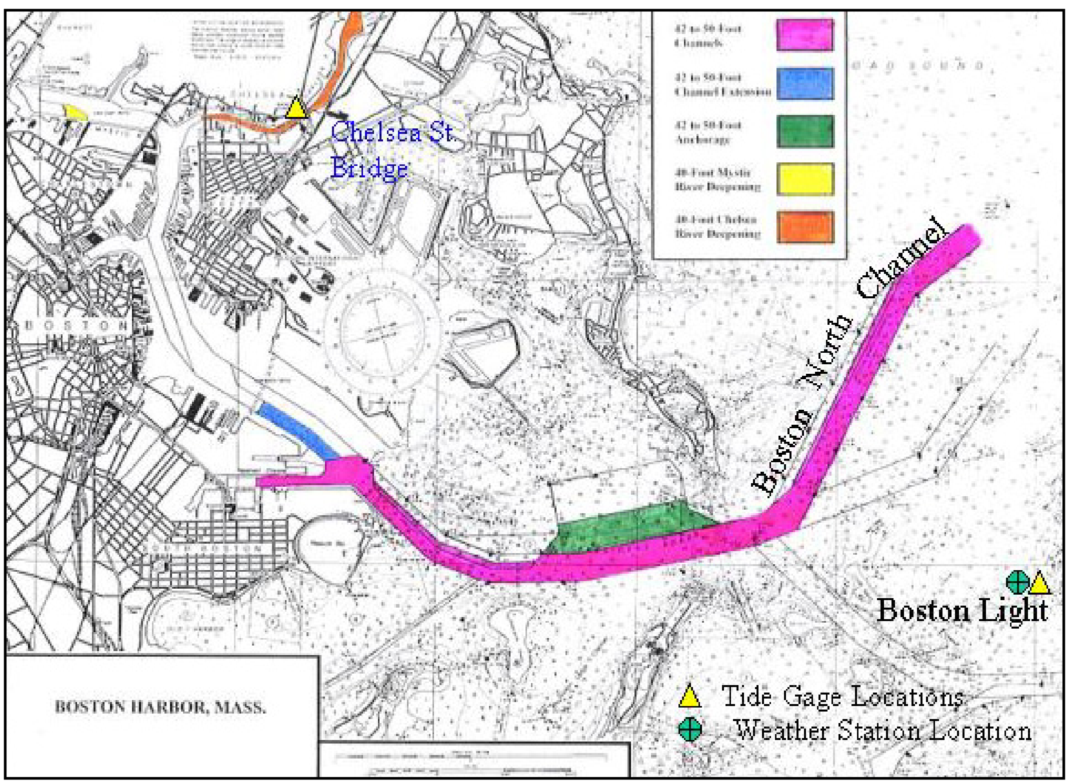


Figure A1. Boston Harbor and adjacent areas.

Approach

Typical navigationally significant currents in Boston Harbor are primarily the result of tidal forcing. The M_2 tidal component, which has a 12.42-hr period, is the most significant component. However, the currents are modulated by the S_2 and N_2 components, resulting in spring tidal currents that are 33 percent stronger than average currents. The spring tidal currents occur every 15 days. The wind also drives currents that can interact with, and modify the tidal-driven currents. There is relatively little freshwater input to the harbor, and resulting density-driven currents are not significant in terms of their effect on ship navigation. Water-level differences over the harbor (at any one time) are reported to be small in the absence of wind. Without wind-driven effects, water levels in the harbor are controlled by the astronomical tides, and the magnitudes and timing of their variations are nearly the same over the entire harbor. For this reason, the technical approach of the field data collection program emphasizes obtaining needed current information, and relies on minimal water-level measurements to provide elevation data.

NOAA maintains a tide measuring station in Boston's inner harbor, and has established five tidal benchmarks at various locations around the harbor. Thus the approach is to make additional tide measurements at only two locations in the harbor during the field data collection program and to use the existing NOAA tide station and benchmarks to provide the needed tidal elevation information throughout the harbor.

Current information for the ship simulator studies is needed along the navigation channel. Producing this information is the numerical model's primary role, and the focus of the field-data collection program is to obtain current data for verification of the model along the channel. The times of maximum tidal currents are predictable and can be measured by collecting data using a ship-mounted profiling current meter along transects across the navigation channel. It is proposed to do this over a tidal cycle during two separate times of spring tides. The importance of wind-driven currents is expected to be most significant in the channel in the vicinity of Boston North Channel and President Roads. Unlike tidal currents, the times and durations of strong wind-driven currents cannot be reliably predicted. Therefore, the proposed study has a current meter moored in, or very close to, Boston North Channel to collect current data every 15 min during the data collection program. The mooring will be deployed at the beginning of the program and recovered at the end, thereby internally recording data for a 1- to 2-month period.

During this data collection program, it is proposed that wind speed and direction be collected at a site established in the harbor.

Data Collection Program

The proposed field effort, as stated above, will include measuring water levels at two locations, and currents and winds, each at one location, for a 1- to 2-month period, and measuring transects of currents across the navigation channel during two spring tidal cycles. Each tidal-cycle measurement period will be approximately 13 hr long. The locations of the two proposed tide stations are Boston Light and Chelsea St. Bridge. These two locations, shown in Figure A1, have established NOAA benchmarks. Boston Light is also the location for the proposed wind-measuring station. Choosing the exact location for the Boston North Channel current meter mooring, and the locations of the tidal current transects requires further study. Time is included in the proposal to conduct the study needed for determining these locations.

Current Measurements

Tidal-current transect measurements will be performed using a 1,200 or 600 kHz ADCP mounted on a boat. RDI instruments of San Diego manufacture the proposed instrument. The current meter is mounted over the side of the boat, with the acoustic transducers submerged and data are collected while the vessel is underway (Figure A2). All transect lines will be referenced to differential GPS locations through a navigation software package, HYPACK, to insure repeatability.

The ADCP transmits sound bursts into the water column, which are scattered back to the instrument by particulate matter suspended in the flowing water. The ADCP “listens” for the returning signal and assigns depths and velocity to the received signal based on techniques used in correlation sonar. The ADCP is also capable of measuring vessel velocity during collection and bottom bathymetry. Communication with the instrument for set-up, and data recording, are performed with a portable computer and manufacturer-supplied software, hardware, and communication cables.

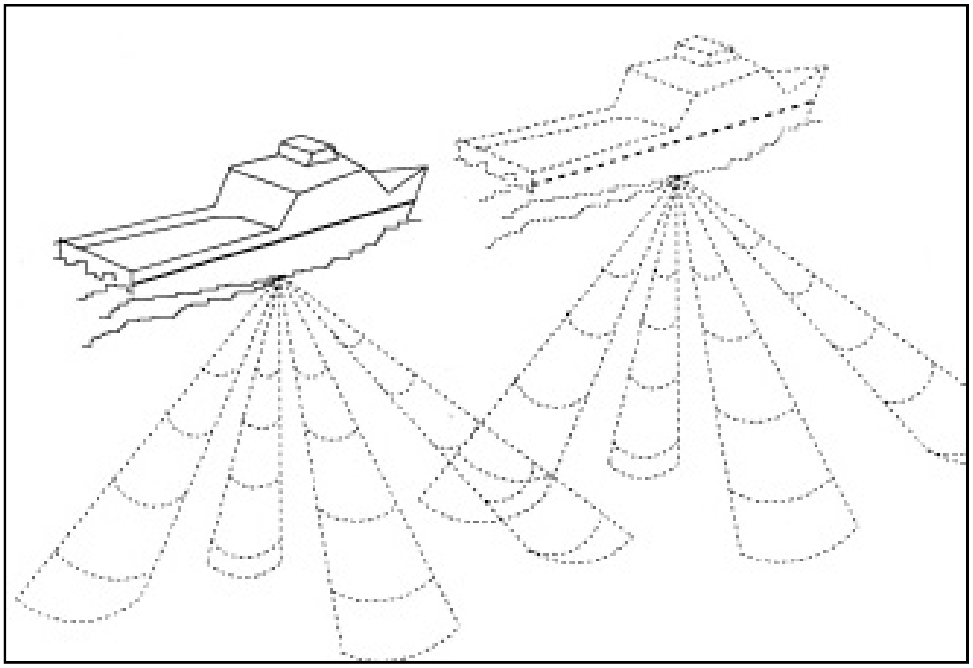


Figure A2. Typical ADCP collection operations.

Current measurements at the current-meter mooring will be made using an RDI instruments Work Horse current meter. The Work Horse is also a profiling current meter, and uses the same measurement techniques as the broadband ADCP. It will be mounted in a mooring similar to the one shown in Figure A3, and will record data internally. The mooring will be placed on the seafloor using a “slip-line,” which makes it possible to deploy it without the assistance of divers. The meter will include an acoustic release that will release a buoy in response to an acoustic signal sent through the water from the boat used for the recovery operation. During deployment the buoy is attached to the mooring, and located near the seafloor. When it is released, it floats to the surface and brings with it a line attached to the mooring. This line is used to pull the mooring to the surface, thereby making it possible to recover the mooring without divers. After recovery, internally recorded data are downloaded to a portable computer.

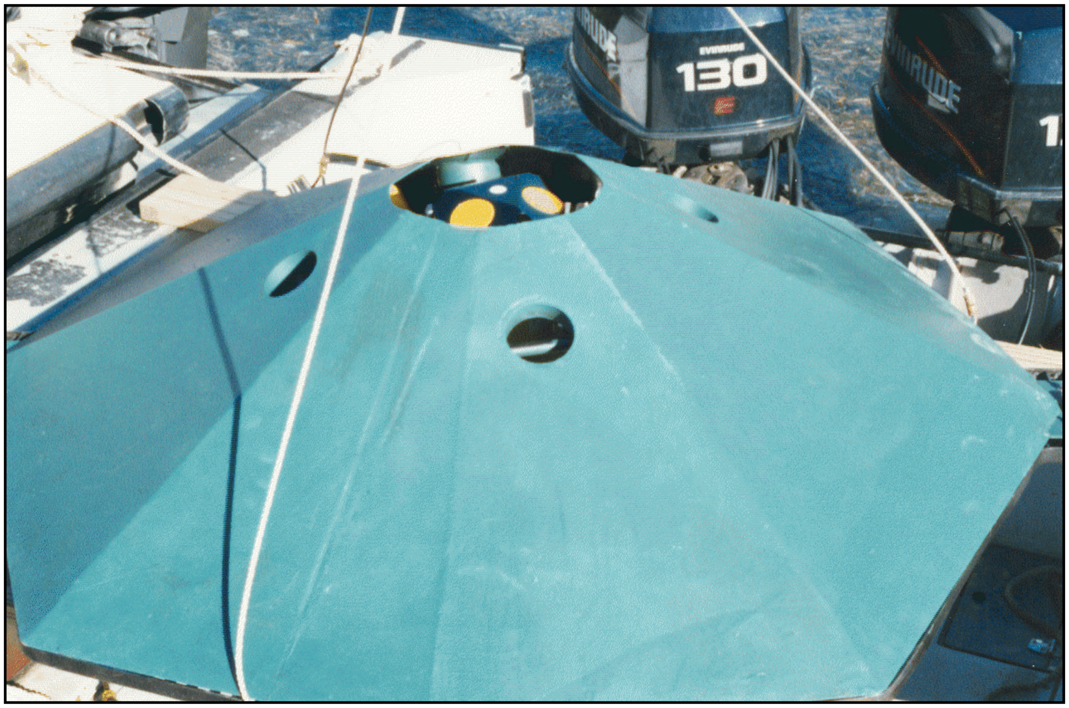


Figure A3. Current-meter mooring.

Water-Level Measurements

The Coastal Leasing Microtides system is the instrument proposed for making the water-level measurements. It uses an absolute pressure gage and records data internally. The instrument is deployed below the surface, thereby reducing site security risks. The deployed position of each instrument will be surveyed to determine its location relative to the NOAA tidal benchmark at each site. A barometric pressure gage will be also deployed at each site for use in correcting water-level measurements for atmospheric pressure changes.

Wind Measurements

Wind speed and direction measurements will be made at the Boston Light location using a Young Anemometer. The system uses a propeller and vane assembly to make the measurements and records data internally. It will be mounted at an open location on a 3-meter aluminum tower. The position of the tower will be surveyed using a portable GPS receiver.

Data Reporting

Processing and reporting of data is focused on providing information to verify ADCIRC. This requires several steps. The first is to check the data for quality to insure its accuracy. After the quality assurance step, data products are prepared that relate to demonstrating that certain assumptions inherent in the hydrodynamic model are valid for the study area, and that provide measures for verifying model current simulations. This requires that the processed and analyzed data be formatted to facilitate comparisons with ADCIRC output. The final step is documenting and storing the information for future reference. The proposed data products include:

- Time series of tides from measurements and interpolation at all benchmarked locations in the harbor.
- Vectorized current velocity data from the transect data entered into a GIS database.
- Time series of currents at the current-meter mooring.
- Correlations between the mooring and transect current data.
- Correlations between wind data and filtered mooring current data.
- Summary of wind statistics for the deployment period.
- Correlations between current and water-level data.

Appendix B: Water-Level Measurement Plots

NOAA TG Water-Level Measurement Plots

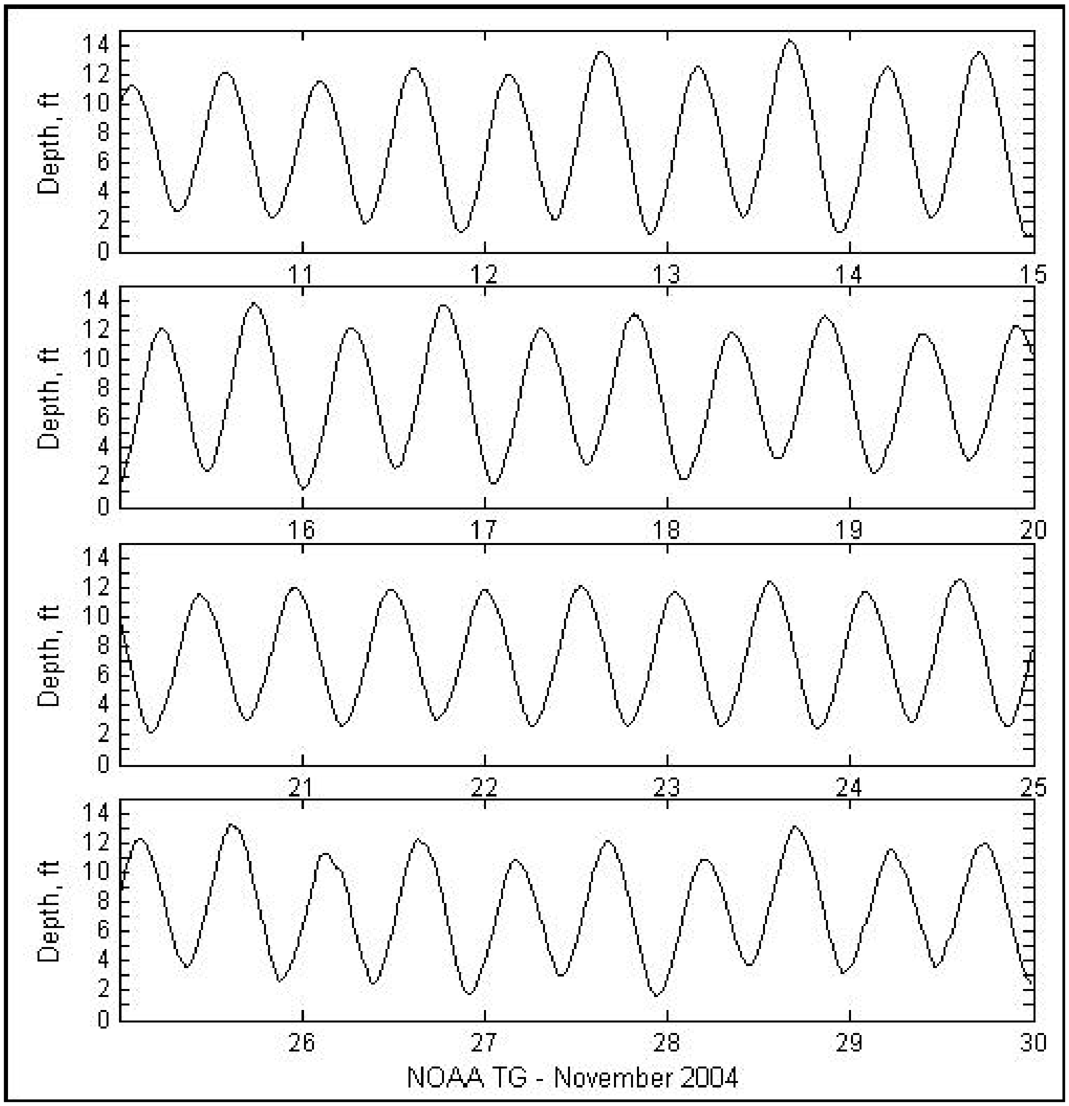


Figure B1. NOAA TG water-level measurement plot, November 2004.

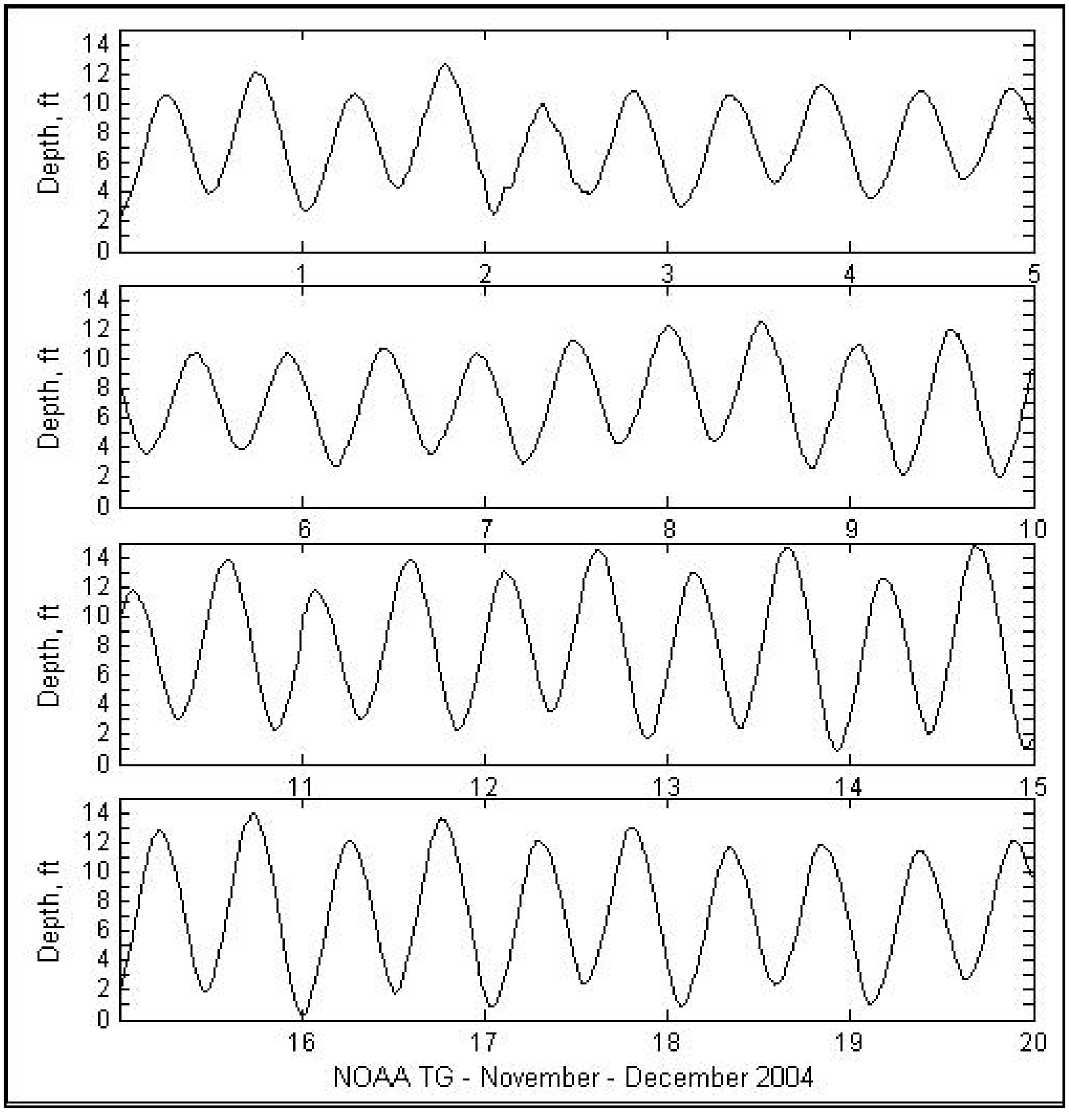


Figure B2. NOAA TG water-level measurement plot, November-December 2004.

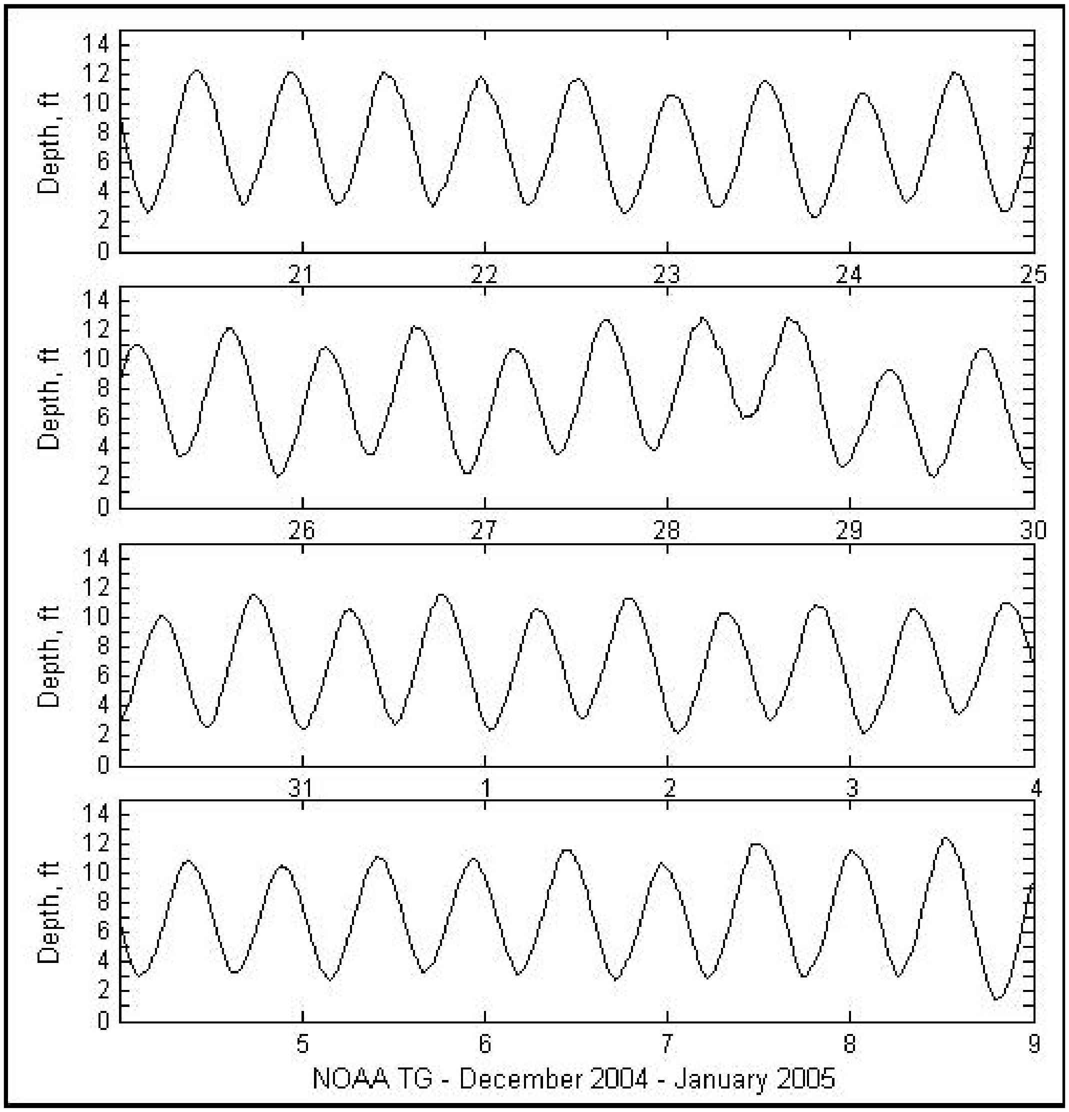


Figure B3. NOAA TG water-level measurement plot, December 2004-January 2005.

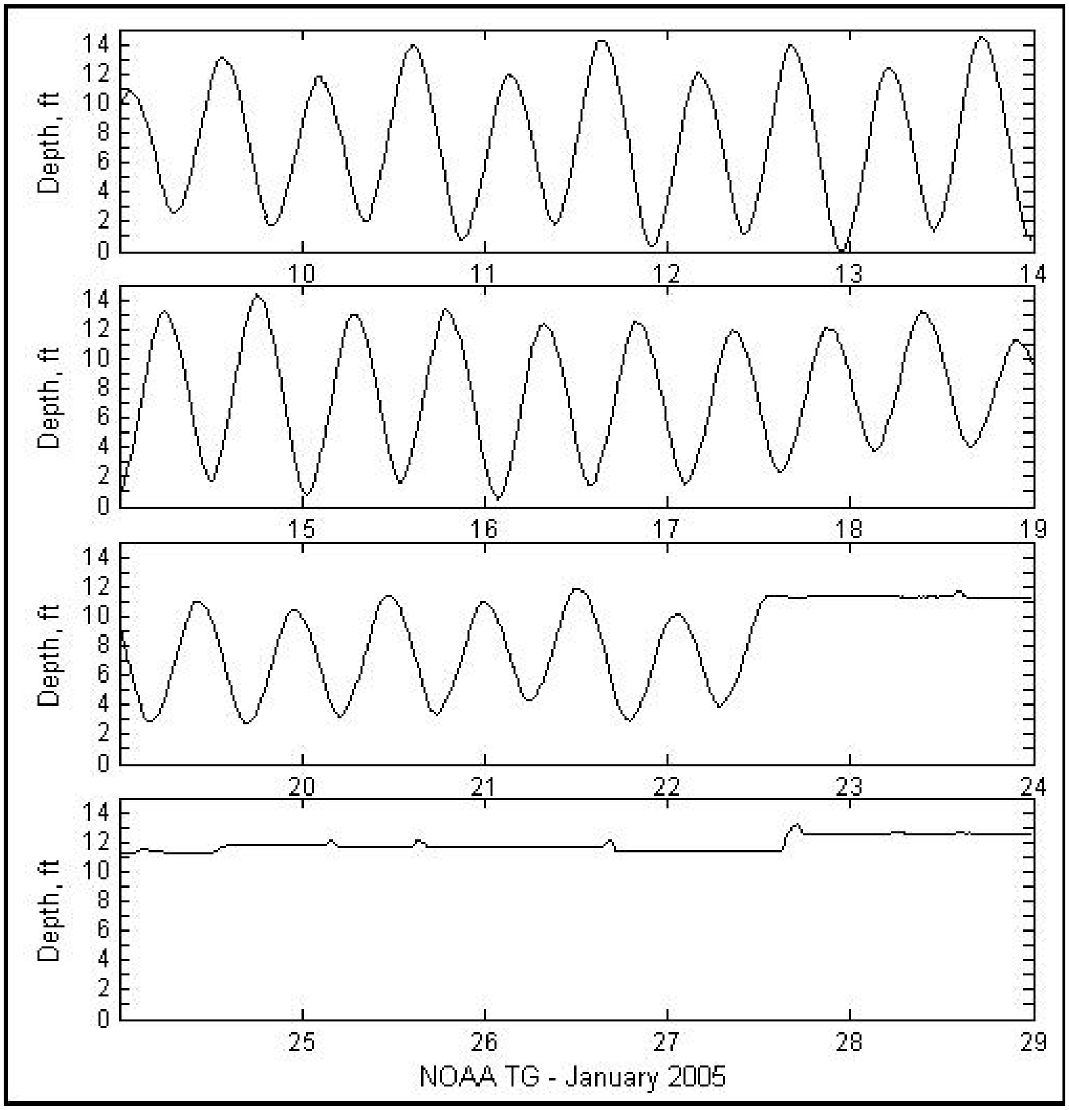


Figure B4. NOAA TG water-level measurement plot, January 2005.

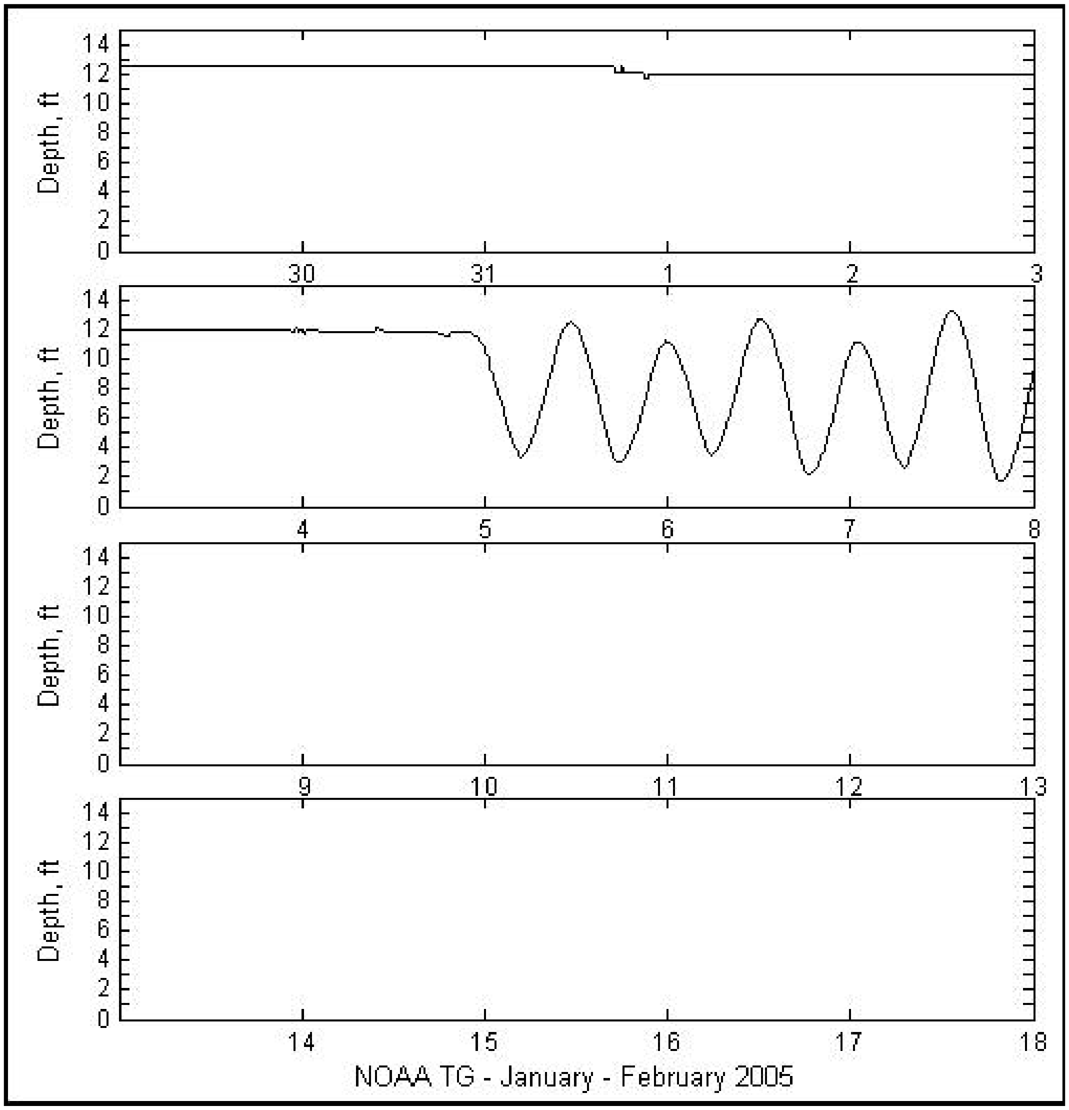


Figure B5. NOAA TG water-level measurement plot, January-February 2005.

TG1 Water-Level Measurement Plots

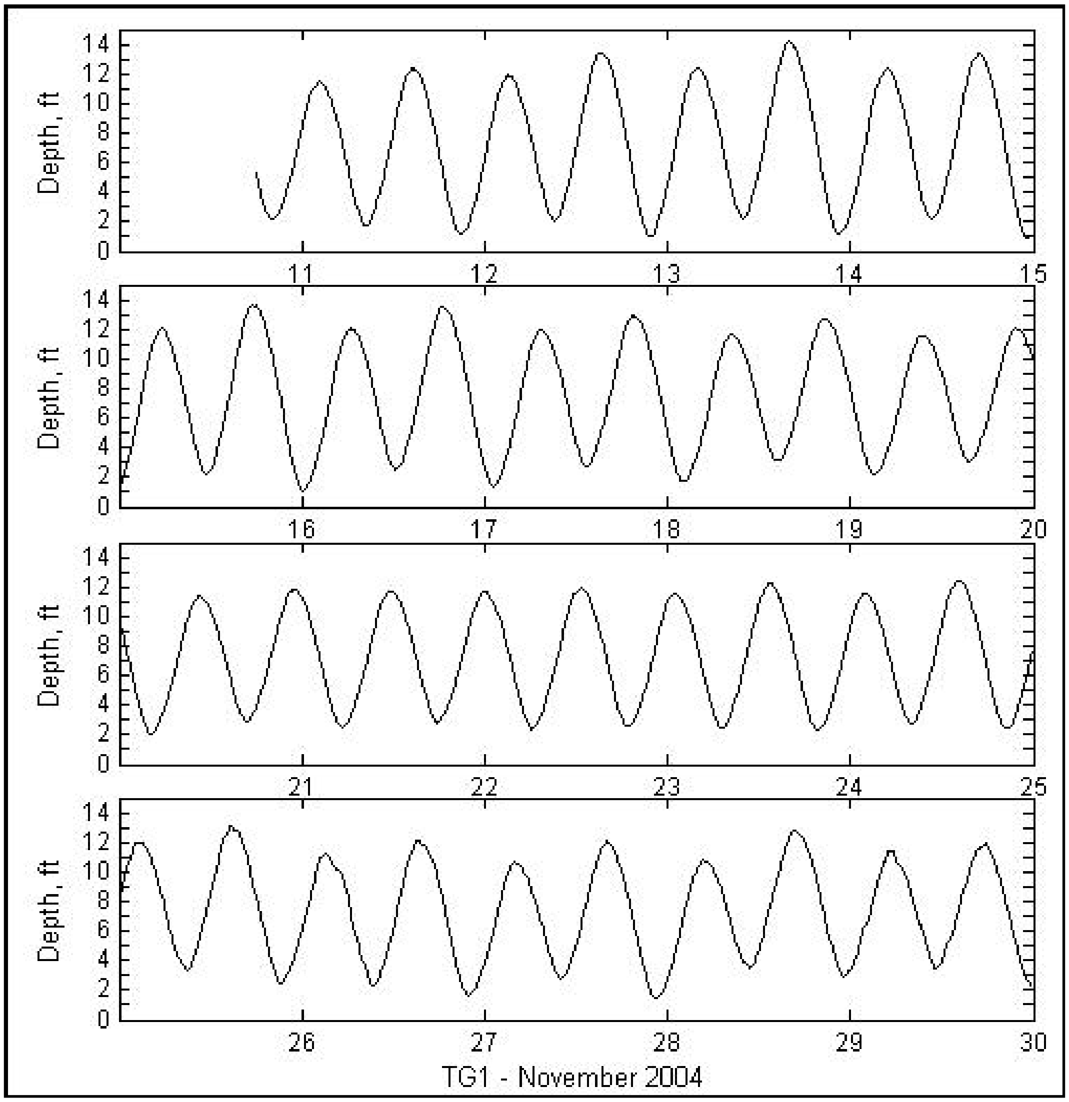


Figure B6. TG1 water-level measurement plot, November 2004.

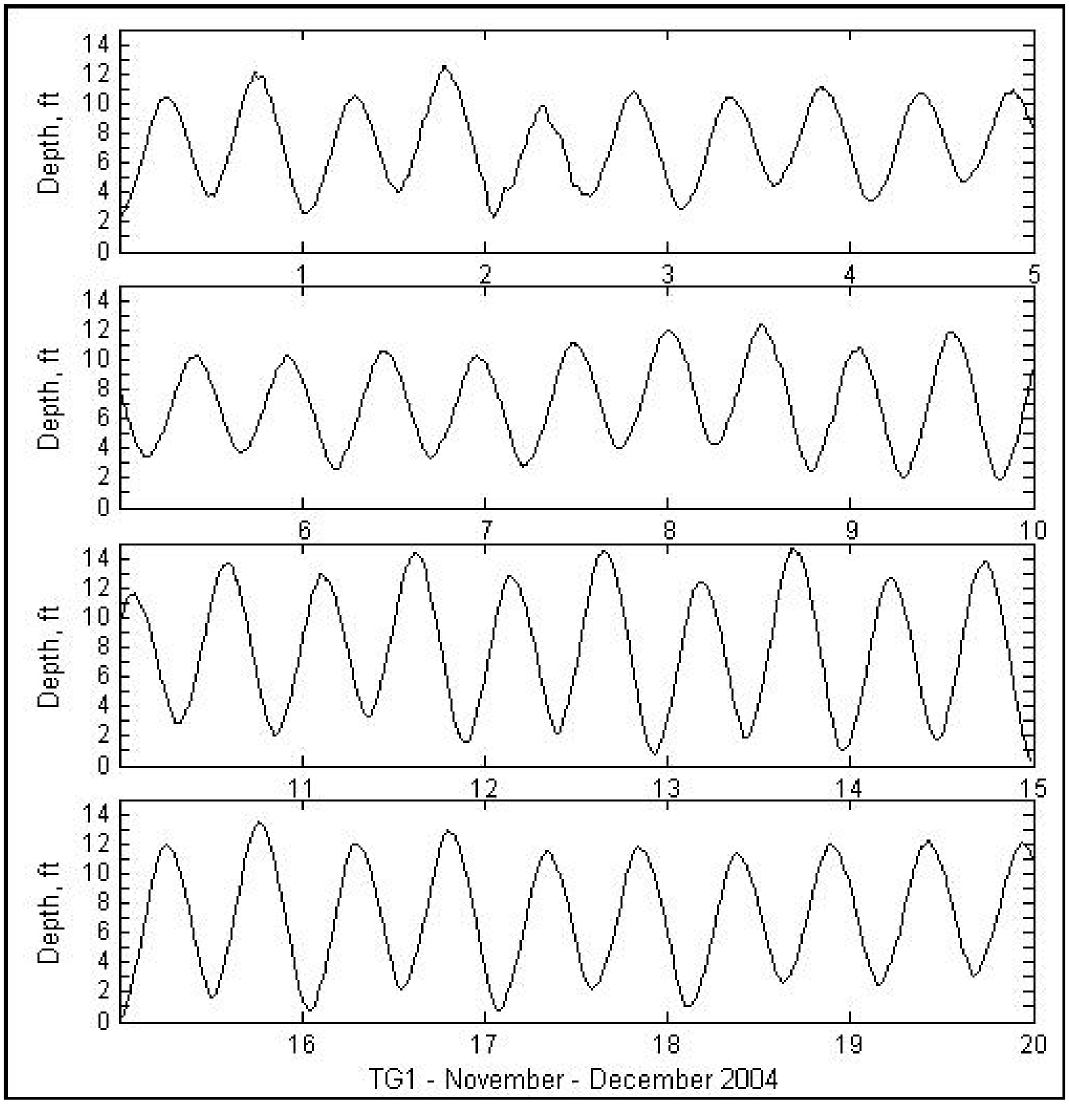


Figure B7. TG1 water-level measurement plot, November-December 2004.

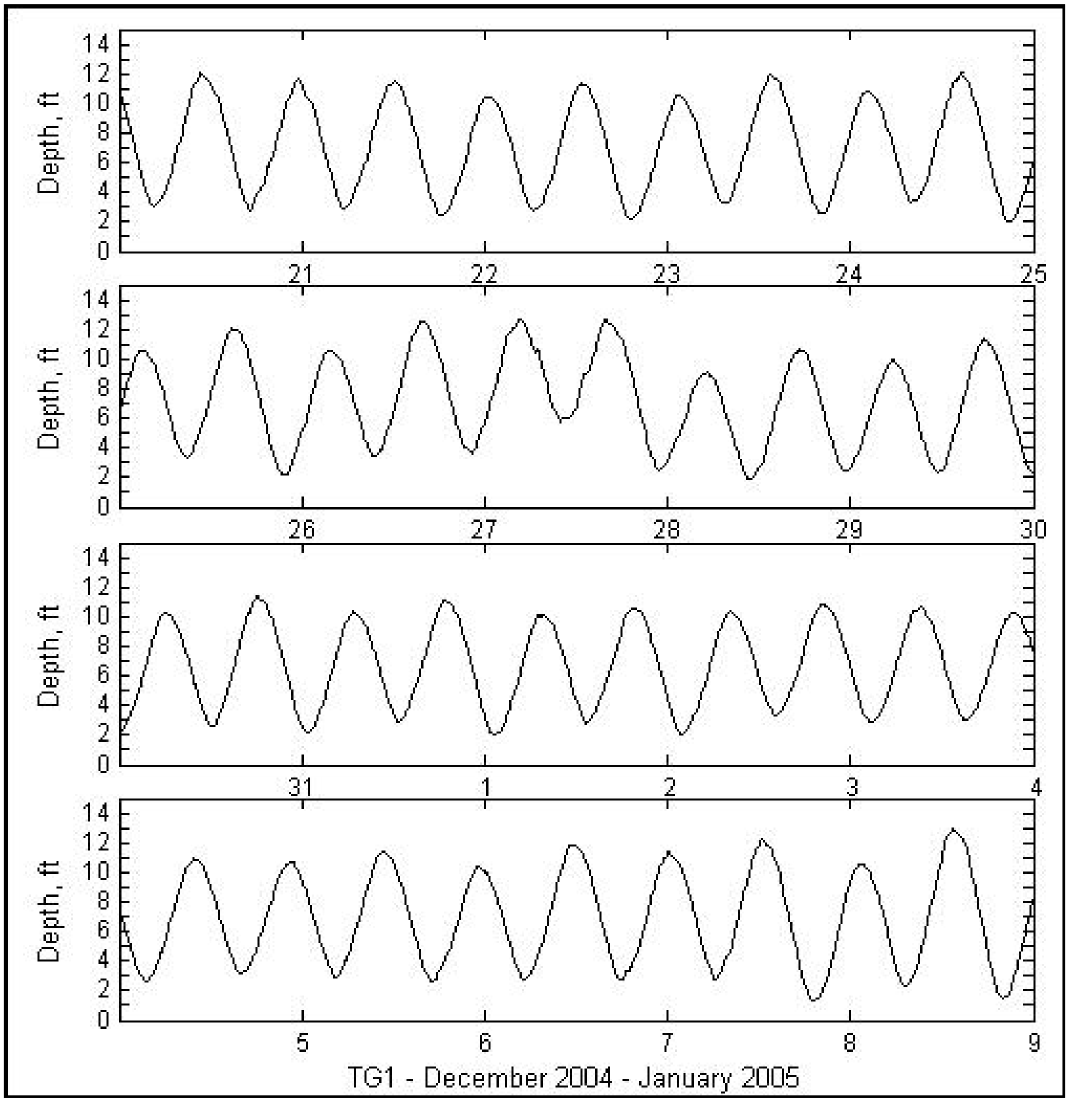


Figure B8. TG1 water-level measurement plot, December 2004-January 2005.

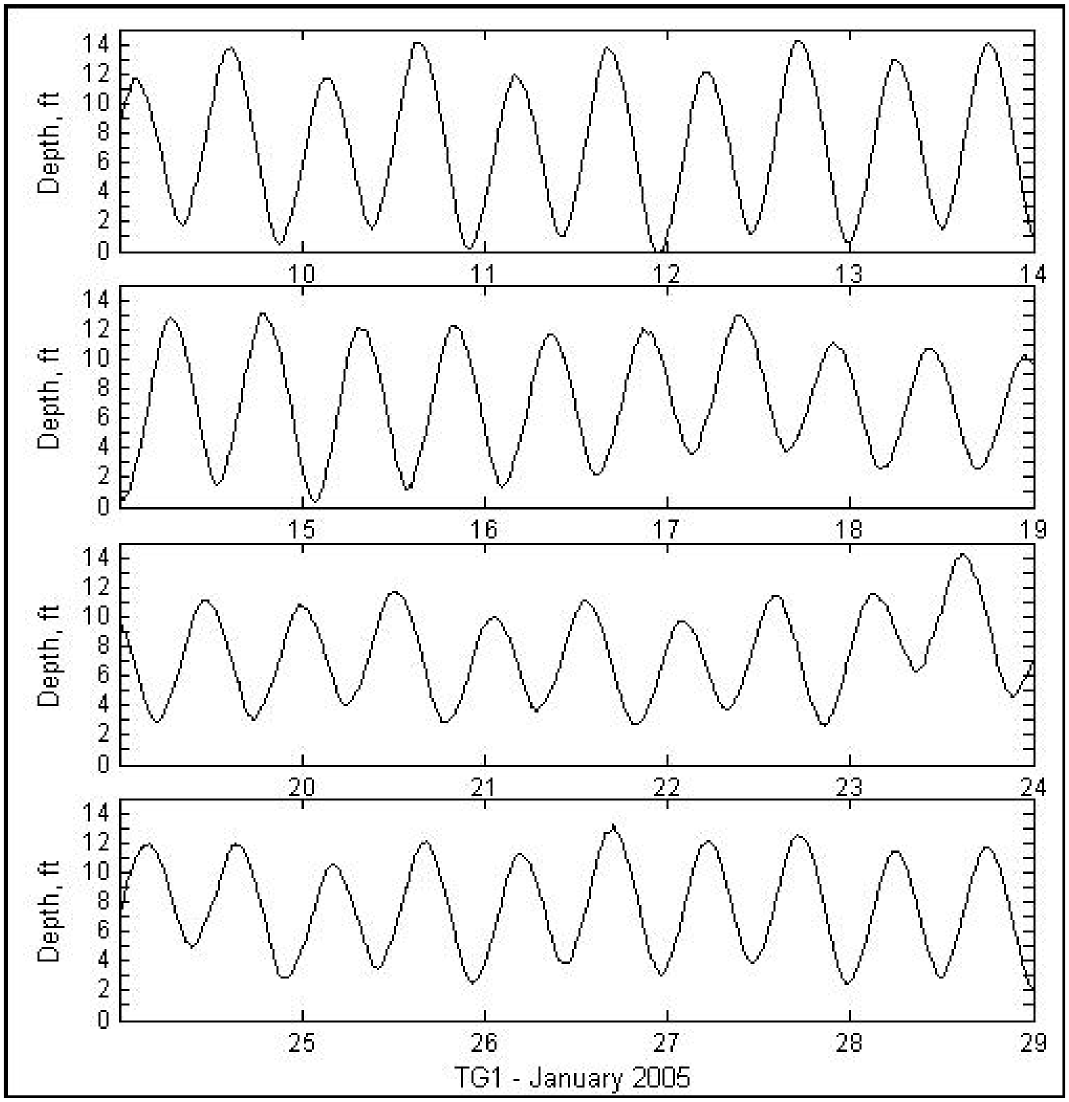


Figure B9. TG1 water-level measurement plot, January 2005.

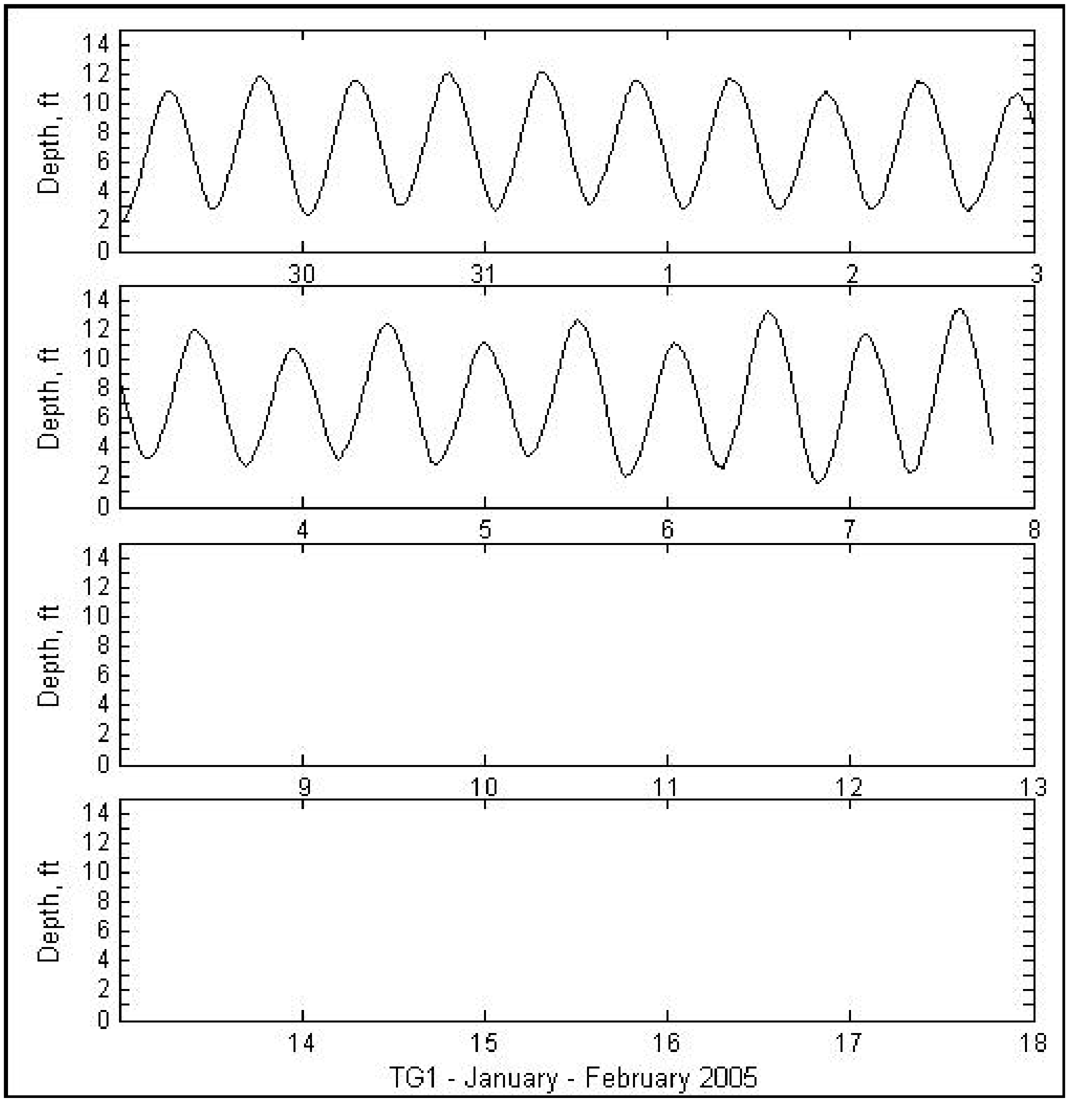


Figure B10. TG1 water-level measurement plot, January-February 2005.

TG2 Water-Level Measurement Plots

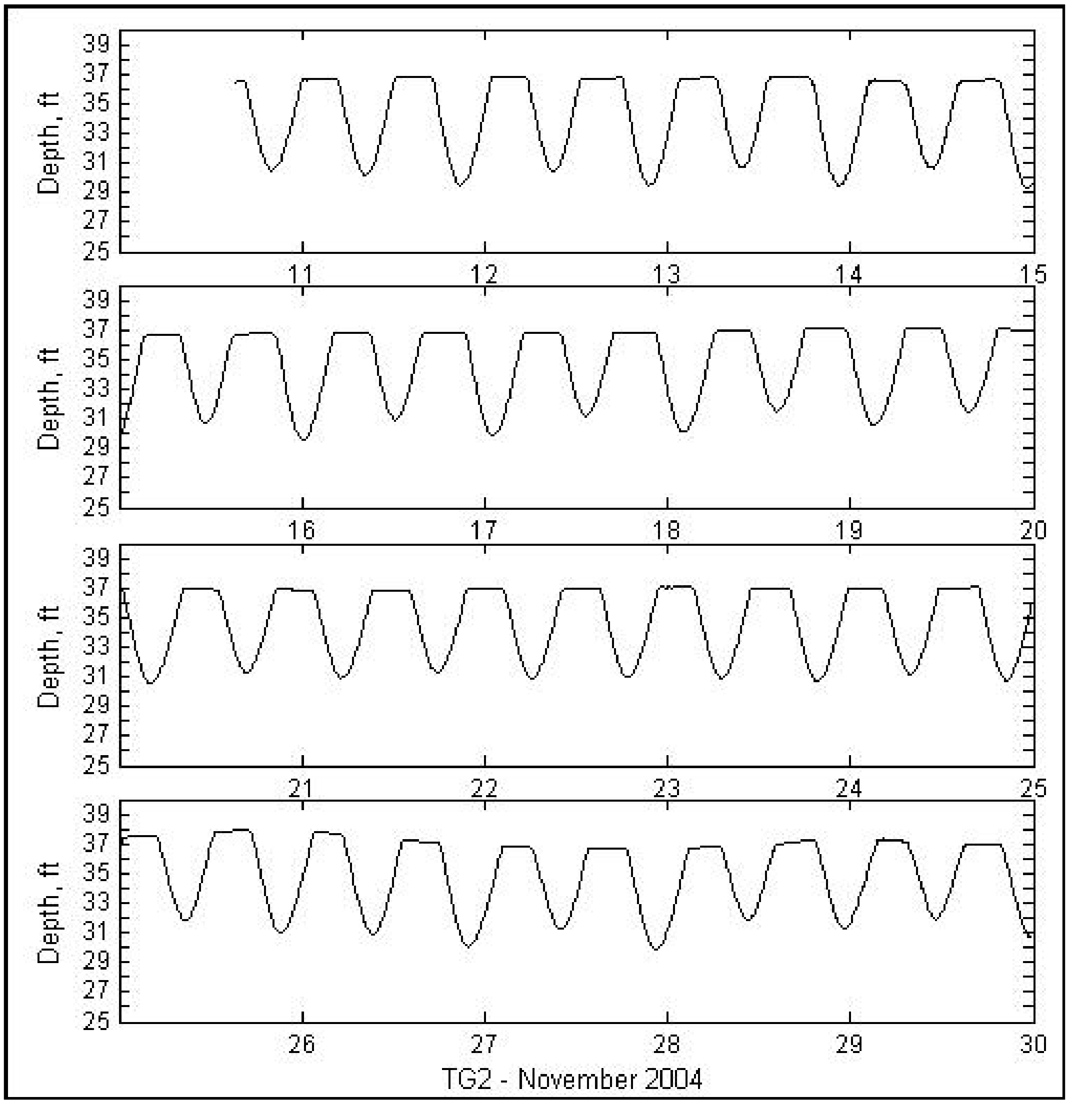


Figure B11. TG2 water-level measurement plot, November 2004.

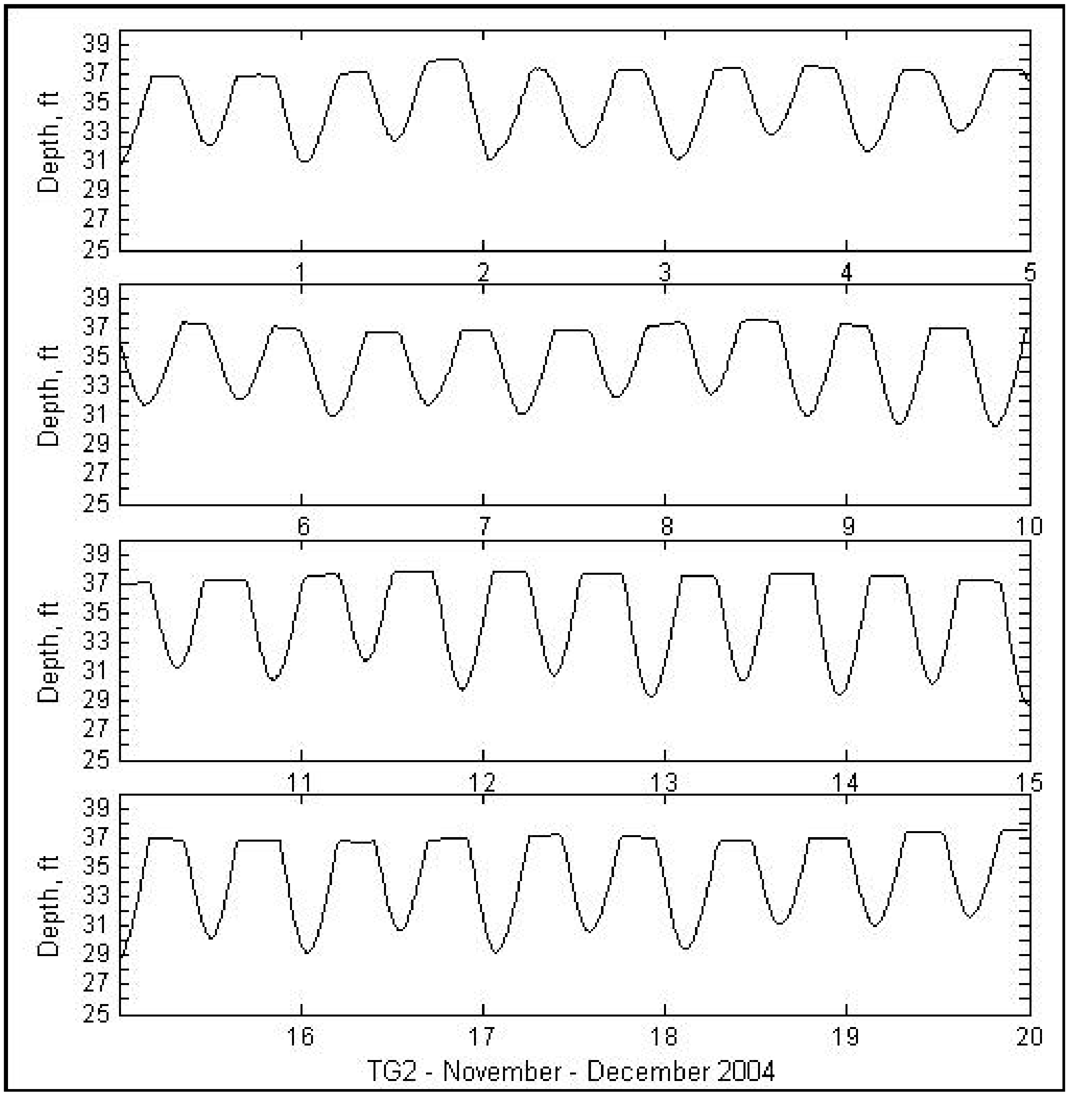


Figure B12. TG2 water-level measurement plot, November-December 2004.

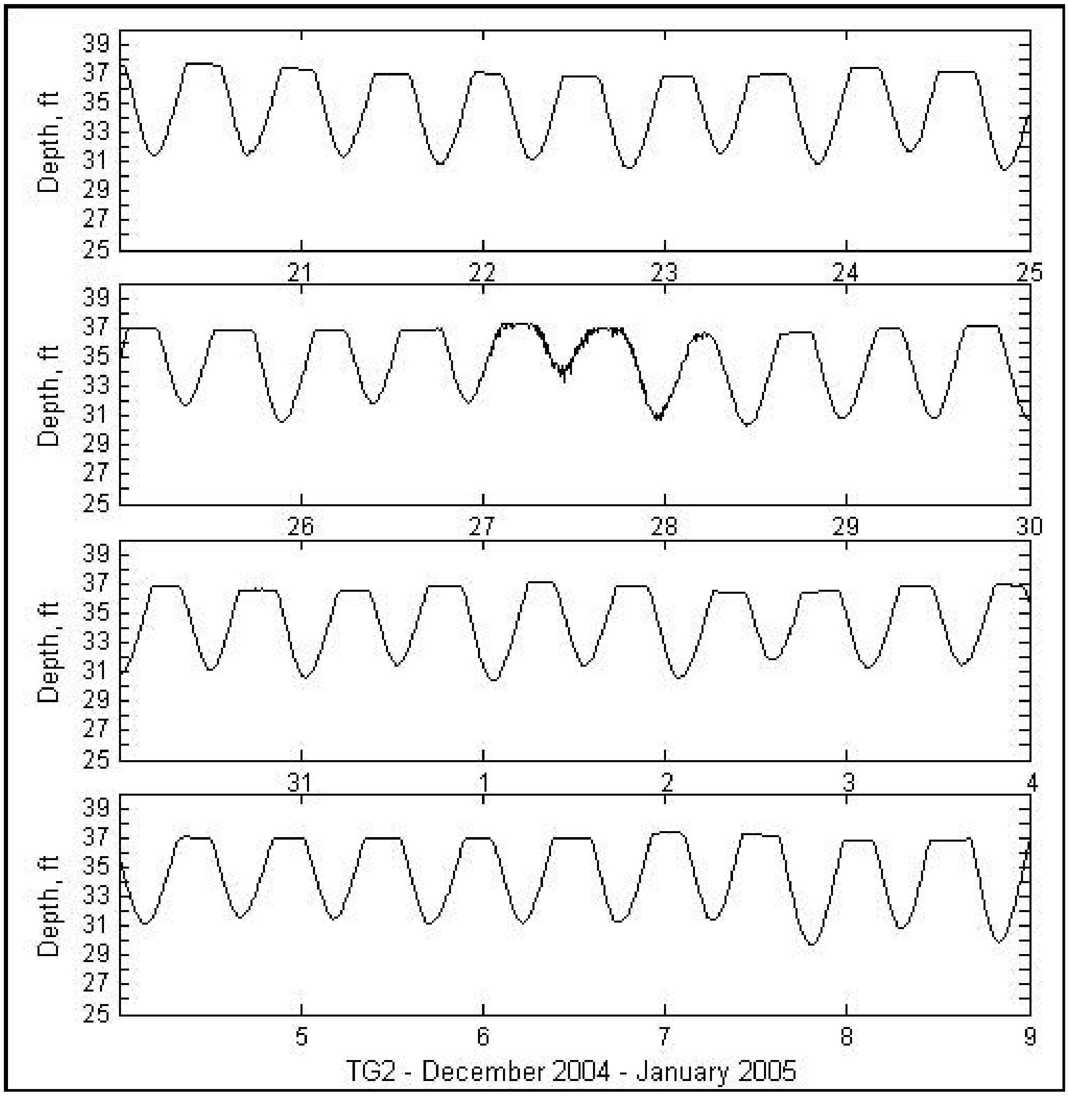


Figure B13. TG2 water-level measurement plot, November-December 2004–January 2005.

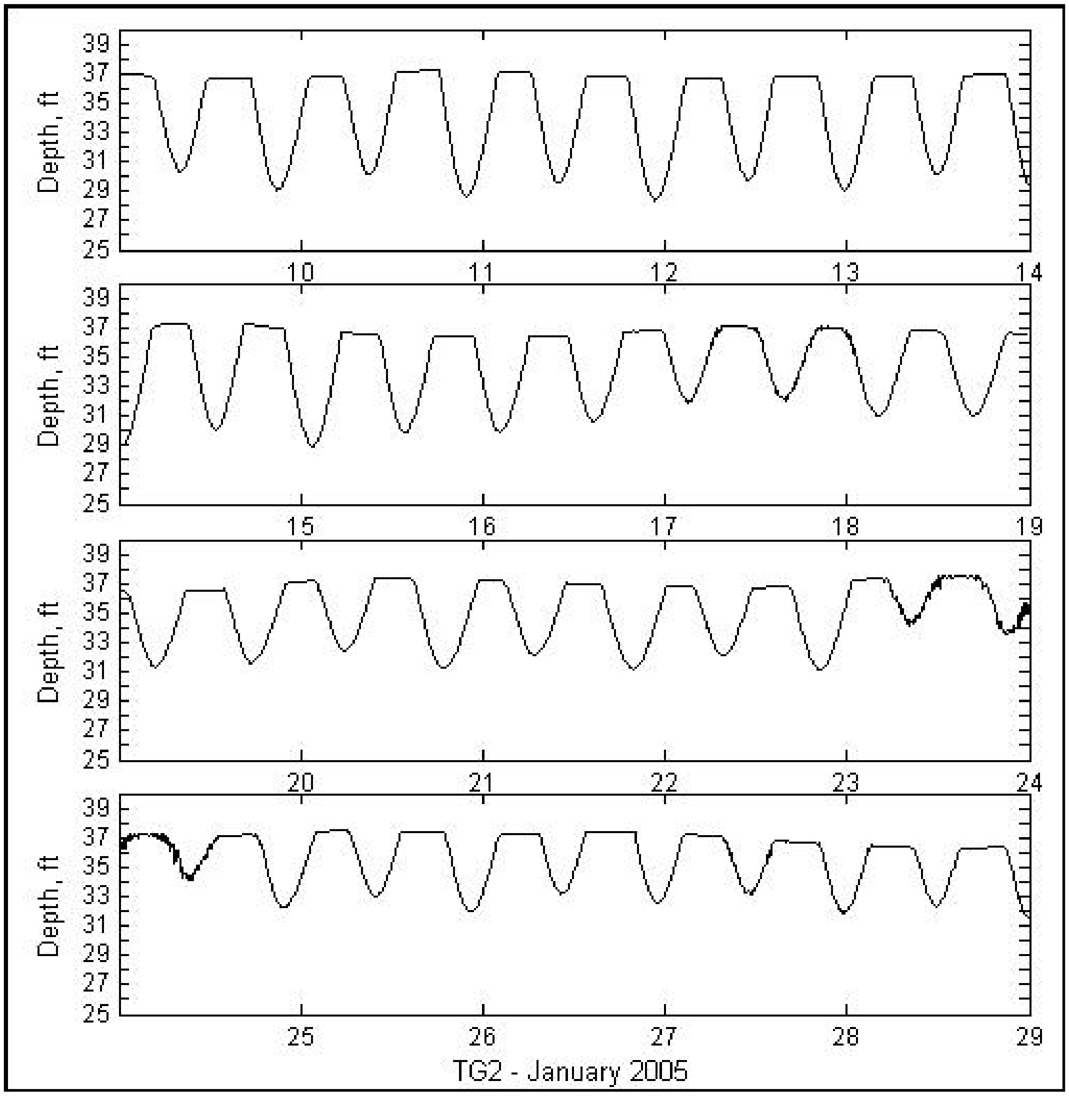


Figure B14. TG2 water-level measurement plot, January 2005.

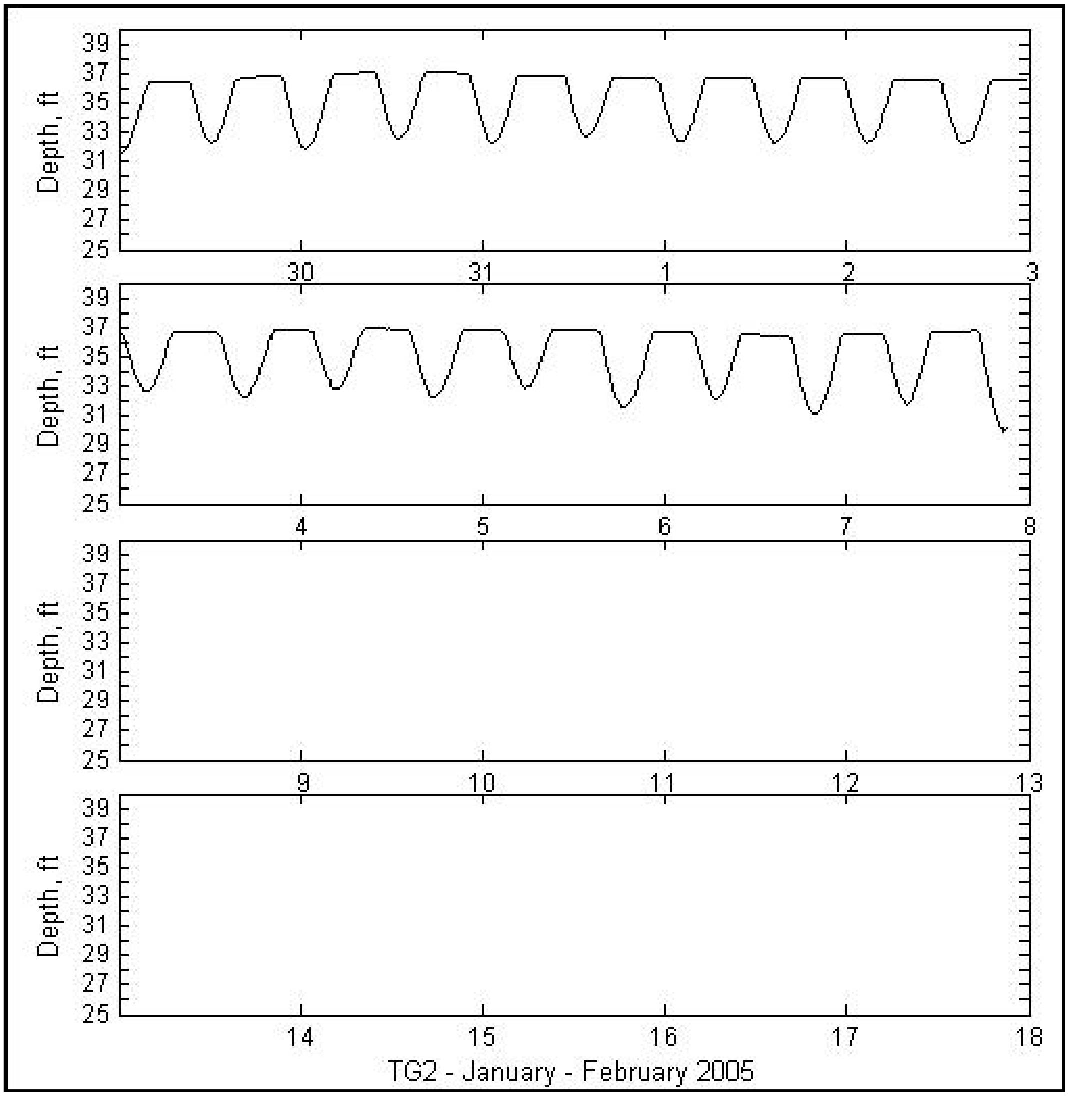


Figure B15. TG2 water-level measurement plot, January–February 2005.

TG3 Water-Level Measurement Plots

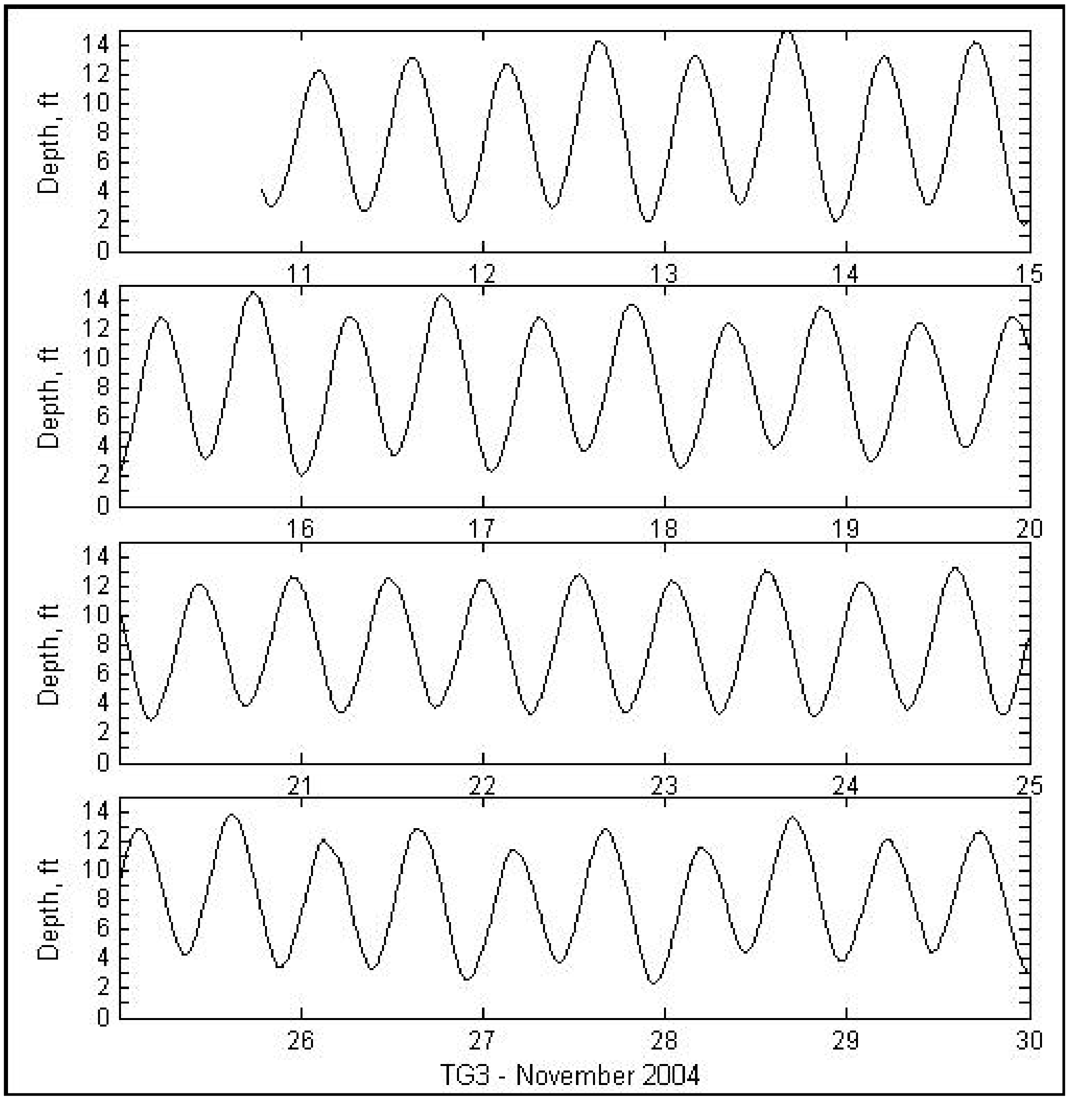


Figure B16. TG3 water-level measurement plot, November 2004.

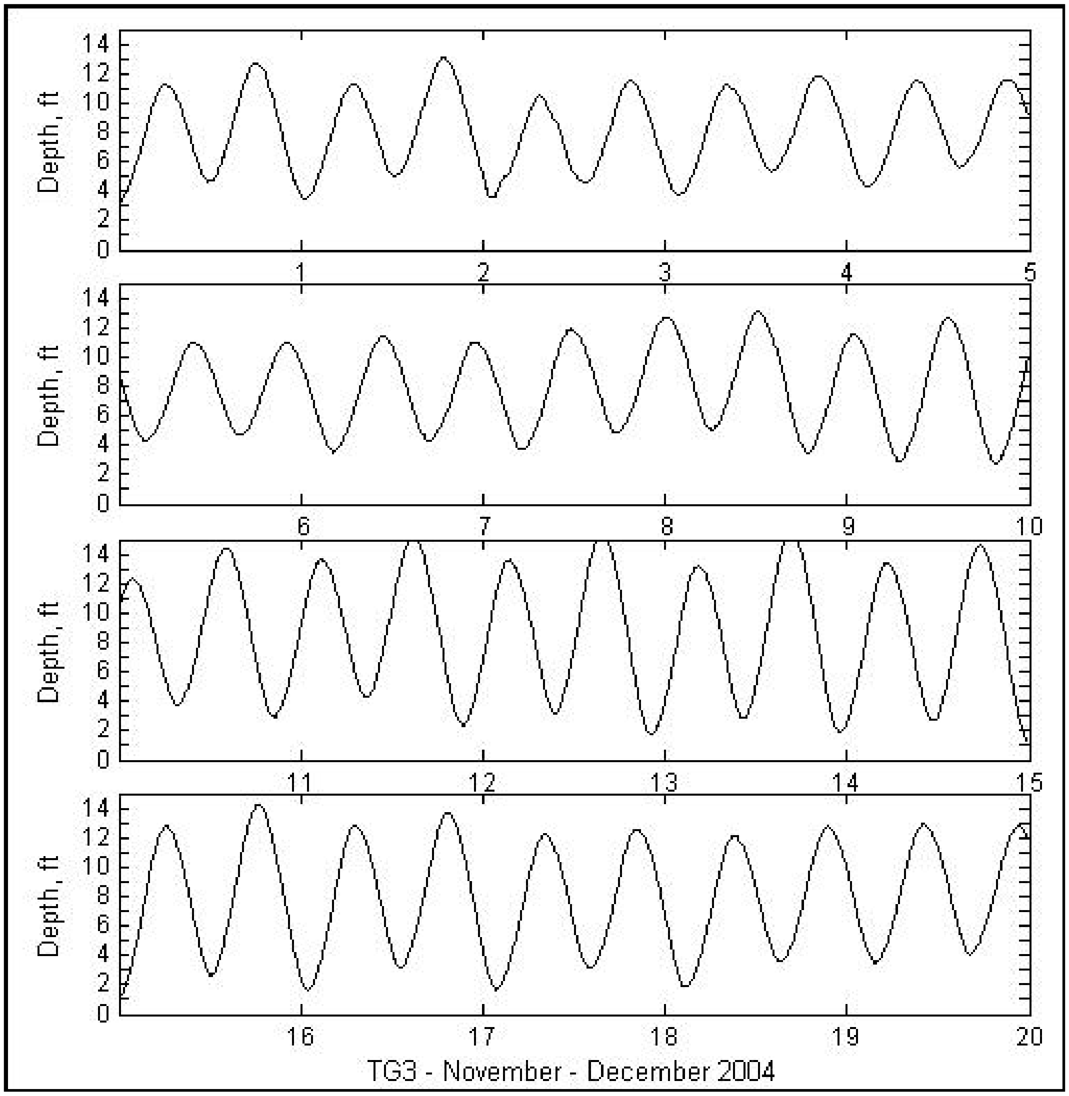


Figure B17. TG3 water-level measurement plot, November-December 2004.

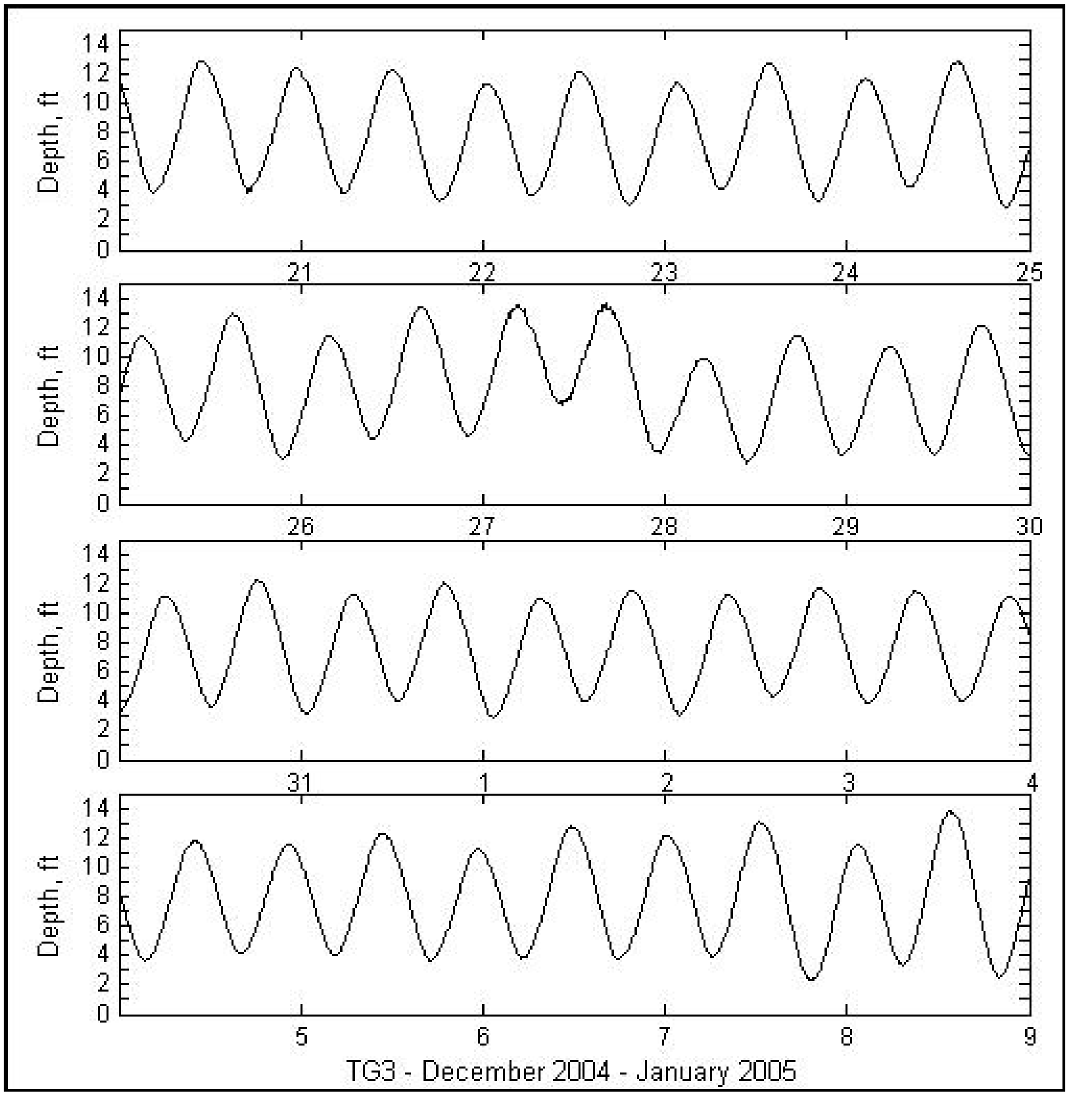


Figure B18. TG3 water-level measurement plot, December 2004–January 2005.

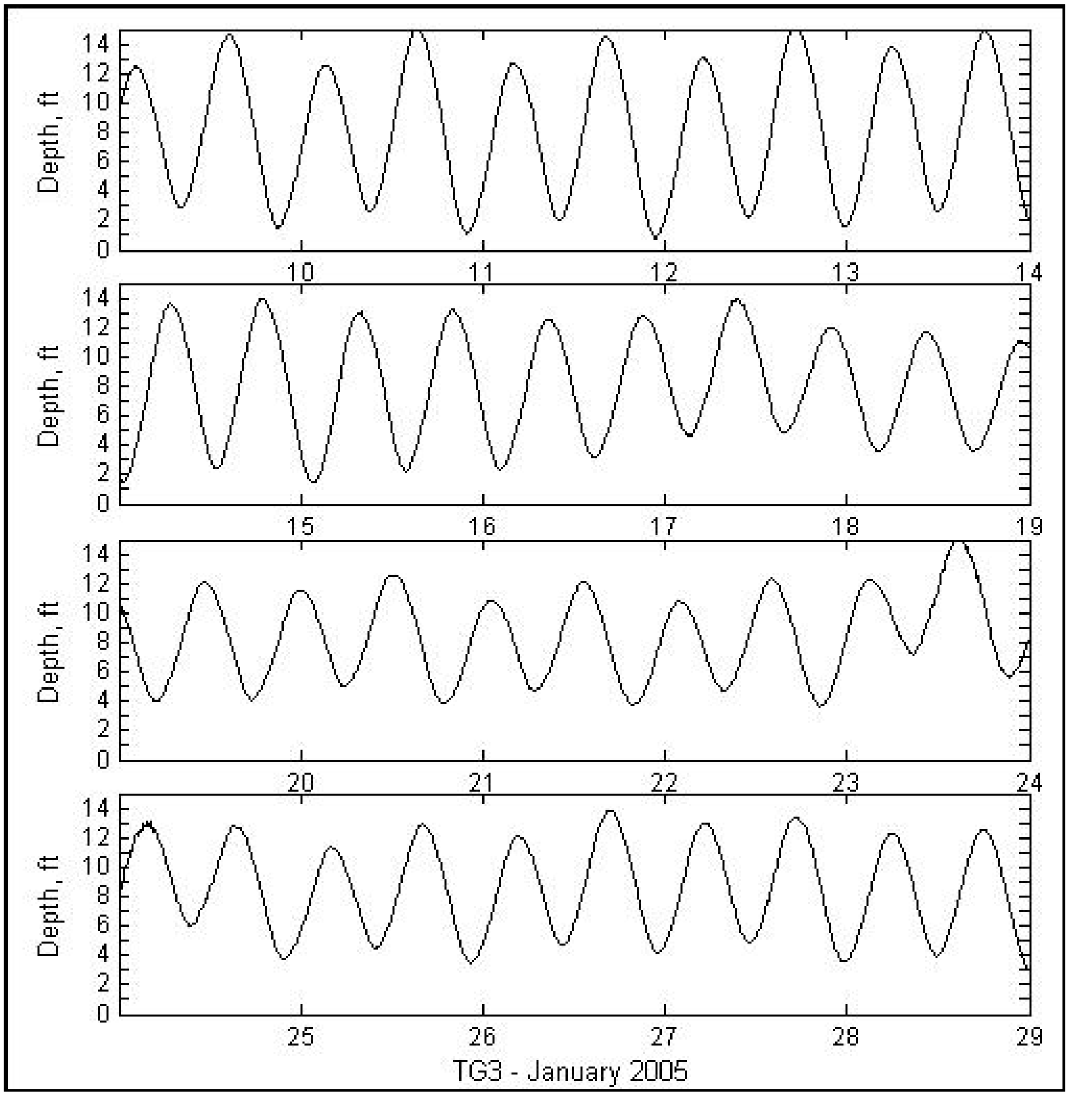


Figure B19. TG3 water-level measurement plot, January 2005.

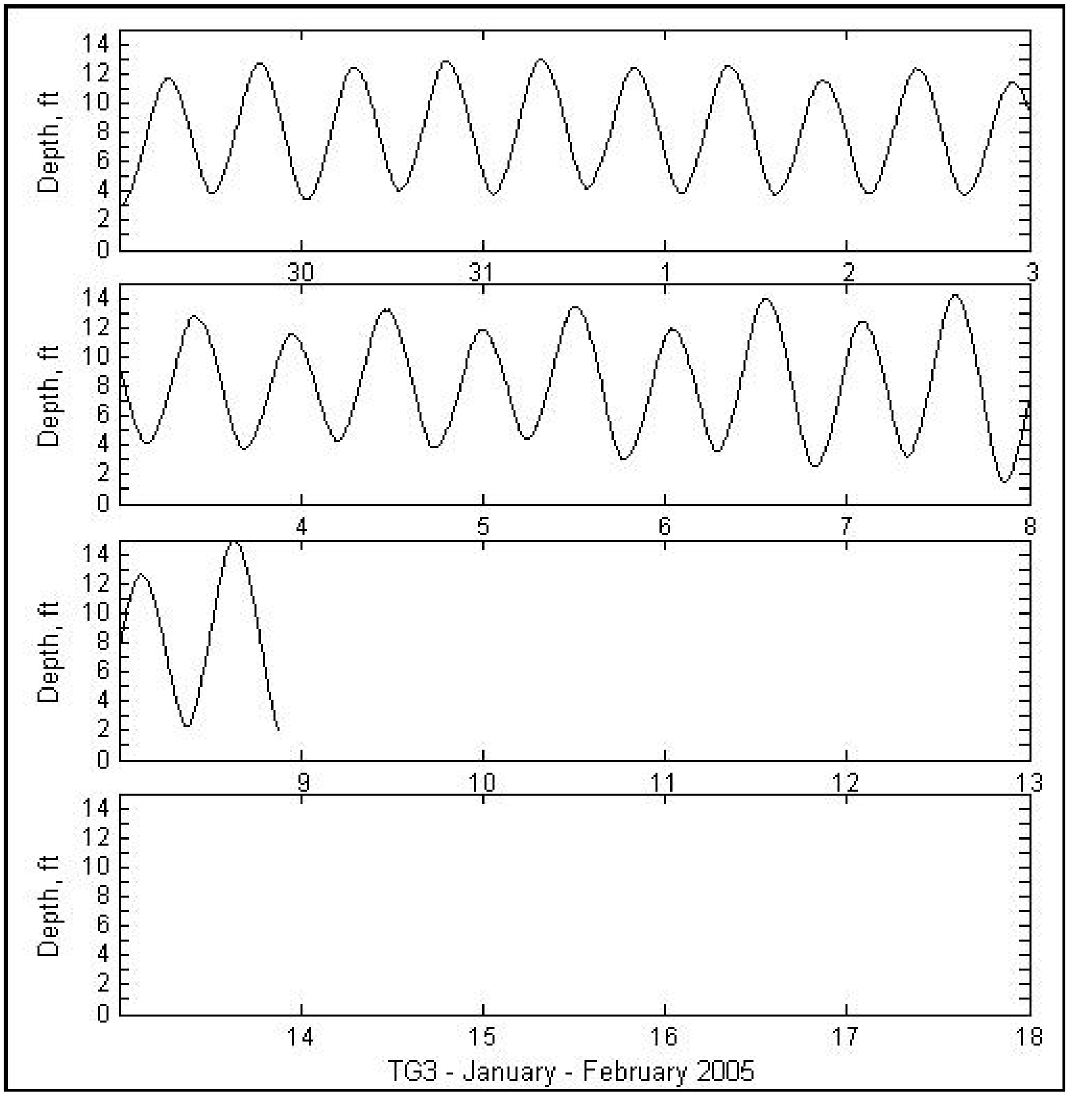


Figure B20. TG3 water-level measurement plot, January-February 2005.

TG4 Water-Level Measurement Plots

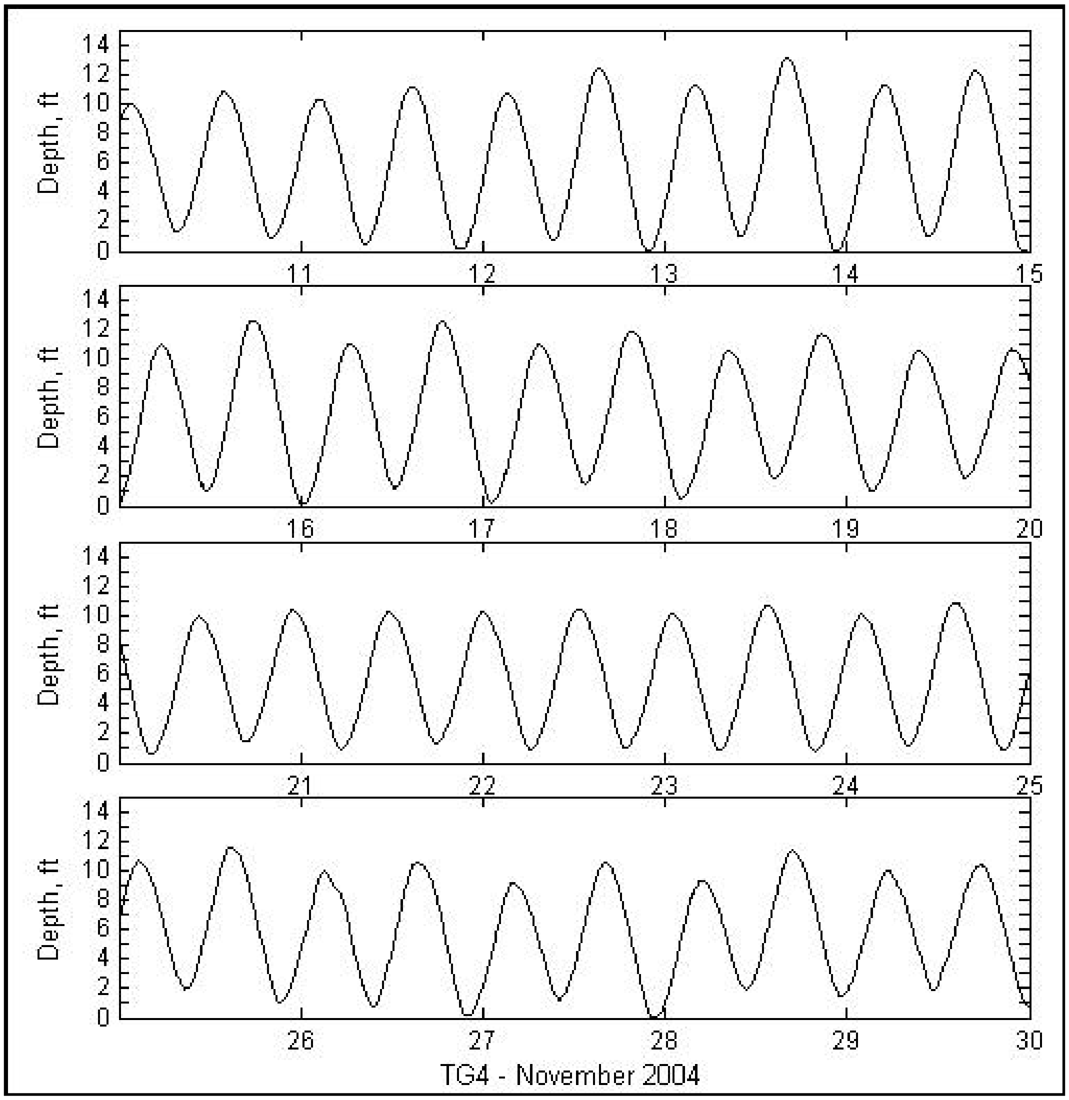


Figure B21. TG4 water-level measurement plot, November 2004.

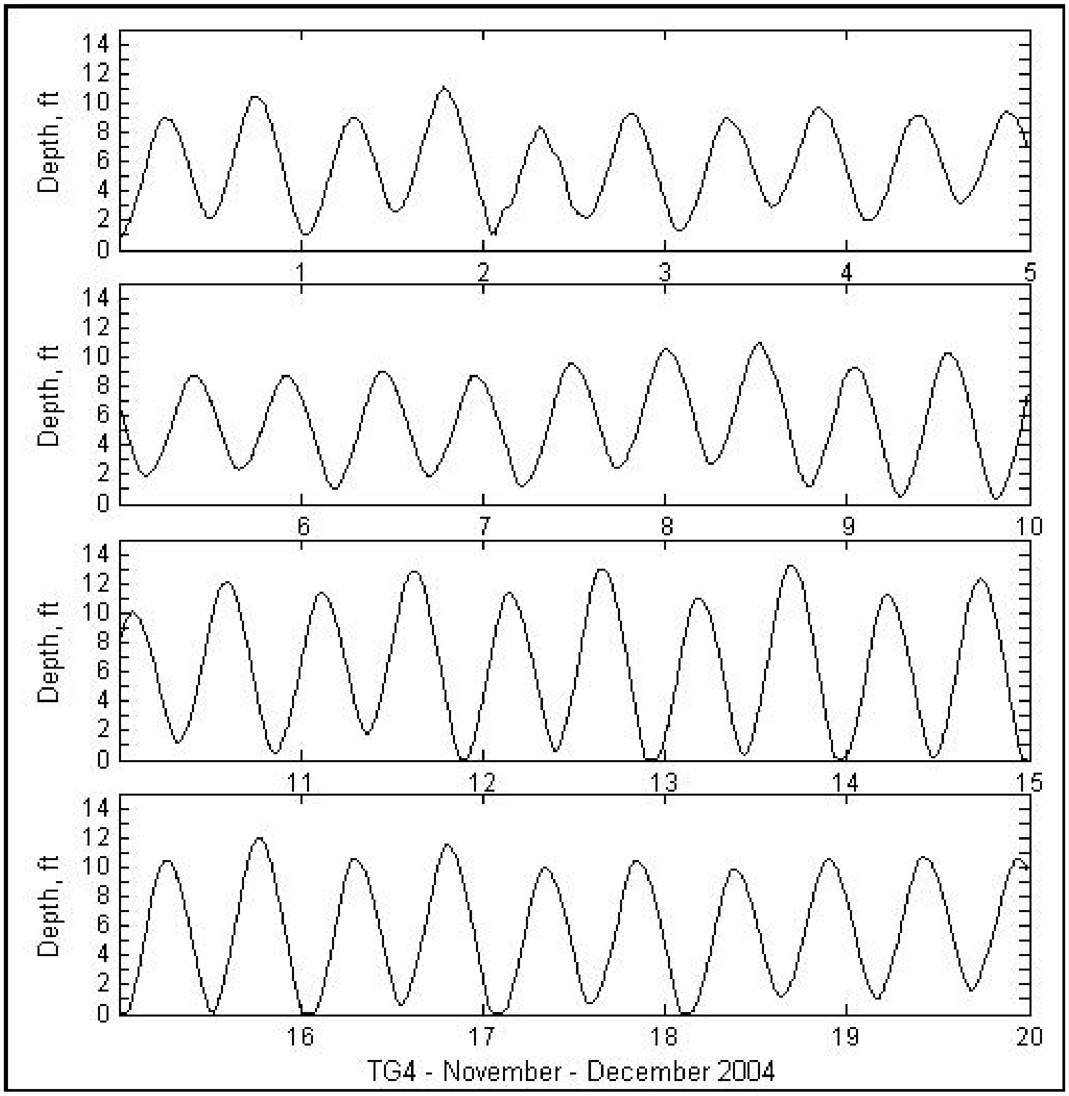


Figure B22. TG4 water-level measurement plot, November-December 2004.

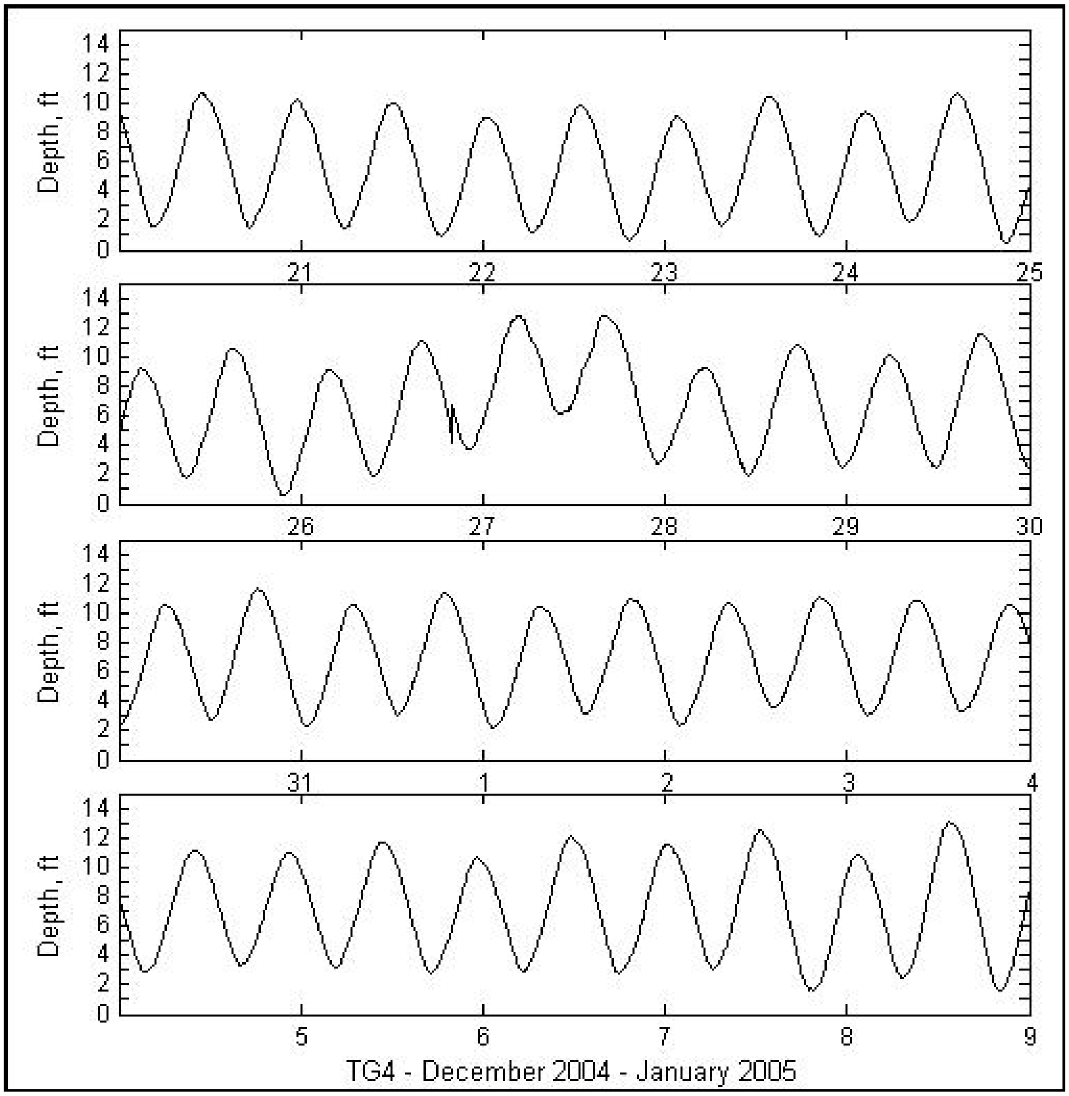


Figure B23. TG4 water-level measurement plot, December 2004–January 2005.

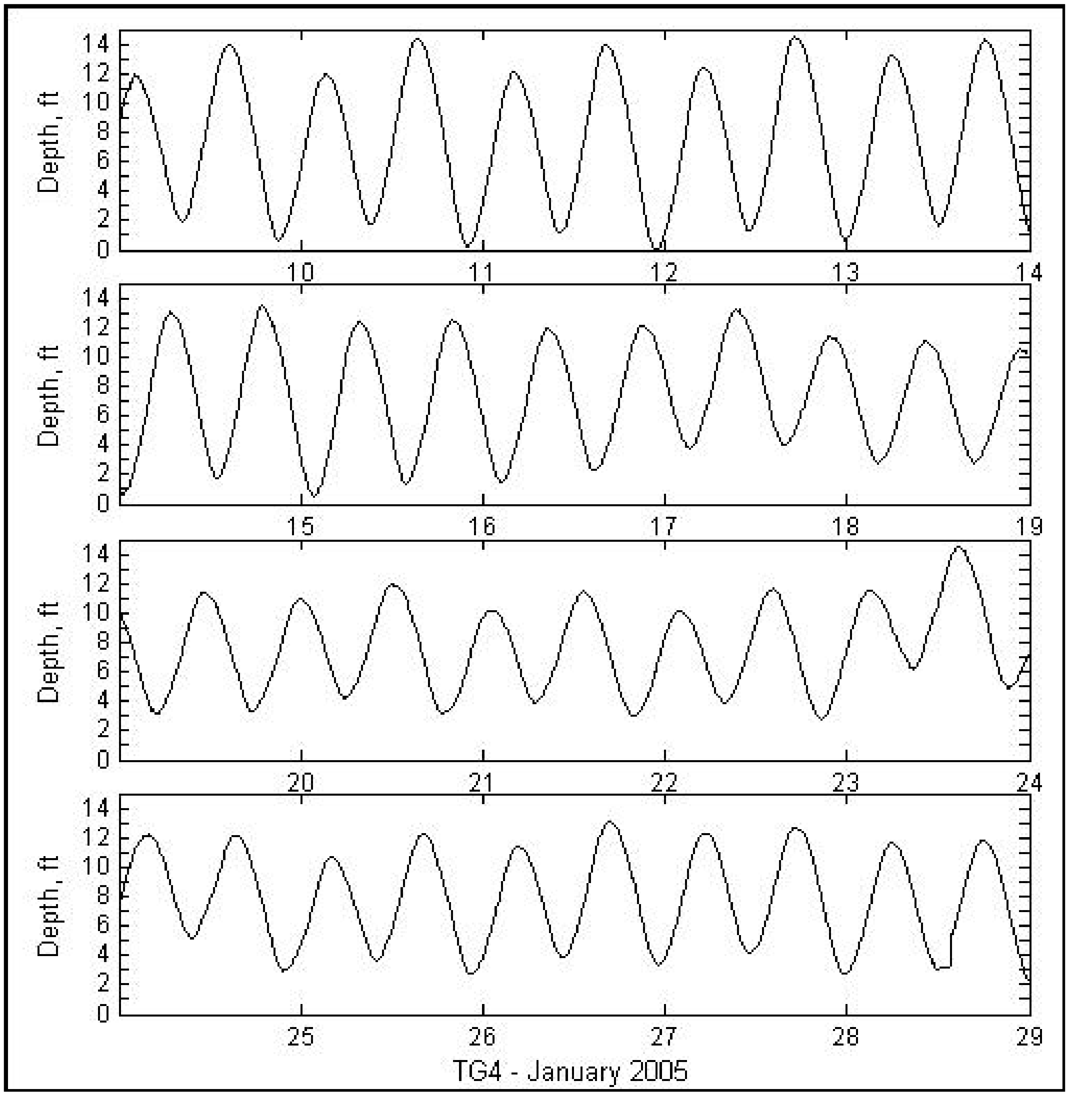


Figure B24. TG4 water-level measurement plot, January 2005.

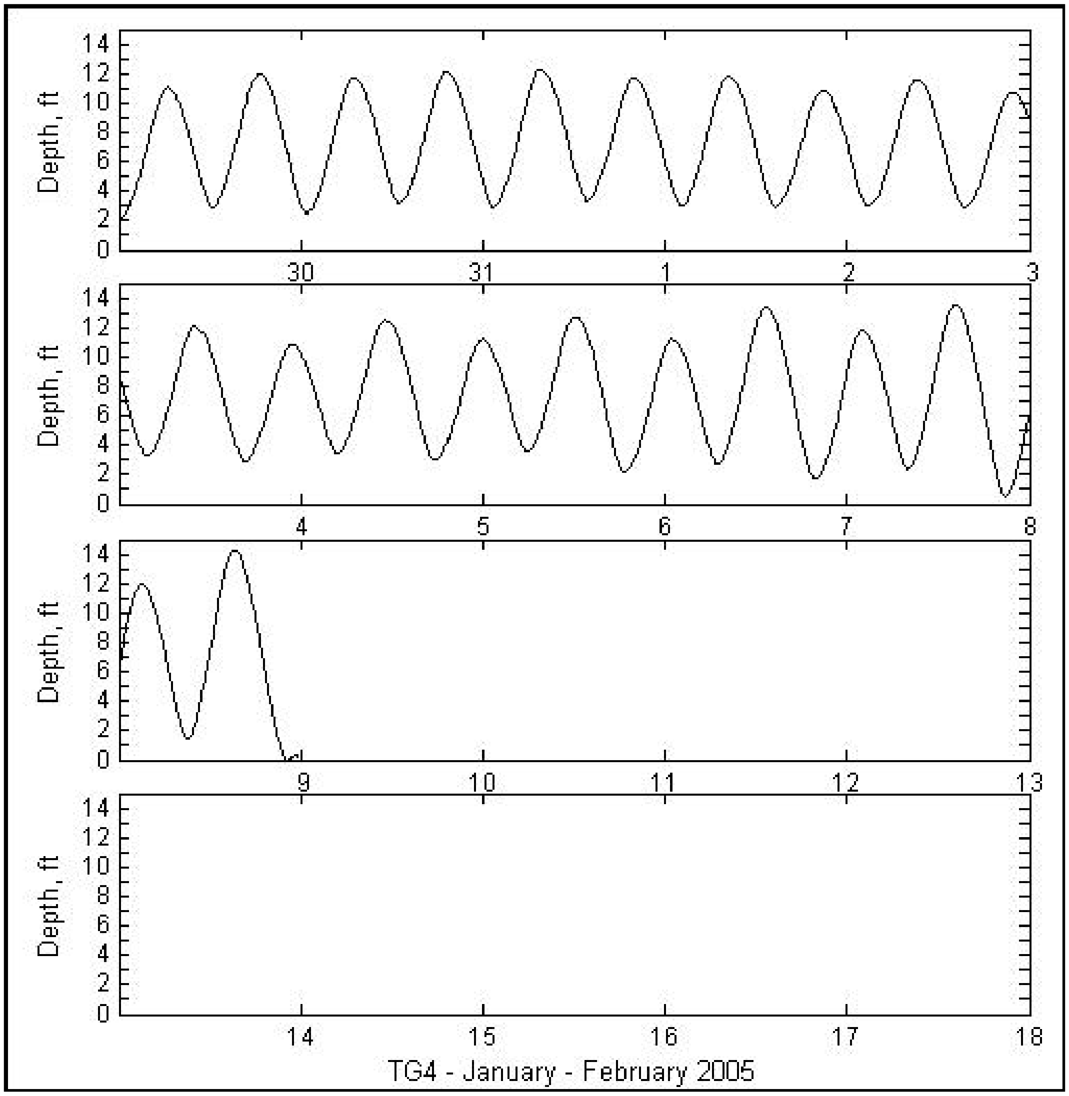


Figure B25. TG4 water-level measurement plot, January-February 2005.

Appendix C: Moored Current Measurement Plots

CM2 Moored Current Measurement Plots

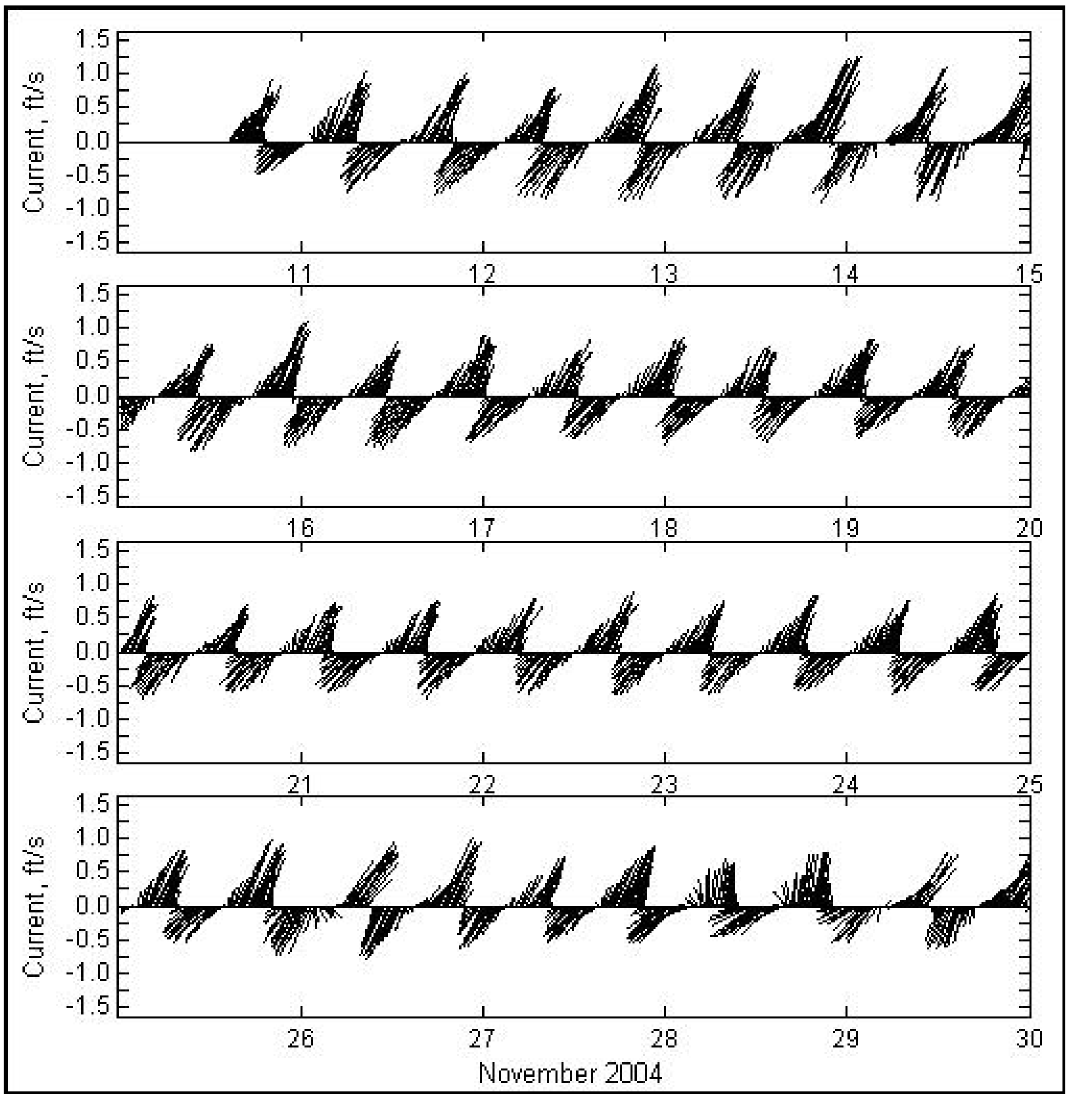


Figure C1. CM2 moored current measurement plots, November 2004.

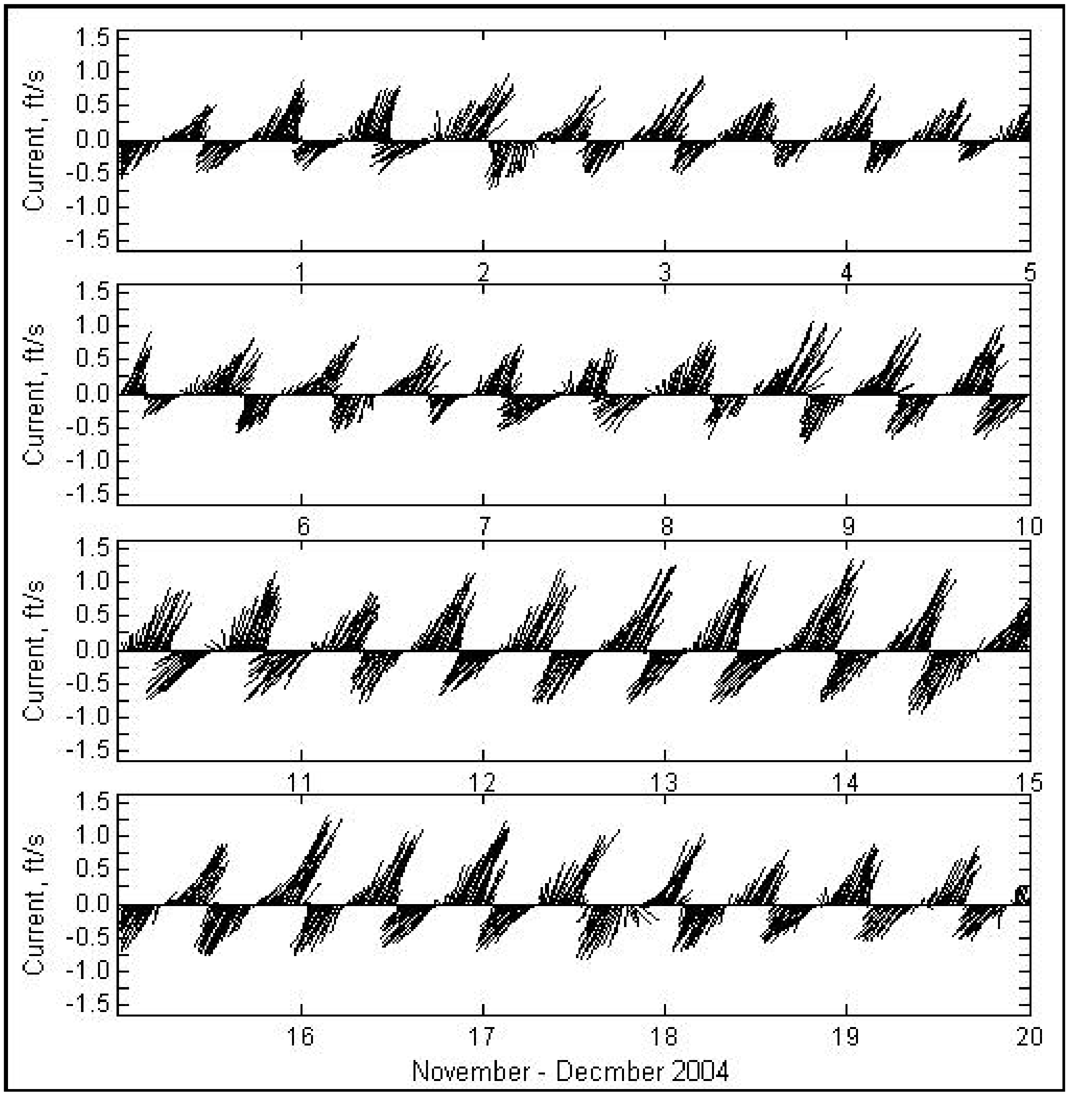


Figure C2. CM2 moored current measurement plots, November-December 2004.

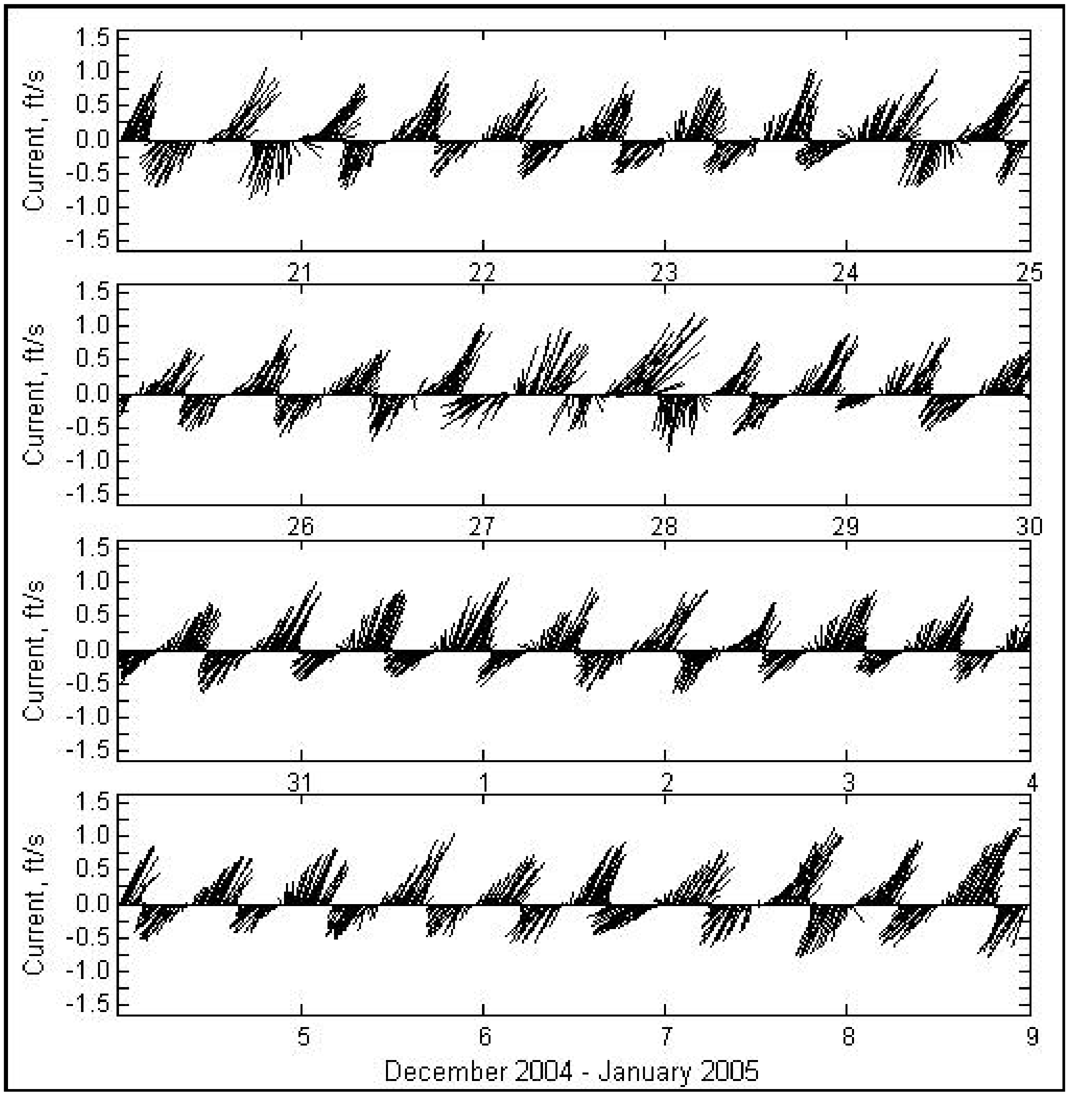


Figure C3. CM2 moored current measurement plots, December 2004–January 2005.

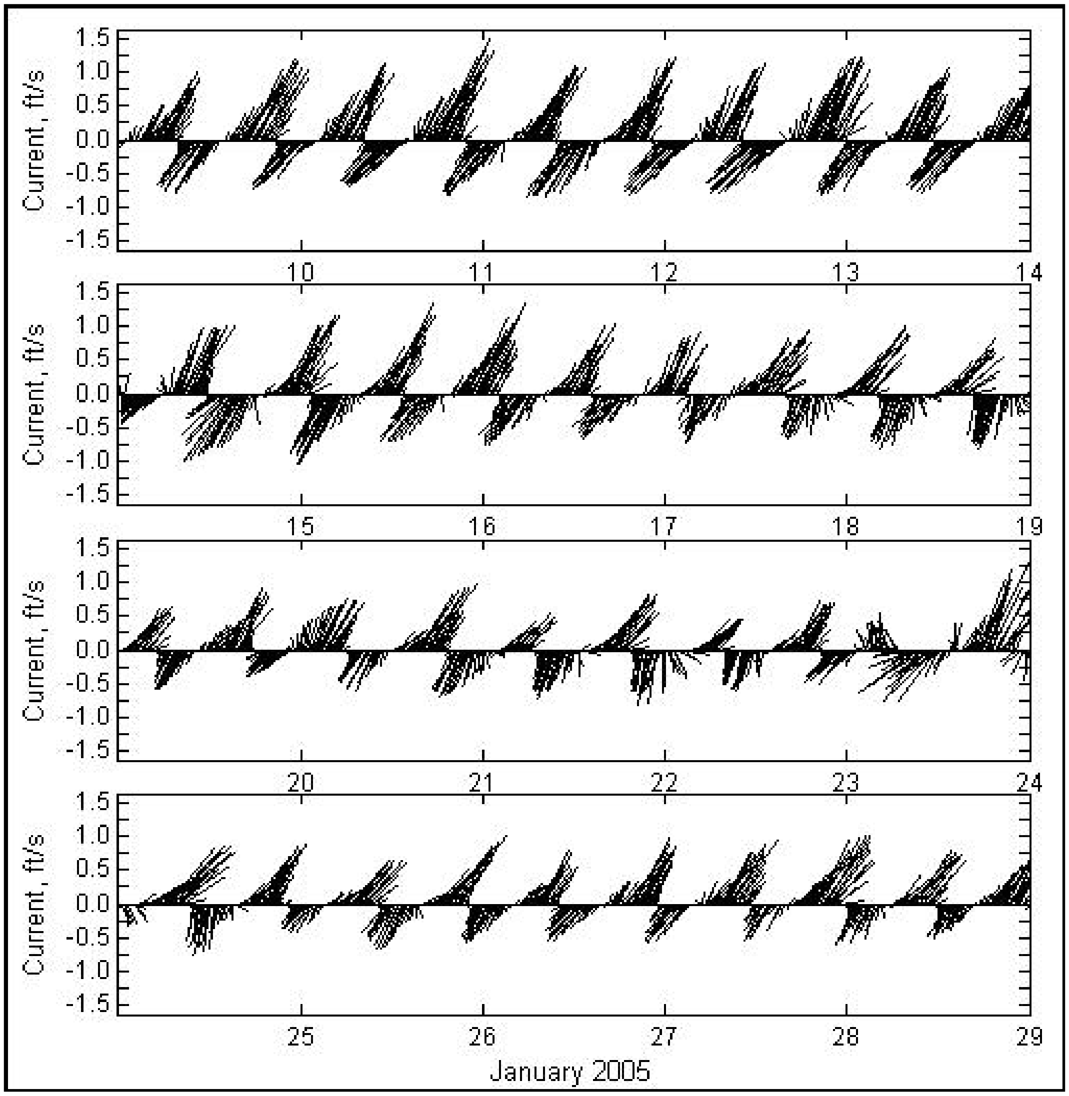


Figure C4. CM2 moored current measurement plots, January 2005.

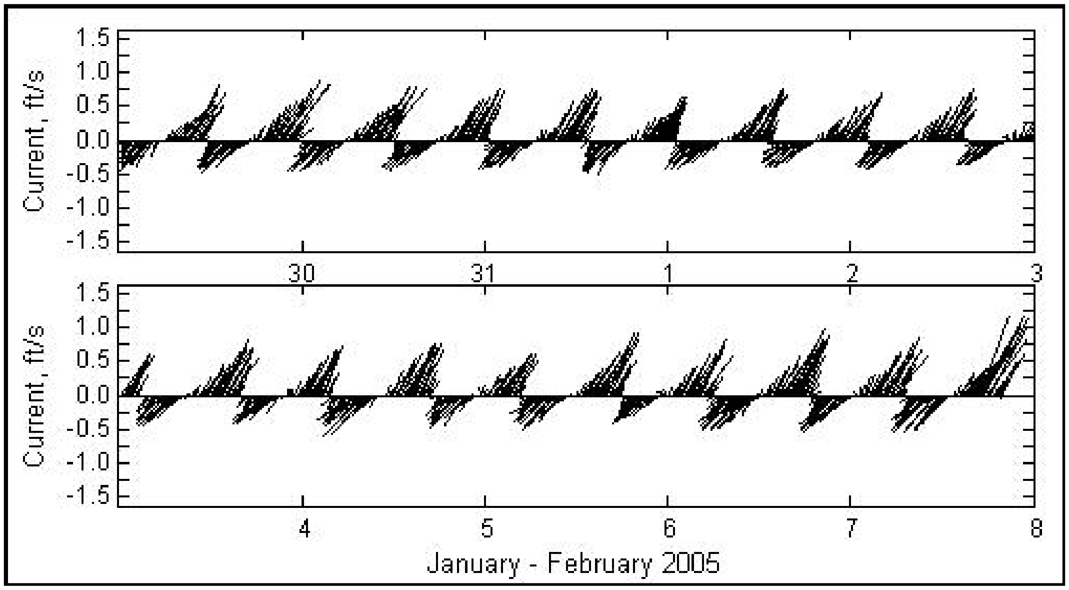


Figure C5. CM2 moored current measurement plots, January-February 2005.

Appendix D: Transect Current Surveys, Depth-Averaged Current Plots

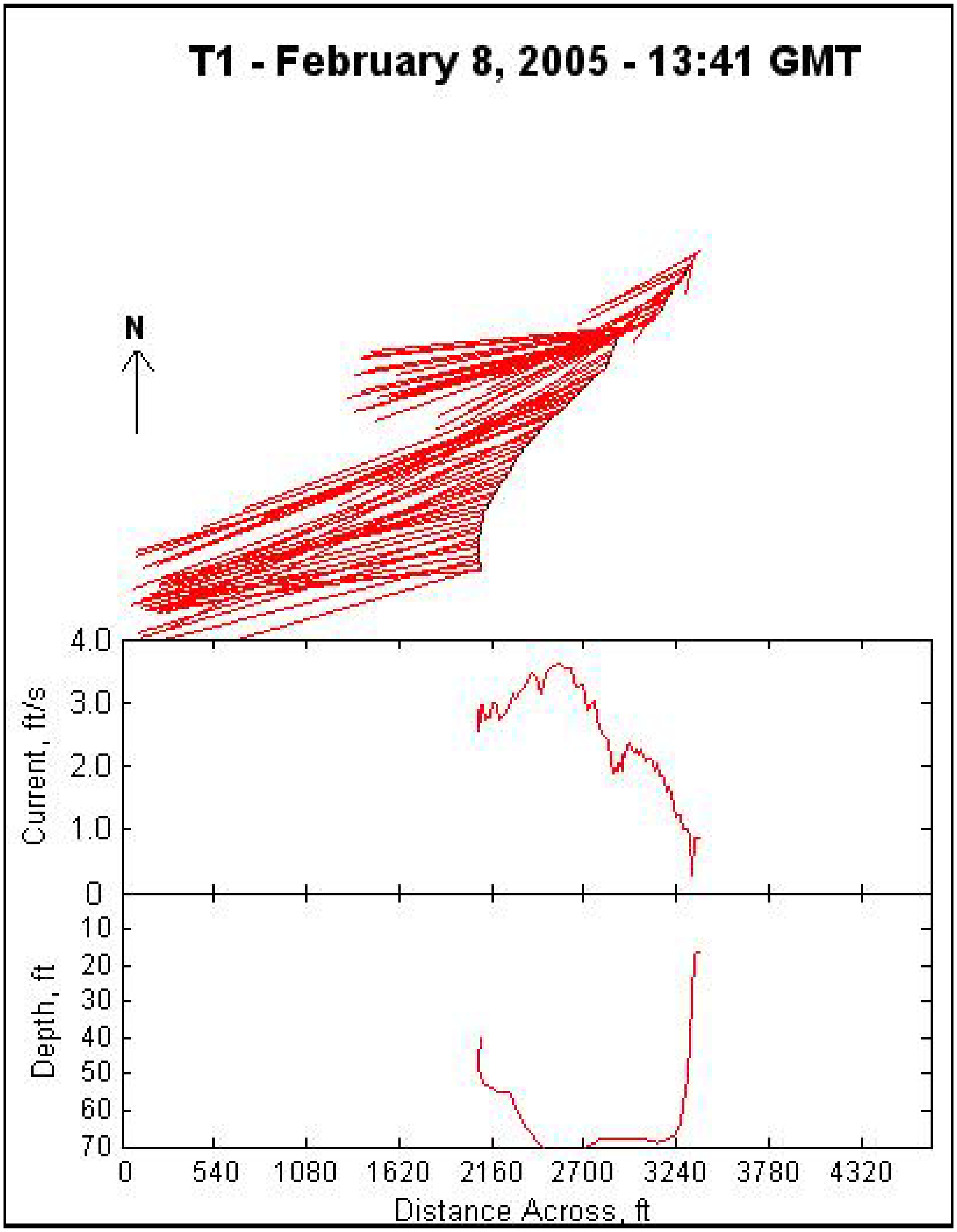


Figure D1. Transect 1 depth-averaged current plots, 8 February 2005, 1341 GMT.

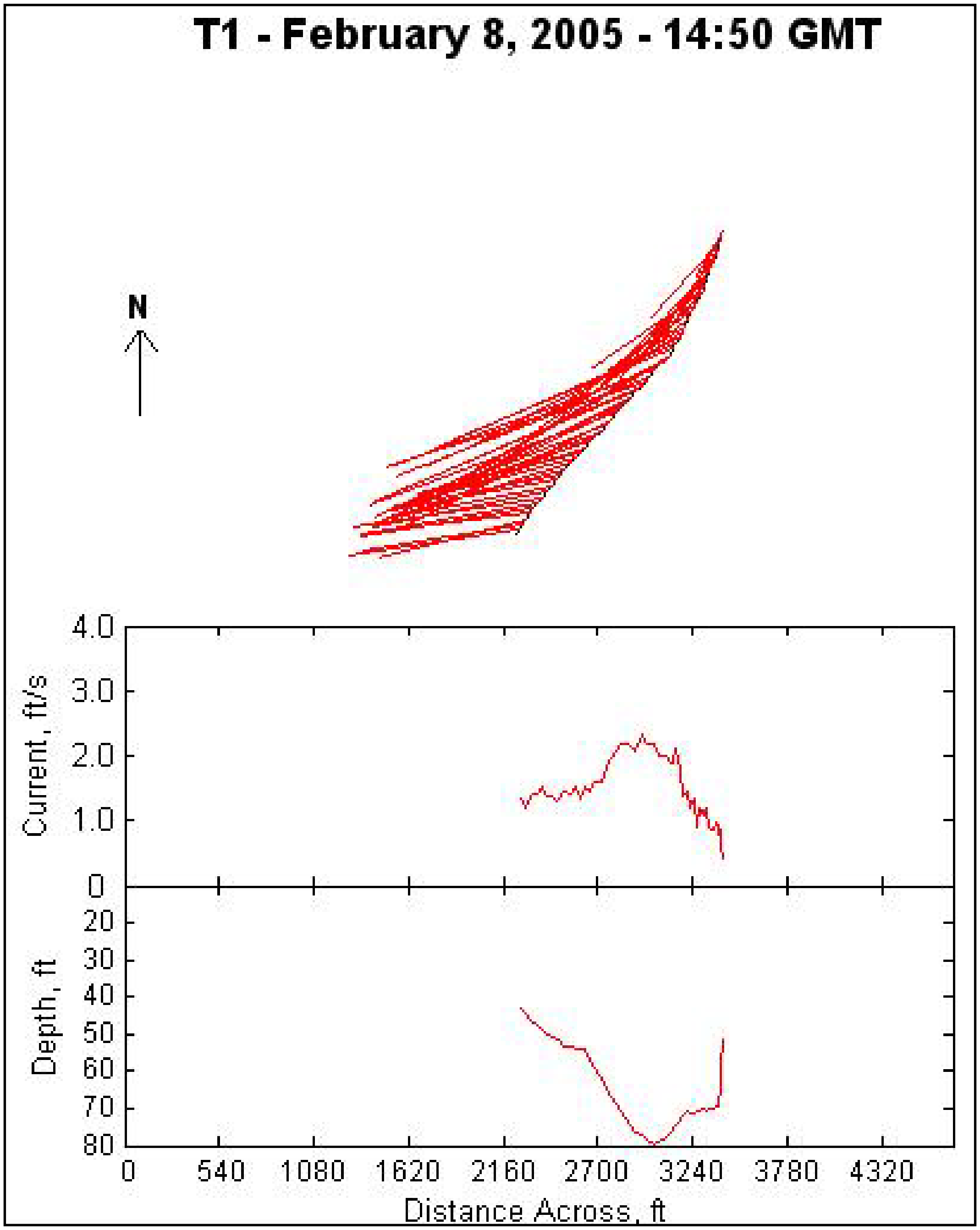


Figure D2. Transect 1 depth-averaged current plots, 8 February 2005, 1450 GMT.

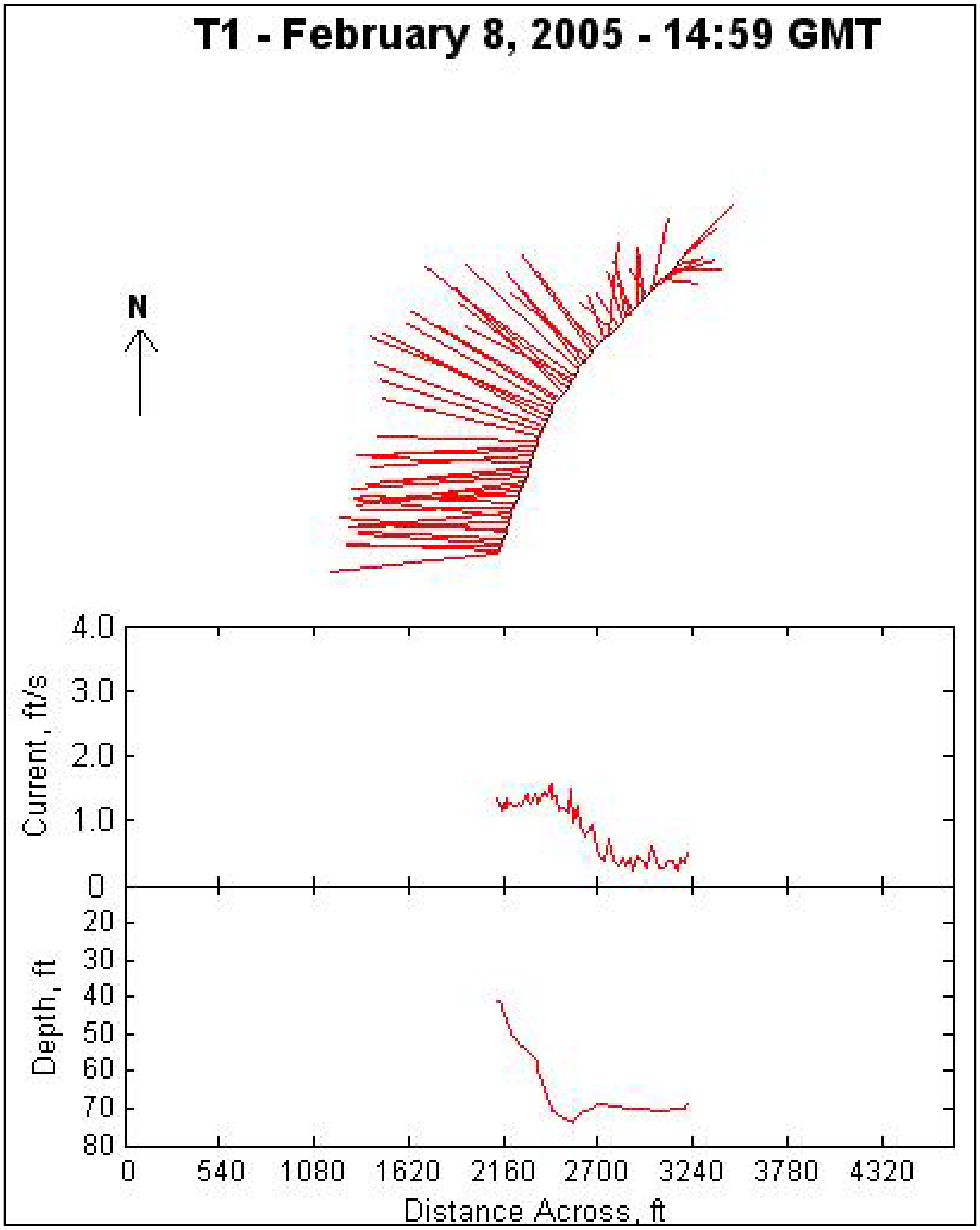


Figure D3. Transect 1 depth-averaged current plots, 8 February 2005, 1459 GMT.

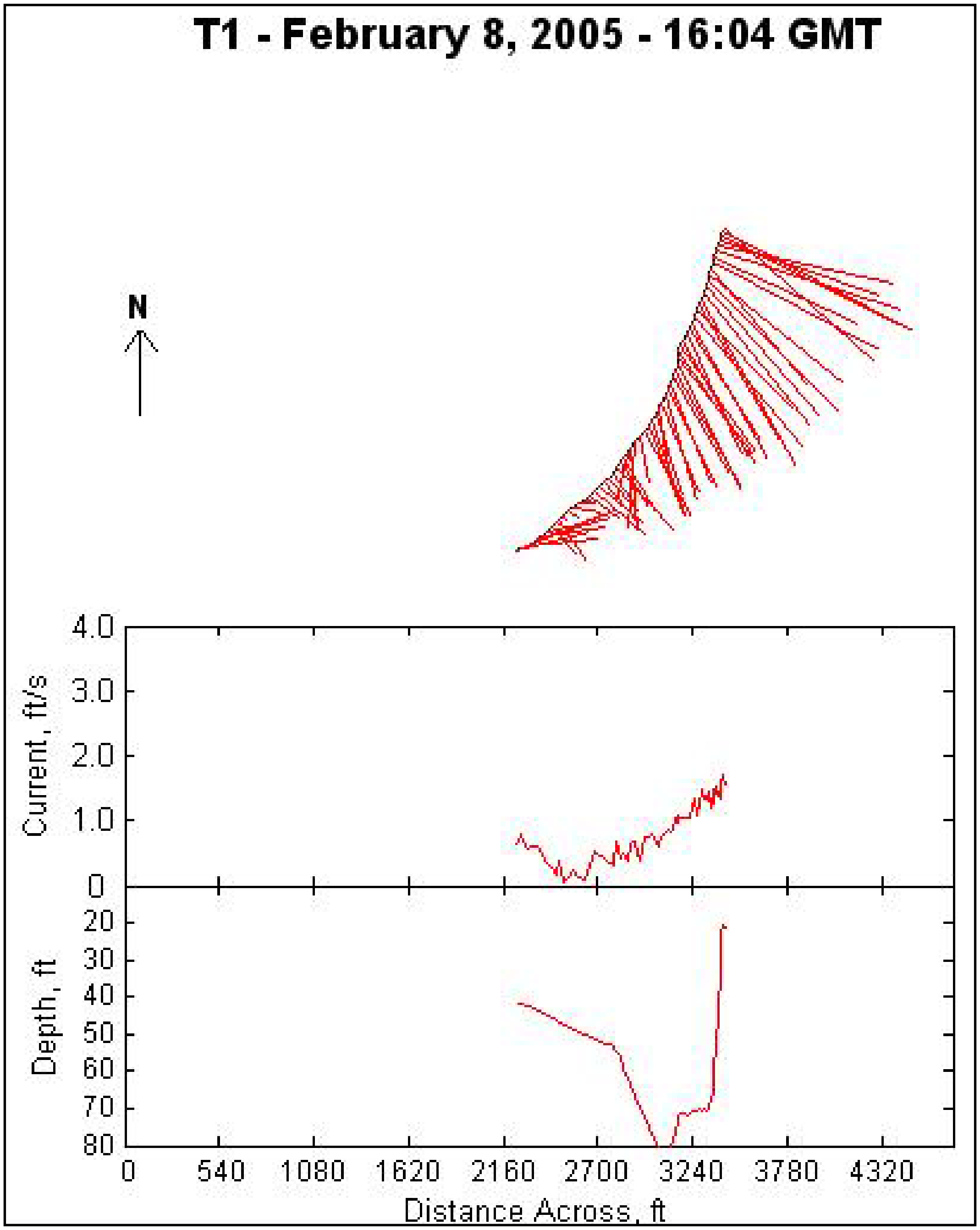


Figure D4. Transect 1 depth-averaged current plots, 8 February 2005, 1604 GMT.

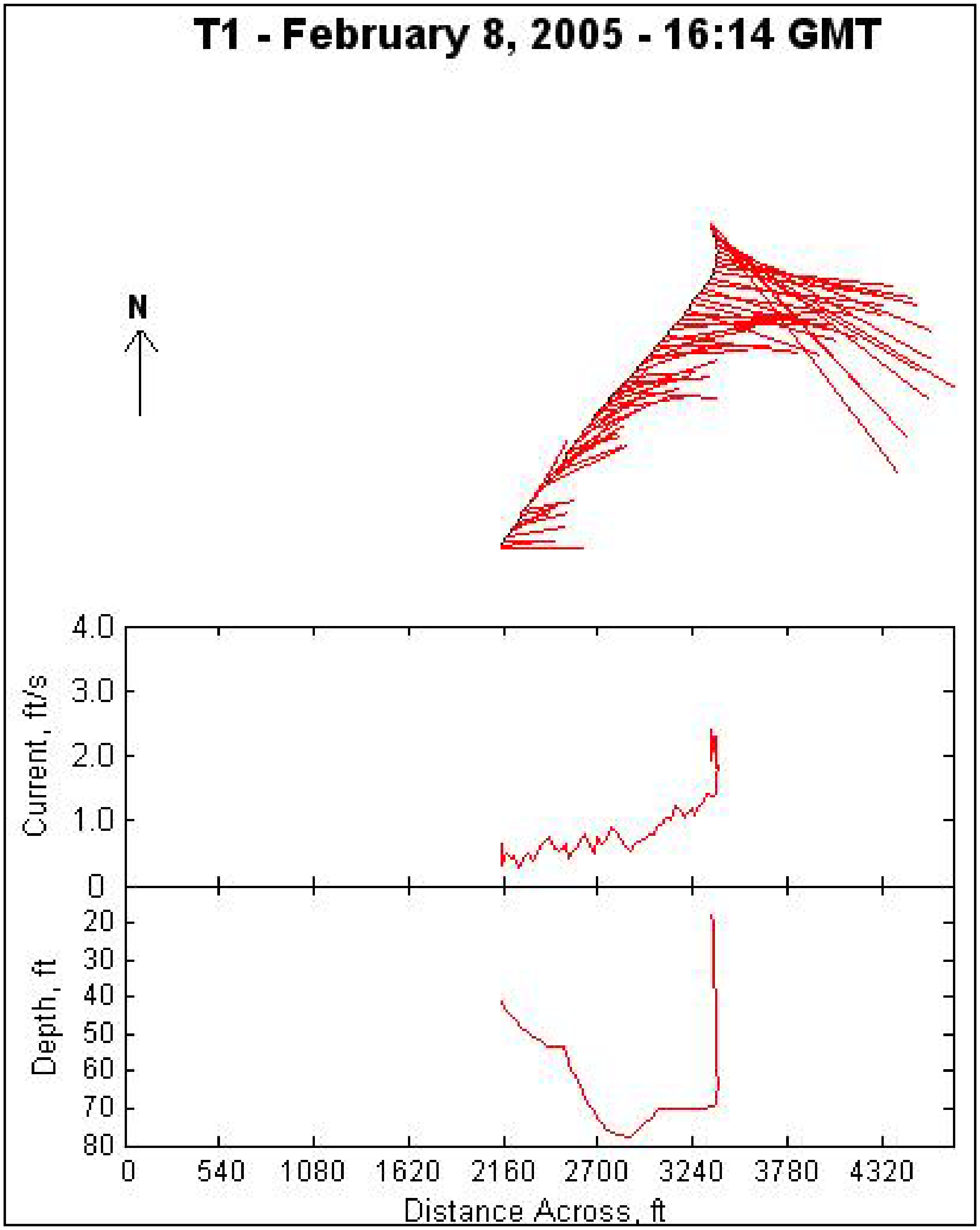


Figure D5. Transect 1 depth-averaged current plots, 8 February 2005, 1614 GMT.

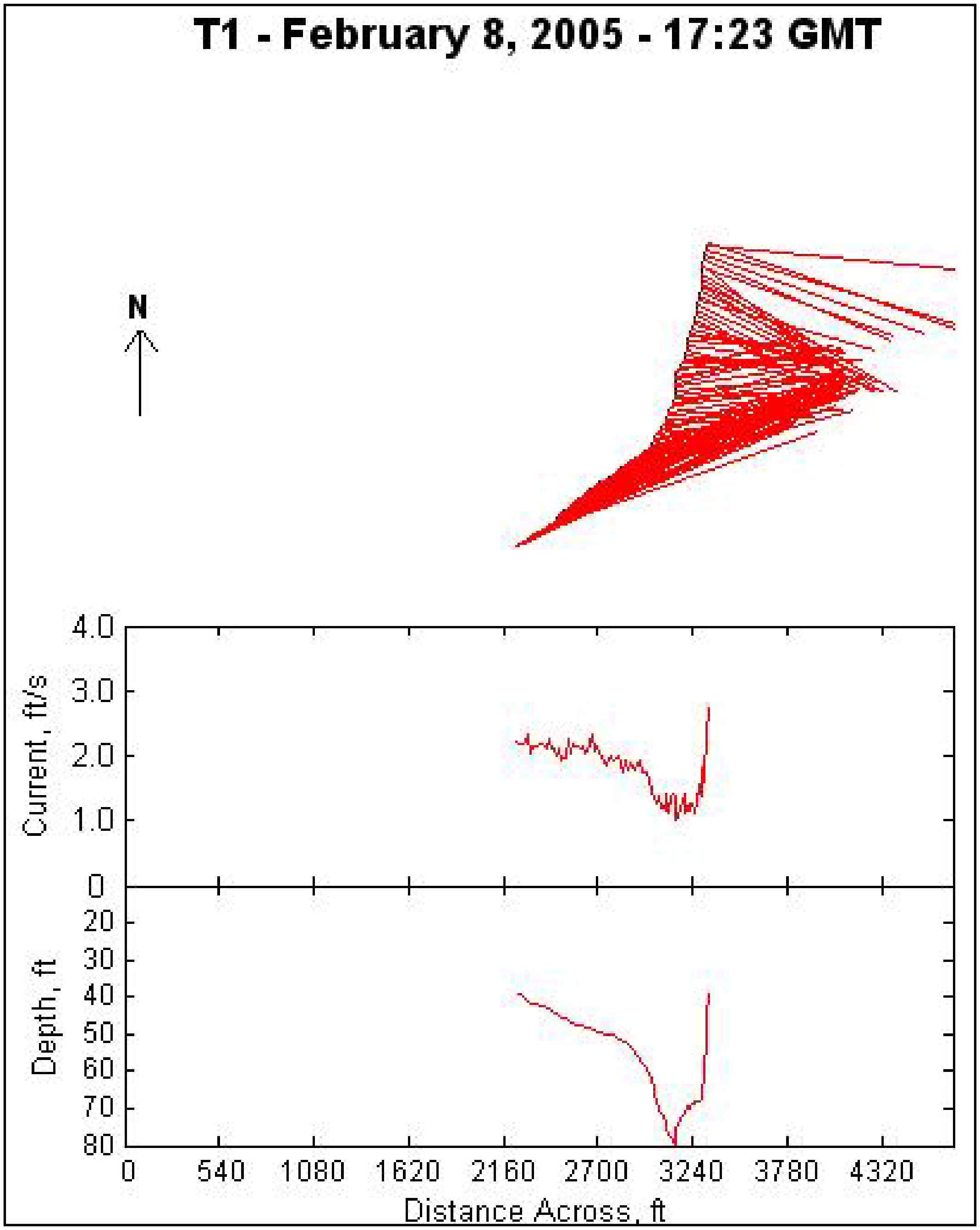


Figure D6. Transect 1 depth-averaged current plots, 8 February 2005, 1723 GMT.

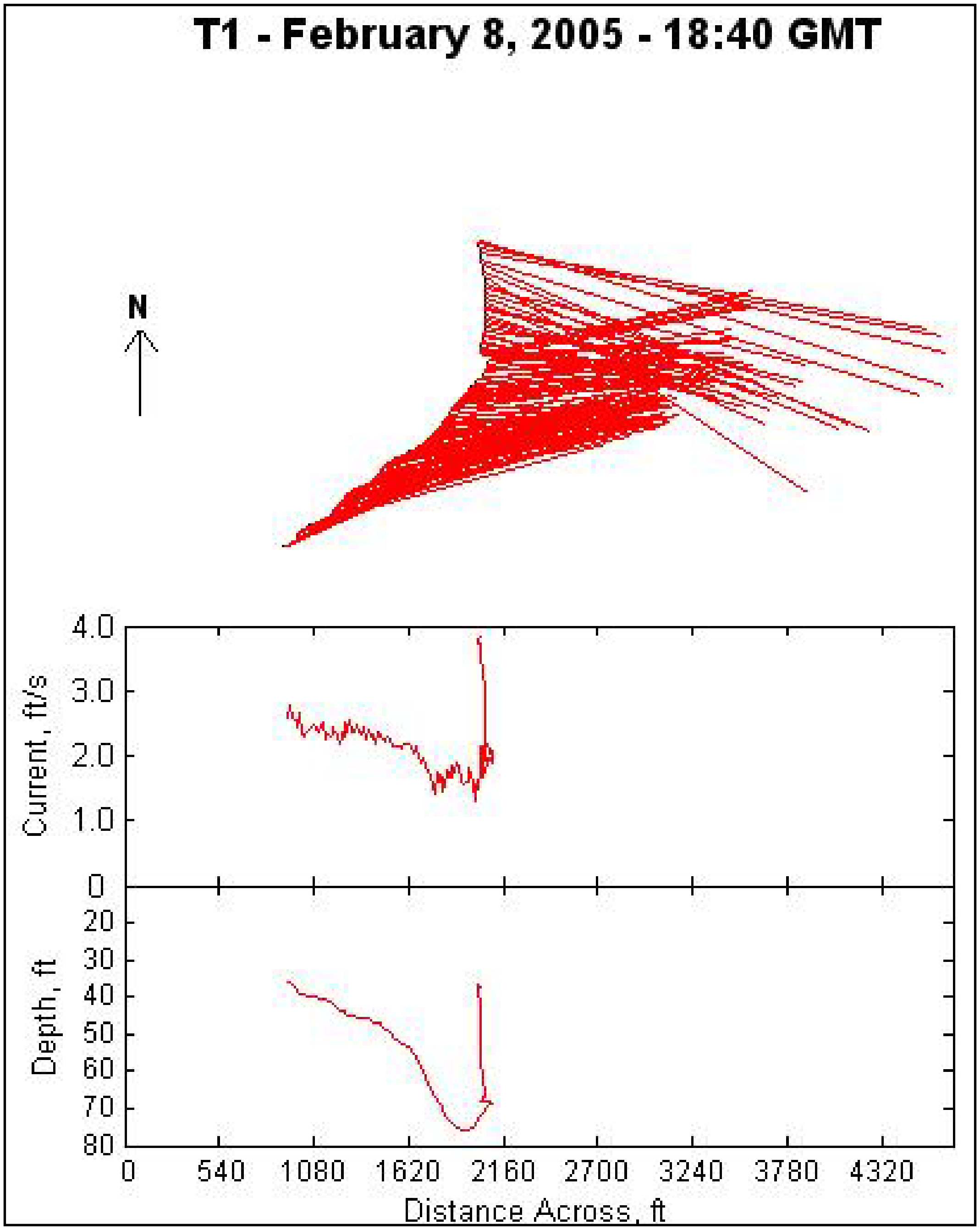


Figure D7. Transect 1 depth-averaged current plots, 8 February 2005, 1840 GMT.

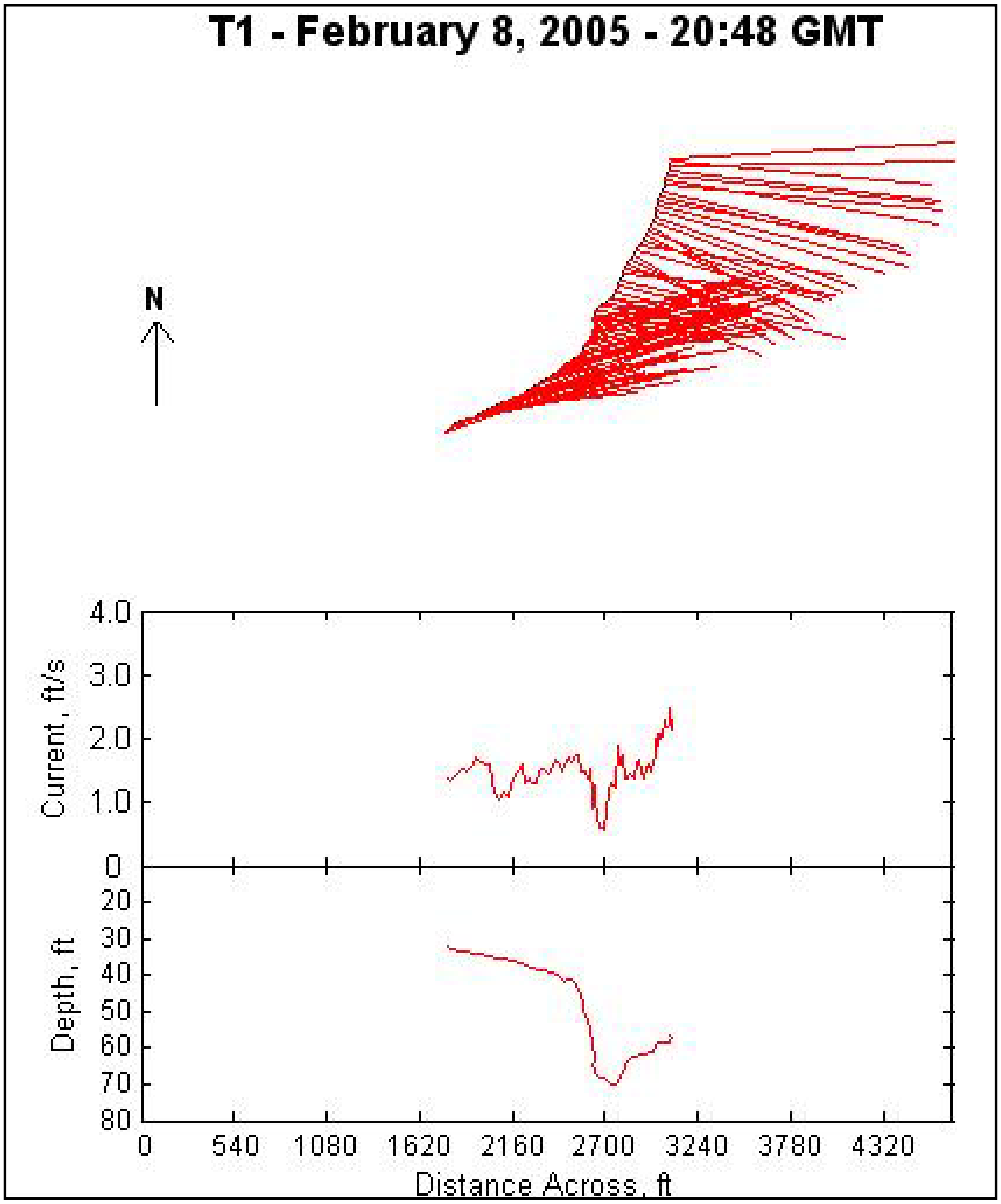


Figure D8. Transect 1 depth-averaged current plots, 8 February 2005, 2048 GMT.

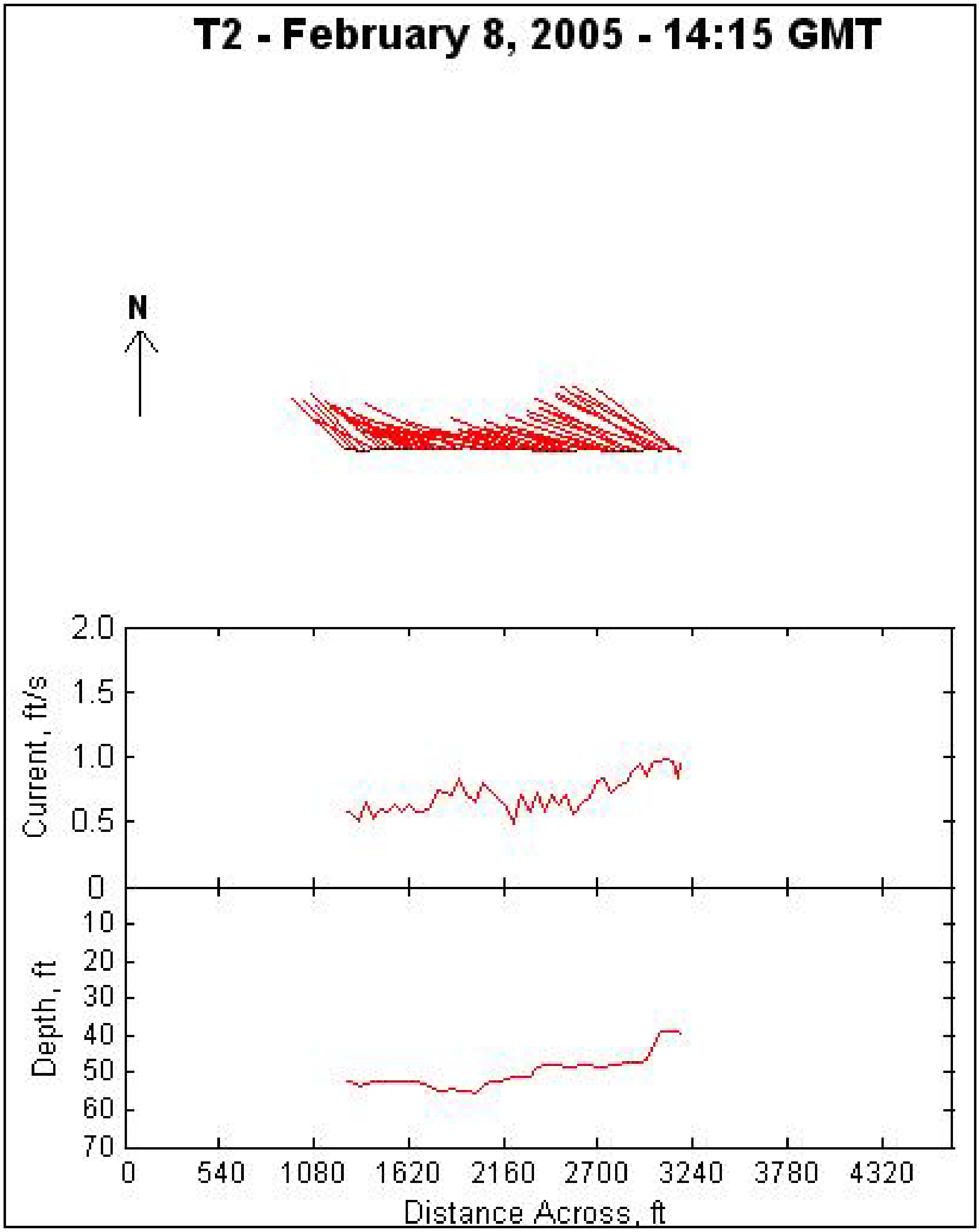


Figure D9. Transect 2 depth-averaged current plots, 8 February 2005, 1415 GMT.

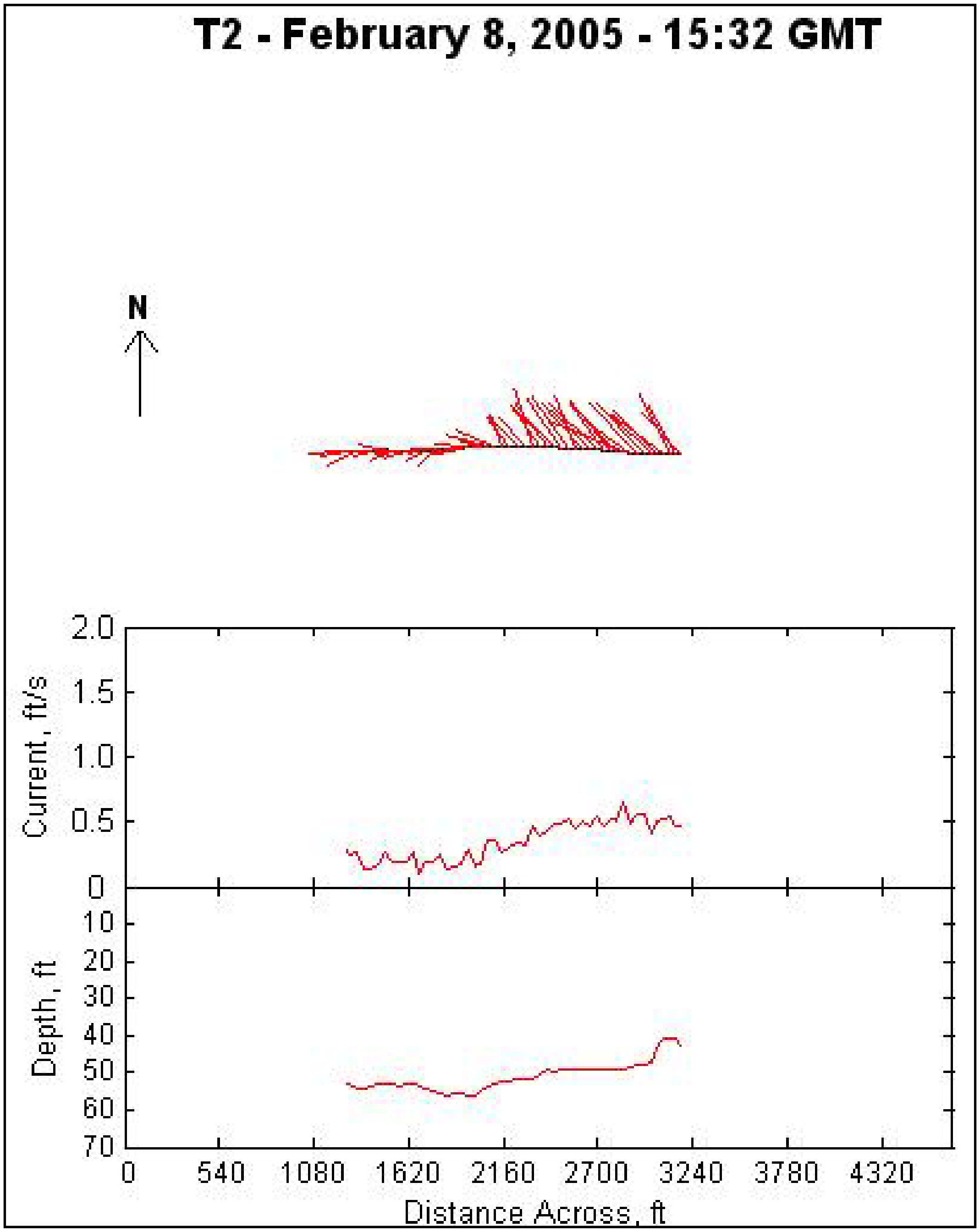


Figure D10. Transect 2 depth-averaged current plots, 8 February 2005, 1532 GMT.

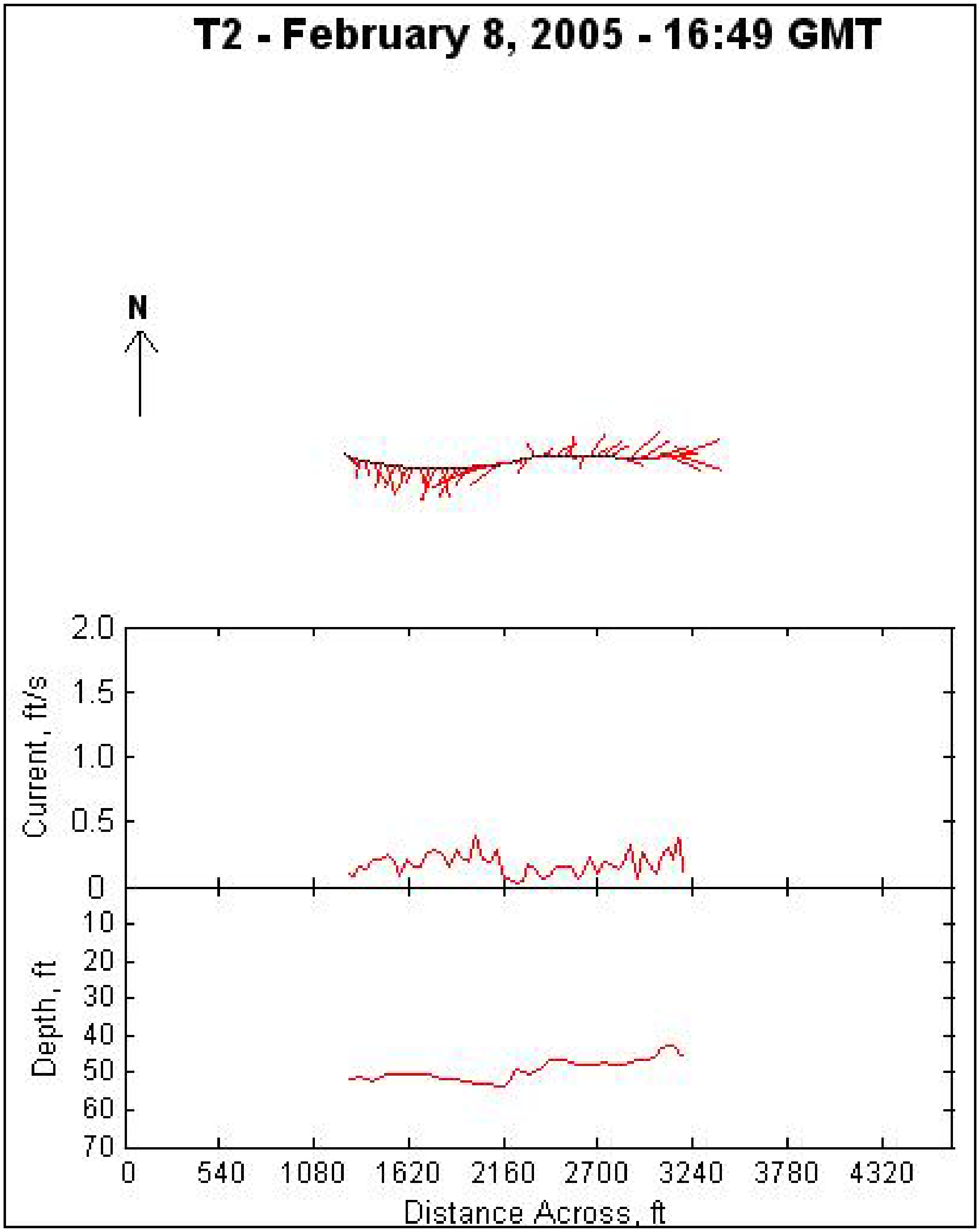


Figure D11. Transect 2 depth-averaged current plots, 8 February 2005, 1649 GMT.

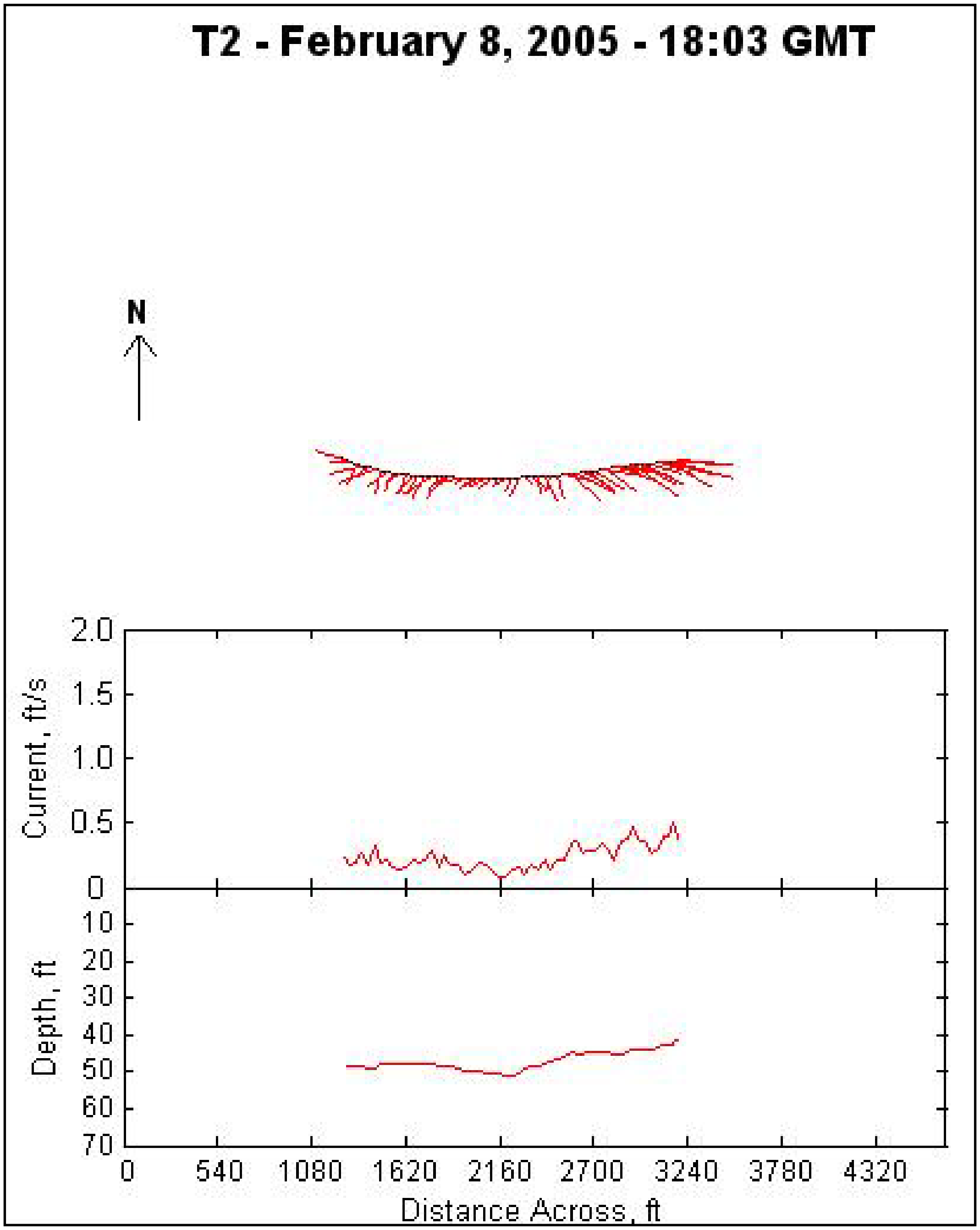


Figure D12. Transect 2 depth-averaged current plots, 8 February 2005, 1803 GMT.

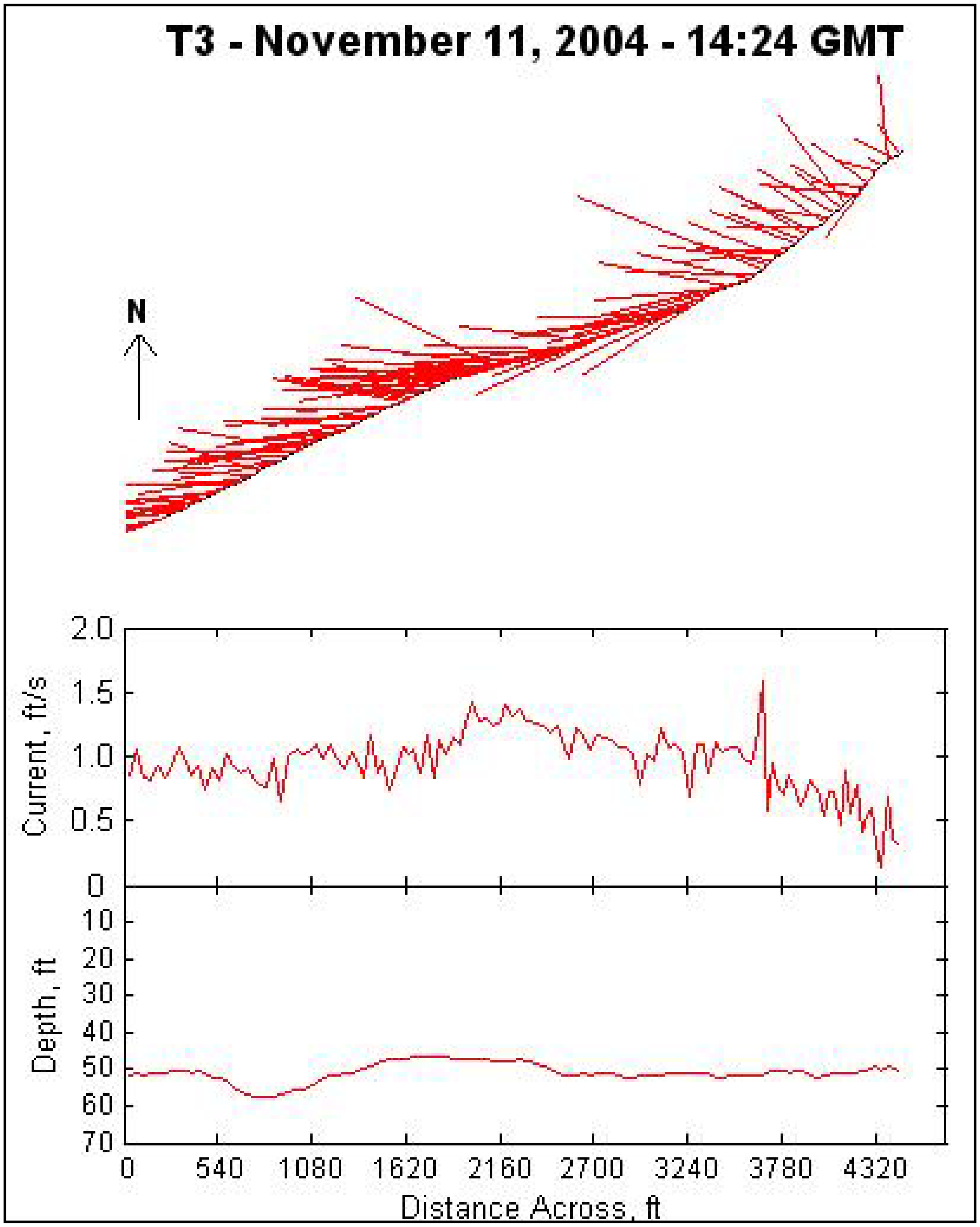


Figure D13. Transect 3 depth-averaged current plots, 11 November 2004, 1424 GMT.

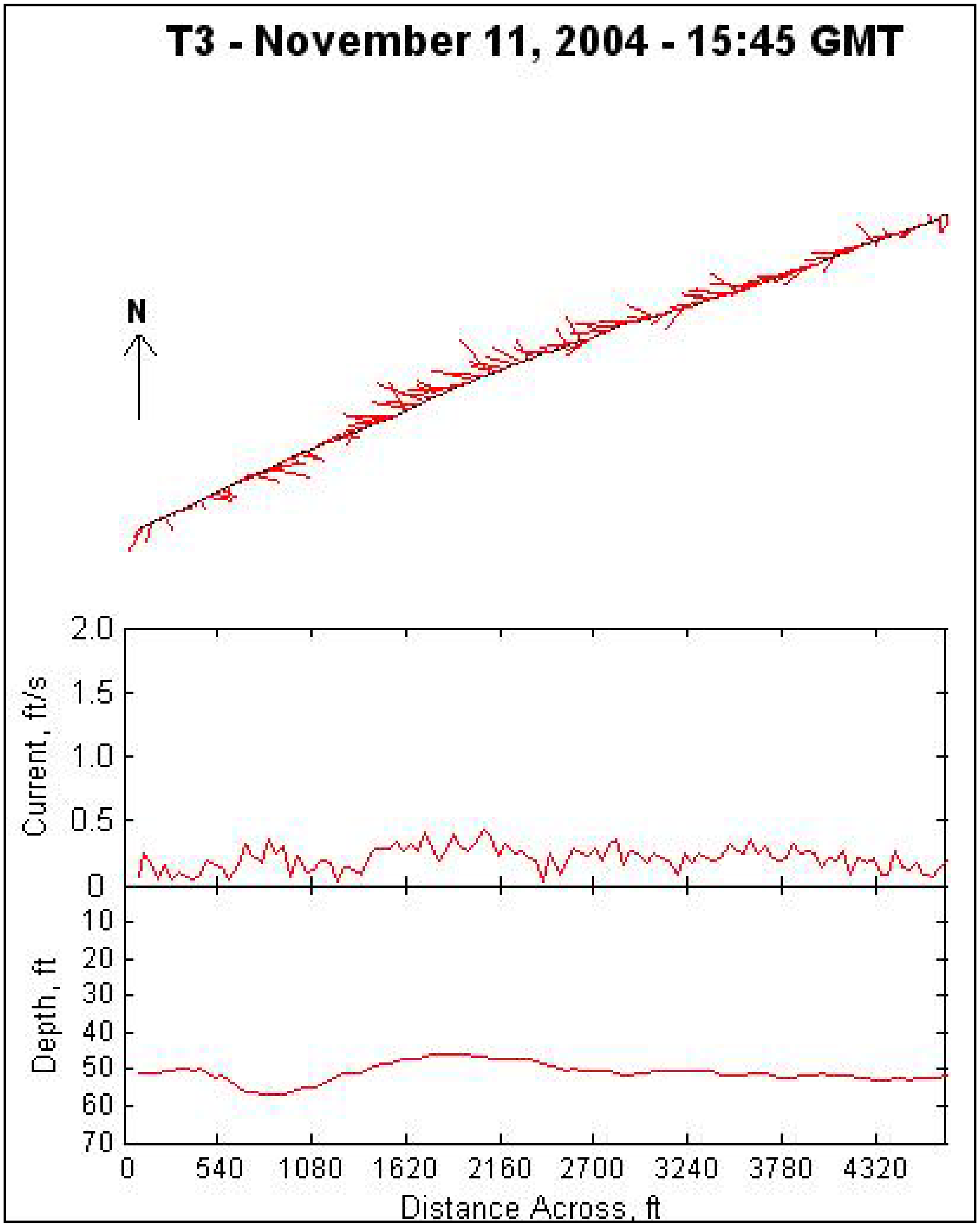


Figure D14. Transect 3 depth-averaged current plots, 11 November 2004, 1545 GMT.

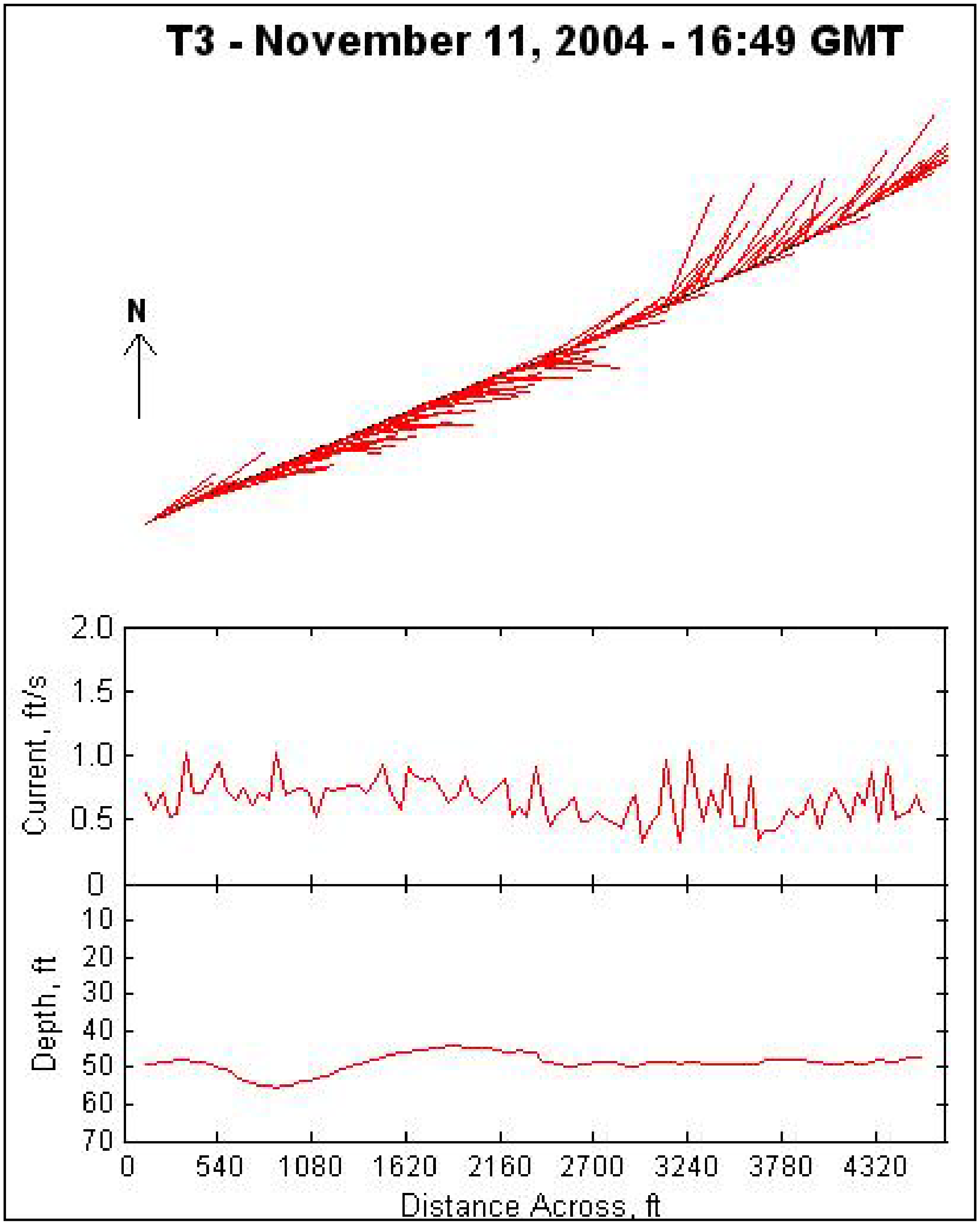


Figure D15. Transect 3 depth-averaged current plots, 11 November 2004, 1649 GMT.

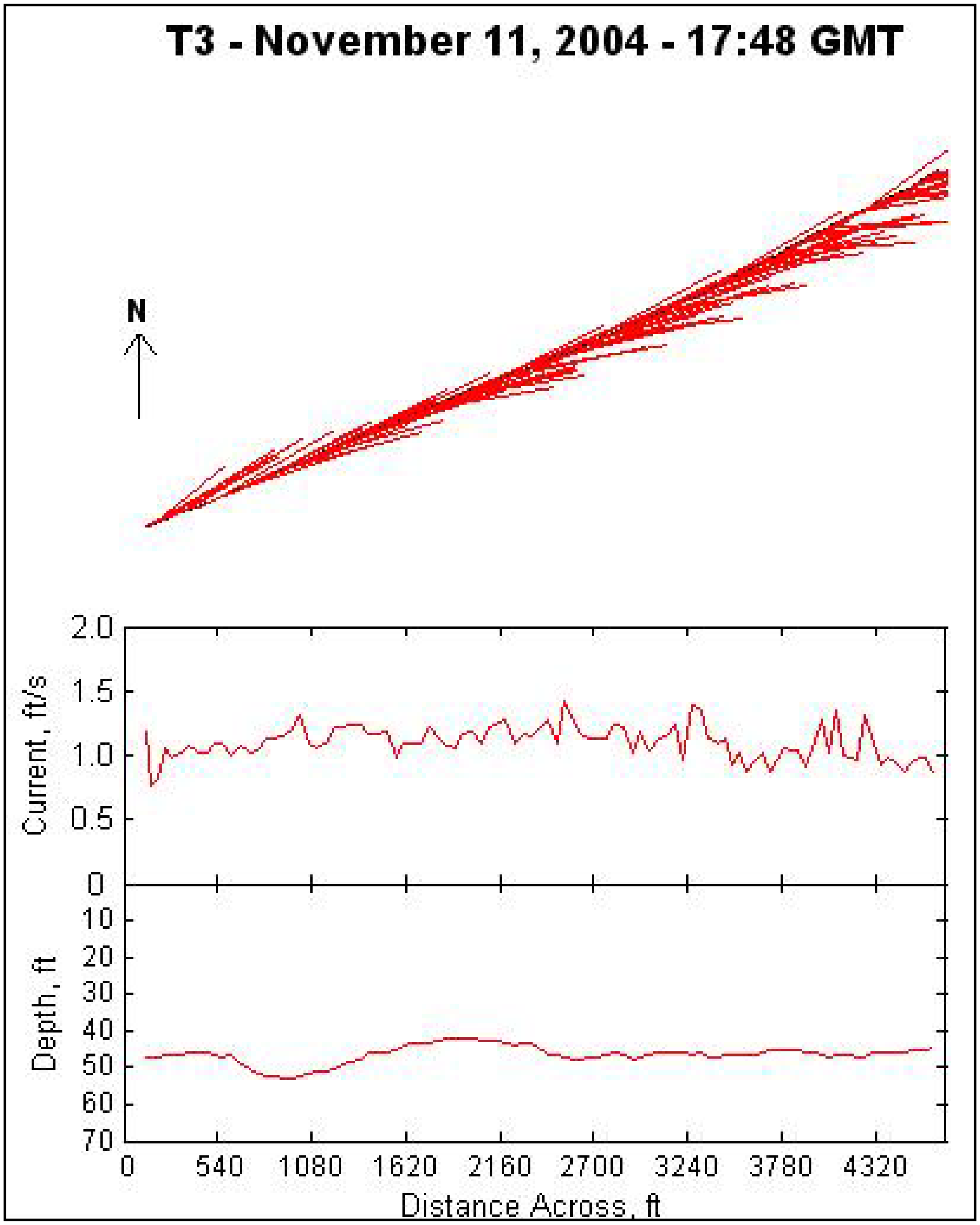


Figure D16. Transect 3 depth-averaged current plots, 11 November 2004, 1748 GMT.

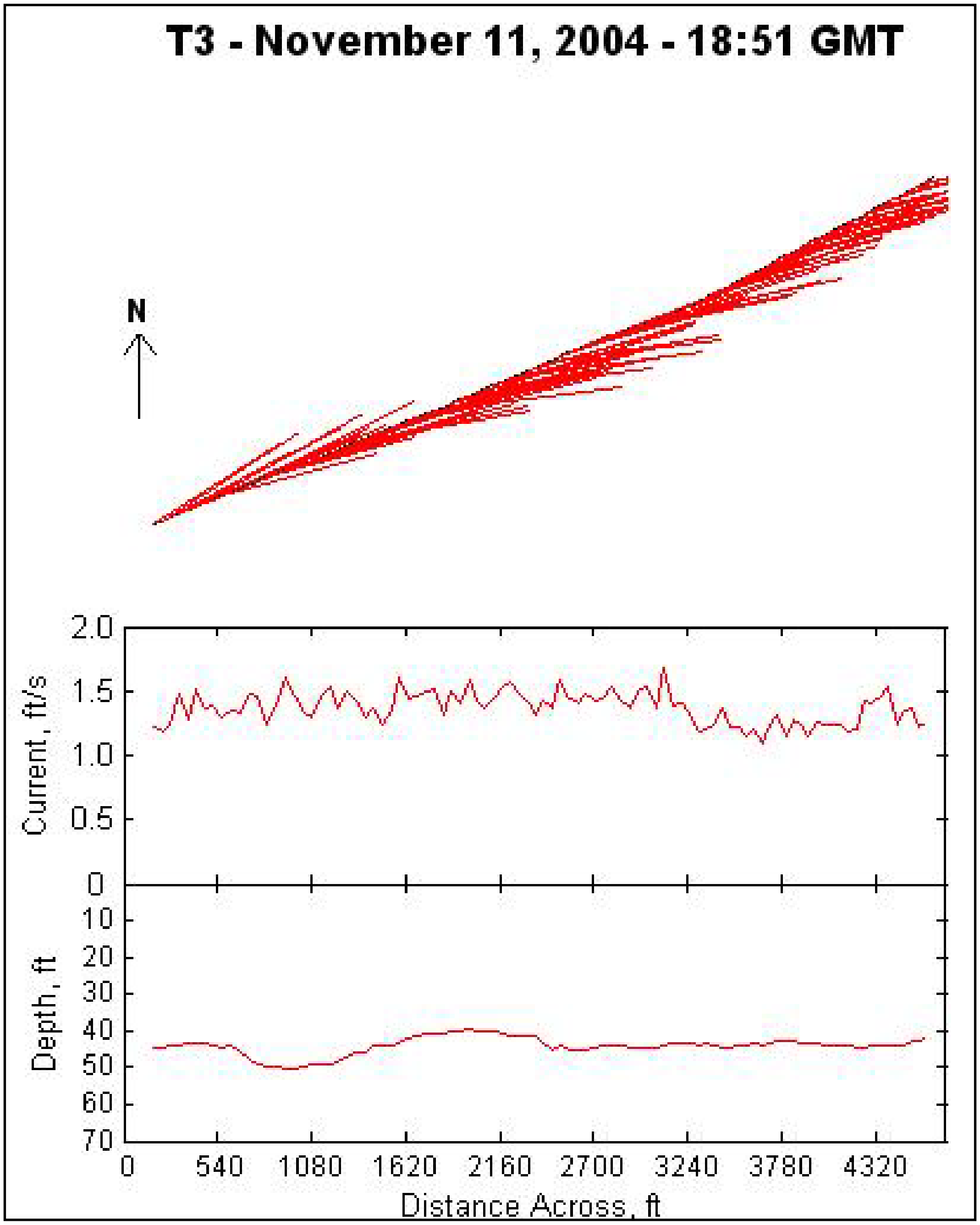


Figure D17. Transect 3 depth-averaged current plots, 11 November 2004, 1851 GMT.

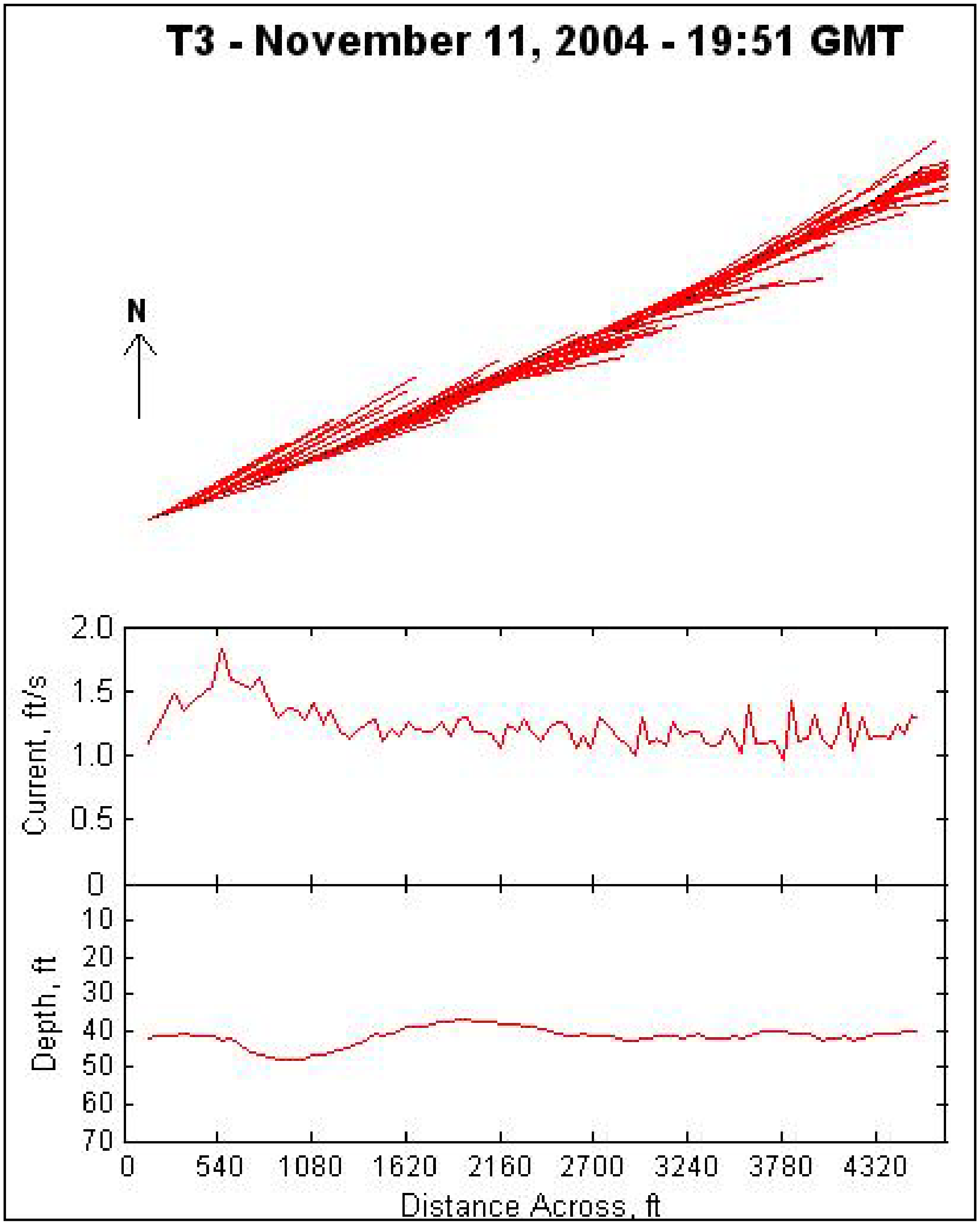


Figure D18. Transect 3 depth-averaged current plots, 11 November 2004, 1951 GMT.

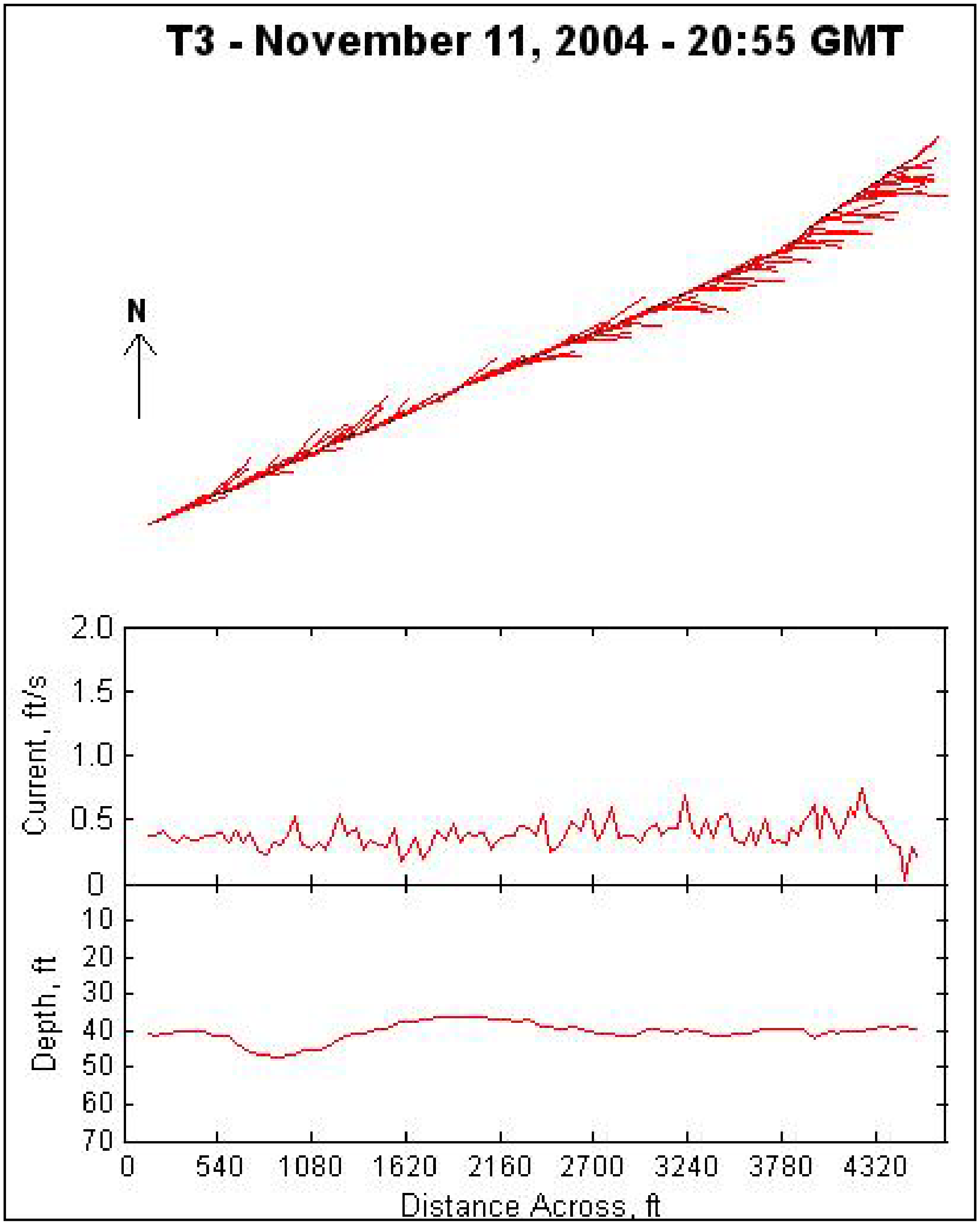


Figure D19. Transect 3 depth-averaged current plots, 11 November 2004, 2055 GMT.

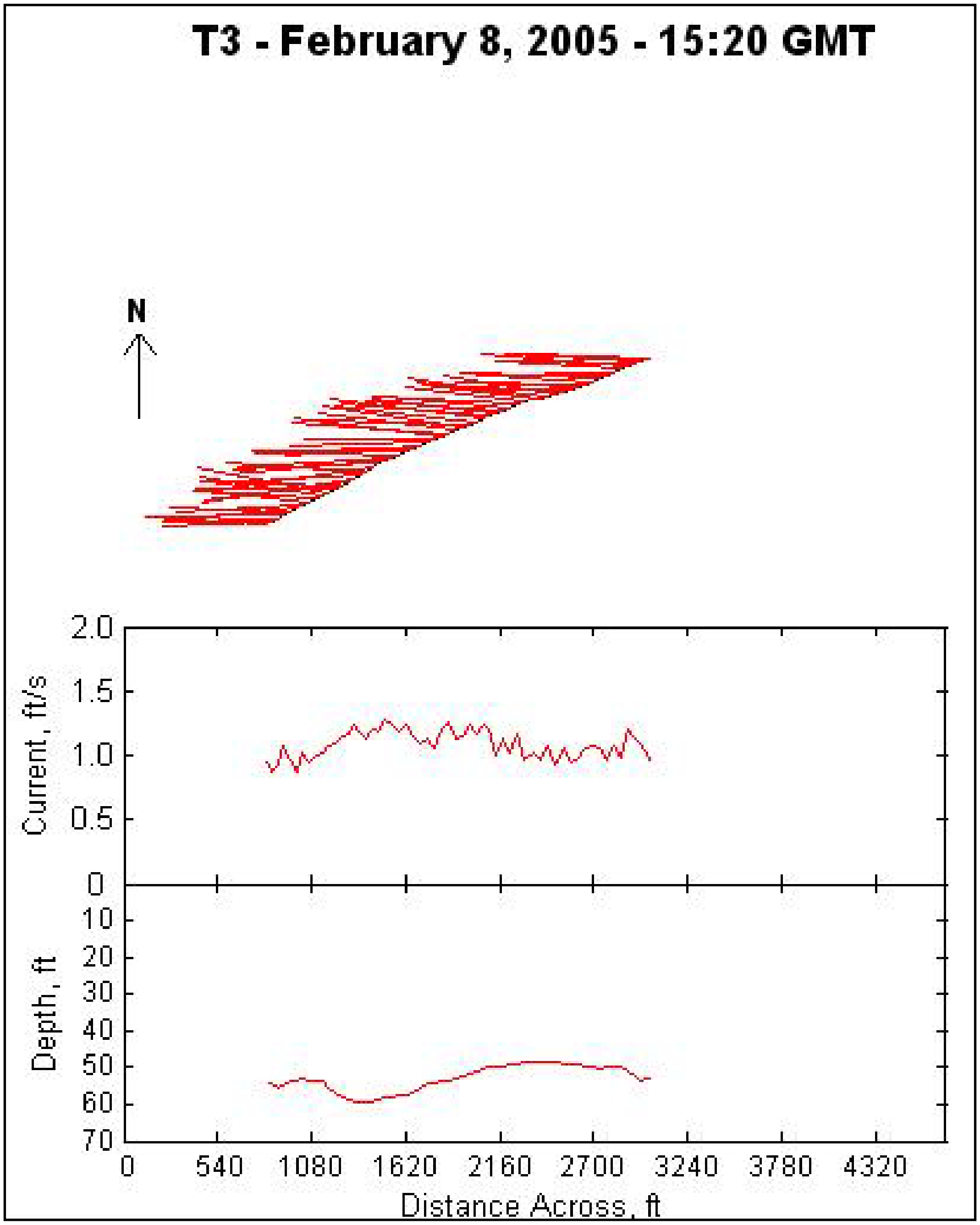


Figure D20. Transect 3 depth-averaged current plots, 8 February 2005, 1520 GMT.

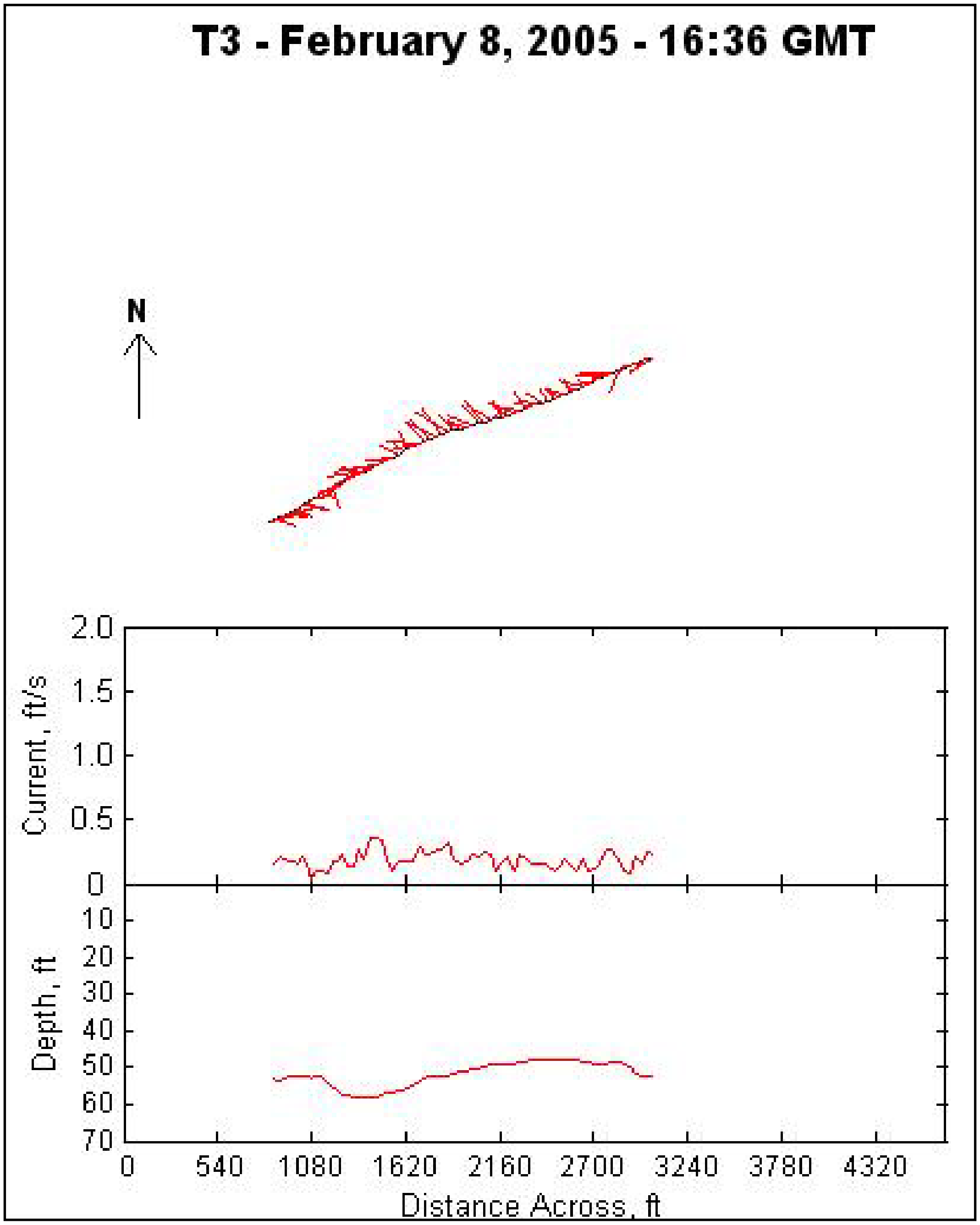


Figure D21. Transect 3 depth-averaged current plots, 8 February 2005, 1636 GMT.

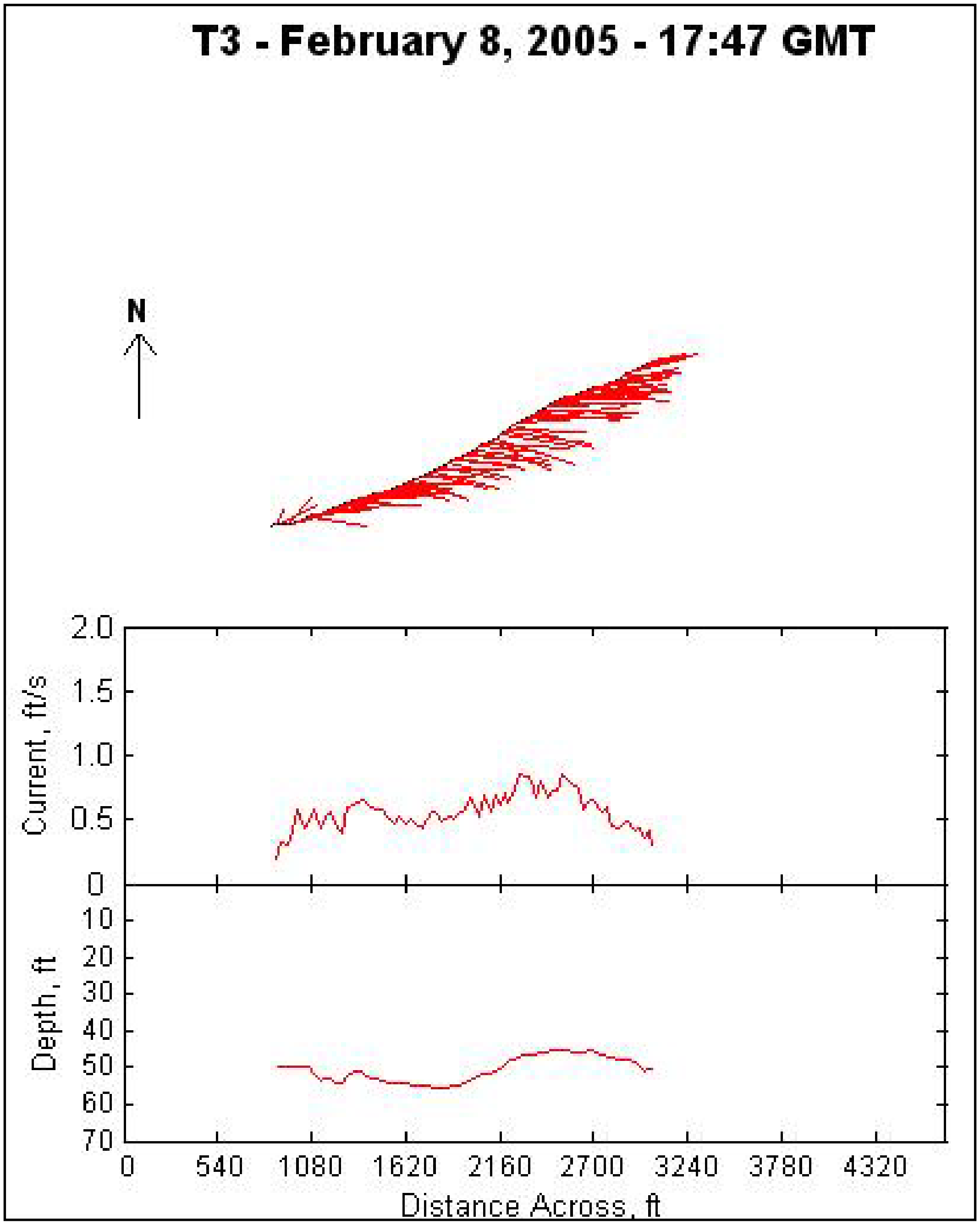


Figure D22. Transect 3 depth-averaged current plots, 8 February 2005, 1747 GMT.

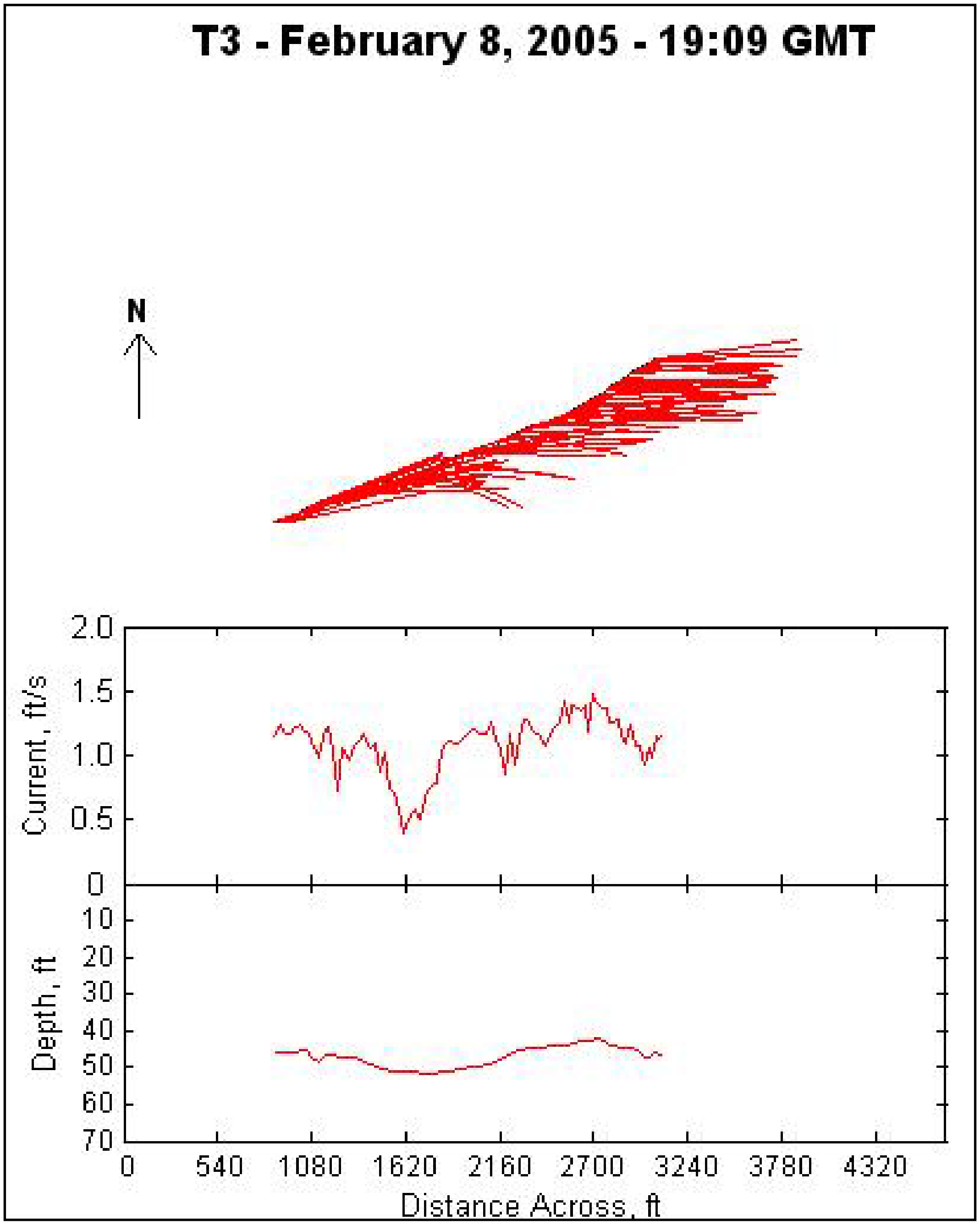


Figure D23. Transect 3 depth-averaged current plots, 8 February 2005, 1909 GMT.

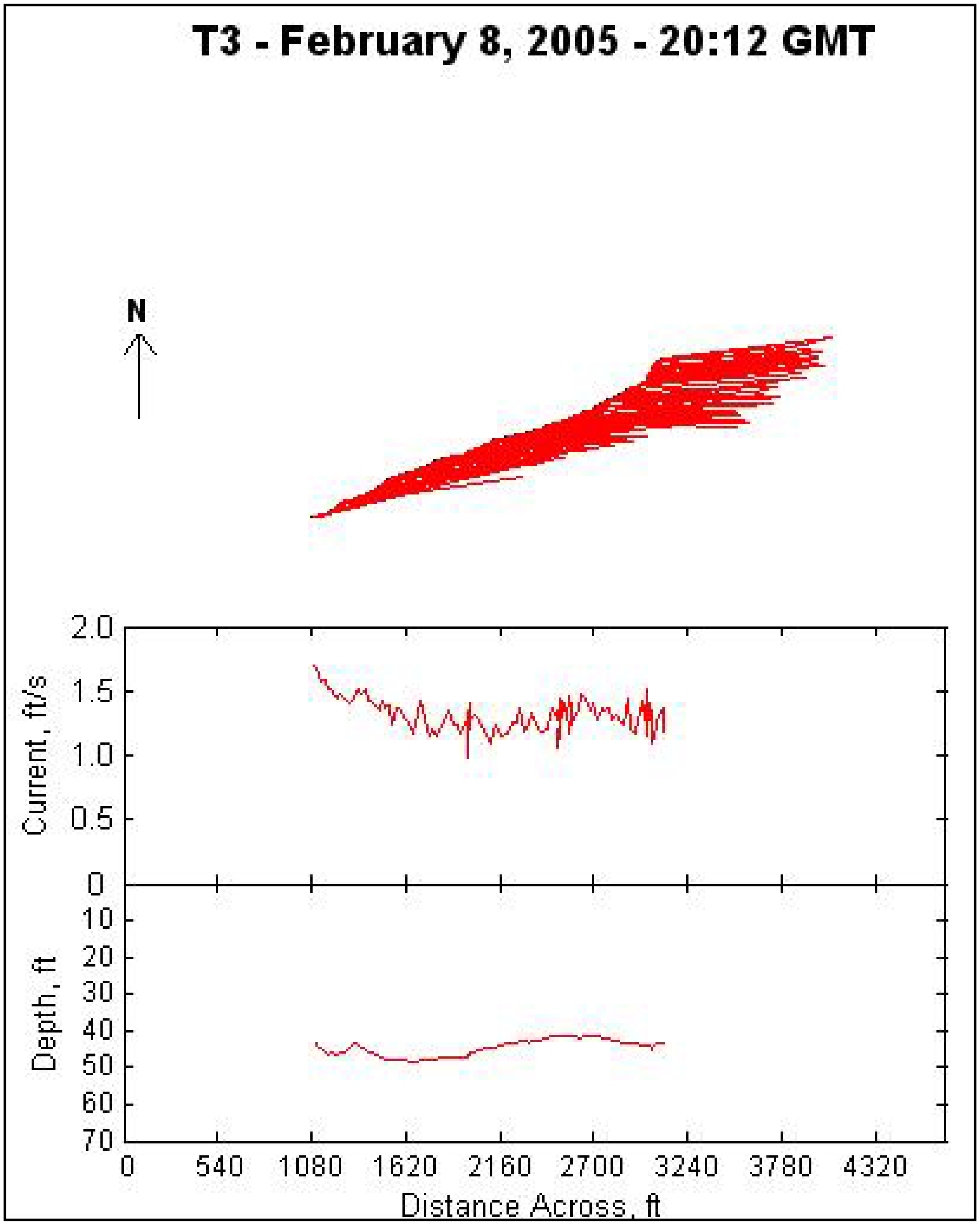


Figure D24. Transect 3 depth-averaged current plots, 8 February 2005, 2012 GMT.

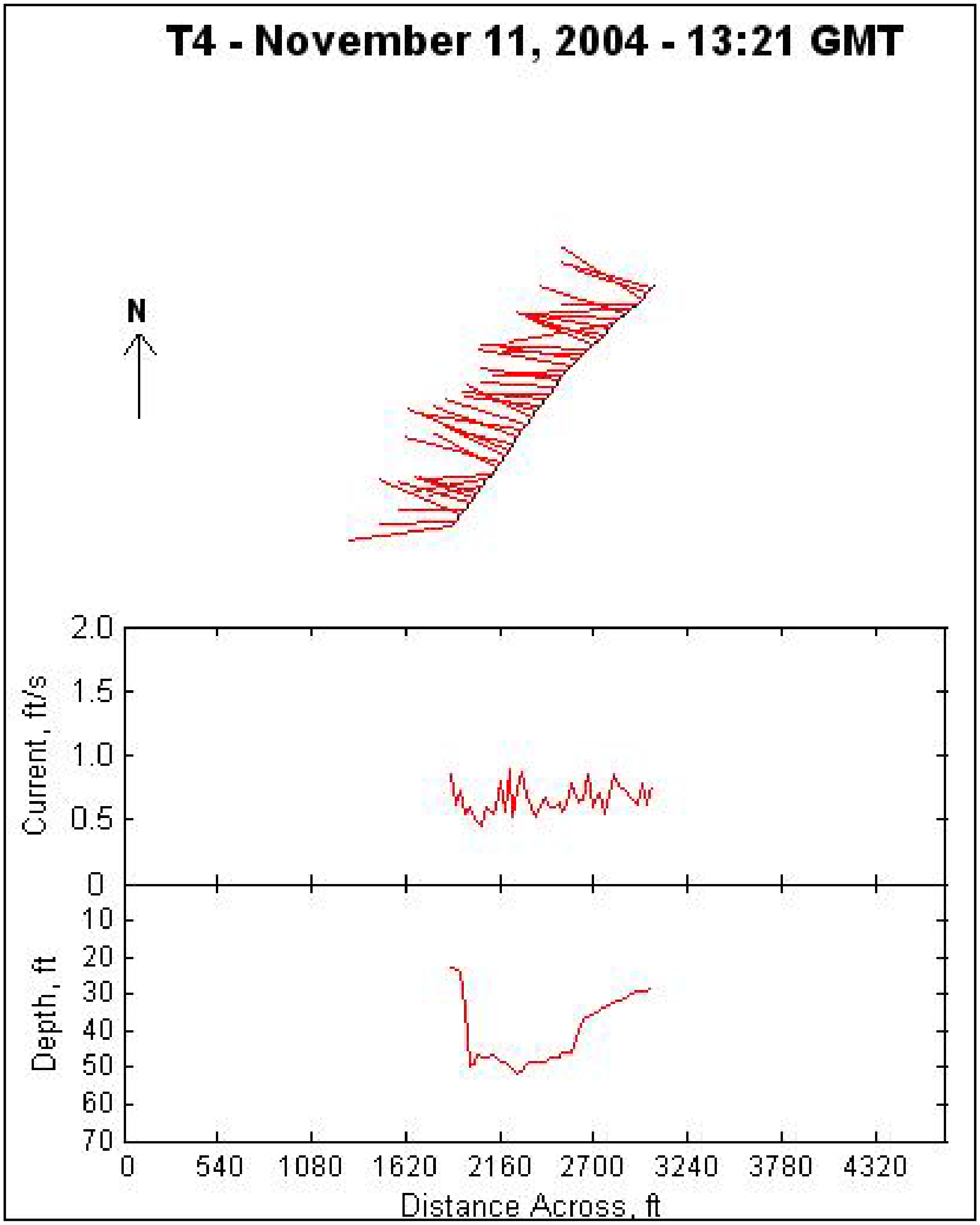


Figure D25. Transect 4 depth-averaged current plots, 11 November 2004, 1321 GMT.

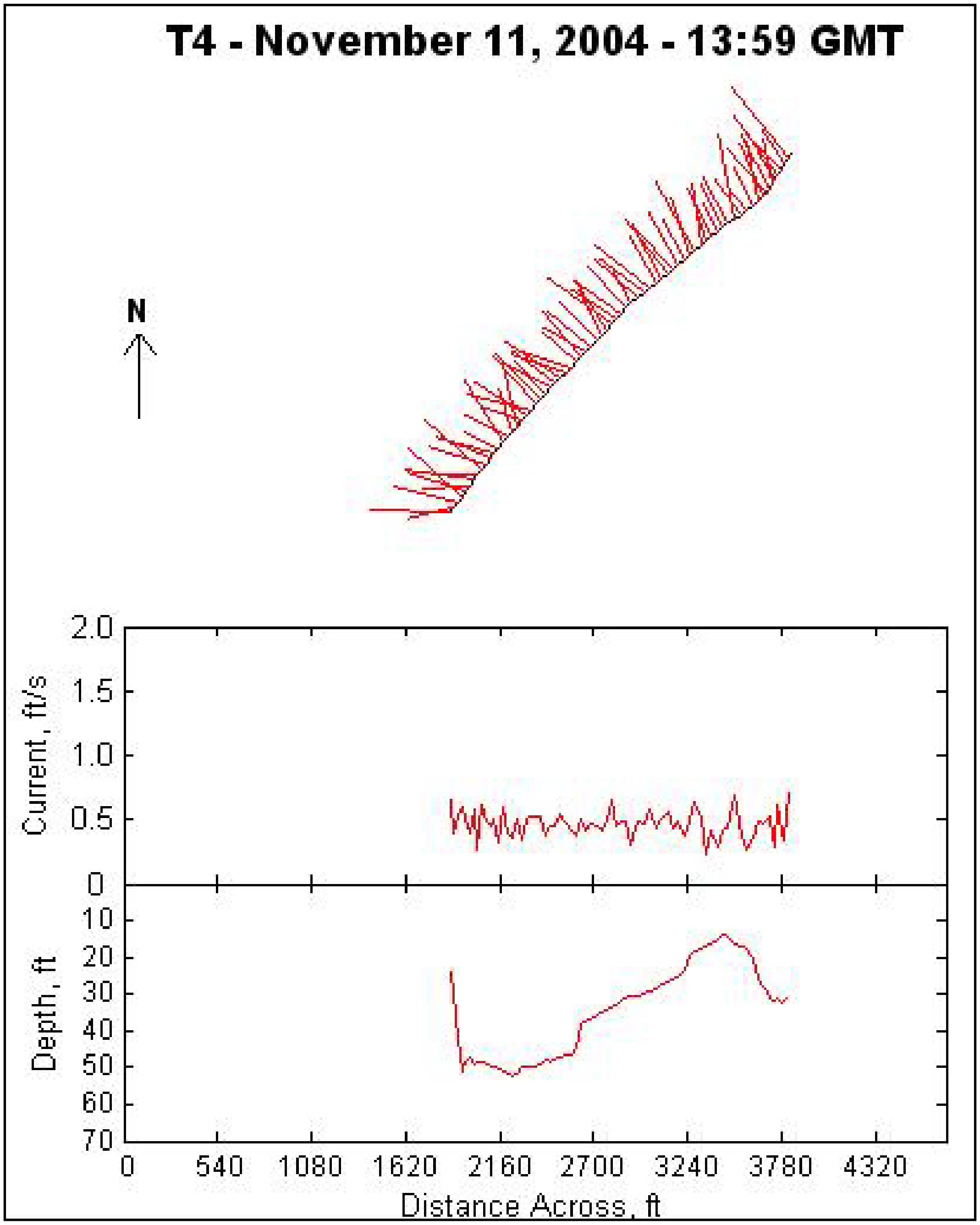


Figure D26. Transect 4 depth-averaged current plots, 11 November 2004, 1359 GMT.

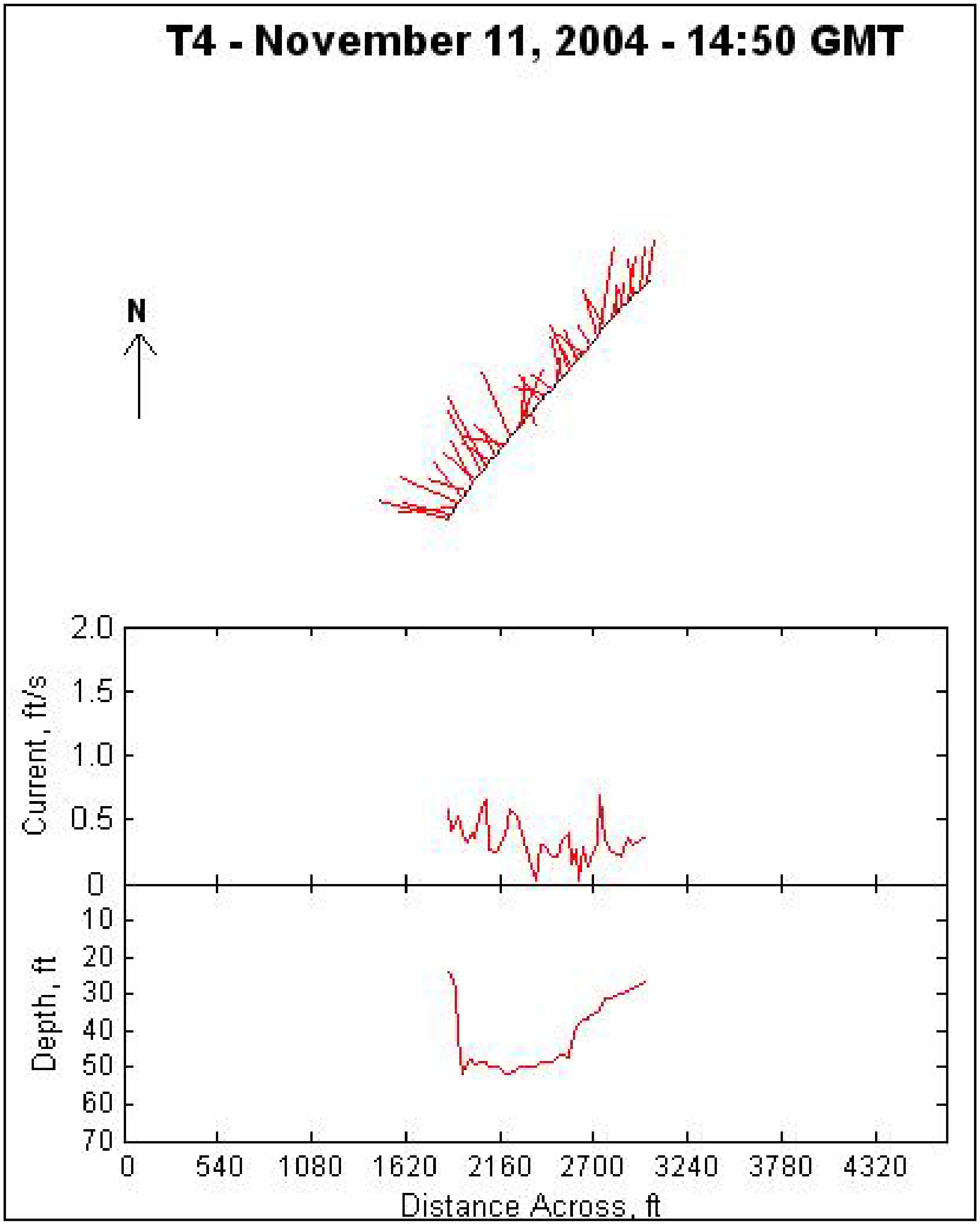


Figure D27. Transect 4 depth-averaged current plots, 11 November 2004, 1450 GMT.

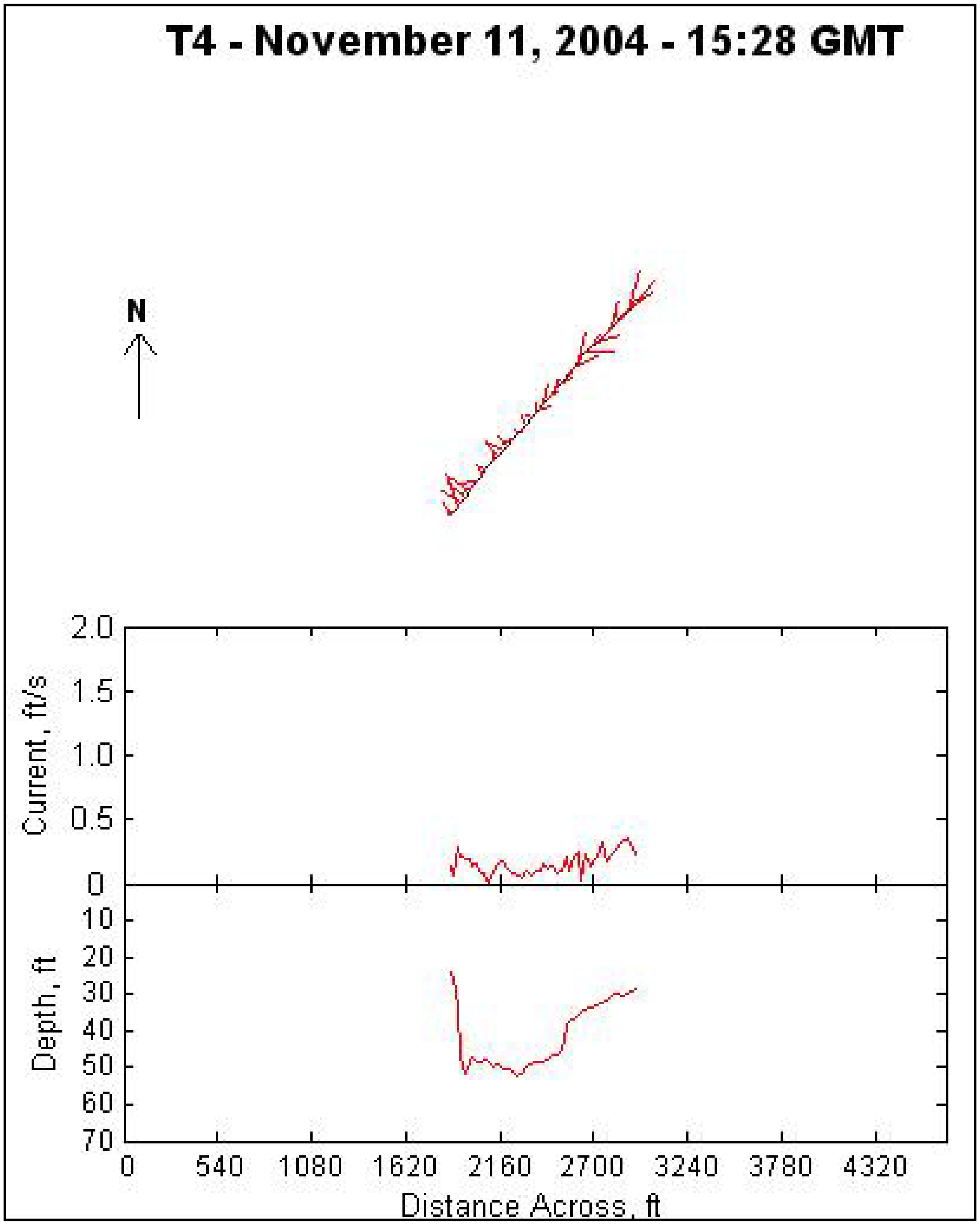


Figure D28. Transect 4 depth-averaged current plots, 11 November 2004, 1528 GMT.

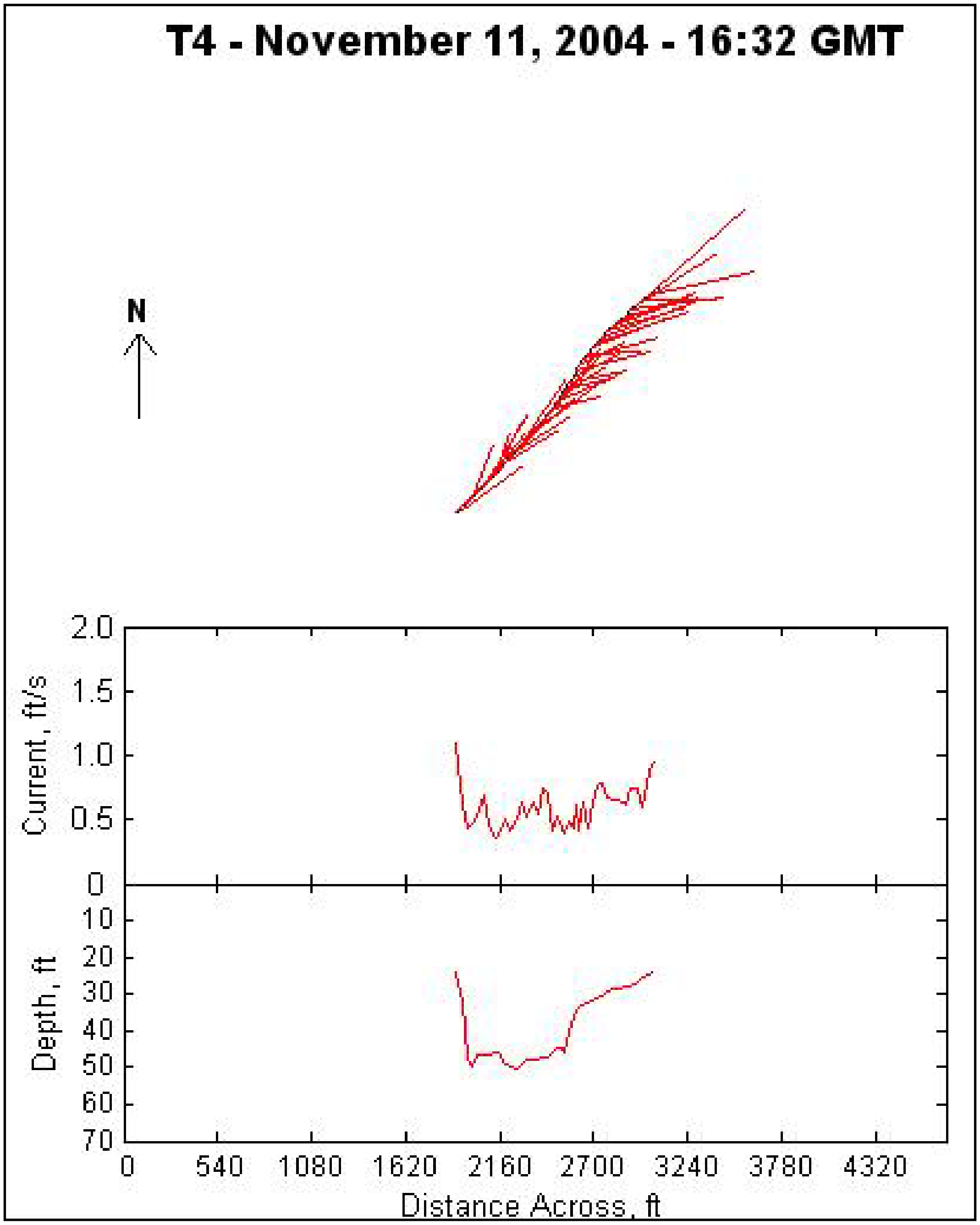


Figure D29. Transect 4 depth-averaged current plots, 11 November 2004, 1632 GMT.

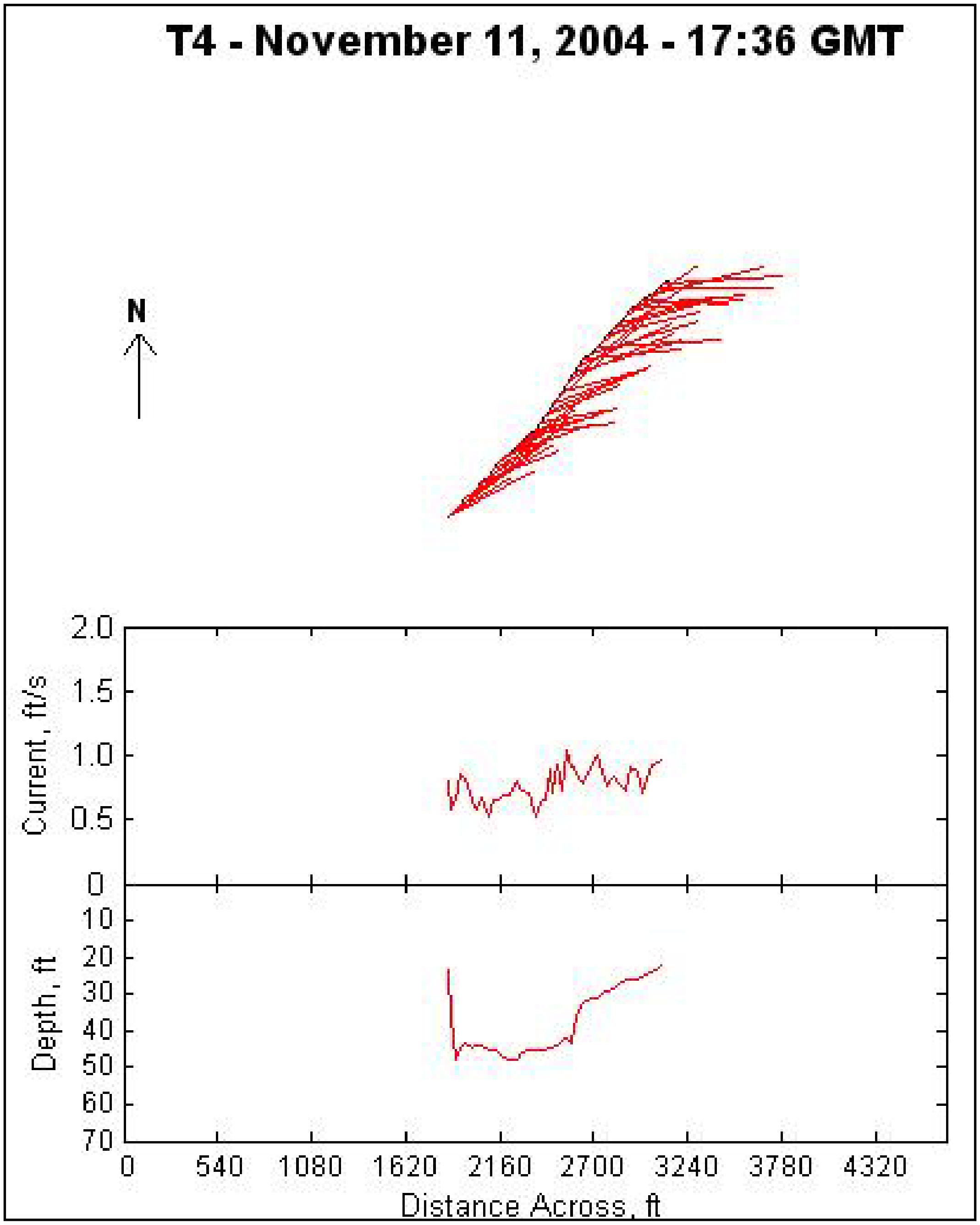


Figure D30. Transect 4 depth-averaged current plots, 11 November 2004, 1736 GMT.

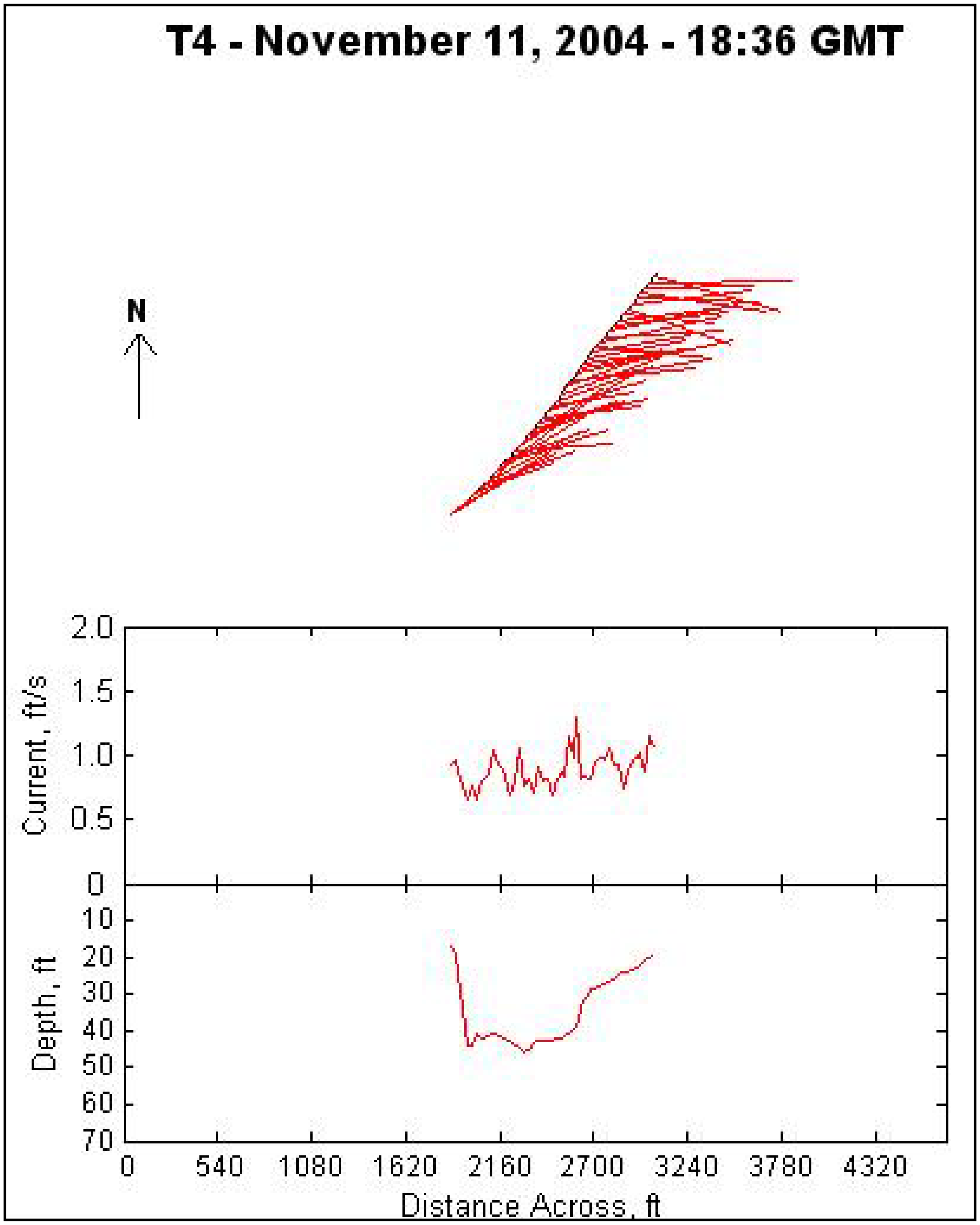


Figure D31. Transect 4 depth-averaged current plots, 11 November 2004, 1836 GMT.

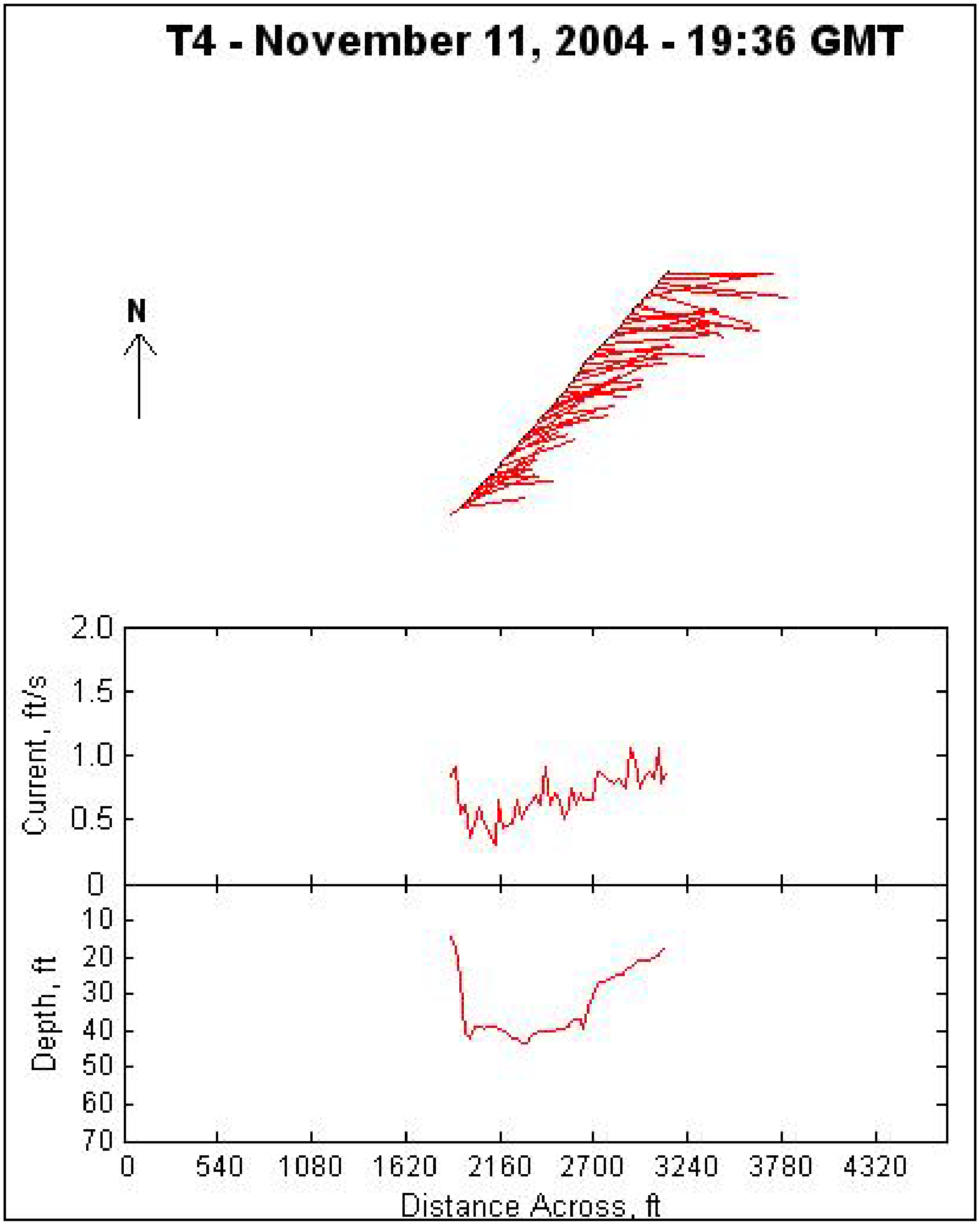


Figure D32. Transect 4 depth-averaged current plots, 11 November 2004, 1936 GMT.

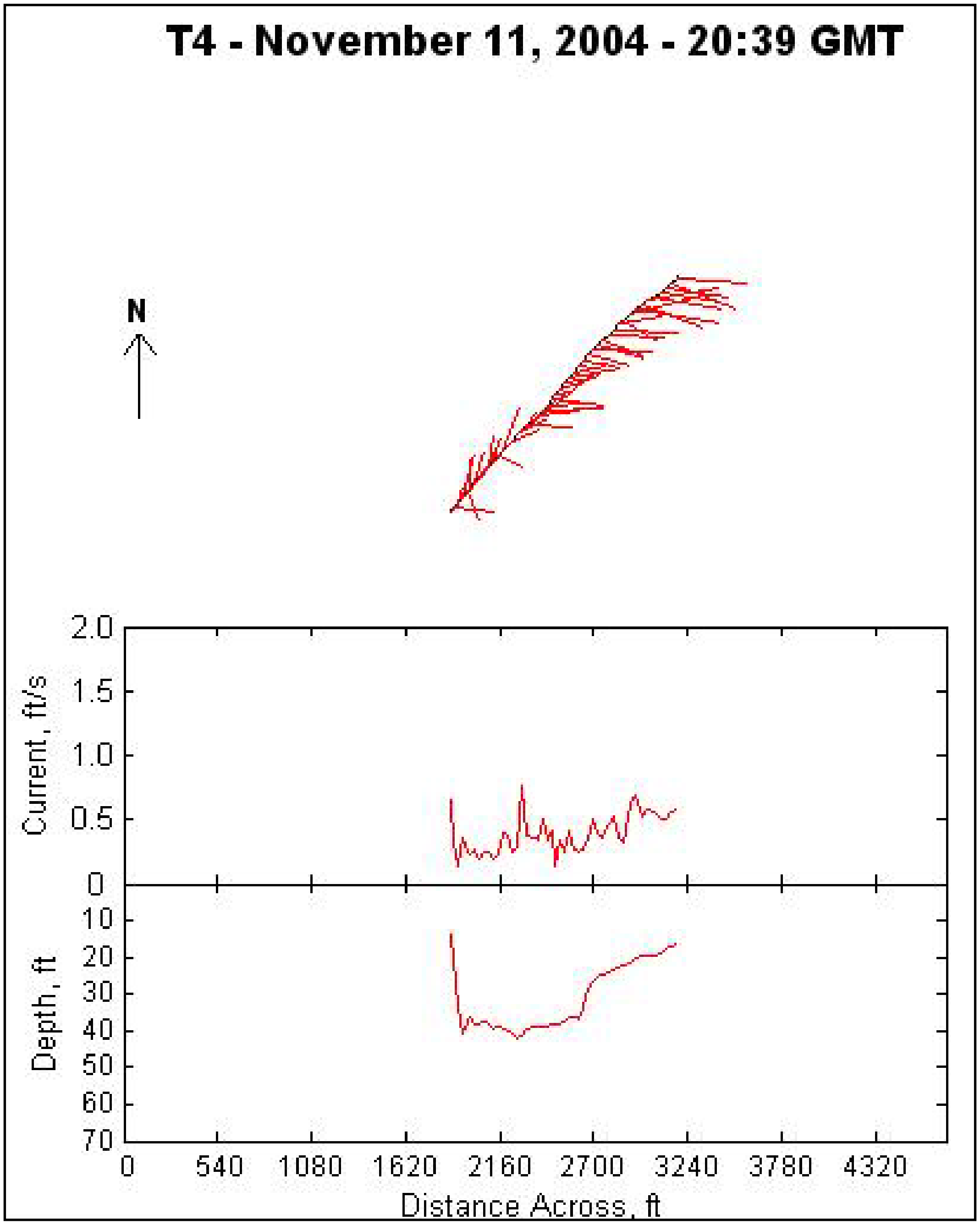


Figure D33. Transect 4 depth-averaged current plots, 11 November 2004, 2039 GMT.

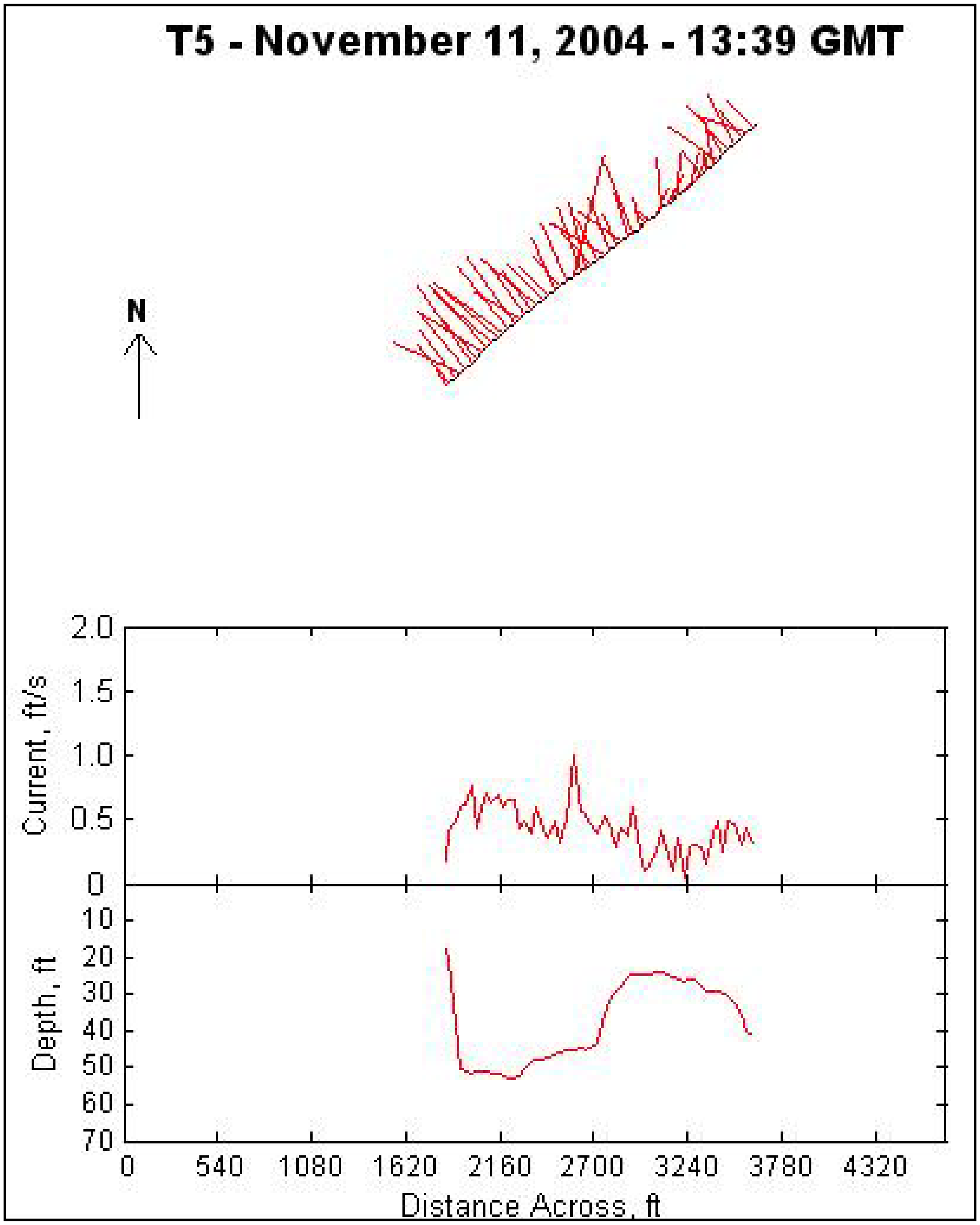


Figure D34. Transect 5 depth-averaged current plots, 11 November 2004, 1339 GMT.

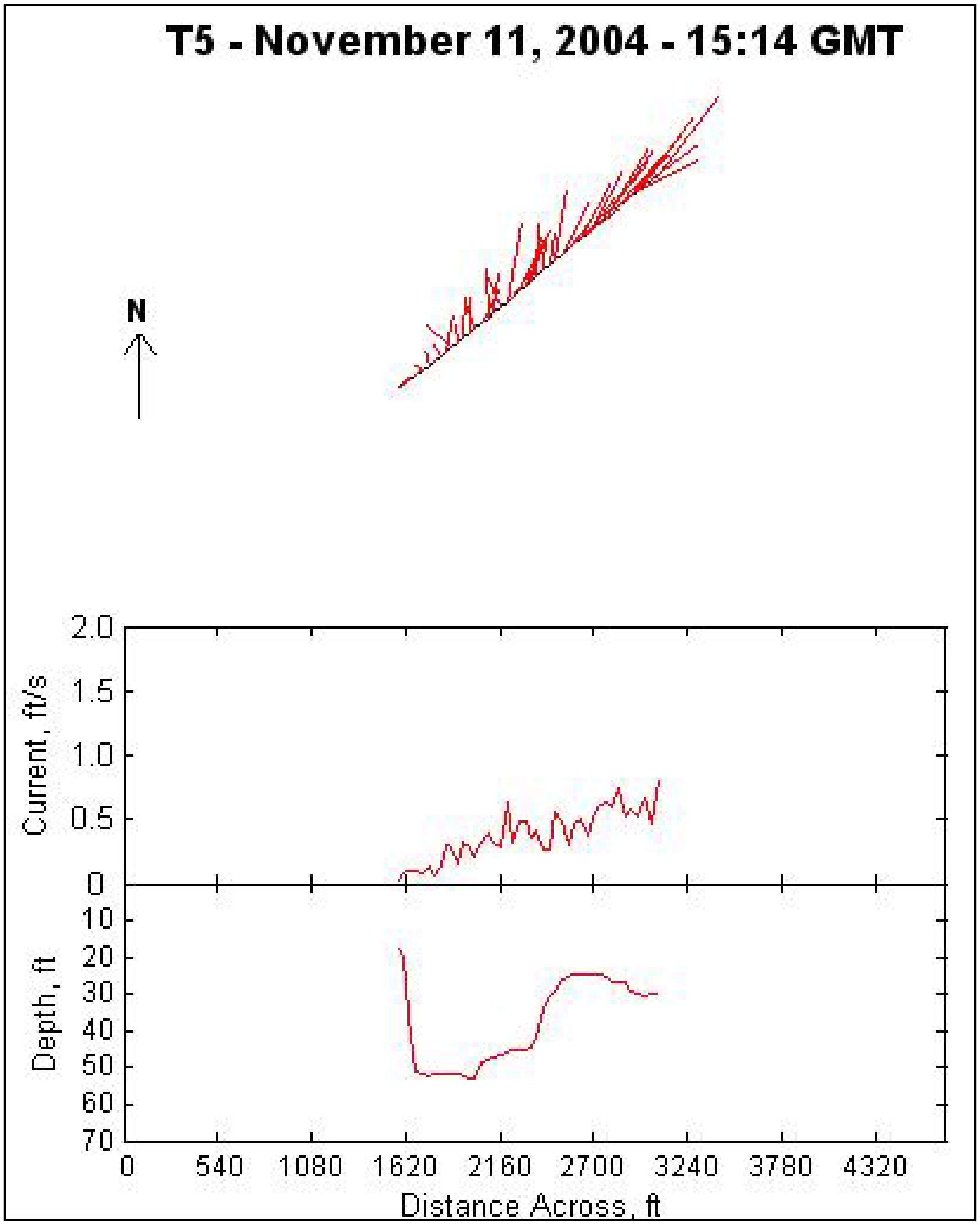


Figure D35. Transect 5 depth-averaged current plots, 11 November 2004, 1514 GMT.

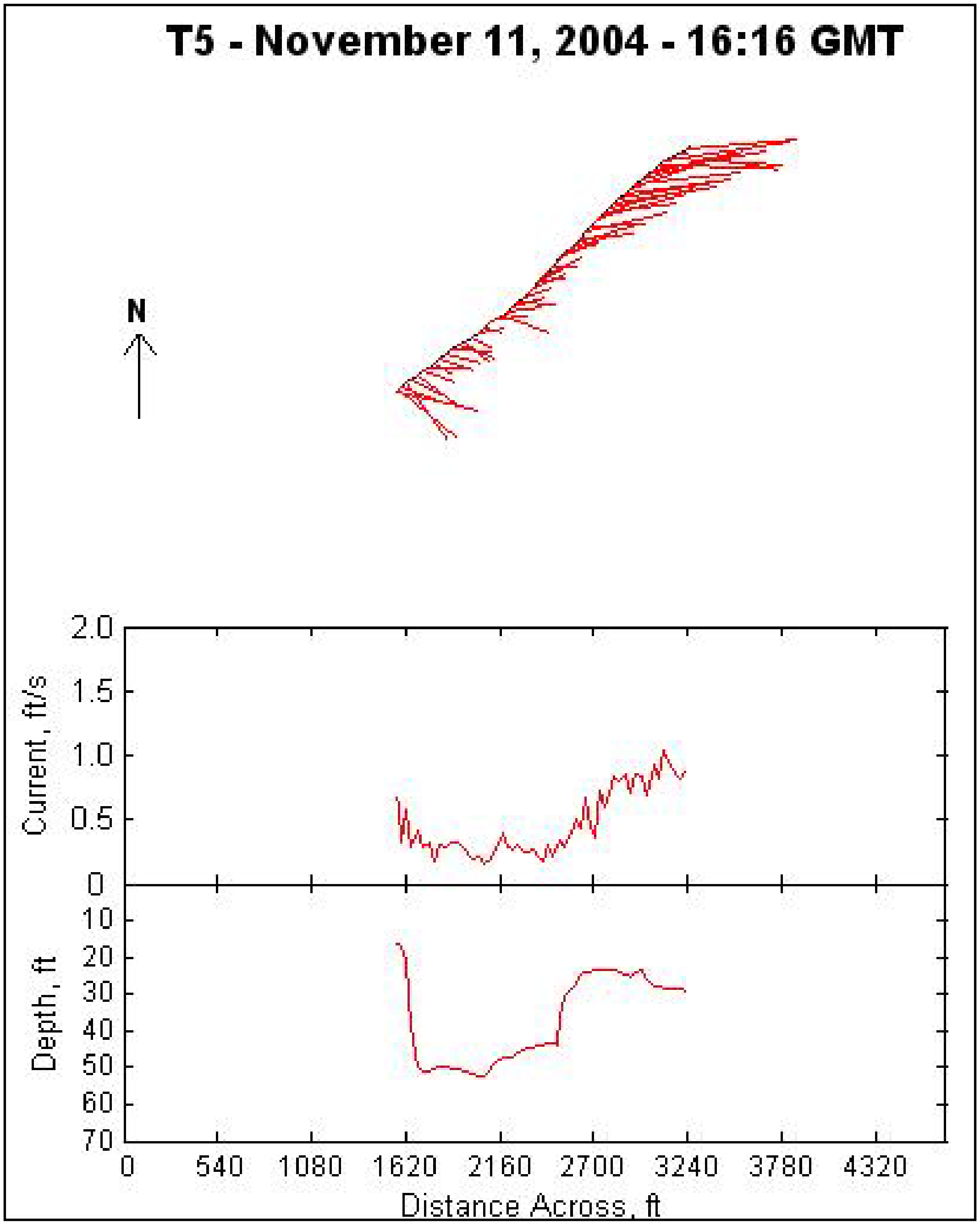


Figure D36. Transect 5 depth-averaged current plots, 11 November 2004, 1616 GMT.

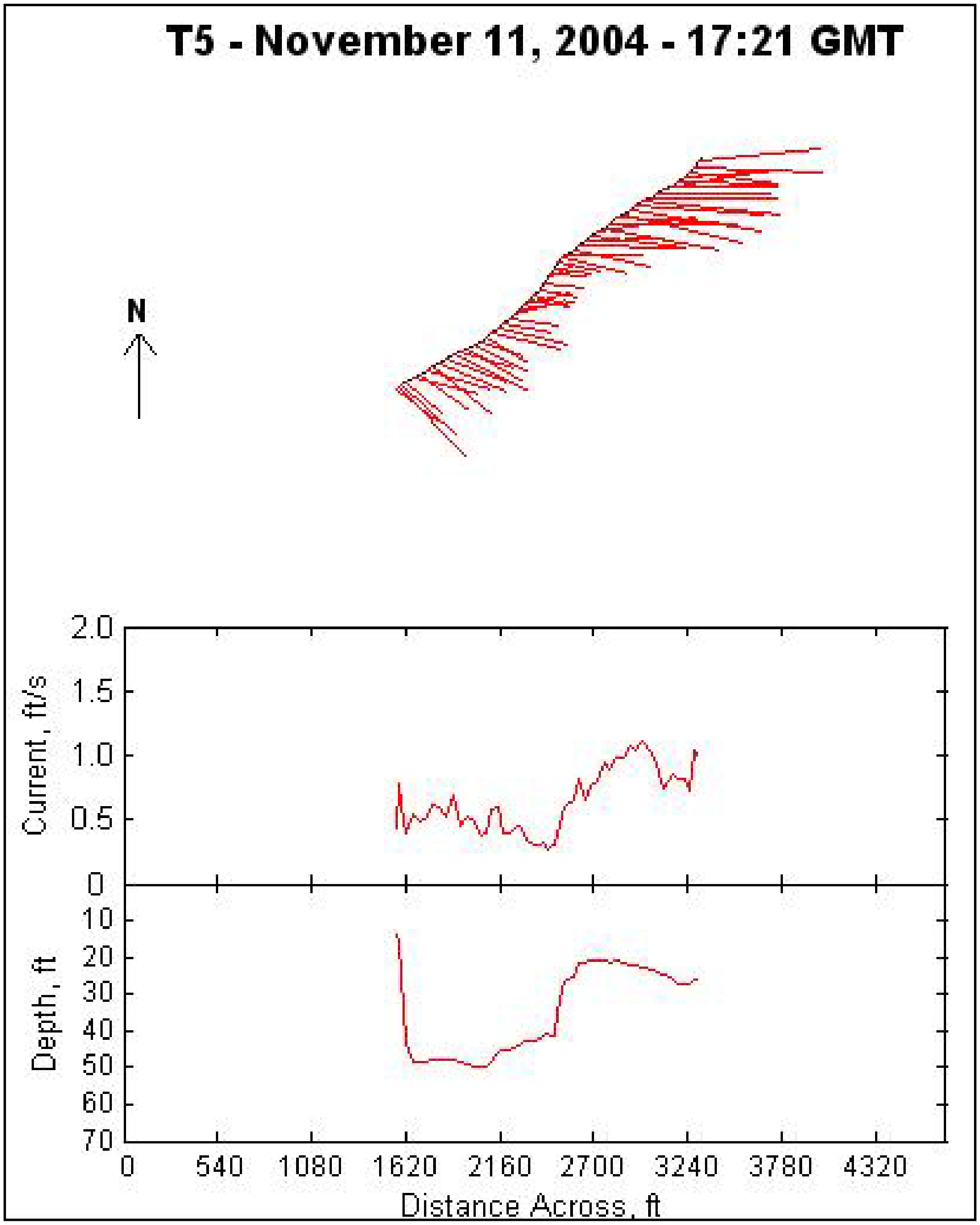


Figure D37. Transect 5 depth-averaged current plots, 11 November 2004, 1721 GMT.

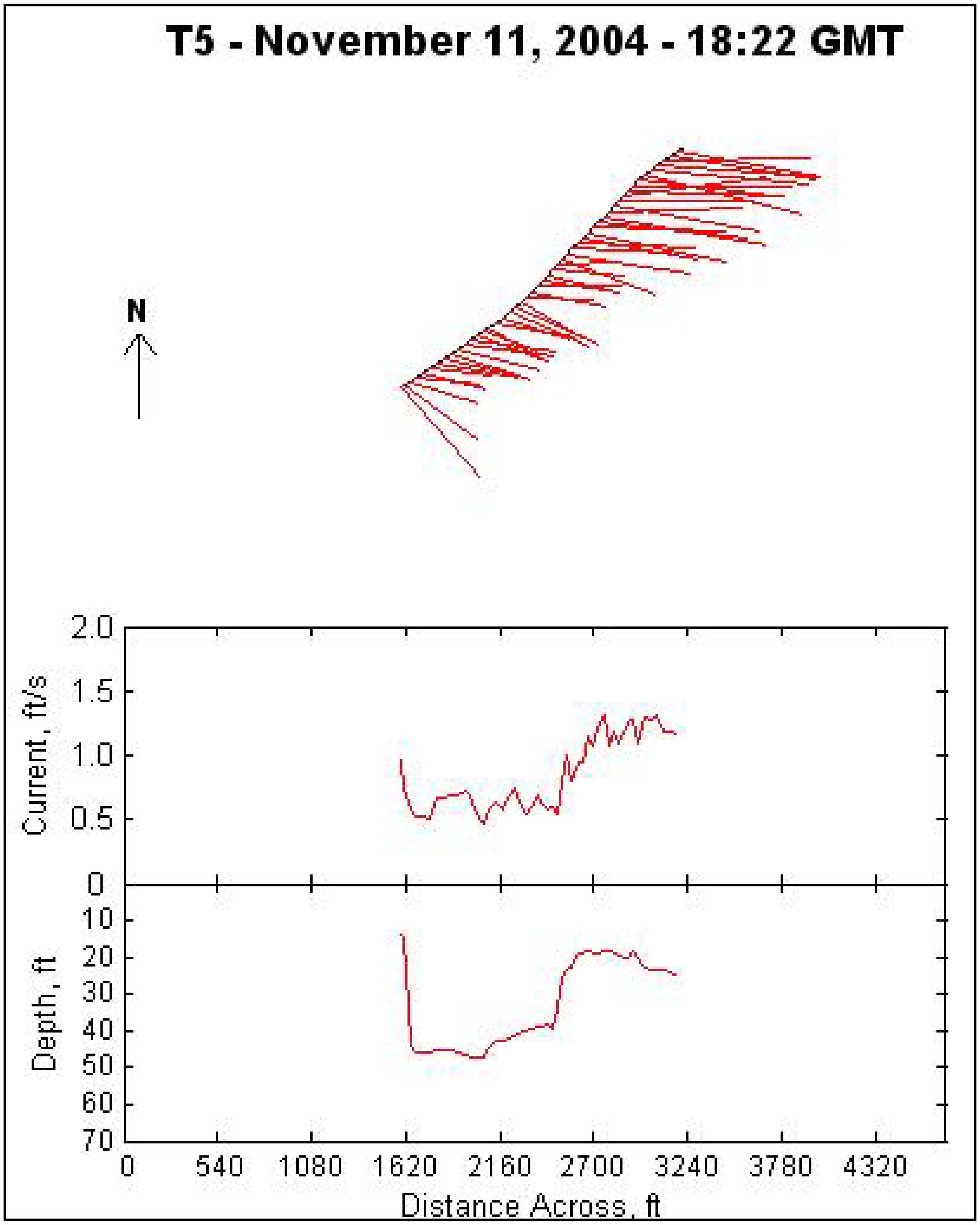


Figure D38. Transect 5 depth-averaged current plots, 11 November 2004, 1822 GMT.

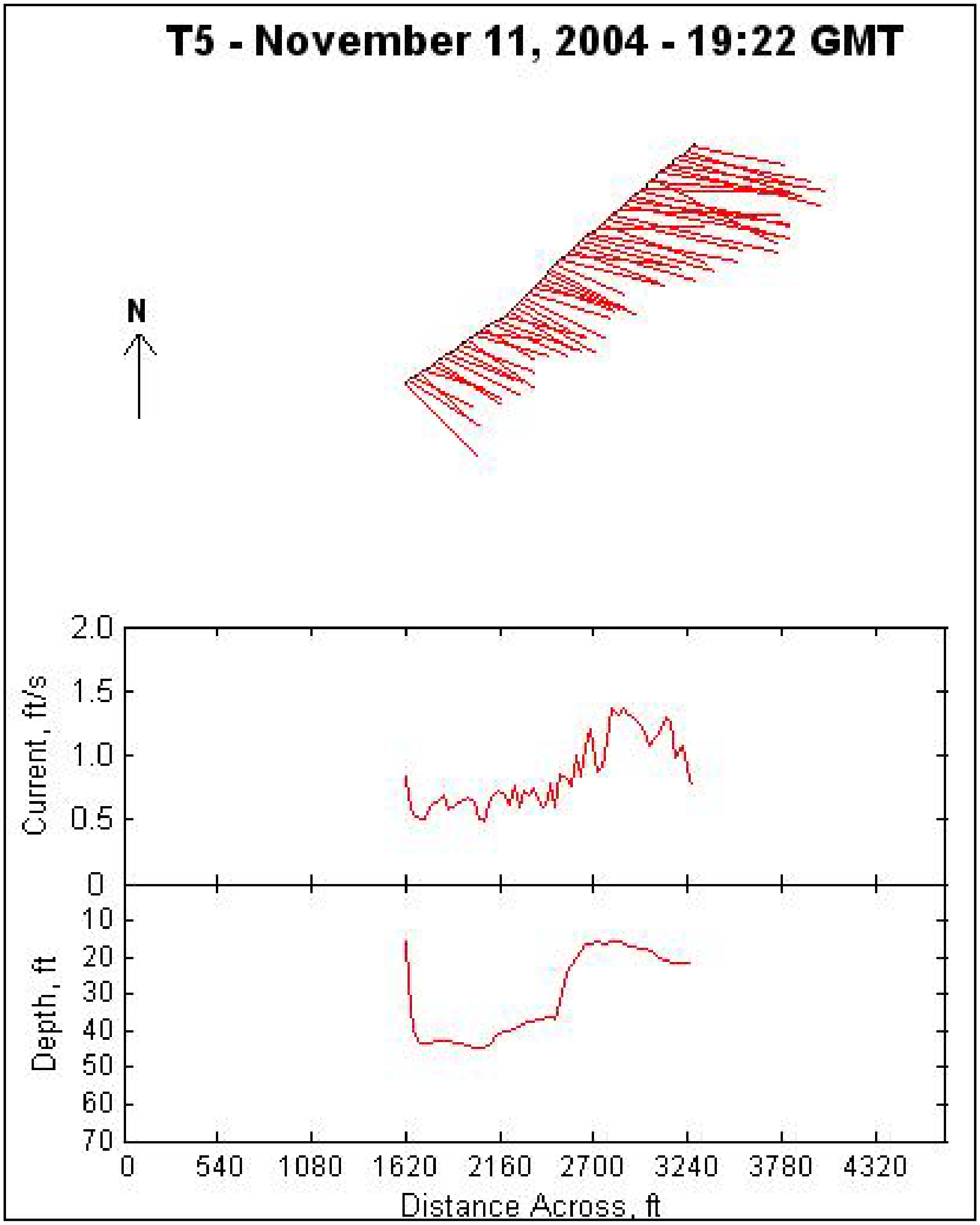


Figure D39. Transect 5 depth-averaged current plots, 11 November 2004, 1922 GMT.

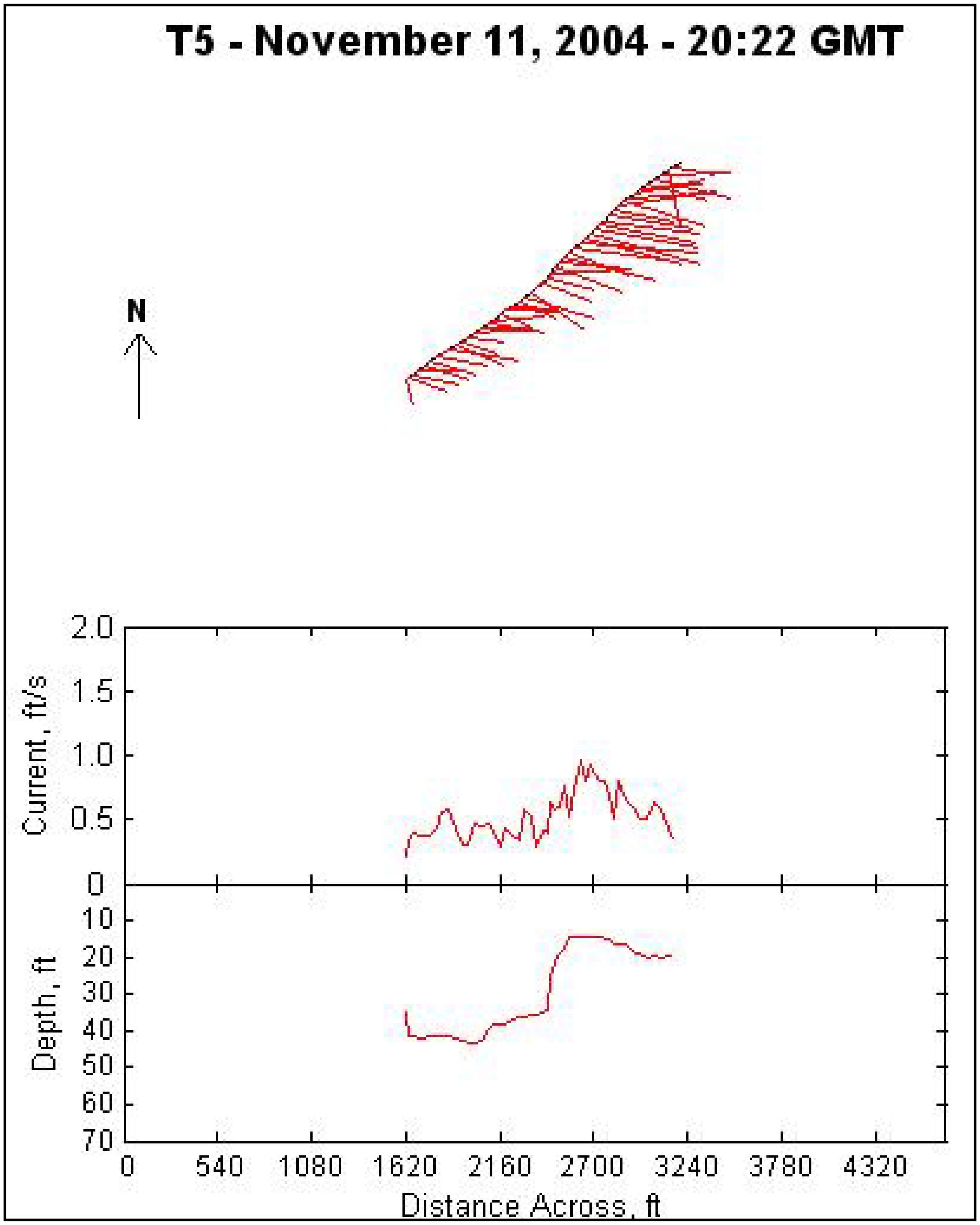


Figure D40. Transect 5 depth-averaged current plots, 11 November 2004, 2022 GMT.

Appendix E: Transect Current Surveys, Current Velocity Cross Sections

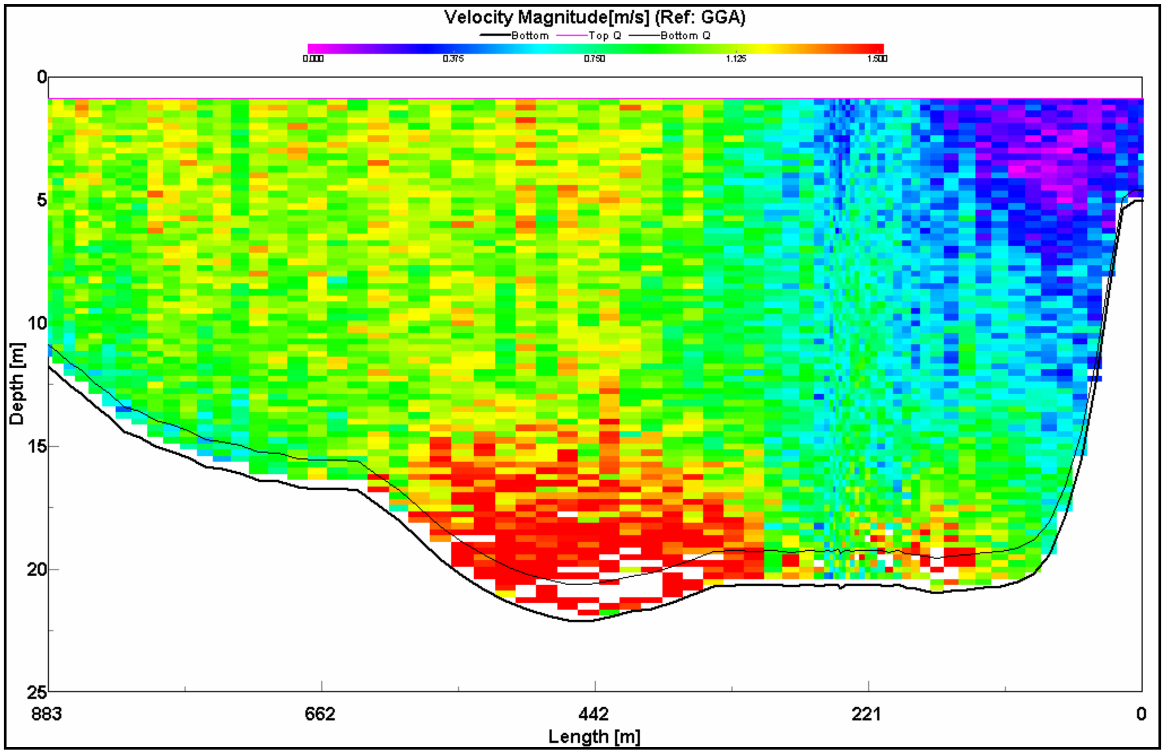


Figure E1. Transect 1 current velocity cross sections, 8 February 2005, 1341 GMT.

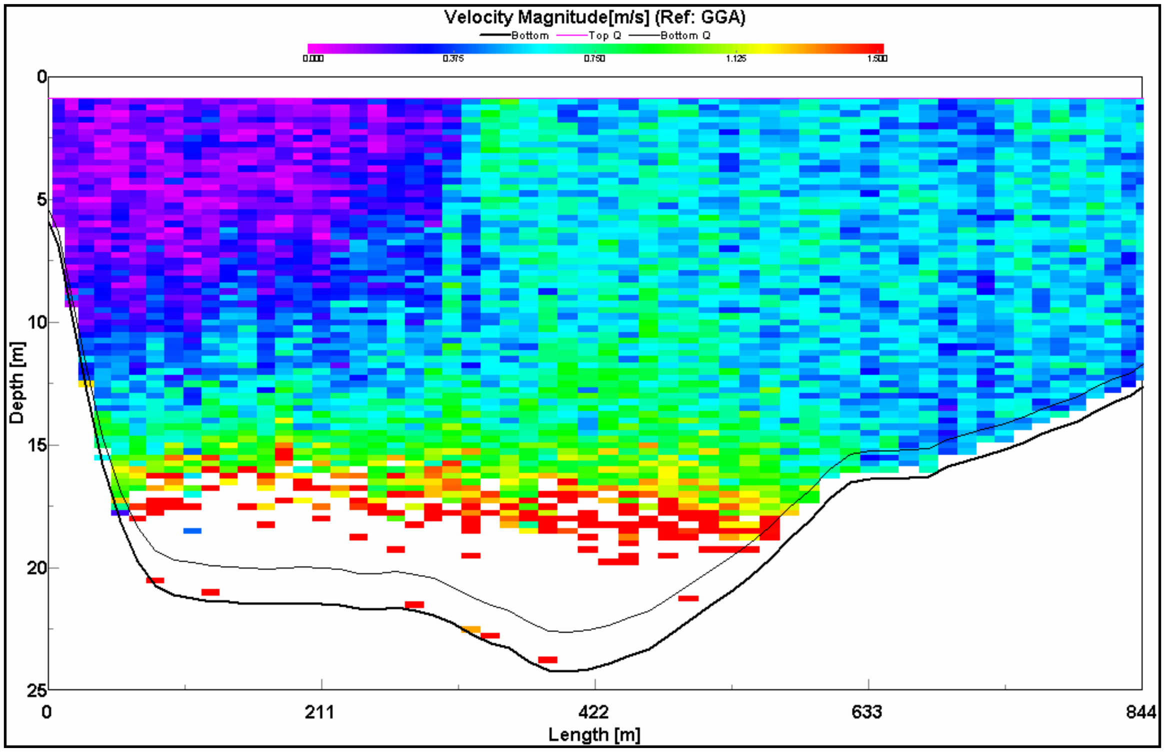


Figure E2. Transect 1 current velocity cross sections, 8 February 2005, 1450 GMT.

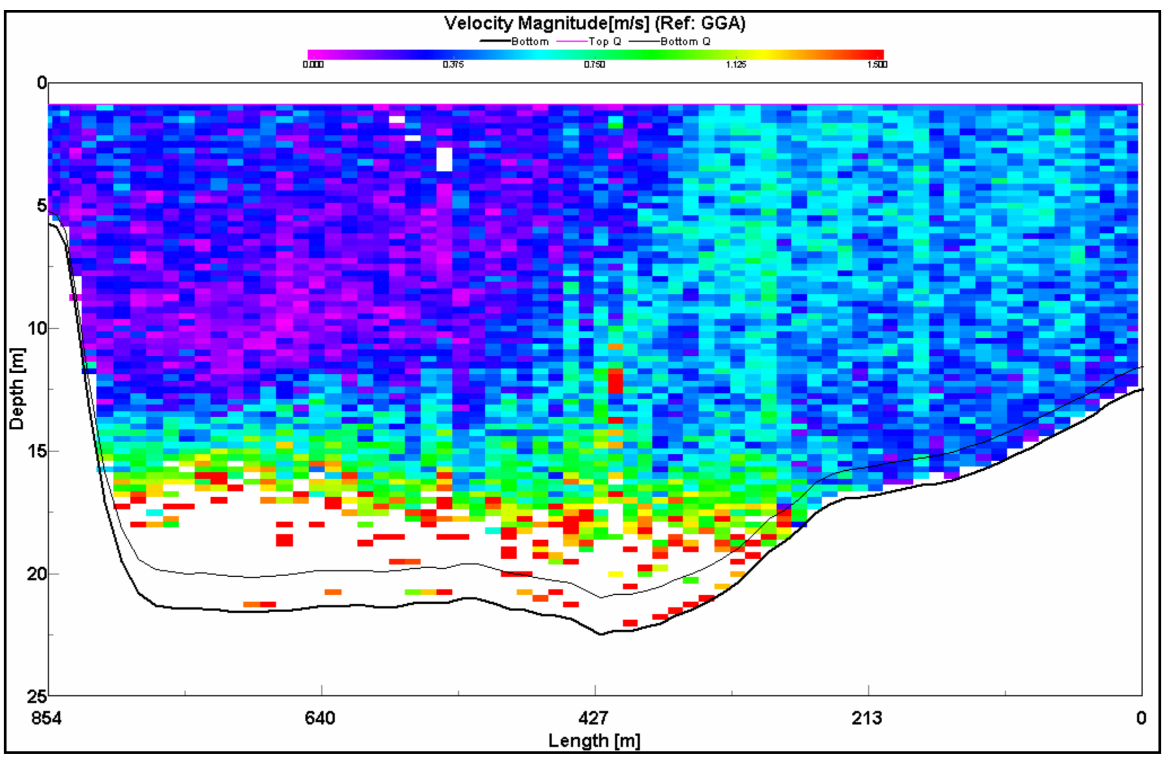


Figure E3. Transect 1 current velocity cross sections, 8 February 2005, 1459 GMT.

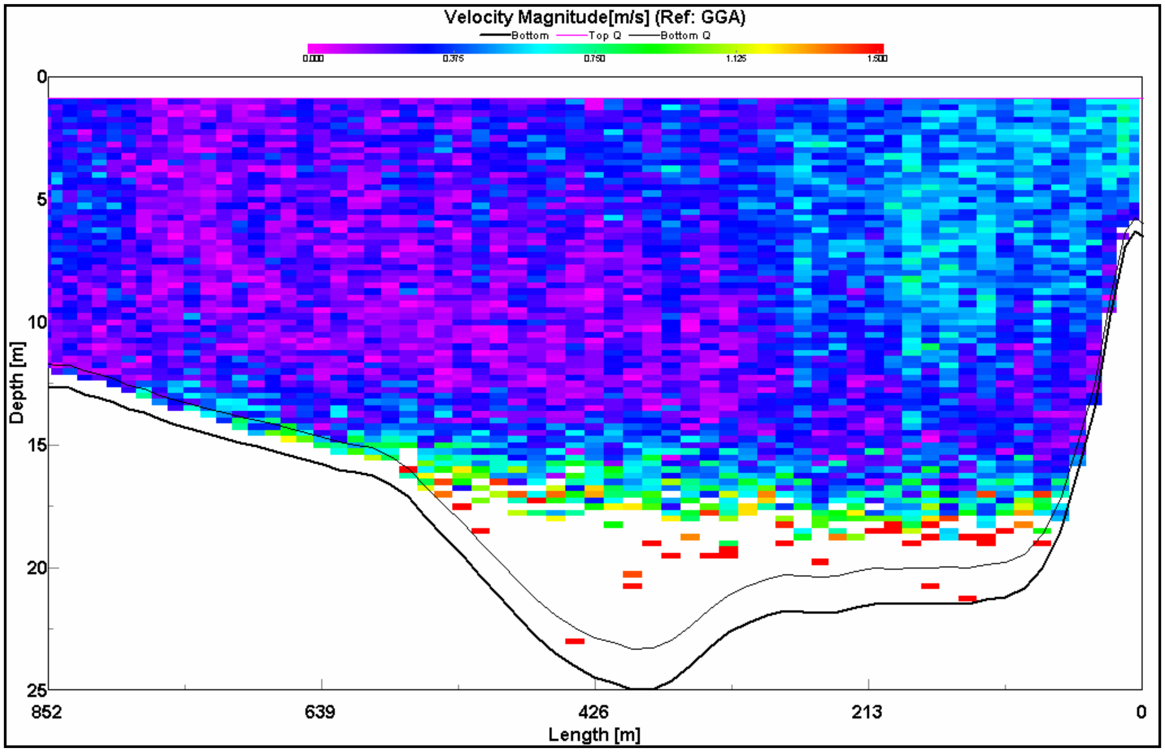


Figure E4. Transect 1 current velocity cross sections, 8 February 2005, 1604 GMT.

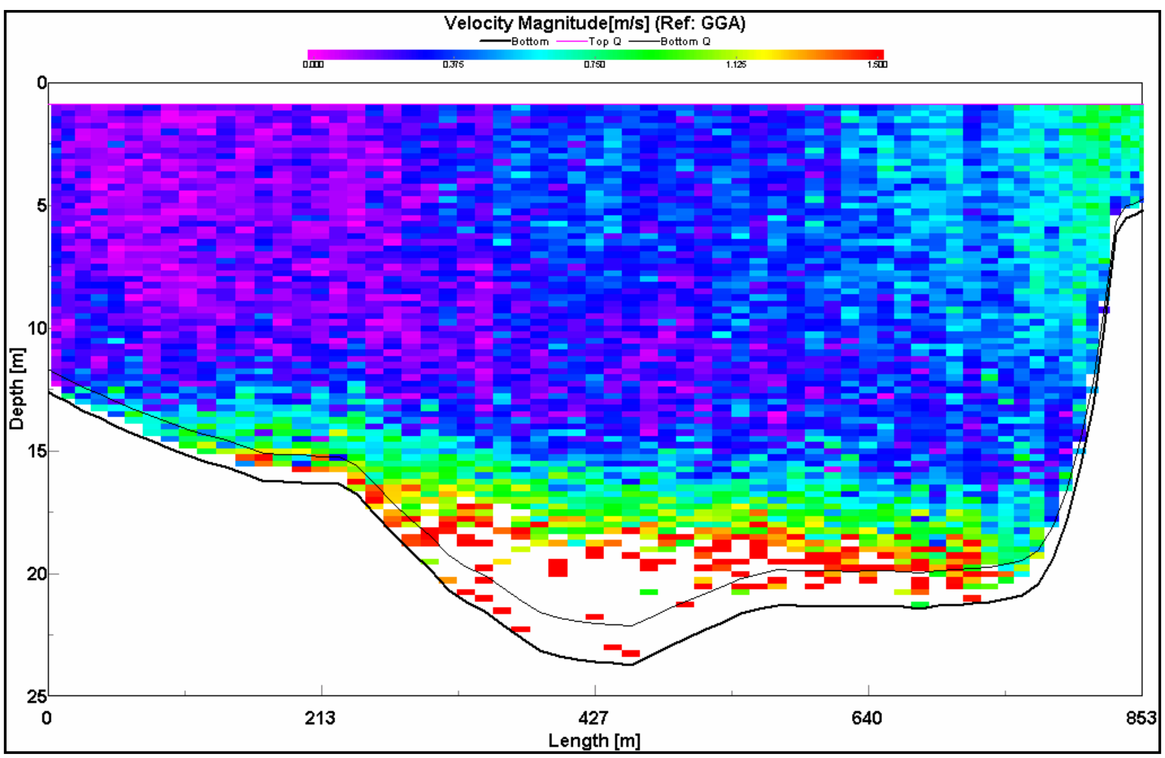


Figure E5. Transect 1 current velocity cross sections, 8 February 2005, 1614 GMT.

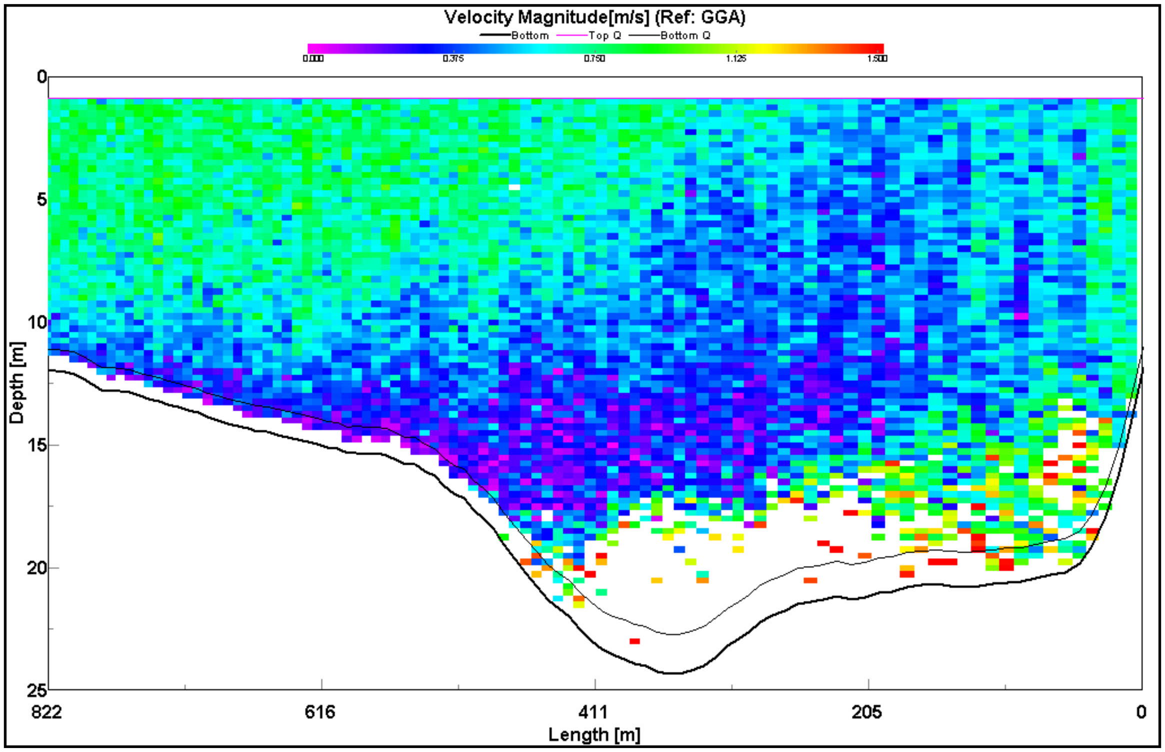


Figure E6. Transect 1 current velocity cross sections, 8 February 2005, 1723 GMT.

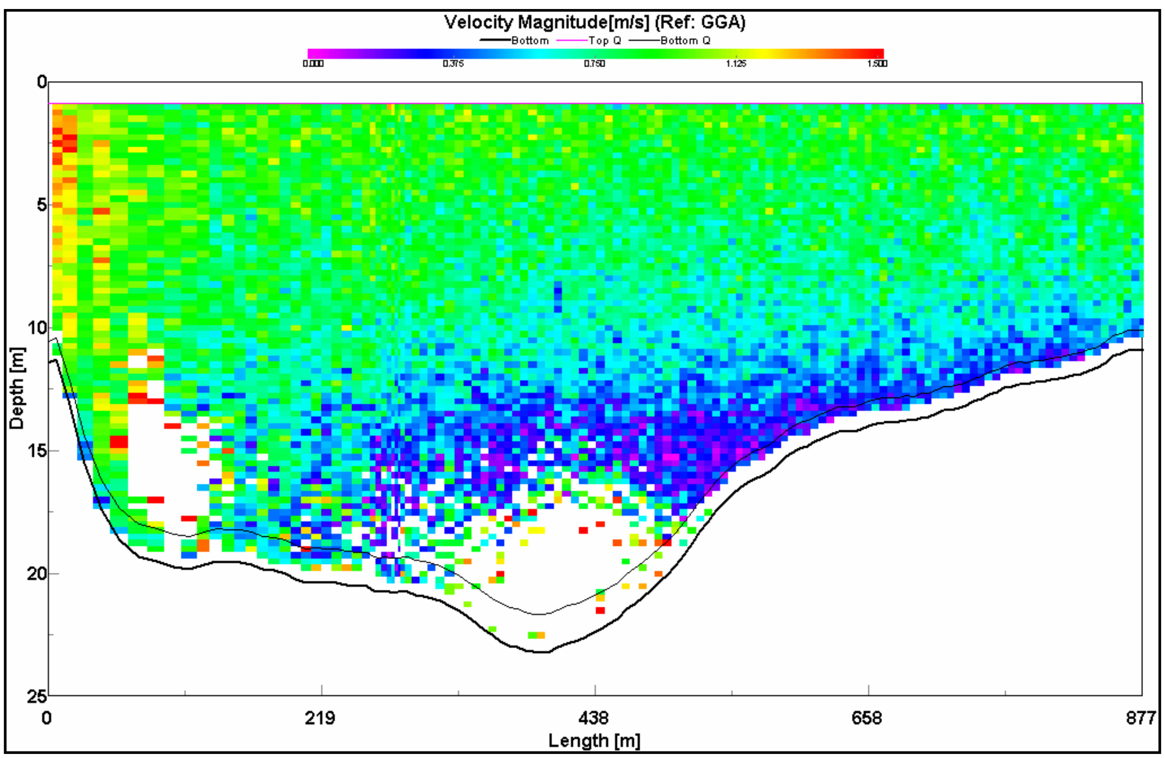


Figure E7. Transect 1 current velocity cross sections, 8 February 2005, 1840 GMT.

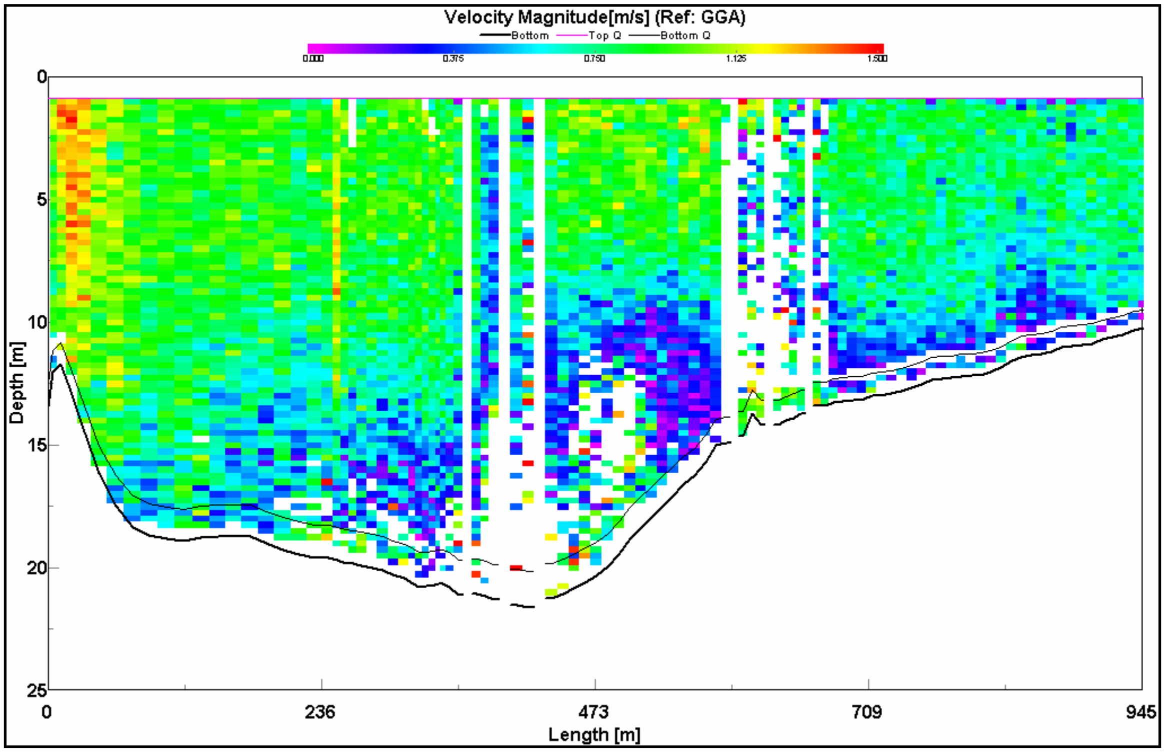


Figure E8. Transect 1 current velocity cross sections, 8 February 2005, 2048 GMT.

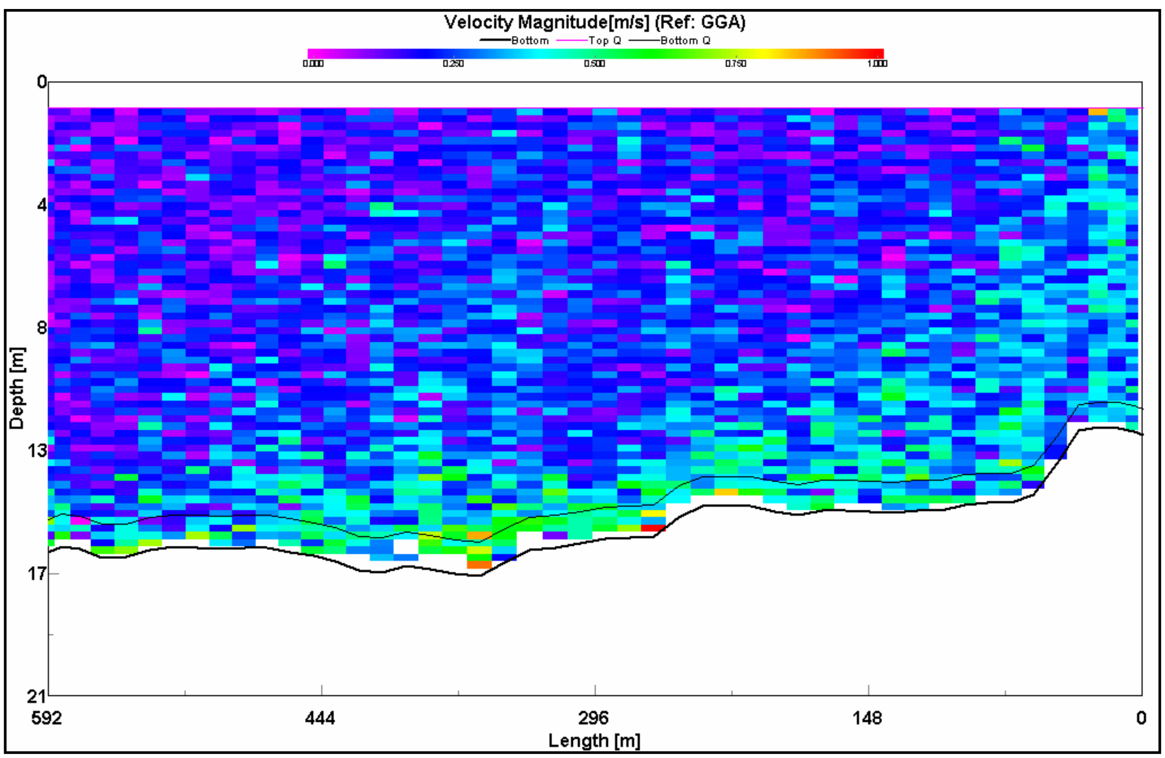


Figure E9. Transect 2 current velocity cross sections, 8 February 2005, 1415 GMT.

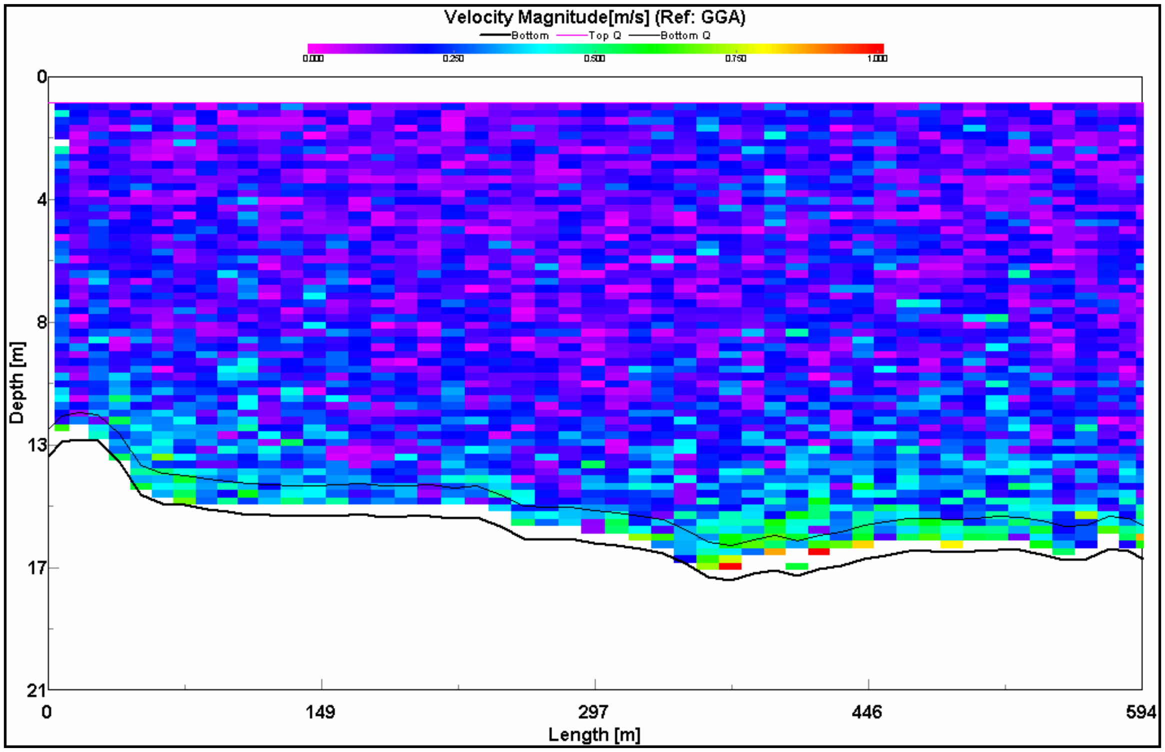


Figure E10. Transect 2 current velocity cross sections, 8 February 2005, 1532 GMT.

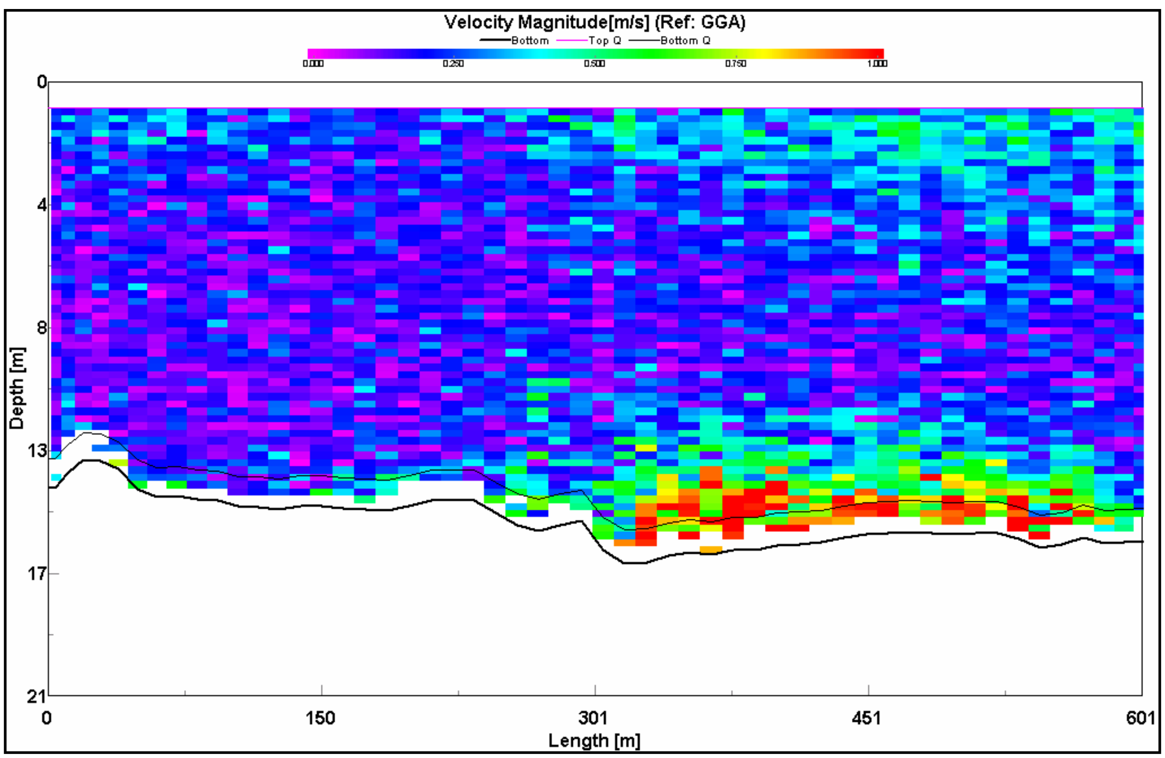


Figure E11. Transect 2 current velocity cross sections, 8 February 2005, 1649 GMT.

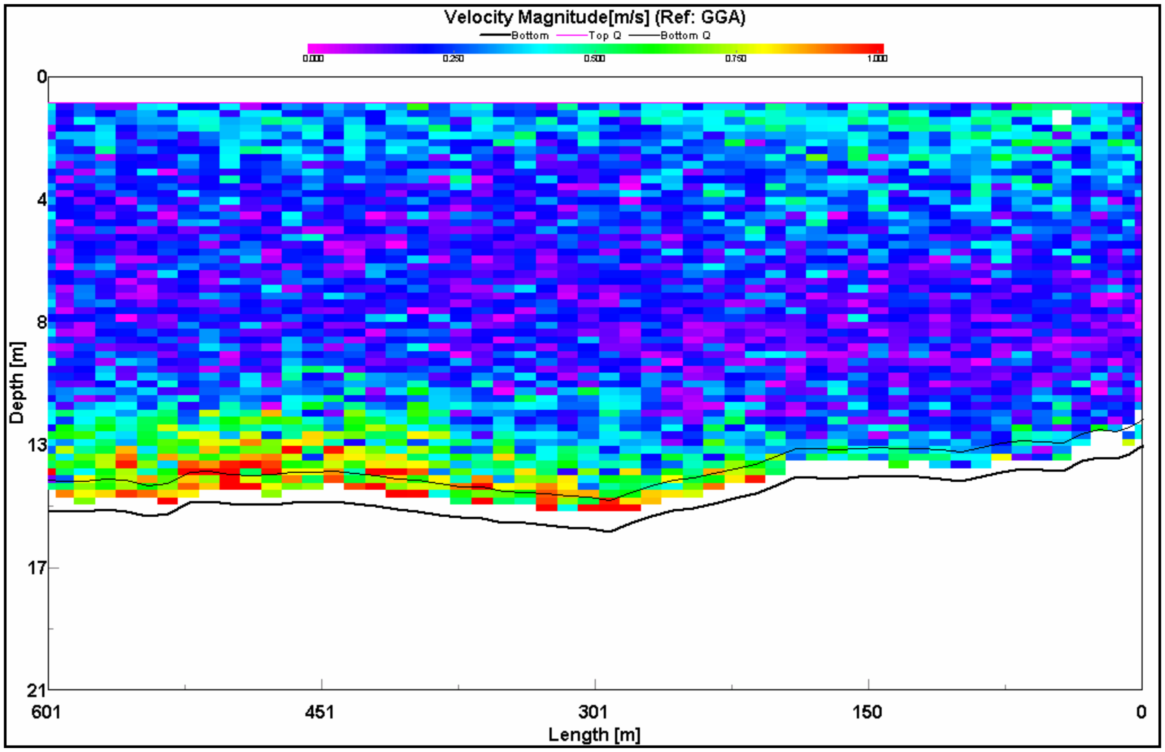


Figure E12. Transect 2 current velocity cross sections, 8 February 2005, 1803 GMT.

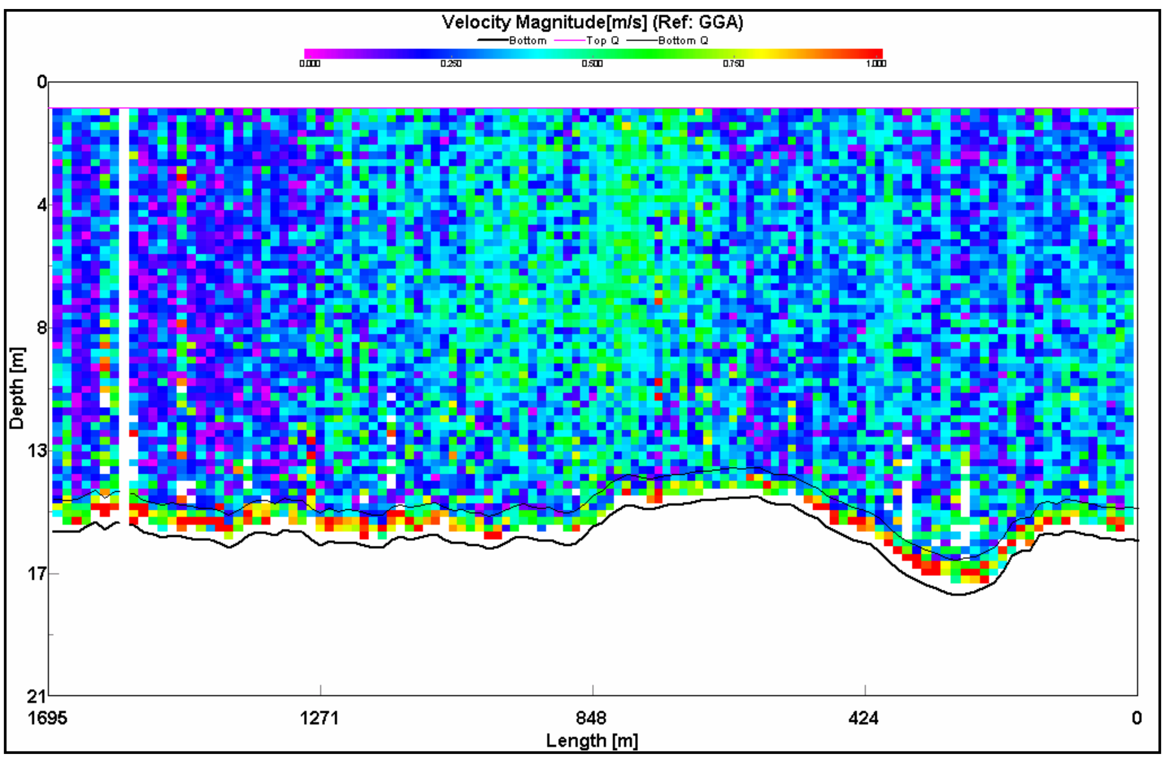


Figure E13. Transect 3 current velocity cross sections, 11 November 2004, 1424 GMT.

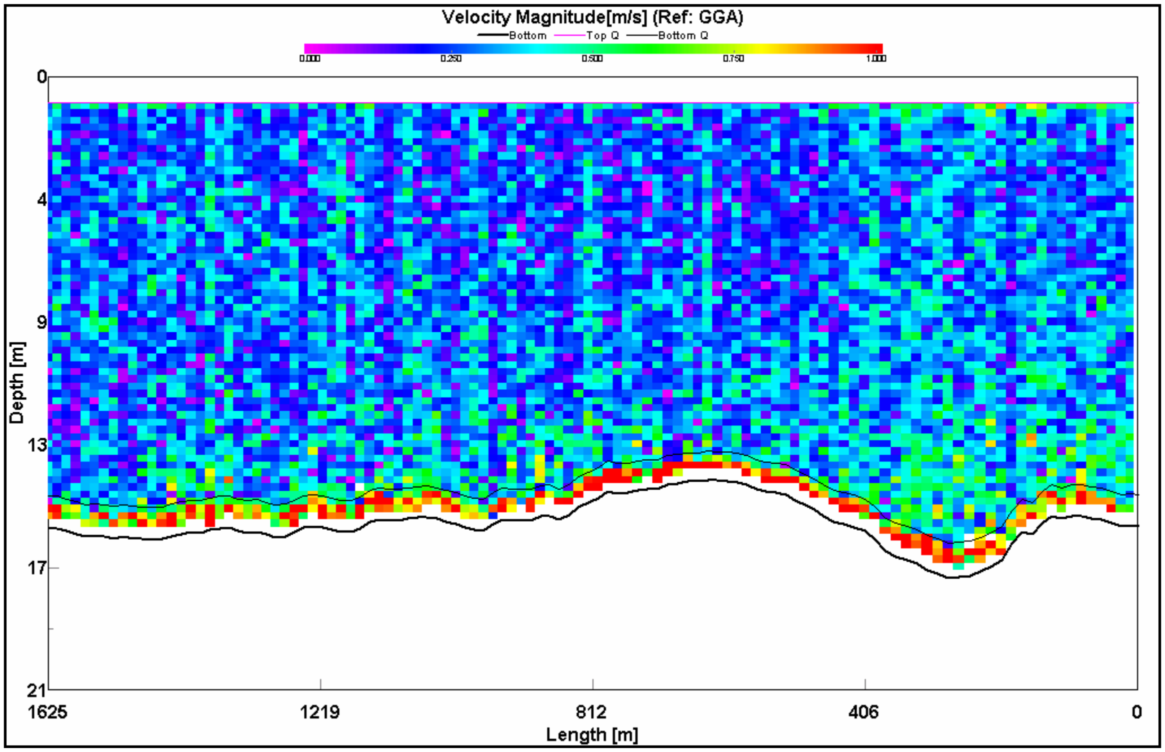


Figure E14. Transect 3 current velocity cross sections, 11 November 2004, 1545 GMT.

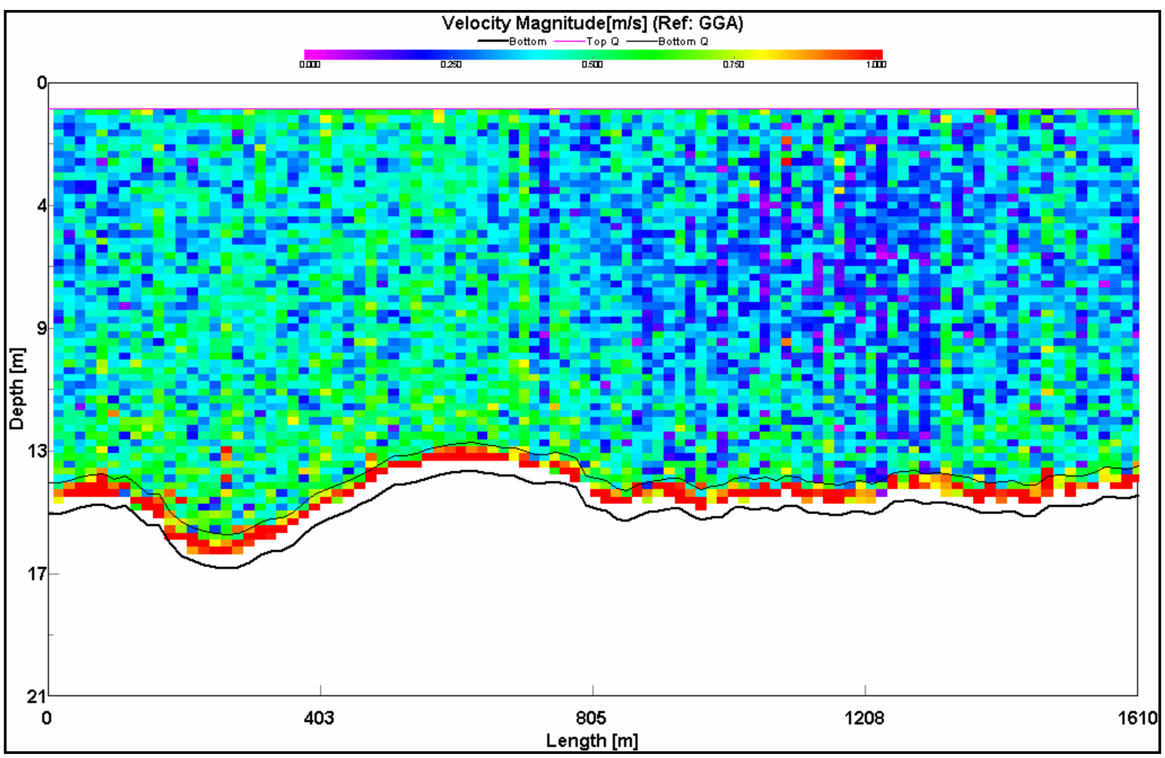


Figure E15. Transect 3 current velocity cross sections, 11 November 2004, 1649 GMT.

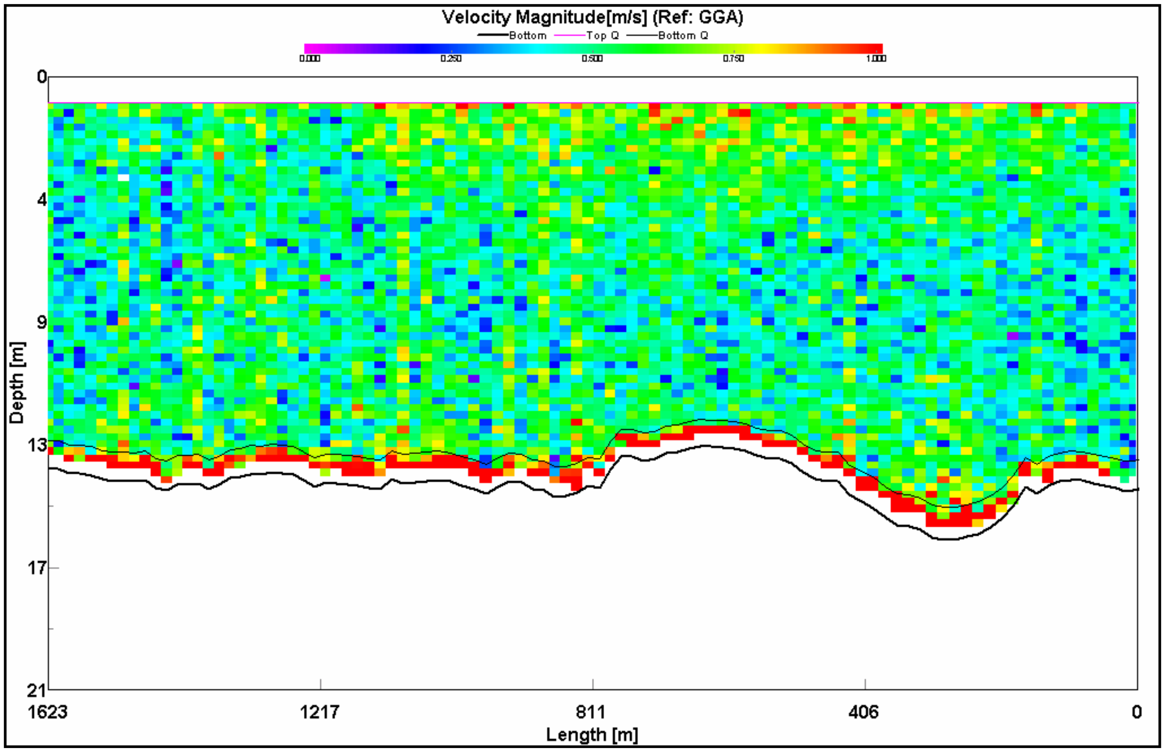


Figure E16. Transect 3 current velocity cross sections, 11 November 2004, 1748 GMT.

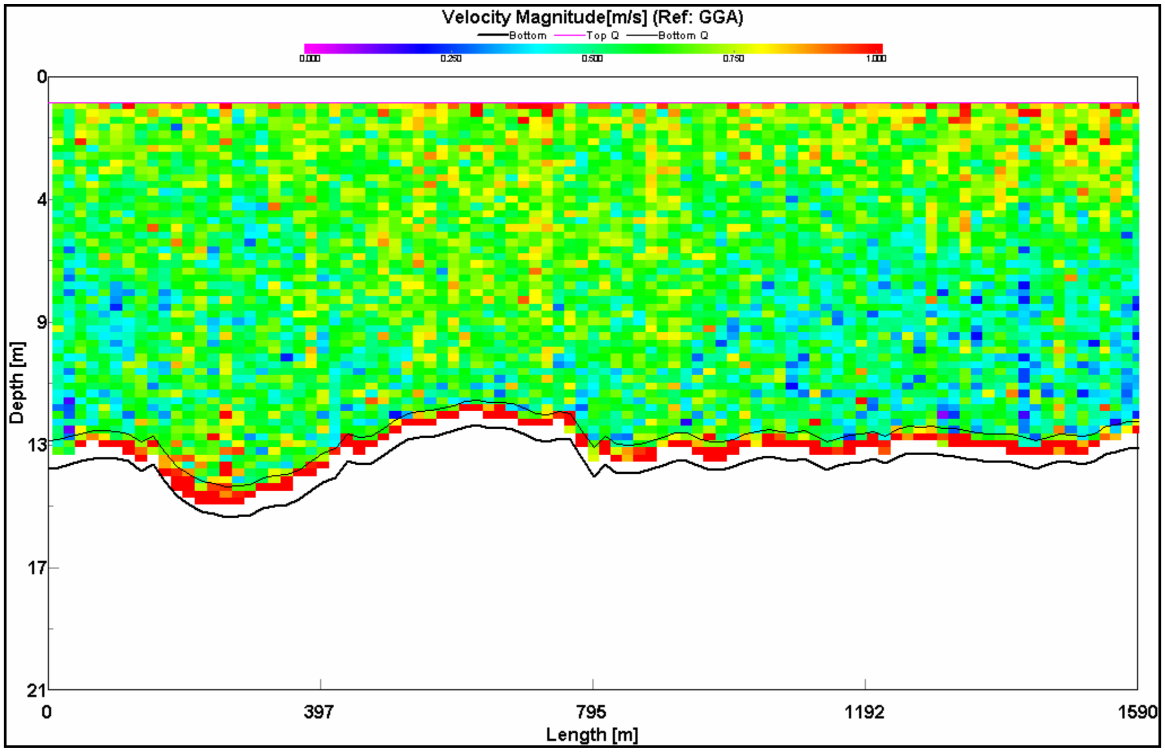


Figure E17. Transect 3 current velocity cross sections, 11 November 2004, 1851 GMT.

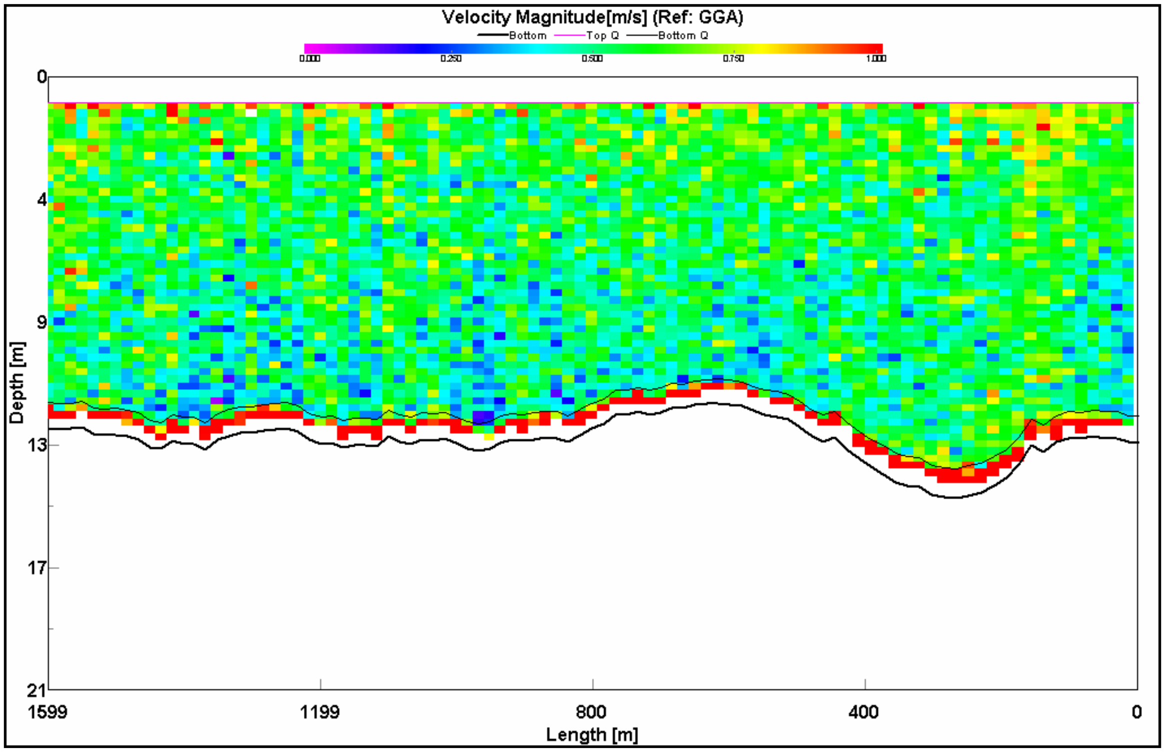


Figure E18. Transect 3 current velocity cross sections, 11 November 2004, 1951 GMT.

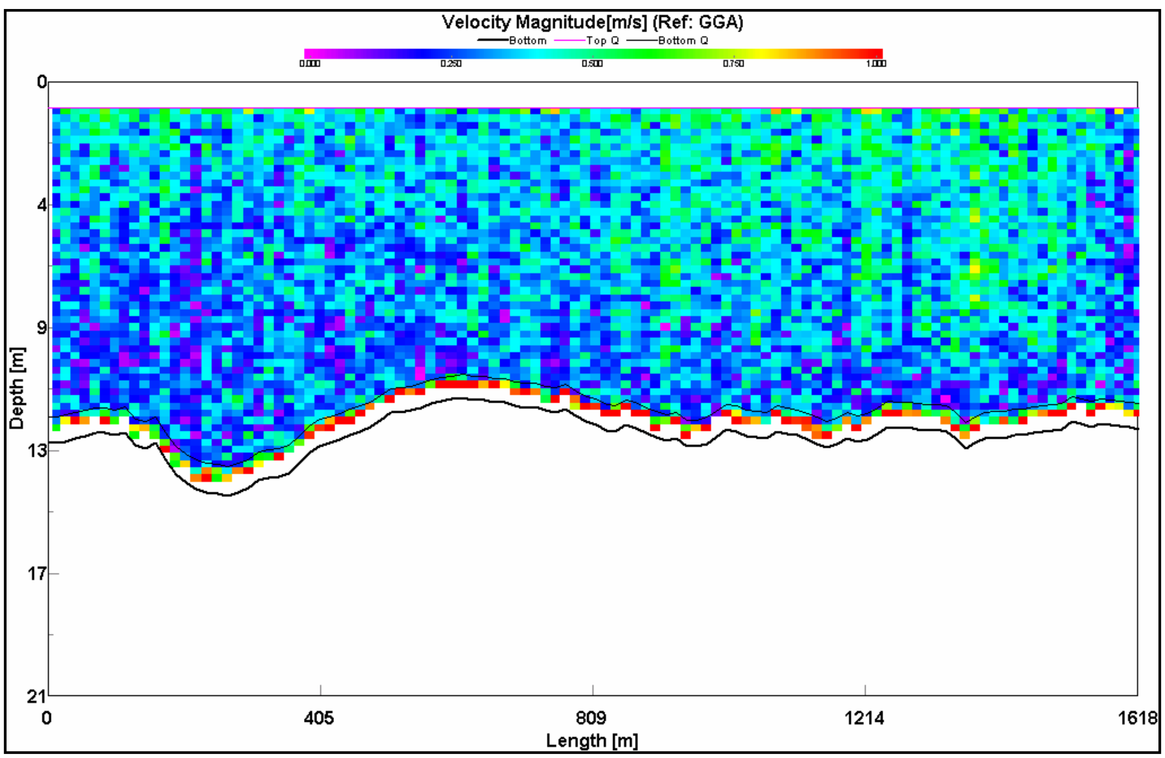


Figure E19. Transect 3 current velocity cross sections, 11 November 2004, 2055 GMT.

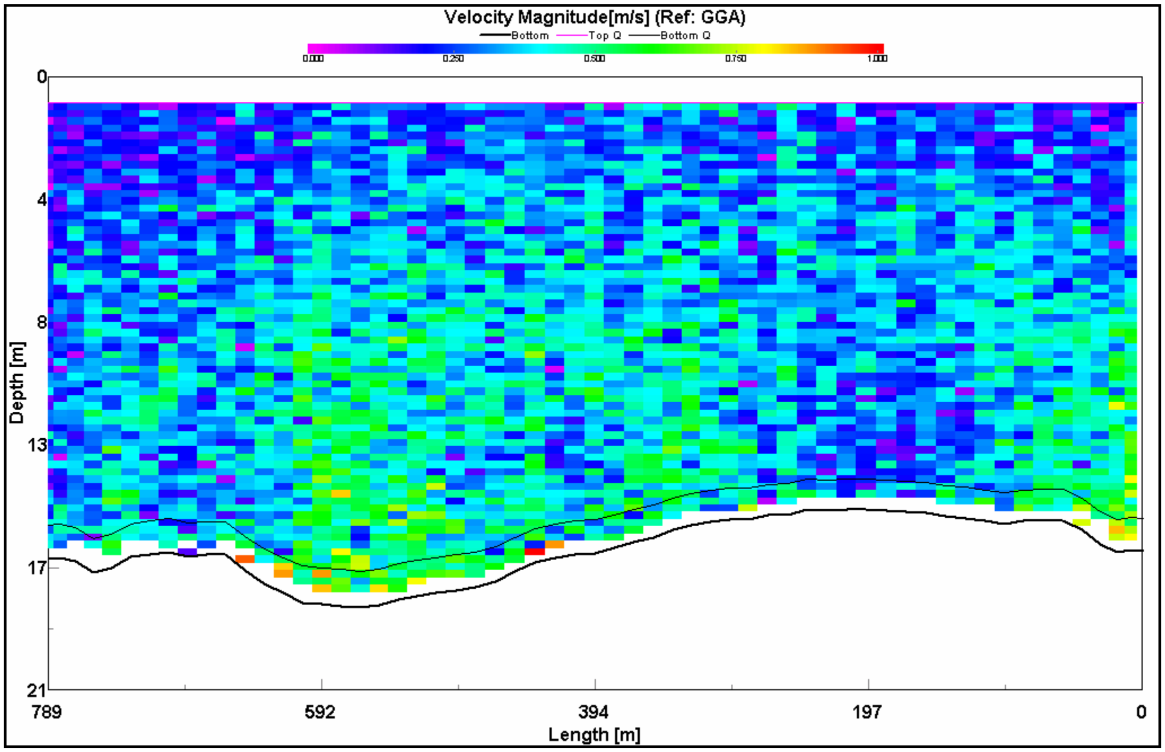


Figure E20. Transect 3 current velocity cross sections, 8 February 2005, 1520 GMT.

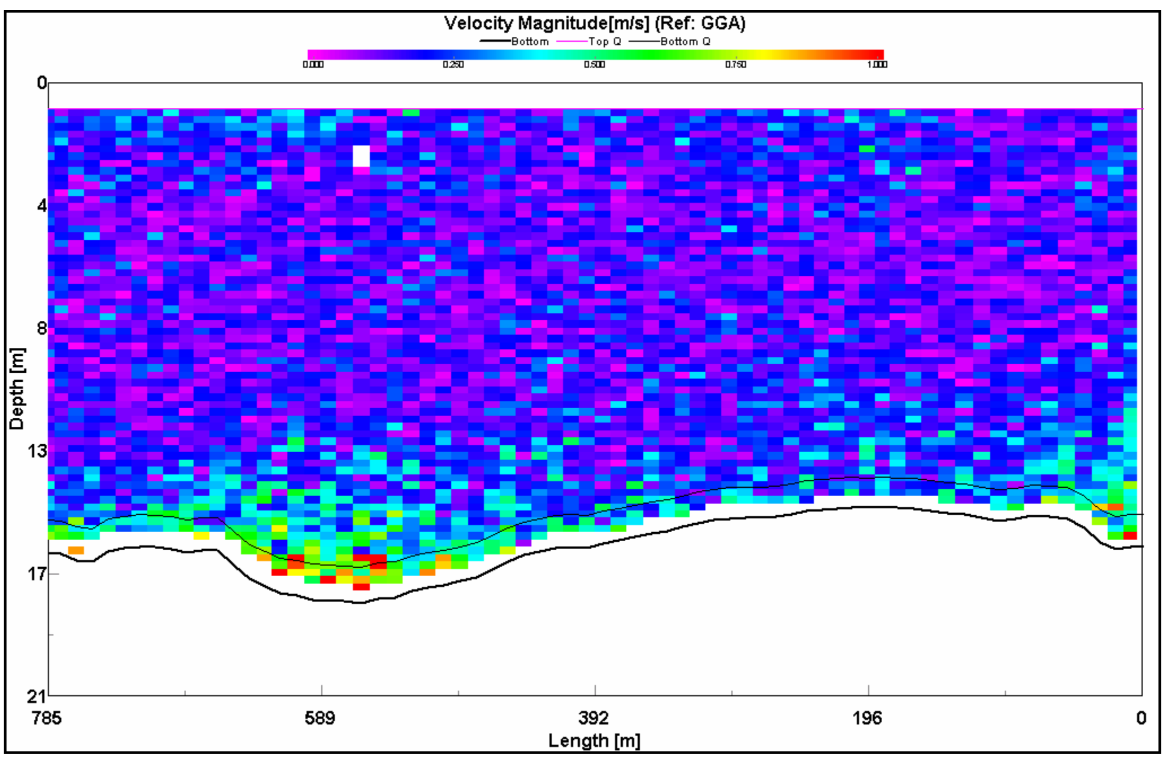


Figure E21. Transect 3 current velocity cross sections, 8 February 2005, 1636 GMT.

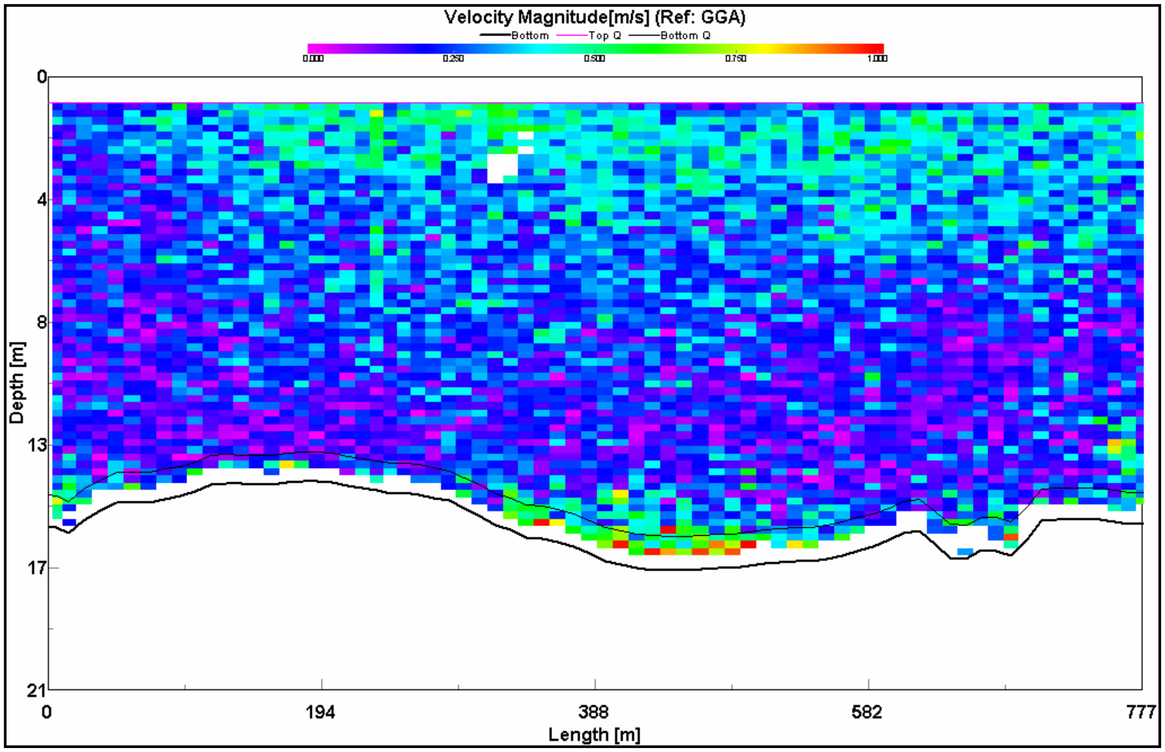


Figure E22. Transect 3 current velocity cross sections, 8 February 2005, 1747 GMT.

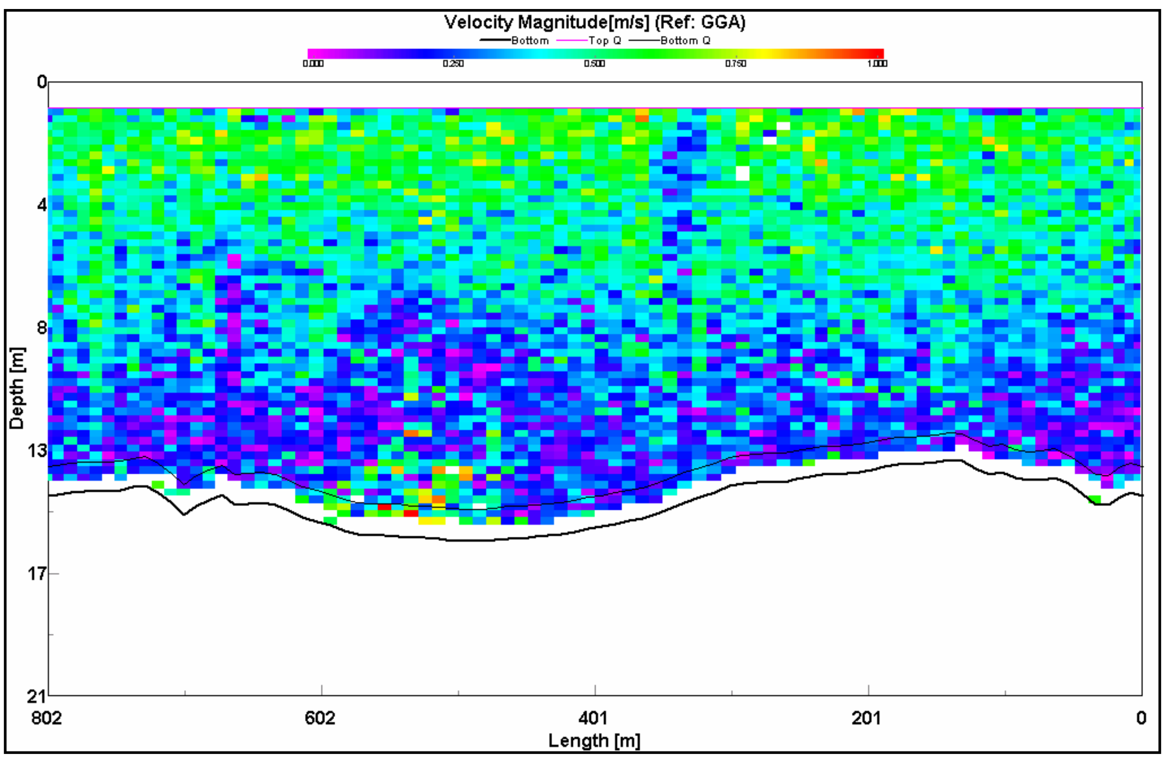


Figure E23. Transect 3 current velocity cross sections, 8 February 2005, 1909 GMT.

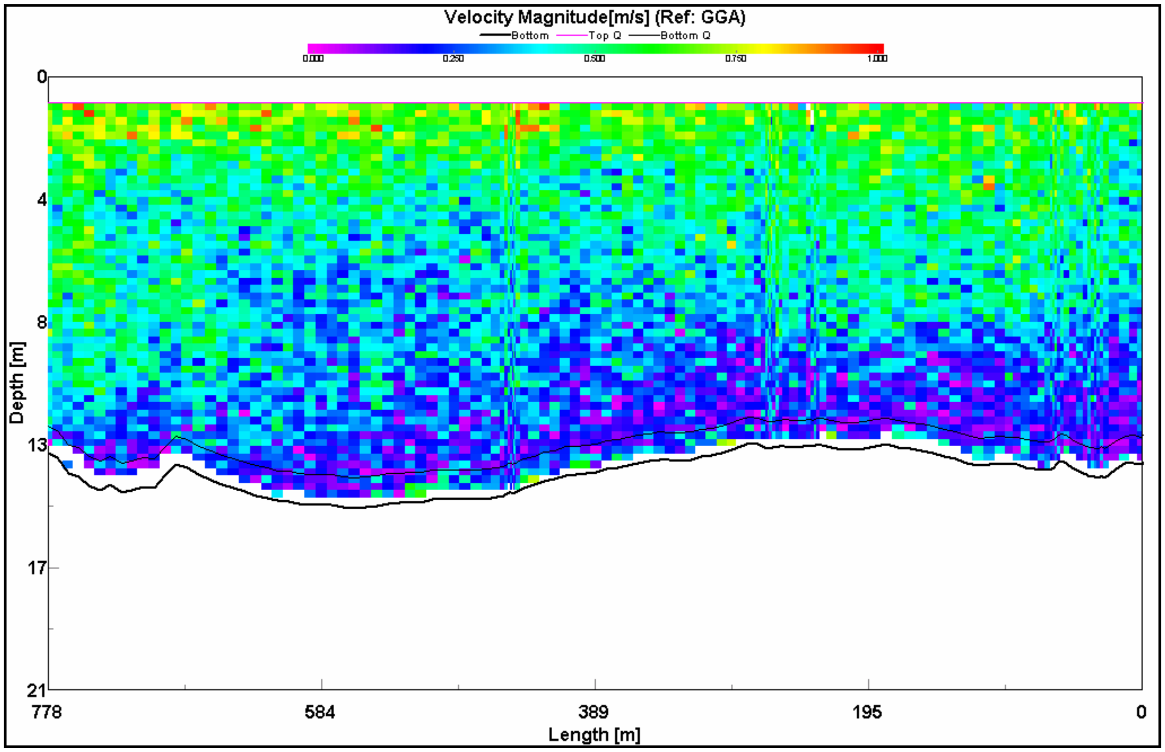


Figure E24. Transect 3 current velocity cross sections, 8 February 2005, 2012 GMT.

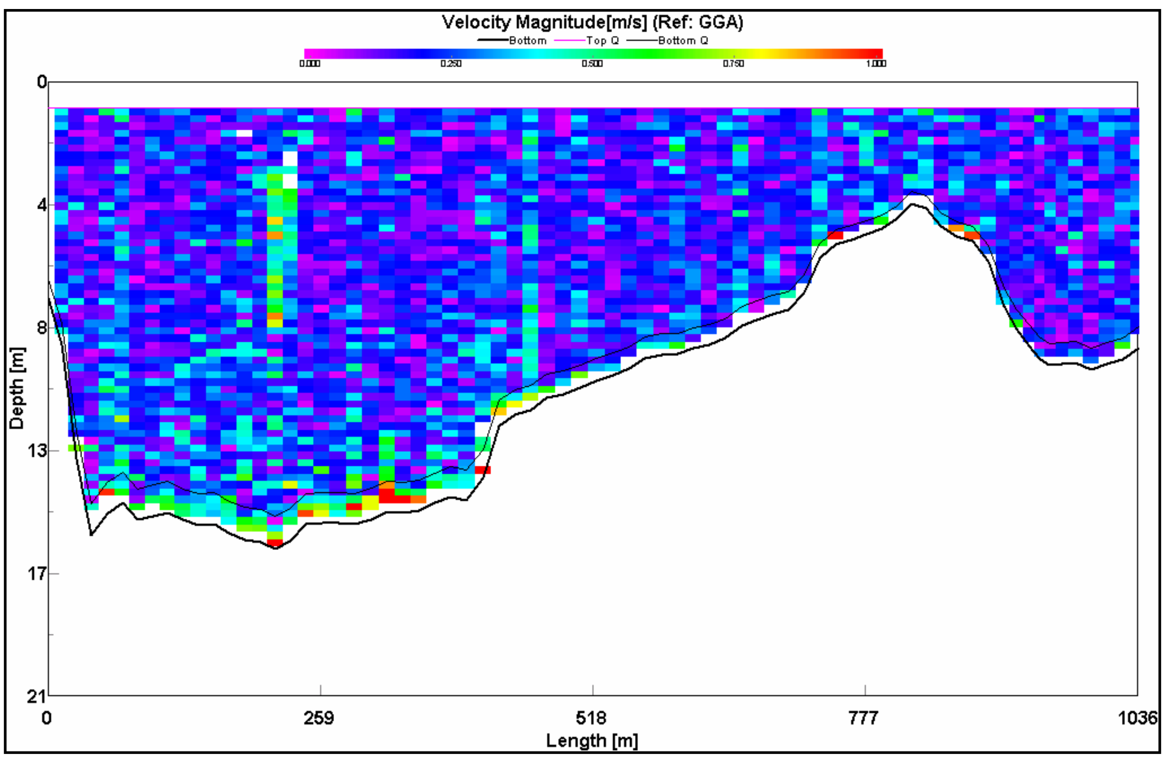


Figure E25. Transect 4 current velocity cross sections, 11 November 2004, 1359 GMT.

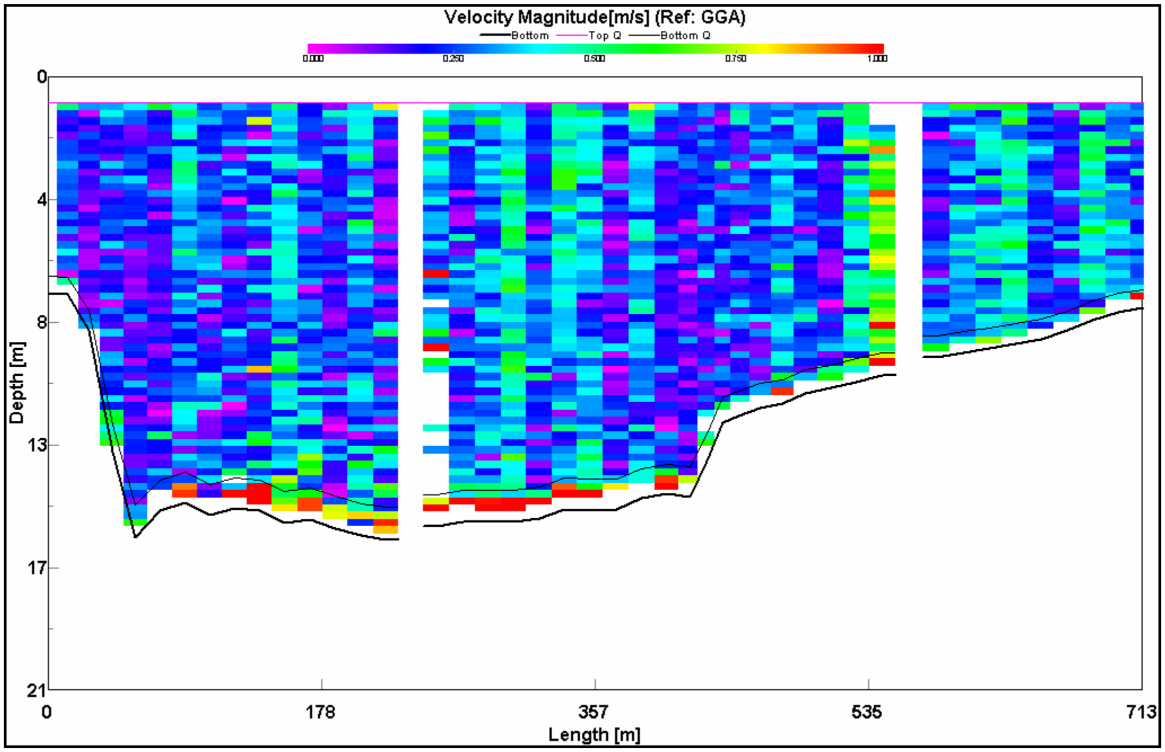


Figure E26. Transect 4 current velocity cross sections, 11 November 2004, 1450 GMT.

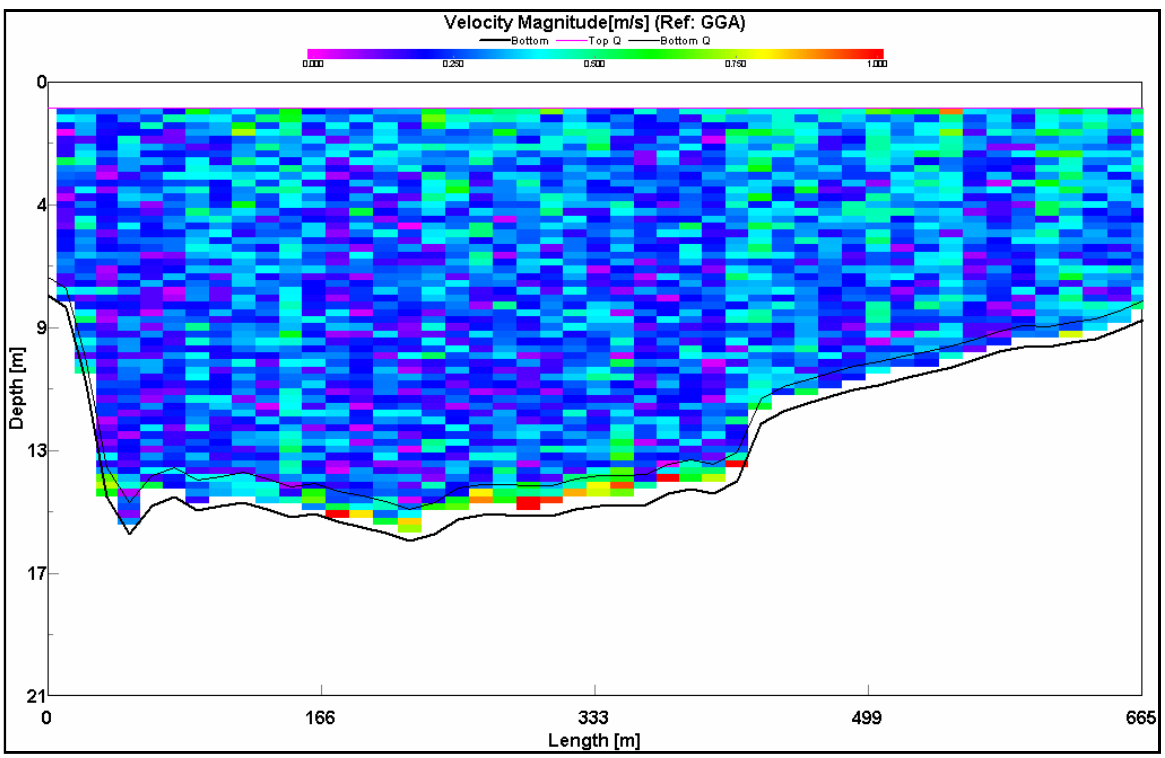


Figure E27. Transect 4 current velocity cross sections, 11 November 2004, 1528 GMT.

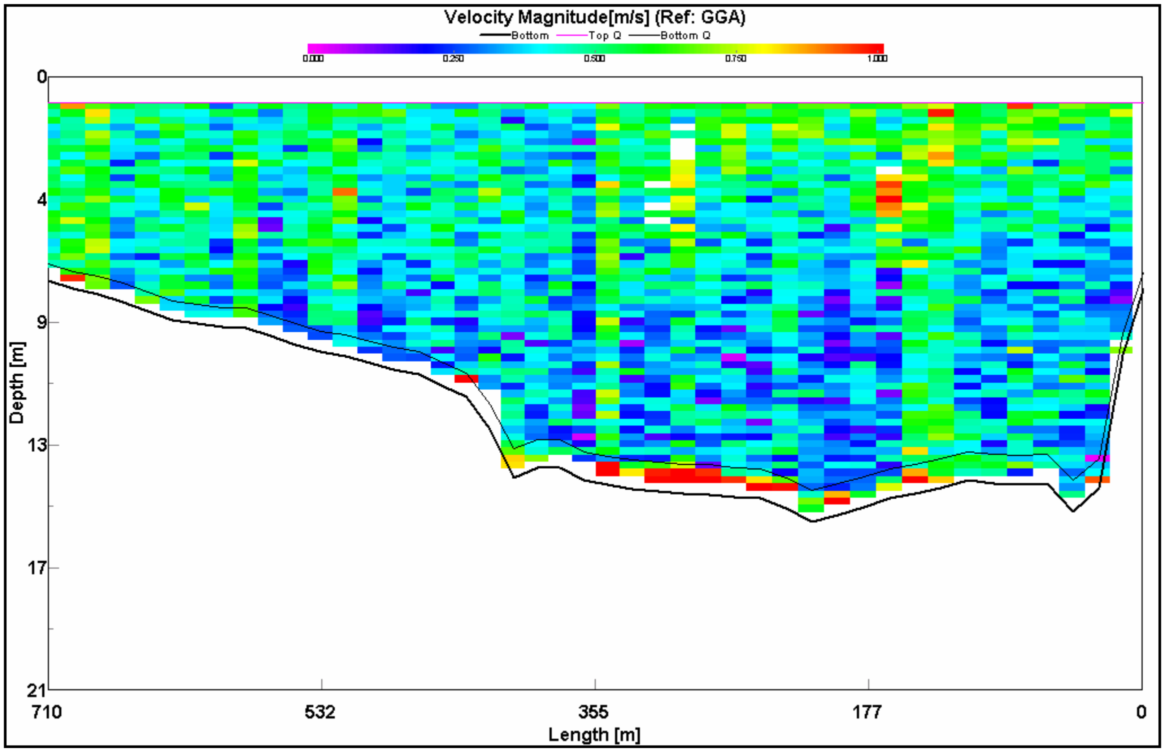


Figure E28. Transect 4 current velocity cross sections, 11 November 2004, 1632 GMT.

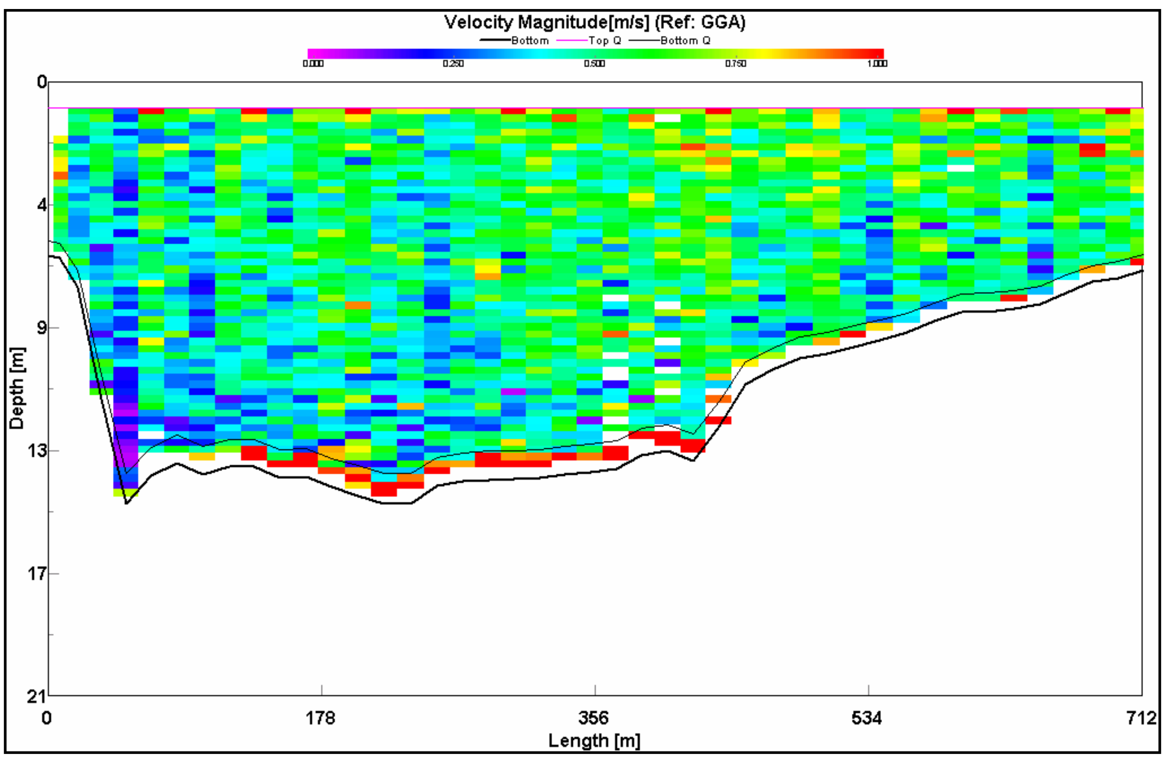


Figure E29. Transect 4 current velocity cross sections, 11 November 2004, 1736 GMT.

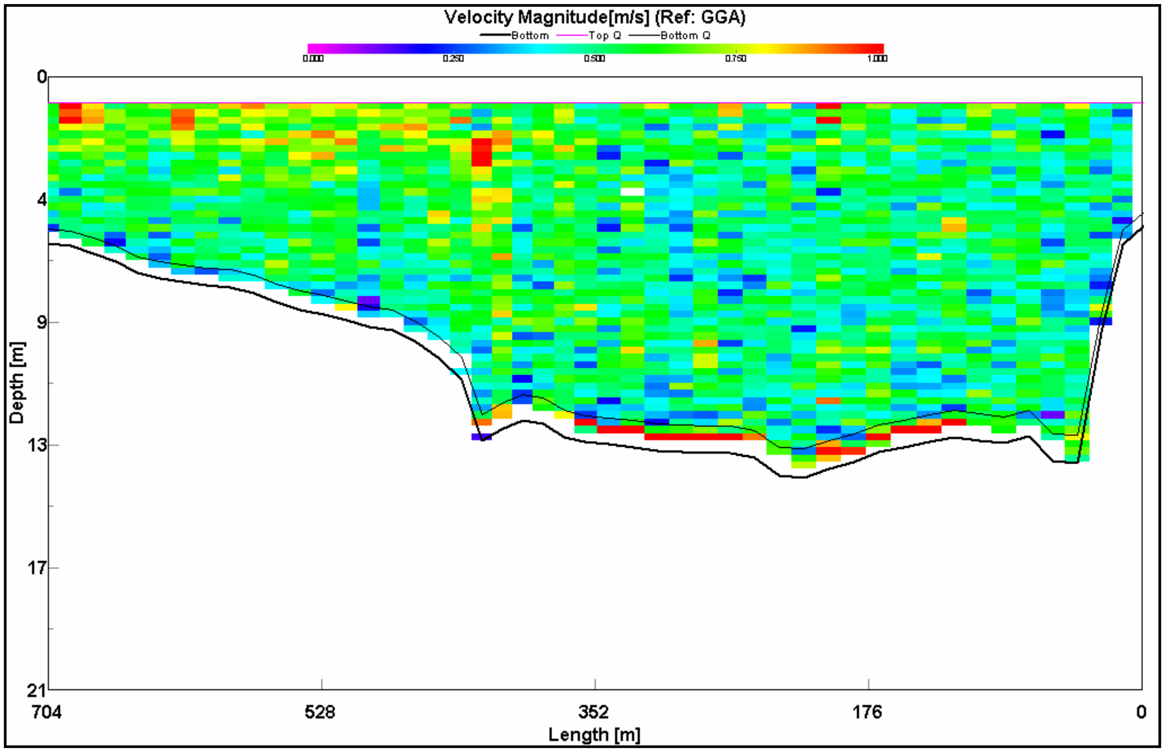


Figure E30. Transect 4 current velocity cross sections, 11 November 2004, 1836 GMT.

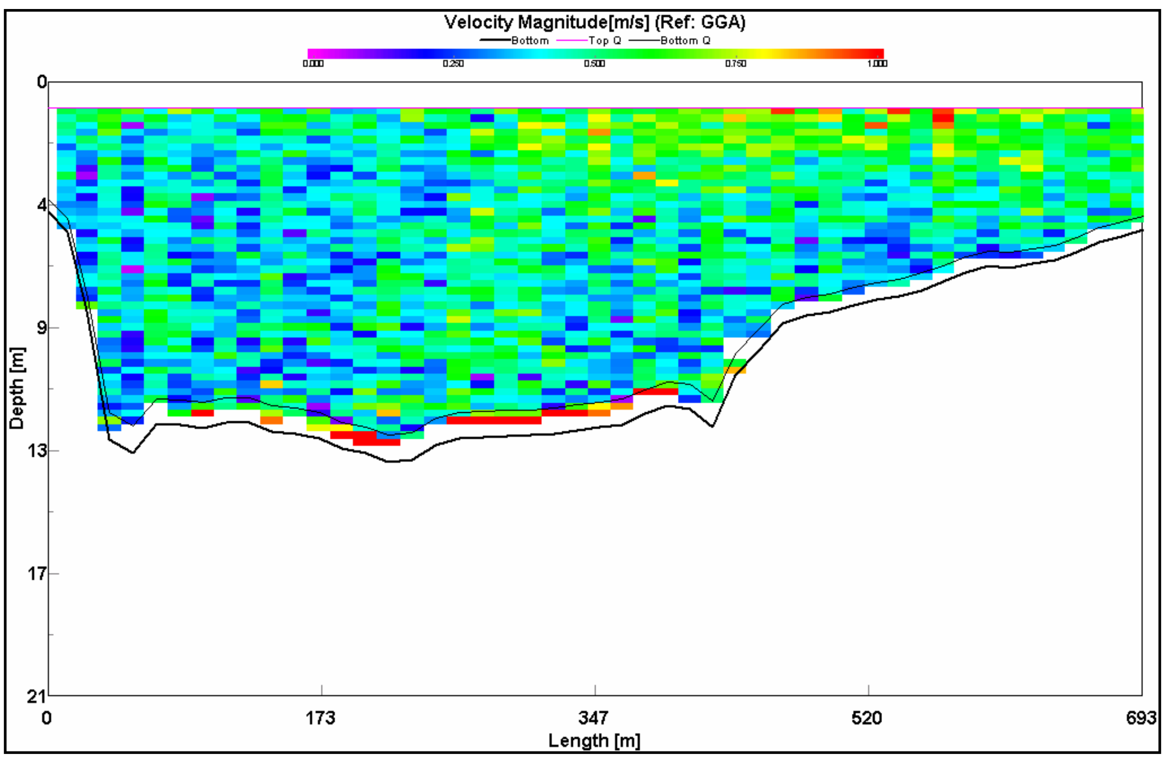


Figure E31. Transect 4 current velocity cross sections, 11 November 2004, 1936 GMT.

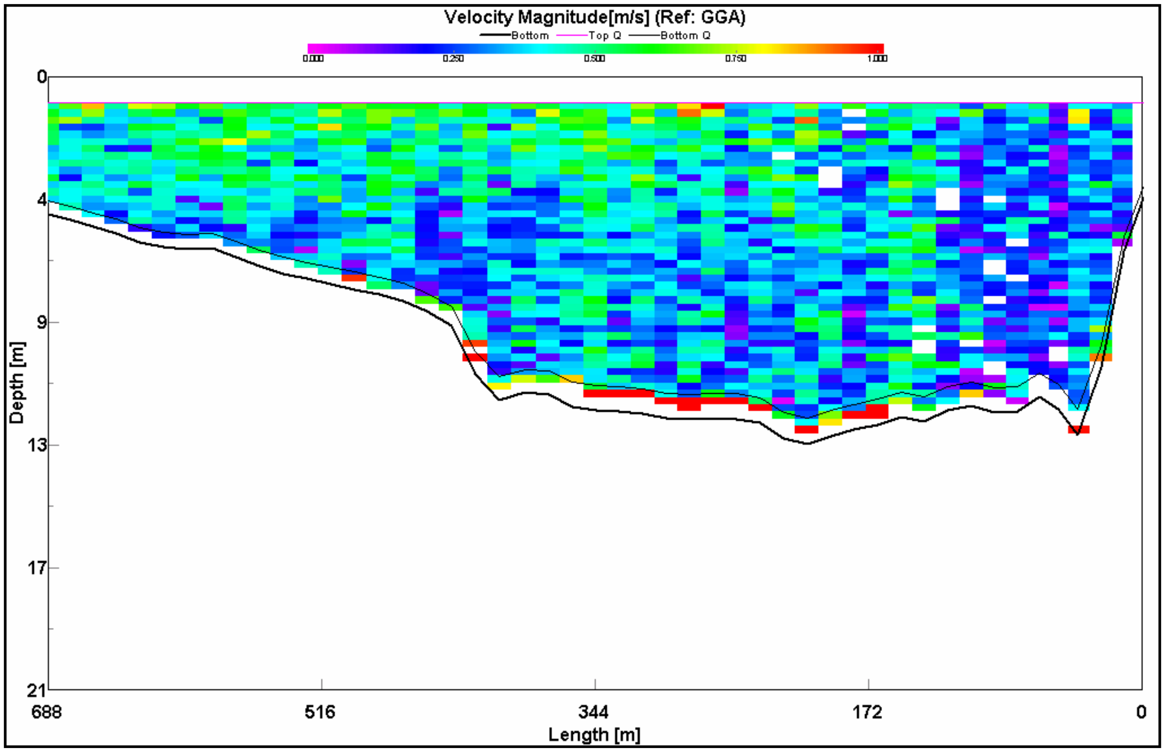


Figure E32. Transect 4 current velocity cross sections, 11 November 2004, 2039 GMT.

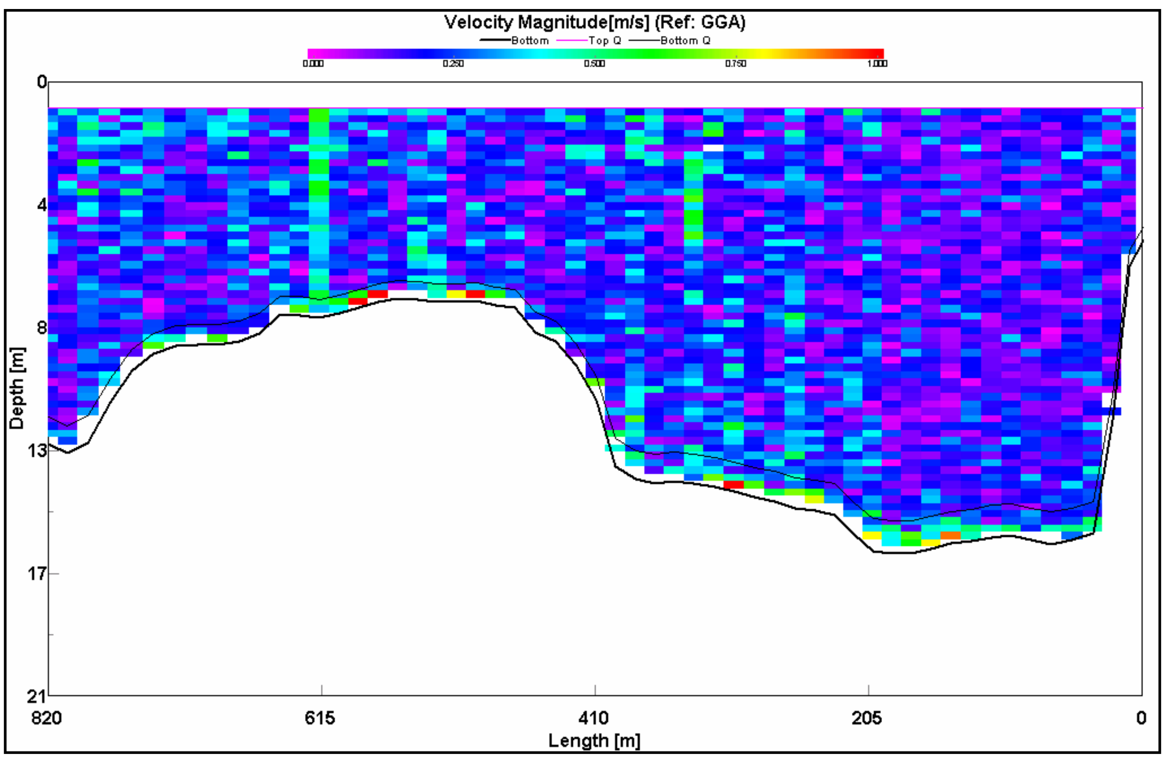


Figure E33. Transect 5 current velocity cross sections, 11 November 2004, 1339 GMT.

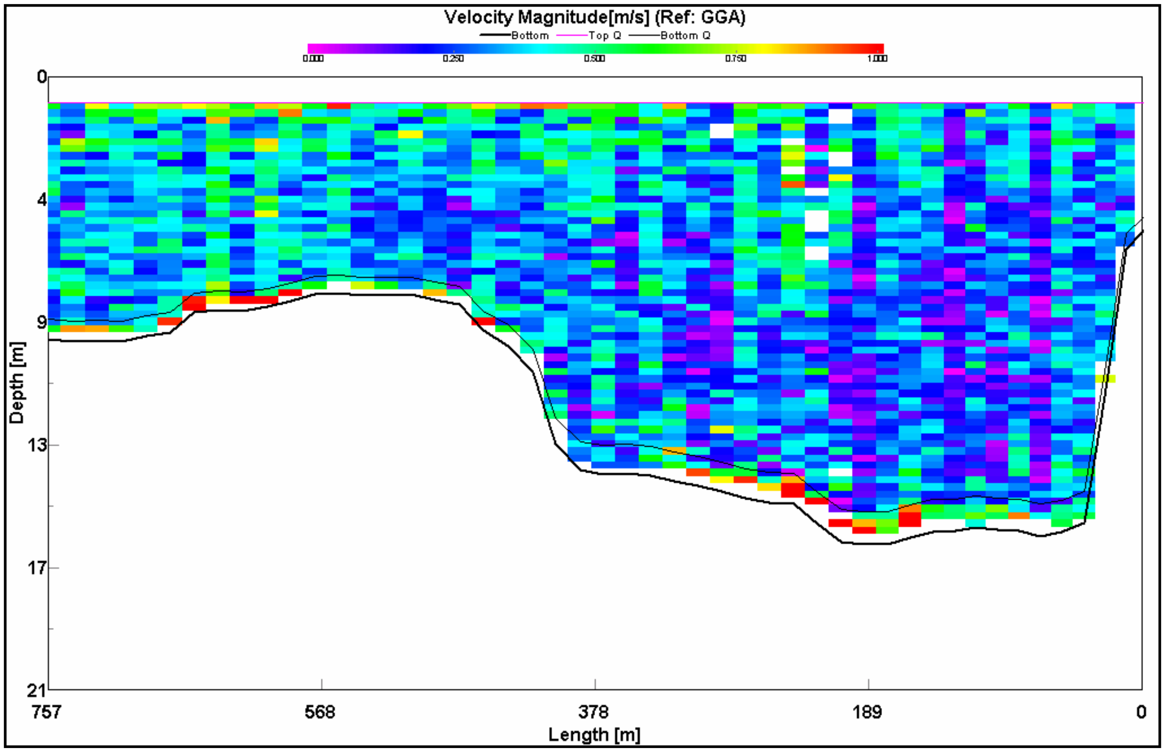


Figure E34. Transect 5 current velocity cross sections, 11 November 2004, 1514 GMT.

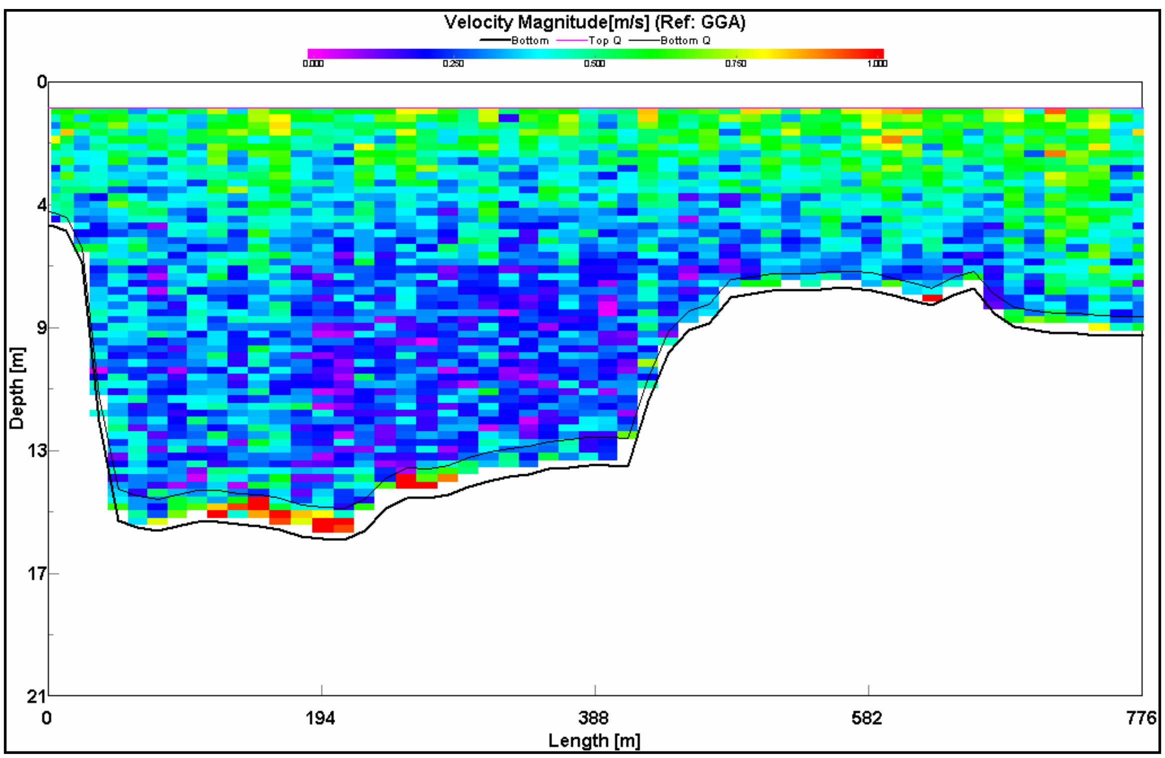


Figure E35. Transect 5 current velocity cross sections, 11 November 2004, 1616 GMT.

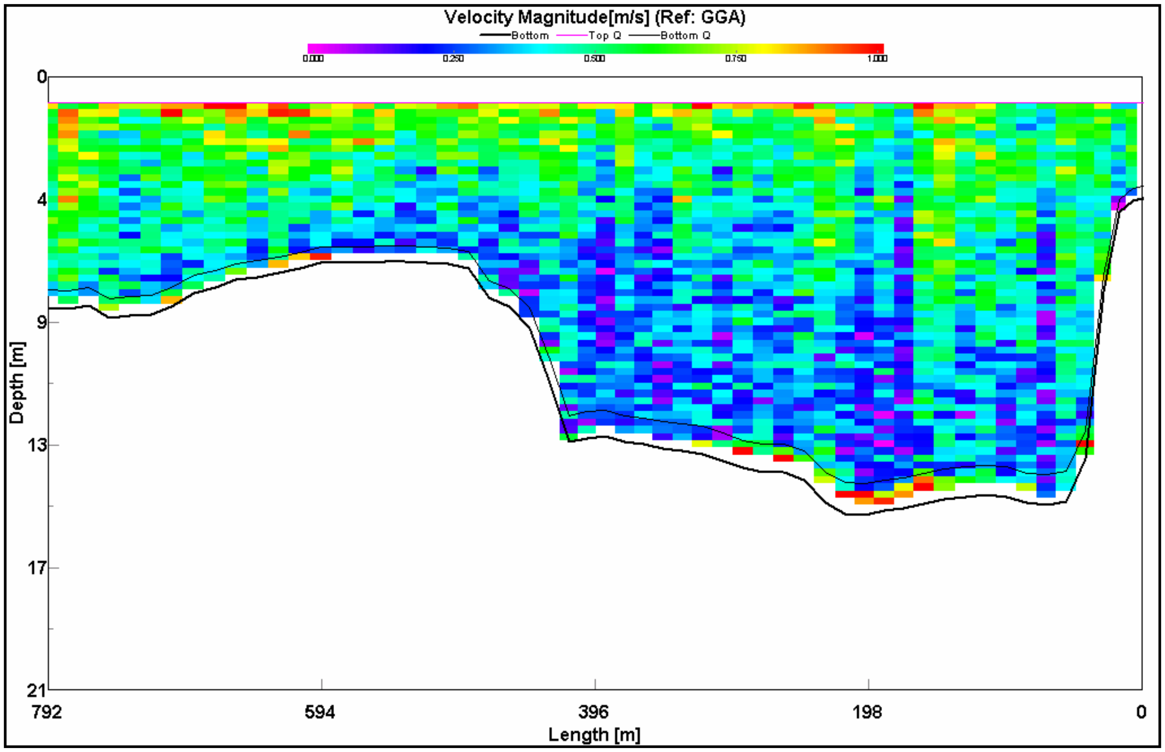


Figure E36. Transect 5 current velocity cross sections, 11 November 2004, 1721 GMT.

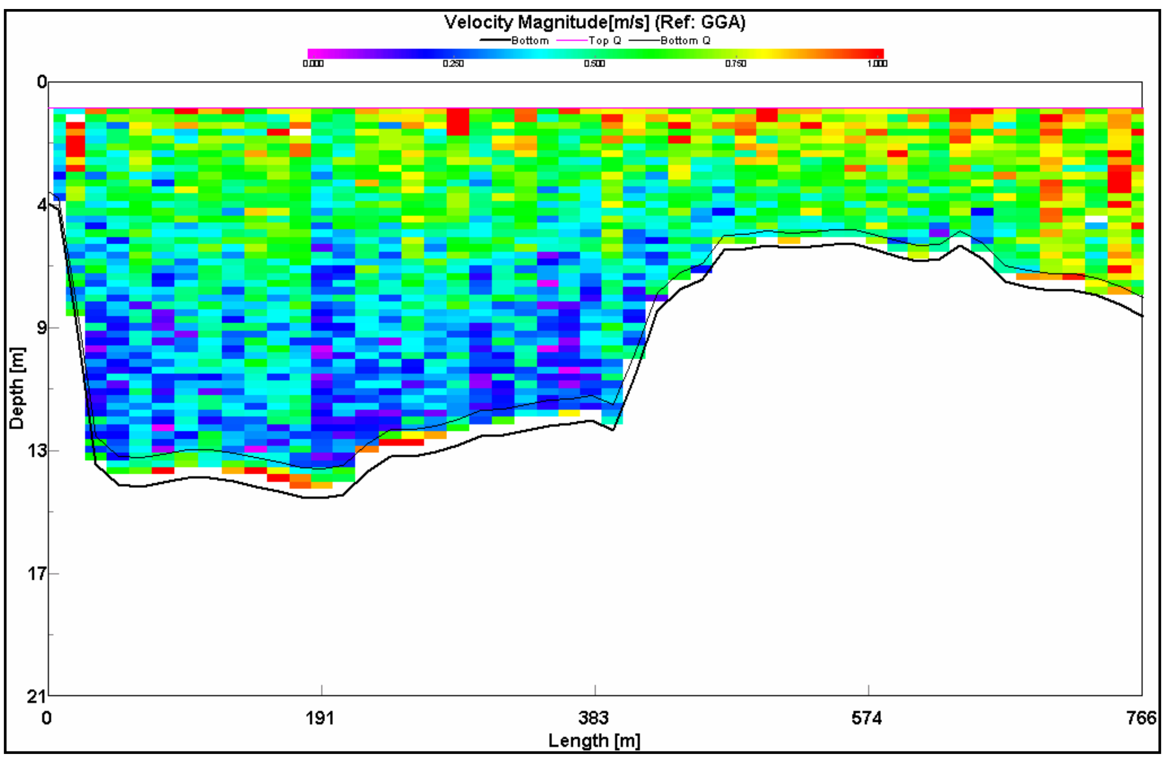


Figure E37. Transect 5 current velocity cross sections, 11 November 2004, 1822 GMT.

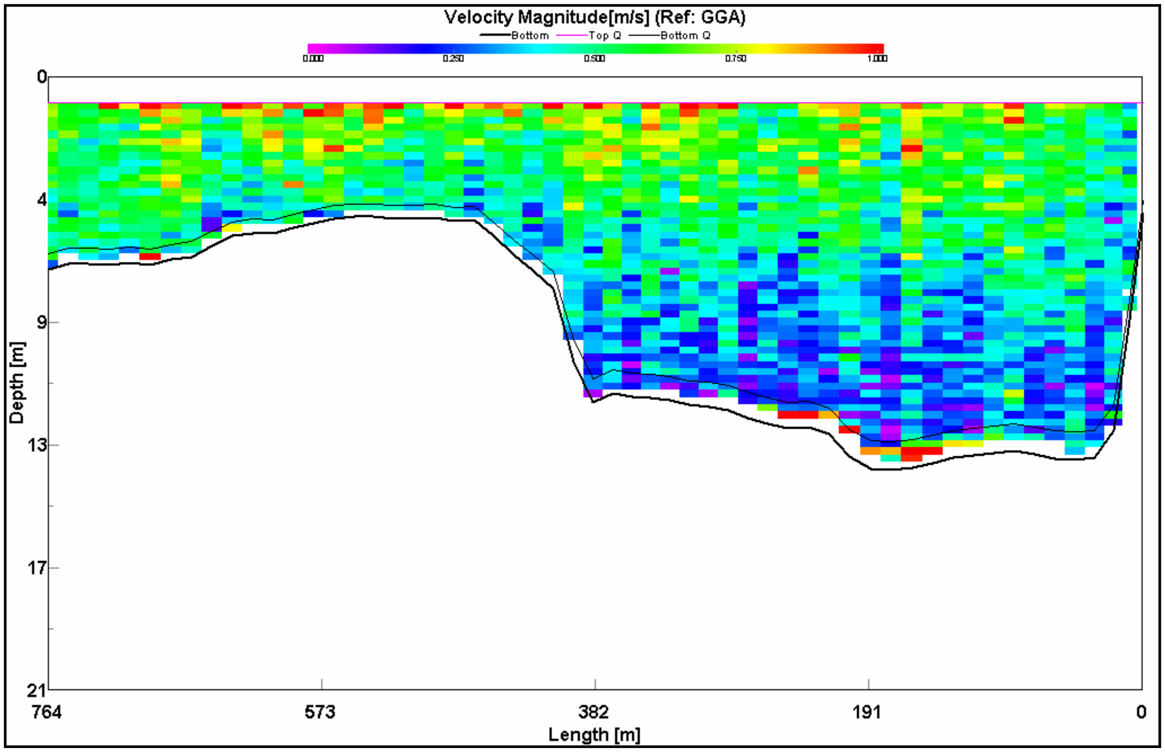


Figure E38. Transect 5 current velocity cross sections, 11 November 2004, 1922 GMT.

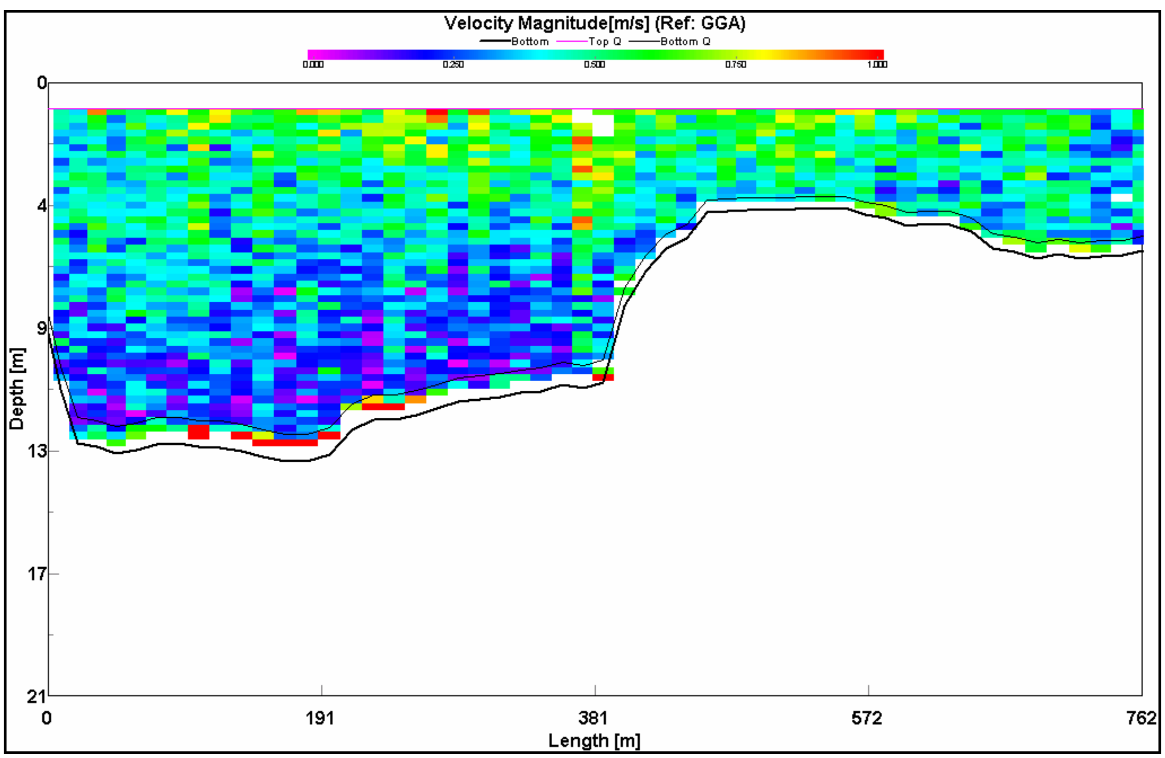


Figure E39. Transect 5 current velocity cross sections, 11 November 2004, 2022 GMT.

Appendix F: Wind Measurement Plots

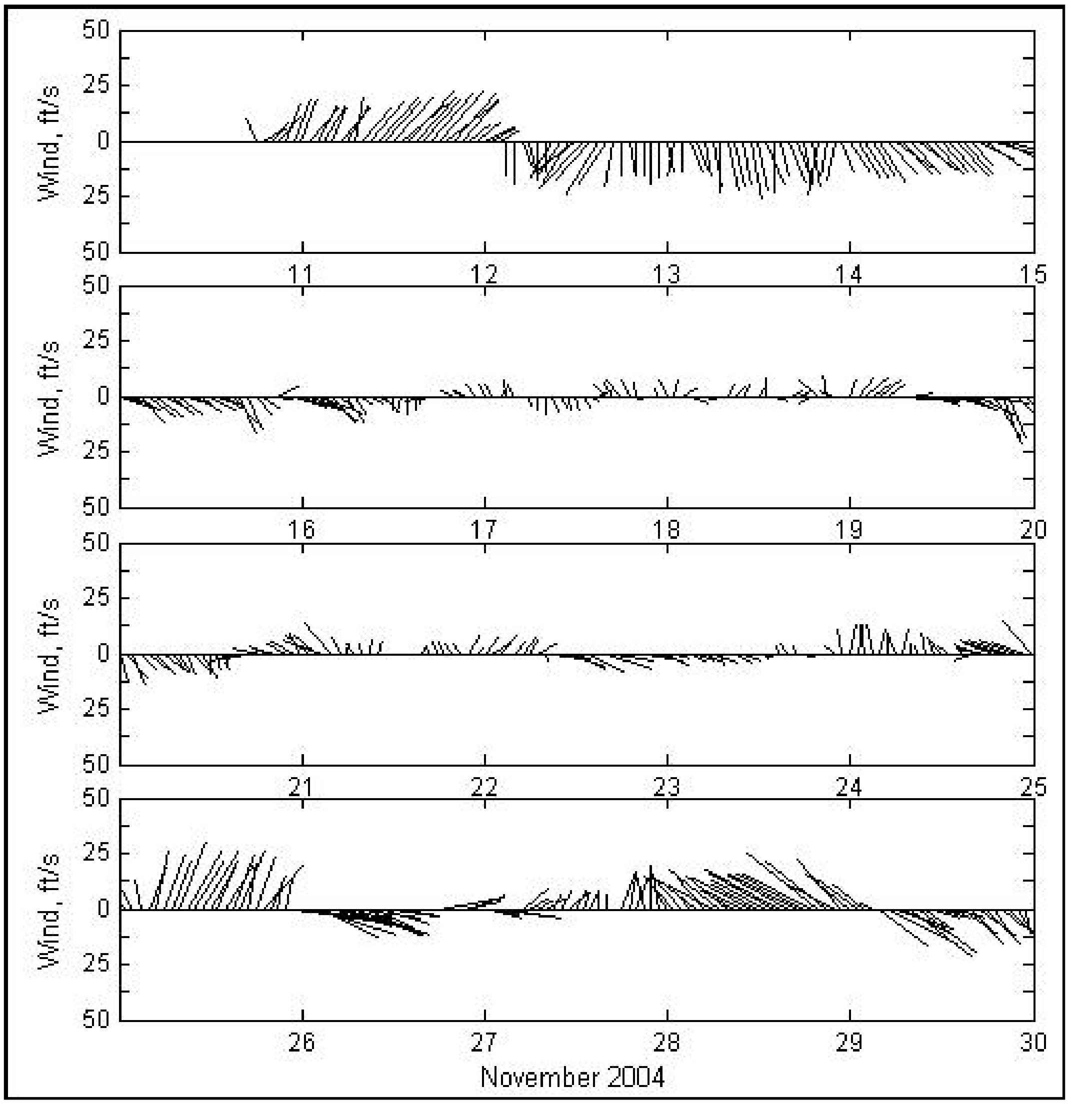


Figure F1. Wind measurement plots at Logan Airport, November 2004.

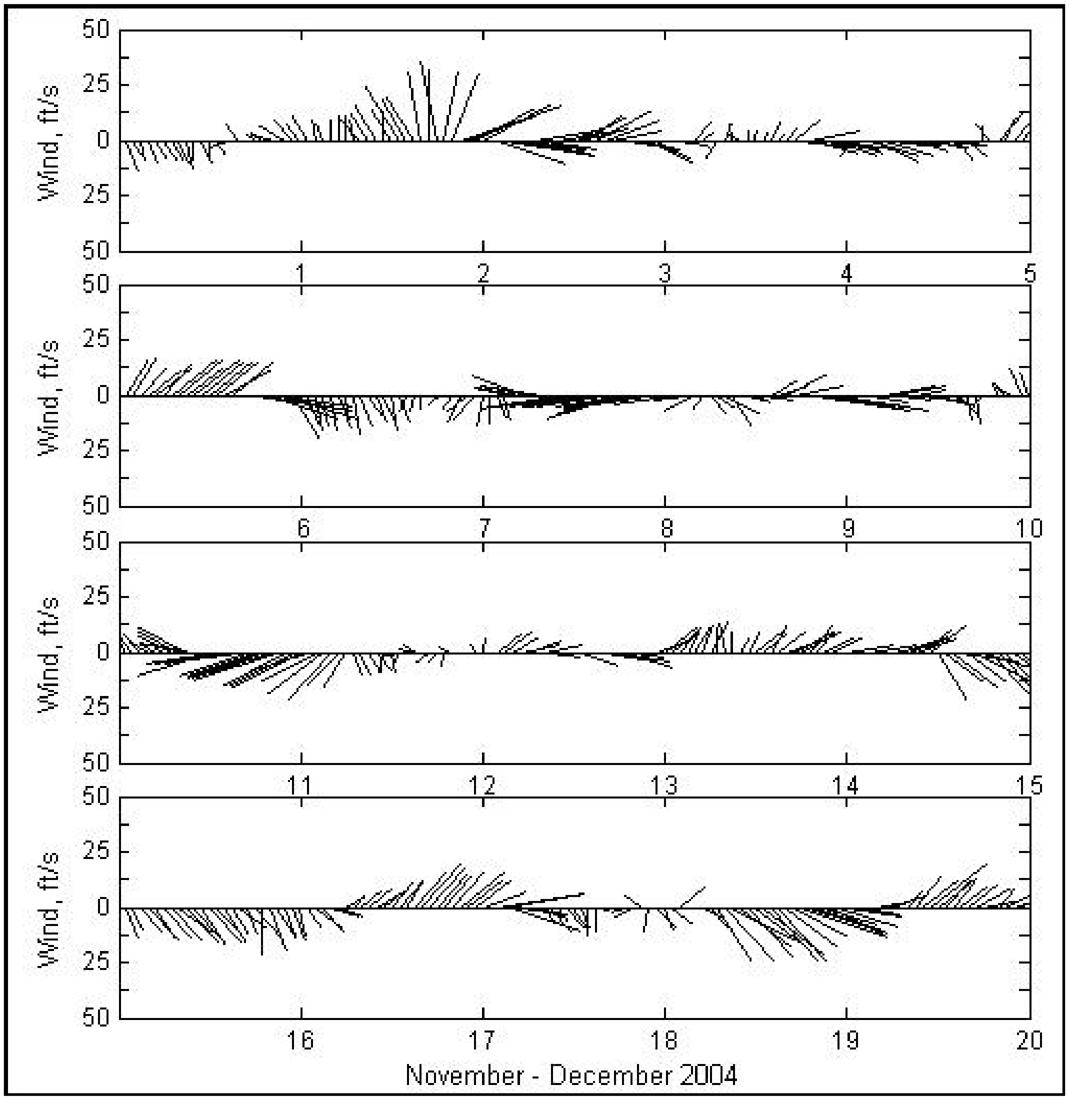


Figure F2. Wind measurement plots at Logan Airport, November-December 2004.

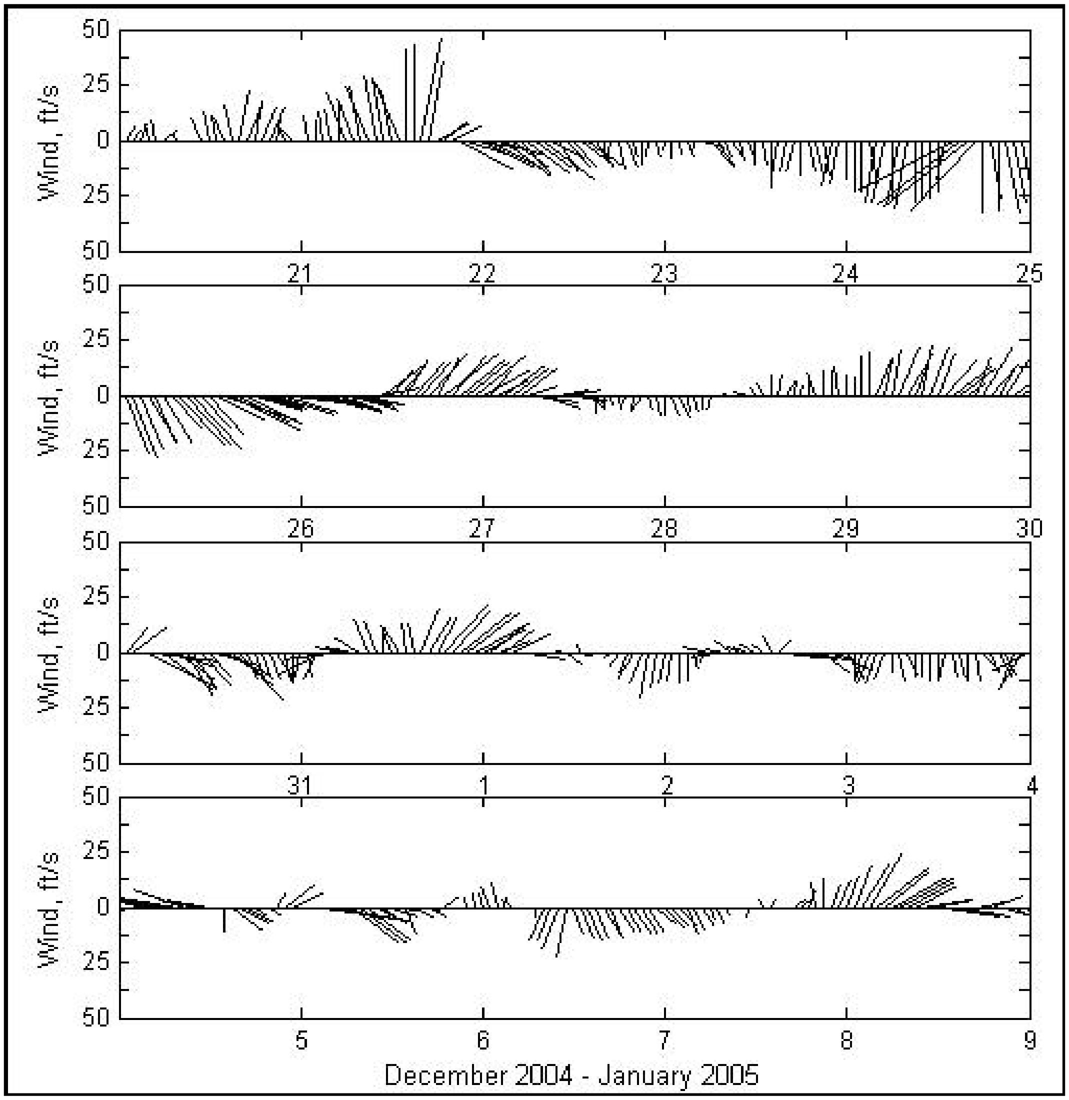


Figure F3. Wind measurement plots at Logan Airport, December 2004–January 2005.

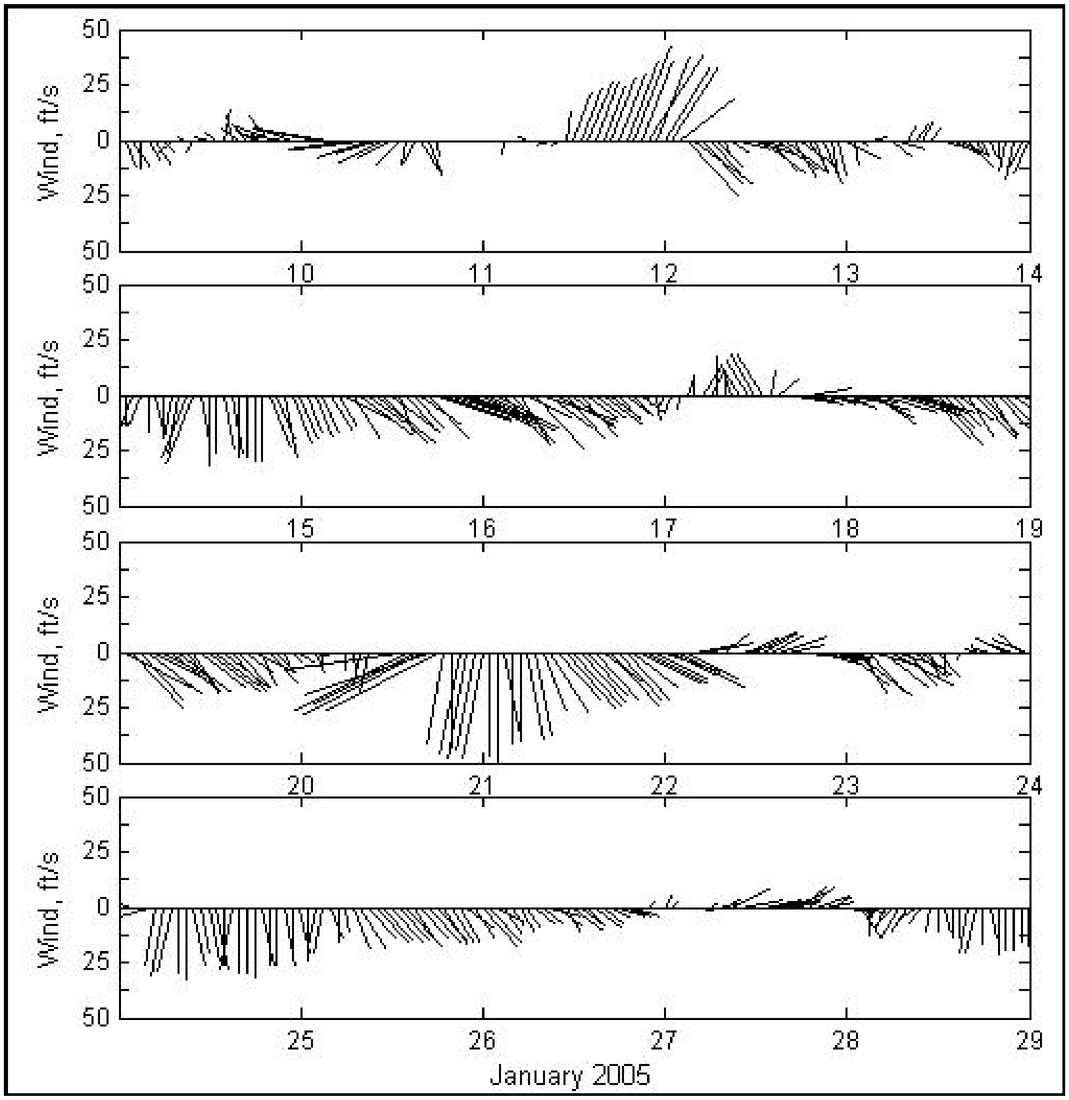


Figure F4. Wind measurement plots at Logan Airport, January 2005.

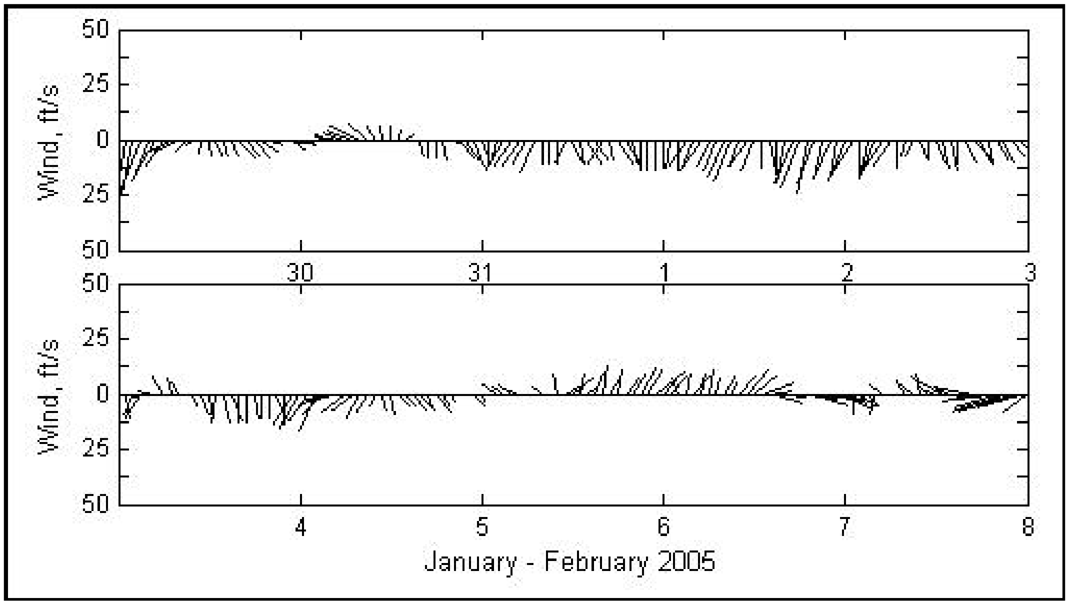


Figure F5. Wind measurement plots at Logan Airport, January-February 2005.

Appendix G: Folder Structure of Project DVD

Table G1. Folder structure of project DVD.

Boston Harbor Field Data Collection Program

- Readme.txt (Table G1)
- Documents
    - Report Contents .doc (report table of contents)
    - Report.doc (the final report without the appendices)
    - Appendix A.doc (Scope of Work)
    - Appendix B.doc (Water-level Measurements Plots))
    - Appendix C.doc (Moored Current Measurements Plots)
    - Appendix D.doc (Transect Current Surveys, Depth-averaged Current Plots)
    - Appendix E.doc (Transect Current Surveys, Current Velocity Cross-sections Plots)
    - Appendix F.doc (Wind Measurements Plots)
    - Appendix G.doc (Folder Structure on Project DVD)
    - Appendix E.doc (Data File Formats)
    - First Field Report.doc ("Instrumentation Deployment and Tidal-Current Survey – 8–12 November 2004")
    - Second Field Report.doc ("Instrumentation Recovery and Tidal-Current Transect Survey – 6–9 February 2005")
- Plots
    - Readme.txt (Figures 2 and 12, showing the instrument locations and designations, and the transect locations)
    - Water-Level Measurements
        - TG1_1.jpeg (time series plot of water levels from TG1 – 10– 30 November 2004)
        - TG1_2.jpeg (time series plot of water levels from TG1 – 30 November 30 – 20 December 2004)
        - TG1_3.jpeg (time series plot of water levels from TG1 – 20 December 2004 – 9 January 2005)
        - TG1_4.jpeg (time series plot of water levels from TG1 – 9–29 January 2005)
        - TG1_5.jpeg (time series plot of water levels from TG1 – 29 January – 8 February 2005)
        - TG2_1.jpeg (time series plot of water levels from TG2 – 10–30 November 2004)
        - TG2_2.jpeg (time series plot of water levels from TG2 – 30 November – 20 December 2004)
        - TG2_3.jpeg (time series plot of water levels from TG2 – 20 December 2004 – 9 January 2005)
        - TG2_4.jpeg (time series plot of water levels from TG2 – 9–29 January 2005)

(Sheet 1 of 7)

Table G1. (Continued)

Water-Level Measurements (continued) TG2_5.jpeg (time series plot of water levels from TG2 – 29 January – 8 February 2005) TG3_1.jpeg (time series plot of water levels from TG3 – 10–30 November 2004) TG3_2.jpeg (time series plot of water levels from TG3 – 30 November – 20 December 2004) TG3_3.jpeg (time series plot of water levels from TG3 – 20 December 2004 – 9 January 2005) TG3_4.jpeg (time series plot of water levels from TG3 – 9–29 January 2005) TG3_5.jpeg (time series plot of water levels from TG3 – 29 January – 8 February 2005) TG4_1.jpeg (time series plot of water levels from TG4 – 10–30 November 2004) TG4_2.jpeg (time series plot of water levels from TG4 – 30 November – 20 December 2004) TG4_3.jpeg (time series plot of water levels from TG4 – 20 December 2004 – 9 January 2005) TG4_4.jpeg (time series plot of water levels from TG4 – 9–29 January 2005) TG4_5.jpeg (time series plot of water levels from TG4 – 29 January – 8 February 2005) NOAA_1.jpeg (time series plot of water levels from the NOAA tide gage – 10–30 November 2004) NOAA_2.jpeg (time series plot of water levels from the NOAA tide gage – 30 November – 20 December 2004) NOAA_3.jpeg (time series plot of water levels from the NOAA tide gage – 20 December 2004 – 9 January 2005) NOAA_4.jpeg (time series plot of water levels from the NOAA tide gage – 9–29 January 2005) NOAA_5.jpeg (time series plot of water levels from the NOAA tide gage – 29 January – 8 February 2005) Moored Current Measurements CM2_1.jpeg (time series plot of depth-averaged currents from CM2 – 10–30 November 2004) CM2_2.jpeg (time series plot of depth-averaged currents from CM2 – 30 November – 20 December 2004) CM2_3.jpeg (time series plot of depth-averaged currents from CM2 – 20 December 2004 – 9 January 2005) CM2_4.jpeg (time series plot of depth-averaged currents from CM2 – 9–29 January 2005) CM2_5.jpeg (time series plot of depth-averaged currents from CM2 – 29 January – 8 February 2005)
(Sheet 2 of 7)

Table G1. (Continued)

Logan Airport Wind Measurements LA_1.jpeg (time series plot of winds from Logan Airport – 10–30 November 2004) LA_2.jpeg (time series plot of winds from Logan Airport – 30 November – 20 December 2004) LA_3.jpeg (time series plot of winds from Logan Airport – 20 December 2004 – 9 January 2005) LA_4.jpeg (time series plot of winds from Logan Airport – 9–29 January 2005) LA_5.jpeg (time series plot of winds from Logan Airport – 29 January – 8 February 2005) Current Transect Measurements Current Cross-Sections.doc (vertical profiles of current speed across each transect) T4_11_11_1321.jpeg (depth-averaged current velocities across transect T4 at 1321 (GMT) on 11 November 2004) T5_11_11_1339.jpeg (depth-averaged current velocities across transect T5 at 1339 (GMT) on 11 November 2004) T4_11_11_1359.jpeg (depth-averaged current velocities across transect T4 at 1359 (GMT) on 11 November 2004) T3_11_11_1424.jpeg (depth-averaged current velocities across transect T3 at 1424 (GMT) on 11 November 2004) T4_11_11_1450.jpeg (depth-averaged current velocities across transect T4 at 1450 (GMT) on 11 November 2004) T5_11_11_1514.jpeg (depth-averaged current velocities across transect T5 at 1514 (GMT) on 11 November 2004) T4_11_11_1528.jpeg (depth-averaged current velocities across transect T4 at 1528 (GMT) on 11 November 2004) T3_11_11_1545.jpeg (depth-averaged current velocities across transect T3 at 1545 (GMT) on 11 November 2004) T5_11_11_1616.jpeg (depth-averaged current velocities across transect T5 at 1616 (GMT) on 11 November 2004) T4_11_11_1632.jpeg (depth-averaged current velocities across transect T4 at 1632 (GMT) on 11 November 2004) T3_11_11_1649.jpeg (depth-averaged current velocities across transect T3 at 1649 (GMT) on 11 November 2004) T5_11_11_1721.jpeg (depth-averaged current velocities across transect T5 at 1721 (GMT) on 11 November 2004) T4_11_11_1736.jpeg (depth-averaged current velocities across transect T4 at 1736 (GMT) on 11 November 2004) T3_11_11_1748.jpeg (depth-averaged current velocities across transect T3 at 1748 (GMT) on 11 November 2004) T5_11_11_1822.jpeg (depth-averaged current velocities across transect T5 at 1822 (GMT) on 11 November 2004)
(Sheet 3 of 7)

Table G1. (Continued)

Current Transect Measurements (continued) T4_11_11_1836.jpeg (depth-averaged current velocities across transect T4 at 1836 (GMT) on 11 November 2004) T3_11_11_1851.jpeg (depth-averaged current velocities across transect T3 at 1851 (GMT) on 11 November 2004) T5_11_11_1922.jpeg (depth-averaged current velocities across transect T5 at 1922 (GMT) on 11 November 2004) T4_11_11_1936.jpeg (depth-averaged current velocities across transect T4 at 1936 (GMT) on 11 November 2004) T3_11_11_1951.jpeg (depth-averaged current velocities across transect T3 at 1951 (GMT) on 11 November 2004) T5_11_11_2022.jpeg (depth-averaged current velocities across transect T5 at 2022 (GMT) on 11 November 2004) T4_11_11_2039.jpeg (depth-averaged current velocities across transect T4 at 2039 (GMT) on 11 November 2004) T3_11_11_2055.jpeg (depth-averaged current velocities across transect T3 at 2055 (GMT) on 11 November 2004) T1_2_8_1341.jpeg (depth-averaged current velocities across transect T1 at 1341 (GMT) on 8 February 2005) T2_2_8_1415.jpeg (depth-averaged current velocities across transect T2 at 1415 (GMT) on 8 February 2005) T1_2_8_1450.jpeg (depth-averaged current velocities across transect T1 at 1450 (GMT) on 8 February 2005) T1_2_8_1459.jpeg (depth-averaged current velocities across transect T1 at 1459 (GMT) on 8 February 2005) T3_2_8_1520.jpeg (depth-averaged current velocities across transect T3 at 1520 (GMT) on 8 February 2005) T2_2_8_1532.jpeg (depth-averaged current velocities across transect T2 at 1532 (GMT) on 8 February 2005) T1_2_8_1604.jpeg (depth-averaged current velocities across transect T1 at 1604 (GMT) on 8 February 2005) T1_2_8_1614.jpeg (depth-averaged current velocities across transect T1 at 1614 (GMT) on 8 February 2005) T3_2_8_1636.jpeg (depth-averaged current velocities across transect T3 at 1636 (GMT) on 8 February 2005) T2_2_8_1649.jpeg (depth-averaged current velocities across transect T2 at 1649 (GMT) on 8 February 2005) T1_2_8_1723.jpeg (depth-averaged current velocities across transect T1 at 1723 (GMT) on 8 February 2005) T3_2_8_1747.jpeg (depth-averaged current velocities across transect T3 at 1747 (GMT) on 8 February 2005) T2_2_8_1803.jpeg (depth-averaged current velocities across transect T2 at 1803 (GMT) on 8 February 2005)
(Sheet 4 of 7)

Table G1. (Continued)

Current Transect Measurements (continued)

- T1_2_8_1840.jpeg (depth-averaged current velocities across transect T1 at 1840 (GMT) on 8 February 2005)
- T3_2_8_1909.jpeg (depth-averaged current velocities across transect T3 at 1909 (GMT) on 8 February 2005)
- T3_2_8_2012.jpeg (depth-averaged current velocities across transect T3 at 2012 (GMT) on 8 February 2005)
- T1_2_8_2048.jpeg (depth-averaged current velocities across transect T1 at 2048 (GMT) on 8 February 2005)

Data Files

Water-Level Measurements

- Readme.txt (Table H1)
- TG1.txt (water levels measured from TG1)
- TG2.txt (water levels measures from TG2)
- TG3.txt (water levels measured from TG3)
- TG3.txt (water levels measured from TG4)
- NOAA.txt (water levels measured from the NOAA tide gage)

Moored Current Measurements

- Readme.txt (Table H2)
- CM2.txt (depth-averaged current velocities from CM2)

Logan Airport Wind Measurements

- Readme.txt (Table H3)
- Wind.txt (wind speed and direction measured at Logan Airport)

Current Transect Measurements

- Readme.txt (Table H4)
- T4_11_11_1321.txt (depth-averaged current velocities across transect T4 at 1321 (GMT) on 11 November 2004)
- T5_11_11_1339.txt (depth-averaged current velocities across transect T5 at 1339 (GMT) on 11 November 2004)
- T4_11_11_1359.txt (depth-averaged current velocities across transect T4 at 1359 (GMT) on 11 November 2004)
- T3_11_11_1424.txt (depth-averaged current velocities across transect T3 at 1424 (GMT) on 11 November 2004)
- T4_11_11_1450.txt (depth-averaged current velocities across transect T4 at 1450 (GMT) on 11 November 2004)
- T5_11_11_1514.TXT (depth-averaged current velocities across transect T5 at 1514 (GMT) on 11 November 2004)
- T4_11_11_1528.txt (depth-averaged current velocities across transect T4 at 1528 (GMT) on 11 November 2004)
- T3_11_11_1545.txt (depth-averaged current velocities across transect T3 at 1545 (GMT) on 11 November 2004)
- T5_11_11_1616.txt (depth-averaged current velocities across transect T5 at 1616 (GMT) on 11 November 2004)
- T4_11_11_1632.txt (depth-averaged current velocities across transect T4 at 1632 (GMT) on 11 November 2004)

(Sheet 5 of 7)

Table G1. (Continued)

Current Transect Measurements (continued) T3_11_11_1649.txt (depth-averaged current velocities across transect T3 at 1649 (GMT) on 11 November 2004) T5_11_11_1721.txt (depth-averaged current velocities across transect T5 at 1721 (GMT) on 11 November 2004) T4_11_11_1736.txt (depth-averaged current velocities across transect T4 at 1736 (GMT) on 11 November 2004) T3_11_11_1748.txt (depth-averaged current velocities across transect T3 at 1748 (GMT) on 11 November 2004) T5_11_11_1822.txt (depth-averaged current velocities across transect T5 at 1822 (GMT) on 11 November 2004) T4_11_11_1836.txt (depth-averaged current velocities across transect T4 at 1836 (GMT) on 11 November 2004) T3_11_11_1851.txt (depth-averaged current velocities across transect T3 at 1851 (GMT) on 11 November 2004) T5_11_11_1922.txt (depth-averaged current velocities across transect T5 at 1922 (GMT) on 11 November 2004) T4_11_11_1936.txt (depth-averaged current velocities across transect T4 at 1936 (GMT) on 11 November 2004) T3_11_11_1951.txt (depth-averaged current velocities across transect T3 at 1951 (GMT) on 11 November 2004) T5_11_11_2022.txt (depth-averaged current velocities across transect T5 at 2022 (GMT) on 11 November 2004) T4_11_11_2039.txt (depth-averaged current velocities across transect T4 at 2039 (GMT) on 11 November 2004) T3_11_11_2055.txt (depth-averaged current velocities across transect T3 at 2055 (GMT) on 11 November 2004) T1_2_8_1341.txt (depth-averaged current velocities across transect T1 at 1341 (GMT) on 8 February 2005) T2_2_8_1415.txt (depth-averaged current velocities across transect T2 at 1415 (GMT) on 8 February 2005) T1_2_8_1450.txt (depth-averaged current velocities across transect T1 at 1450 (GMT) on 8 February 2005) T1_2_8_1459.txt (depth-averaged current velocities across transect T1 at 1459 (GMT) on 8 February 2005) T3_2_8_1520.txt (depth-averaged current velocities across transect T3 at 1520 (GMT) on 8 February 2005) T2_2_8_1532.txt (depth-averaged current velocities across transect T2 at 1532 (GMT) on 8 February 2005) T1_2_8_1604.txt (depth-averaged current velocities across transect T1 at 1604 (GMT) on 8 February 2005) T1_2_8_1614.txt (depth-averaged current velocities across transect T1 at 1614 (GMT) on 8 February 2005)
(Sheet 6 of 7)

Table G1. (Concluded)

Current Transect Measurements T3_2_8_1636.txt (depth-averaged current velocities across transect T3 at 1636 (GMT) on 8 February 2005) T2_2_8_1649.txt (depth-averaged current velocities across transect T2 at 1649 (GMT) on 8 February 2005) T1_2_8_1723.txt (depth-averaged current velocities across transect T1 at 1723 (GMT) on 8 February 2005) T3_2_8_1747.txt (depth-averaged current velocities across transect T3 at 1747 (GMT) on 8 February 2005) T2_2_8_1803.txt (depth-averaged current velocities across transect T2 at 1803 (GMT) on 8 February 2005) T1_2_8_1840.txt (depth-averaged current velocities across transect T1 at 1840 (GMT) on 8 February 2005) T3_2_8_1909.txt (depth-averaged current velocities across transect T3 at 1909 (GMT) on 8 February 2005) T3_2_8_2012.txt (depth-averaged current velocities across transect T3 at 2012 (GMT) on 8 February 2005) T1_2_8_2048.txt (depth-averaged current velocities across transect T1 at 2048 (GMT) on 8 February 2005) Project GIS Boston.apr (ArcView project file for displaying the vectorized current transect data) GIS files Vectorized data files and GIS geospacial information needed for the GIS project)
(Sheet 7 of 7)

Appendix H: Data File Formats

Table H1. Format of water-level measurement files on project DVD.

Water-level measurement files TG1.txt, TG2.txt, TG3.txt, TG4.txt, NOAA.txt		
Row	Field	Description
1	1	Instrument designation
	2	Geographic location description
2	1	Latitude, degrees north
	2	Longitude, degrees west
3	1	Hour of first data value in record (GMT)
	2	Minute of first data value in record (GMT)
	3	Month of first data value in record (GMT)
	4	Day of first data value in record (GMT)
	5	Year of first data value in record (GMT)
4 – end of record	1	Time in hours from first data value in record
	2	Water level in feet relative to the record mean for TG1, TG2, TG3, and TG4, and relative to mean lower low water (MLLW) for NOAA

Example: First 6 rows of TG1.txt.

```
TG1 Chelsea Bridge
42.386556 71.039917
18 00 11 10 2004
 0.00 5.27
 0.10 5.09
 0.20 4.84
```

Table H2. Format of moored current meter measurement file on project DVD.

Moored current meter measurements file CM2.txt		
Row	Field	Description
1	1	Instrument designation
	2	Geographic location description
2	1	Latitude, degrees north
	2	Longitude, degrees west
3	1	Hour of first data value in record (GMT)
	2	Minute of first data value in record (GMT)
	3	Month of first data value in record (GMT)
	4	Day of first data value in record (GMT)
	5	Year of first data value in record (GMT)
4	1	Time in hours from first data value in record
	2	Depth-averaged current speed in feet per second
	3	Depth-averaged direction current is going to in degrees true

Example: First 6 rows of CM2.txt.

```
CM2 Near the seaward end of the navigation channel
42.363833 70.918000
14 21 11 10 2004
 0.00 0.42 47
 0.25 0.52 43
 0.50 0.63 44
```

Table H3. Format of Logan Airport wind measurement file on project DVD.

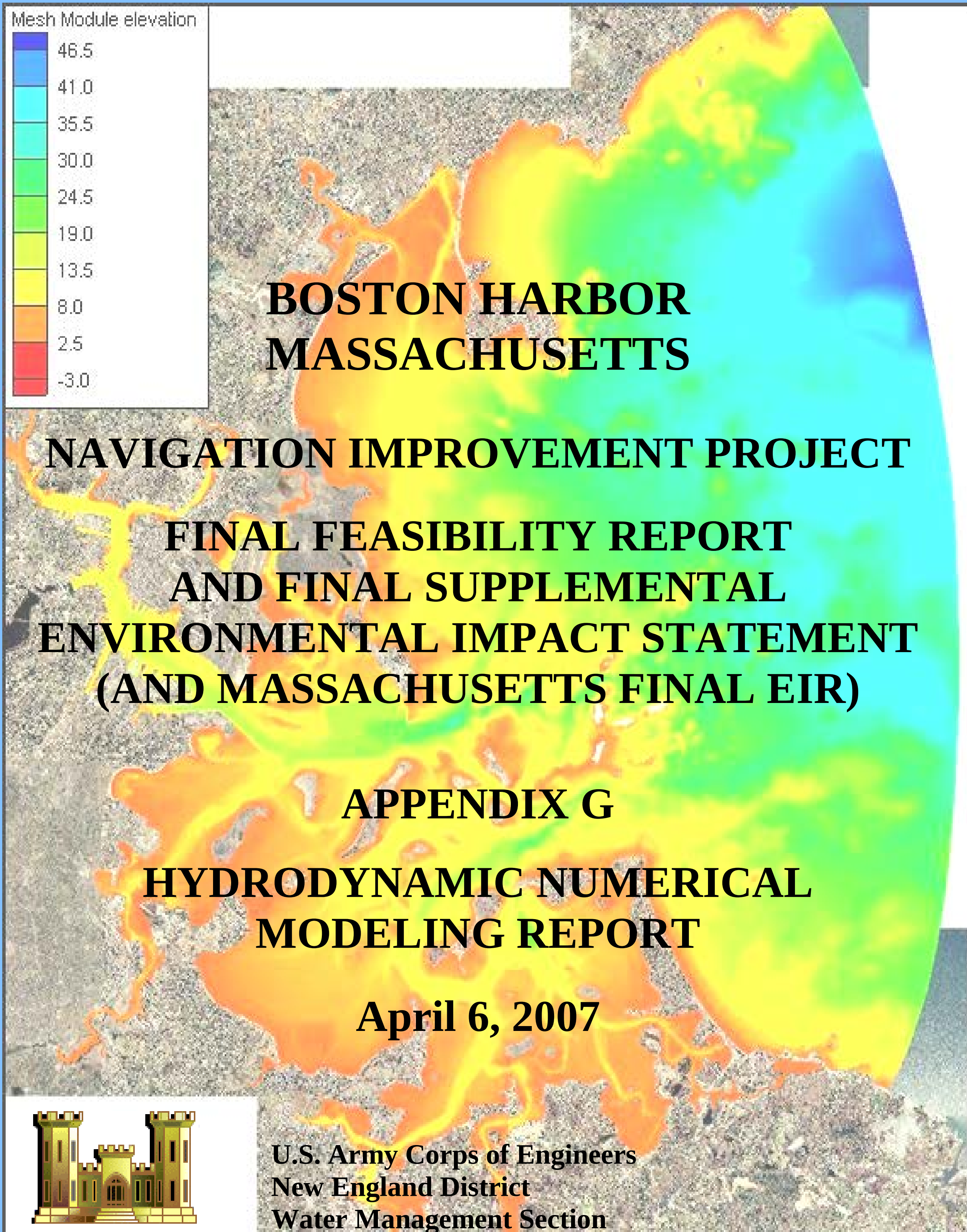
Logan Airport wind measurements file Wind.txt		
Row	Field	Description
1	1	Month and day of measurement (GMT)
	2	Time of measurement (GMT)
	3	Wind speed in meters per second
	4	Direction the wind is blowing from in degrees true
Example: First 6 rows of Wind.txt. Note that the first 6 rows have 4 invalid directions (i.e., 999) and 3 invalid speeds or no wind (i.e., 0.0). 1110 1454 0.0 999 1110 1554 0.0 999 1110 1654 1.5 999 1110 1754 3.6 160 1110 1854 3.6 240 1110 1954 3.6 220		

Table H4. Format of current transect measurement file on project DVD.

Current transect measurements files - name format: transect_month_day_time.txt Example: T5_11_11_1721.txt		
Row	Field	Description
1	1	Year of measurement in 2000 (i.e., either a 4 or a 5) (local)
	2	Month of measurement (local)
	3	Day of measurement (local)
	4	Hour of measurement (local)
	5	Minute of measurement (local)
	6	Second of measurement (local)
	7	Hundredth of a second of measurement (local)
	8	Depth in feet
2	1	Latitude, degrees north
	2	Longitude, degrees west
3	1	Depth-averaged current speed in feet per second
	2	Depth-averaged direction current going to in degrees true

Example: First 6 rows of T5_11_11_1721.txt.

```
4 11 11 12 17 43 32 13.84
 42.3381006 -71.0081996
 0.36 302
 4 11 11 12 17 49 71 14.09
 42.3381592 -71.0081658
 0.43 127
```



BOSTON HARBOR
MASSACHUSETTS

NAVIGATION IMPROVEMENT PROJECT

FINAL FEASIBILITY REPORT
AND FINAL SUPPLEMENTAL
ENVIRONMENTAL IMPACT STATEMENT
(AND MASSACHUSETTS FINAL EIR)

APPENDIX G

HYDRODYNAMIC NUMERICAL
MODELING REPORT

April 6, 2007

U.S. Army Corps of Engineers
New England District
Water Management Section

This Appendix Unchanged Since 2008 Draft Final Report

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List of Figures

1.0 Introduction

As part of the Boston Harbor Deep Draft Navigation Improvement project, a ship simulation model was needed to determine the effectiveness and potential hazards associated with various channel depths and configurations. The ship simulation effort was completed by the Engineering Research Development Center (ERDC) ship simulation section in Vicksburg, MS during the summer of 2005. Mr. Dennis Webb was the lead investigator for the modeling effort. An important component of the ship simulation effort was having correct water velocity information in the simulation so that the ship handling behavior would be realistic. The velocity data was needed along the channel for both the existing and proposed conditions. In order to provide this information a 2-D hydrodynamic model was used. This report will provide an overview of the hydrodynamic modeling effort and the field data collection effort that supported the validation of the model.

2.0 Model Study Approach

The hydrodynamic regime of Boston Harbor has been provided below in a passage taken from the ERDC Data Collection report (discussed in Section 4.0 and provided as Attachment 3)

> *"Boston Harbor and adjacent areas, and the areas of the navigation channel improvement project are shown in Figure 1. Typical navigationally-significant currents in the Harbor are primarily the result of tidal forcing. The semi-diurnal M_2 tidal component, which has a 12.42-hr period, is the most significant. However, these are modulated by the S_2 and N_2 components, resulting in spring tidal currents that are 33 percent stronger than average. The spring tidal currents occur every 15 days. There is relatively little fresh-water input to the Harbor, and density-driven currents are not significant in terms of their effect on ship navigation. Water-level differences over the Harbor (at any one time) are small in the absence of wind. Without wind-driven effects, water levels in the Harbor are controlled by the astronomical tides, and the magnitudes and timing of their variations are nearly the same over the entire Harbor."*

The channel area under consideration for improvement can be seen in Figure 1. The length of channel improvement was nearly 8 miles long. Due to the size of the area being investigated the model domain was large. Considering the size of the model domain and the complexities of the bathymetry a finite element model was chosen for this project.

The ADCIRC model was chosen after looking at both RMA2 and ADCIRC. Through several discussions with users of both models, including modelers from the Engineering Research and Development Centers (ERDC) Waterways Experiment Station (WES), it was clear that either model could perform the task equally well. However, ADCIRC was chosen due to the easier model setup and calibration/validation. The impression was also given that the ADCIRC model was an easier model to learn and less difficult to run.

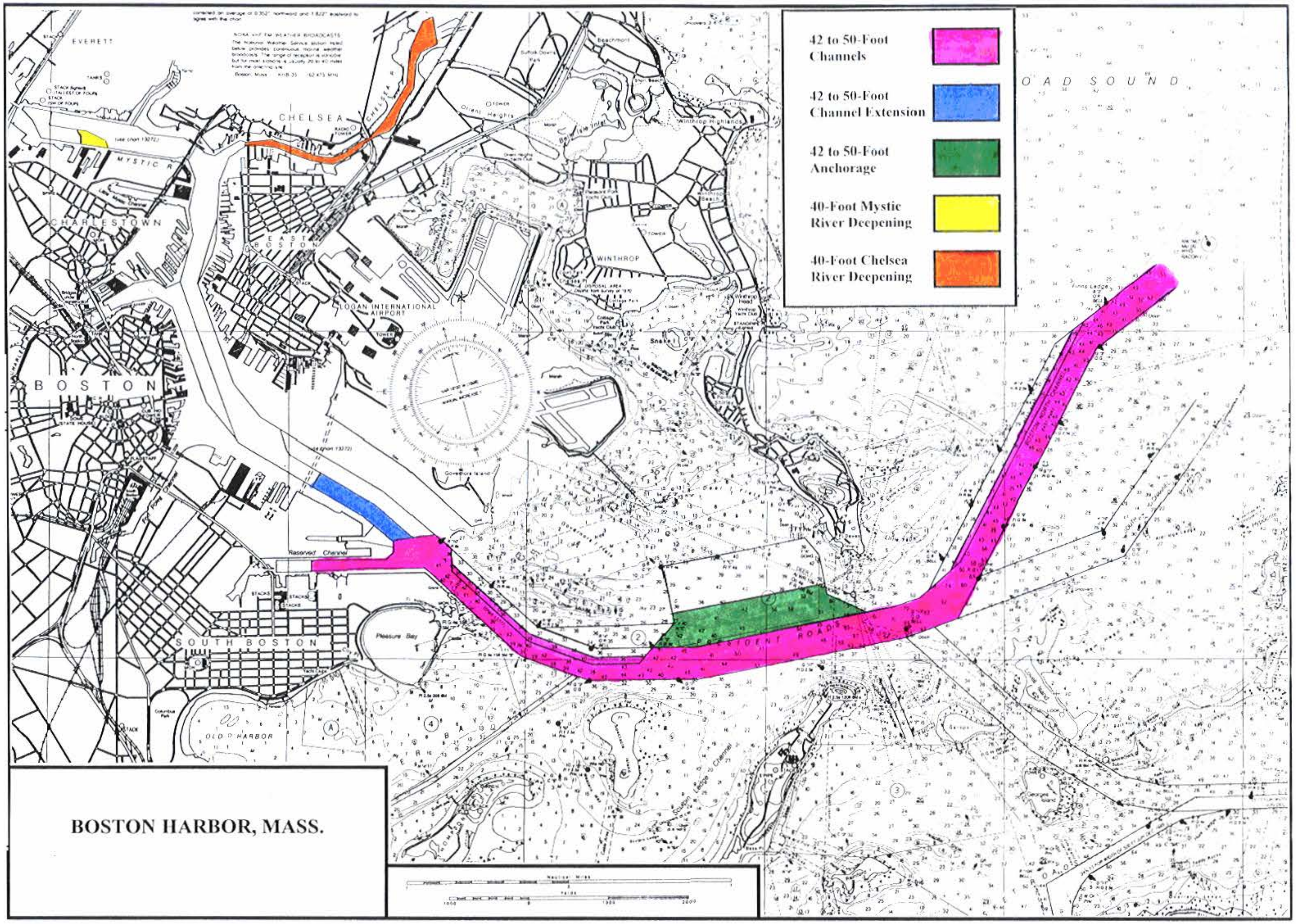


Figure 1. Proposed Channel Improvement Areas

The modeling effort was budgeted and scheduled to be mostly conducted within the New England district. The model budget for set up, validation, and alternative runs was $140,000 with $25,000 of this money earmarked for technical assistance from WES. However, due to a late federal budget approval, funding was not available until later in the fiscal year than anticipated, which shifted the schedule. This required that more of the modeling effort be shifted to WES. Dr. Zeki Demirbilek and Dr. Lihwa Lin from WES provided significant support for this effort. Additionally, three channel alternatives were run in the New York District by Dr. Jennifer Irish due to last minute changes that were necessary to address issues raised by the Massachusetts Port Authority (MASSPort). The NY District had significantly more computing power available to handle the three alternatives and was able to meet the tight time line that was set due to the ship simulator schedule and Boston Harbor Pilot availability. Due to Hurricane Katrina work WES personnel were not available to run the adjusted model alternatives. Additionally, a final set of runs was performed in February of 2007 by WES to provide consistent run lengths and uniform model output in the outer fringes of the model. When the model alternatives were run at the two different locations, different computing platforms were used, which necessitated the alteration of frictional values near the model fringes. This impacted model output away from the channel and did not impact the ship simulation study. The runs were completed for uniformity and to allow for easy comparison between alternative runs, without the interference of model differences on the fringes. All model results have been kept and can be found in digital storage. At the time of this report all files were stored on a set of DVDs. The model results being displayed in this report were from the 02/2007 model runs.

3.0 ADCIRC Model Background

ADCIRC is an acronym for Advanced Circulation Midel and is a widely used and accepted model. A description of the model and its features has been provided below (taken from the ERDC ADCIRC Fact Sheet dated September 24, 2004).

> *"ADCIRC is a finite element hydrodynamic circulation numerical model for water level and current over an unstructured grided domain. ADCIRC can be run as either a two-dimensional depth integrated (2DDI) model or as a three-dimensional model. ADCIRC can be used for modeling tidal and wind- and wave-driven currents in coastal waters; forecasting hurricane storm surge and flooding; inlet sediment transport/morphology change studies, and dredging/material disposal studies. The model has been certified by FEMA for use in performing storm surge analyses.*
>
> *ADCIRC simulates tidal circulation and storm surge propagation over large computational domains, eliminating the need for imposing approximate open-water boundary conditions that can create inaccuracies in model results, while simultaneously providing high resolution in areas of complex shoreline and bathymetry where it is needed to maximize simulation accuracy. The targeted areas for ADCIRC application include continental shelves, near shore coastal areas, inlets, and estuaries.*

Features available in ADCIRC include: wetting/drying of low-lying areas, overflow and through flow barriers, bridge piers, wave radiation stresses, sediment transport, and morphology change. Planned enhancements include modeling salinity, contaminant transport, three-dimensional sediment transport/morphology change modeling, and additional sediment transport algorithms. The model can be run as a single processor code or in parallel mode running efficiently on hundreds of processors."

4.0 <u>Data Collection Effort</u>

In order to provide calibration/validation data, a fairly comprehensive data collection effort was conducted. A team from ERDC in Vicksburg, MS was used to perform the data collection effort with the effort being lead by Mr. Thad Pratt.

The data collection effort consisted of five stationary tide gauges (including NOAA's Boston tide station), two stationary bottom mounted acoustic Doppler current meters, and two boat mounted ADCP data collection efforts. Figures 2 and 3 illustrate the location of the various data collection areas. The boat mounted ADCP data was collected along five transects on 11/11/04 and 02/08/05. The data collection report has been included as Attachment 3.

Three types of data were collected and they were water surface elevation, current velocity data, and wind velocity data. The water surface elevation was recorded using three gages, which actually recorded total pressure. In order to determine tide elevation the pressure transducers were surveyed into NAVD88 and the atmospheric pressure changes were recorded with an un-submersed tide gage/pressure transducer. With the elevation of the pressure transducer known, and the atmospheric pressure changes removed from the recorded signal, the remaining pressure signal was that of the water elevation. The pressure signal was converted to water surface elevation using typical ocean water density. The NOAA Boston Harbor Benchmark/tide collection gage was also used in this study to provide data at a fourth location. The location is also shown on Figure 2.

Since ADCIRC can incorporate wind data, wind was included in this effort. Originally, a meteorological station (MET) was going to be placed on one of the exterior islands outside of the harbor but it was ultimately decided to use the MET station at Boston Logan Airport (Figure 2). Given the exposed condition of this station it was thought that the data would be more than adequate for the purposes of this effort.

Current velocity data was collected using Acoustic Doppler Current Profilers using to different methods. The first was a permanently stationed, bottom mounted, upwards looking, ADCP and the other was using a boat mounted ADCP which was used to run repetitive channel cross sections. The location of the bottom mounted profiler and the boat transects can be seen in Figure 3.

Data collection return was fairly good with only one gage failing. The bottom mounted ADCP at CM1 failed and did not provide any data. The other gages provided data return rates of 85% to 100%. The return rate for each gage can be seen in Figure 4.

As mentioned earlier a complete description of the data collection effort can be found in Attachment 3, along with the formatted data. Only examples of the data will be provided of each data set in the body of this report. The graphical displays of the data can be seen in Figures 5 through 9. In addition to the hard copy data report and data graphics, at the time of this report, the entire set of data resided at the New England District with Mr. John Winkelman in the Water Management Section on a DVD.

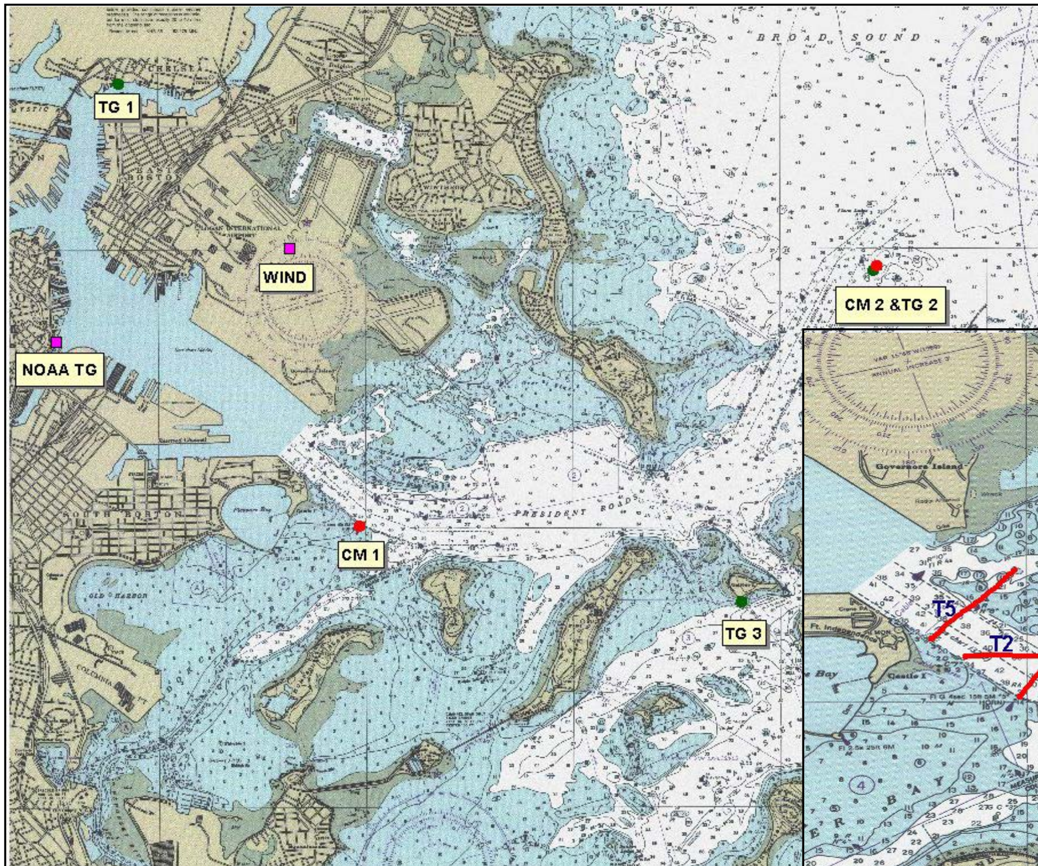


Figure 2. Data collection stations (TG=tide gage and CM= current meter)

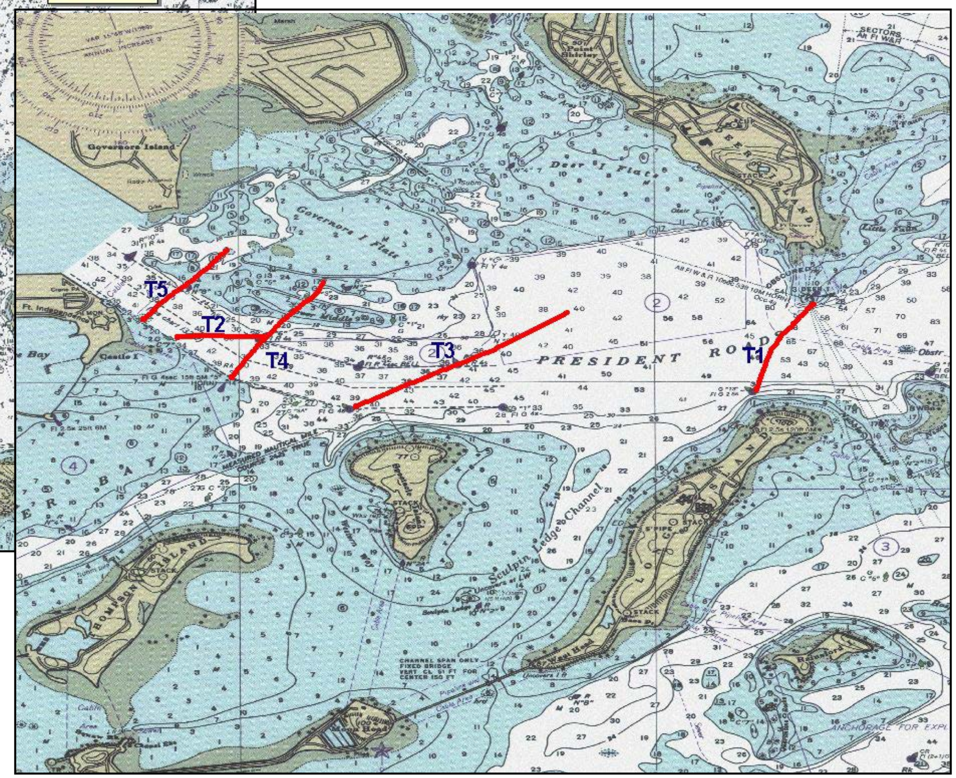


Figure 3. Boat mounted ADCP current profile transects

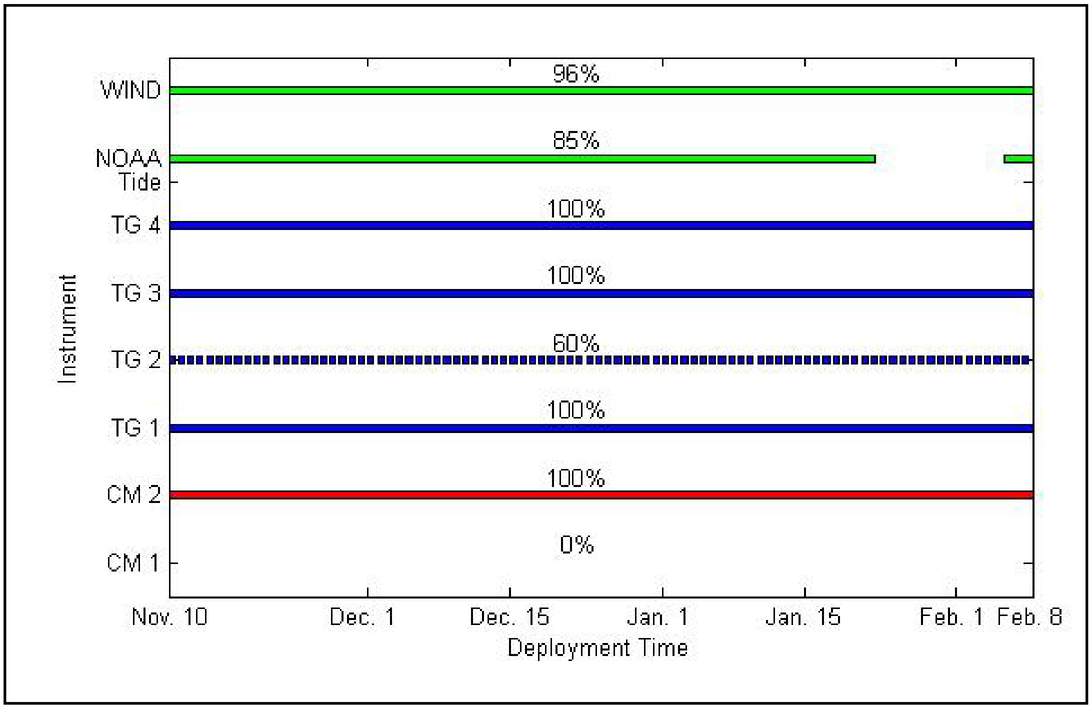


Figure 4. Data retrieval success.

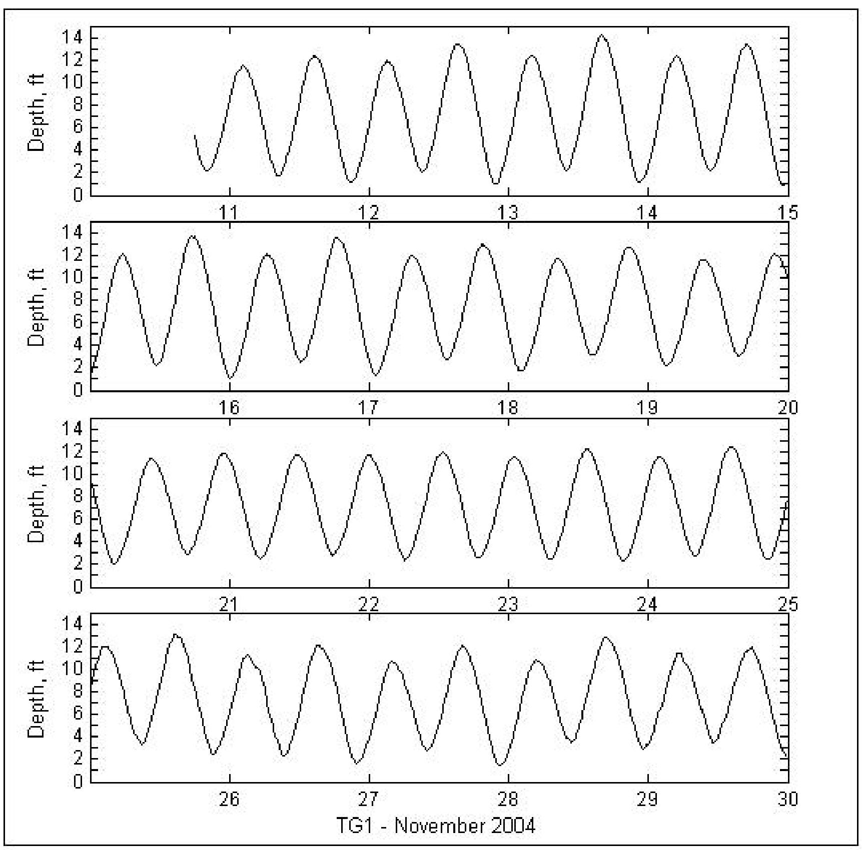


Figure 5. Sample tide data collected at tide gage 1.

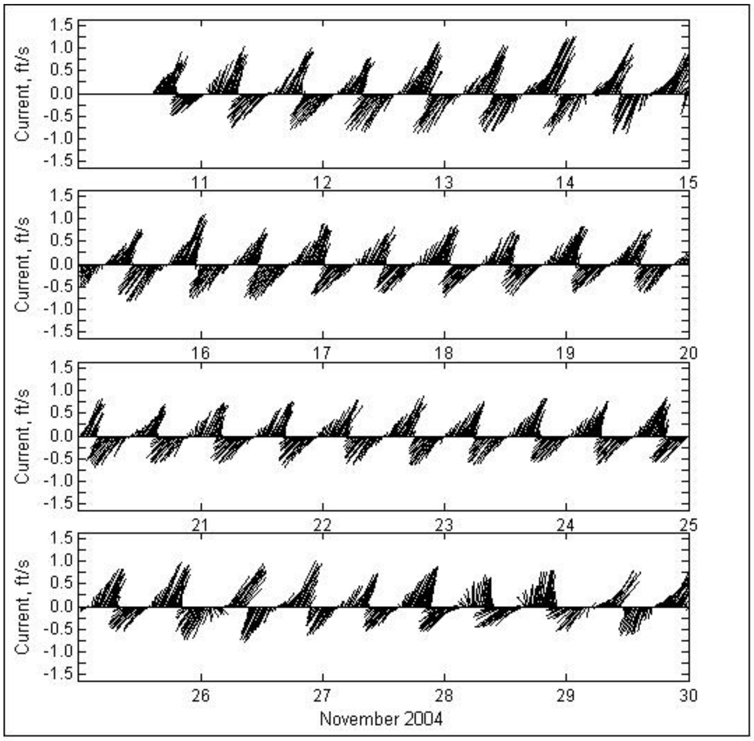


Figure 6. Sample of bottom mounted ADCP current measurements (CM2).

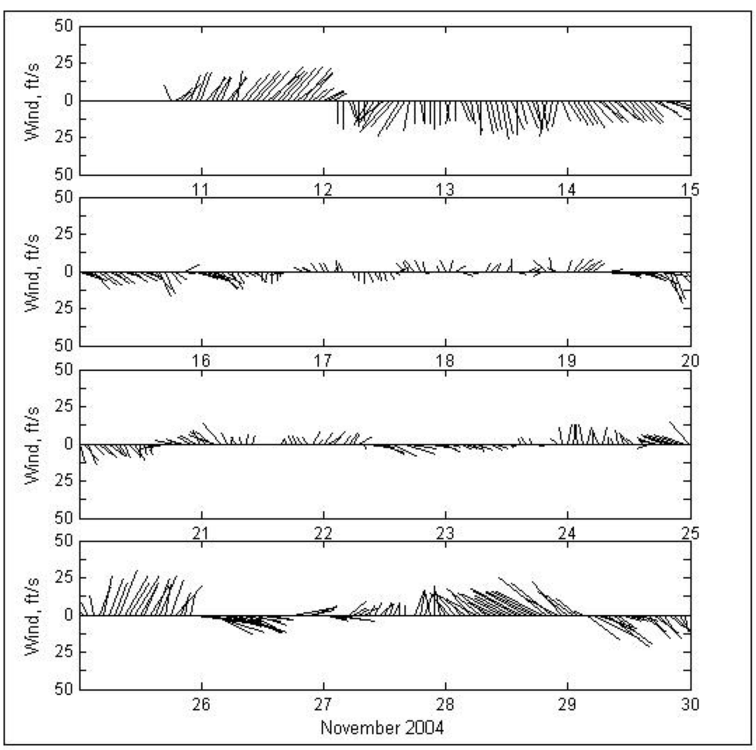


Figure 7. Sample of wind data from Boston Logan International Airport.

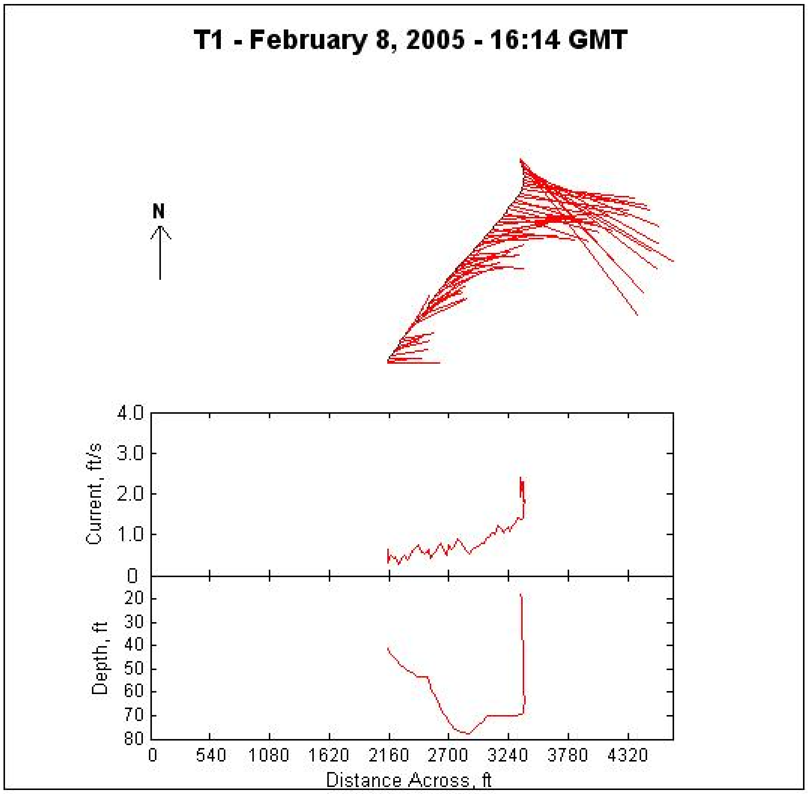


Figure 8. Sample boat mounted ADCP current data transect (depth averaged).

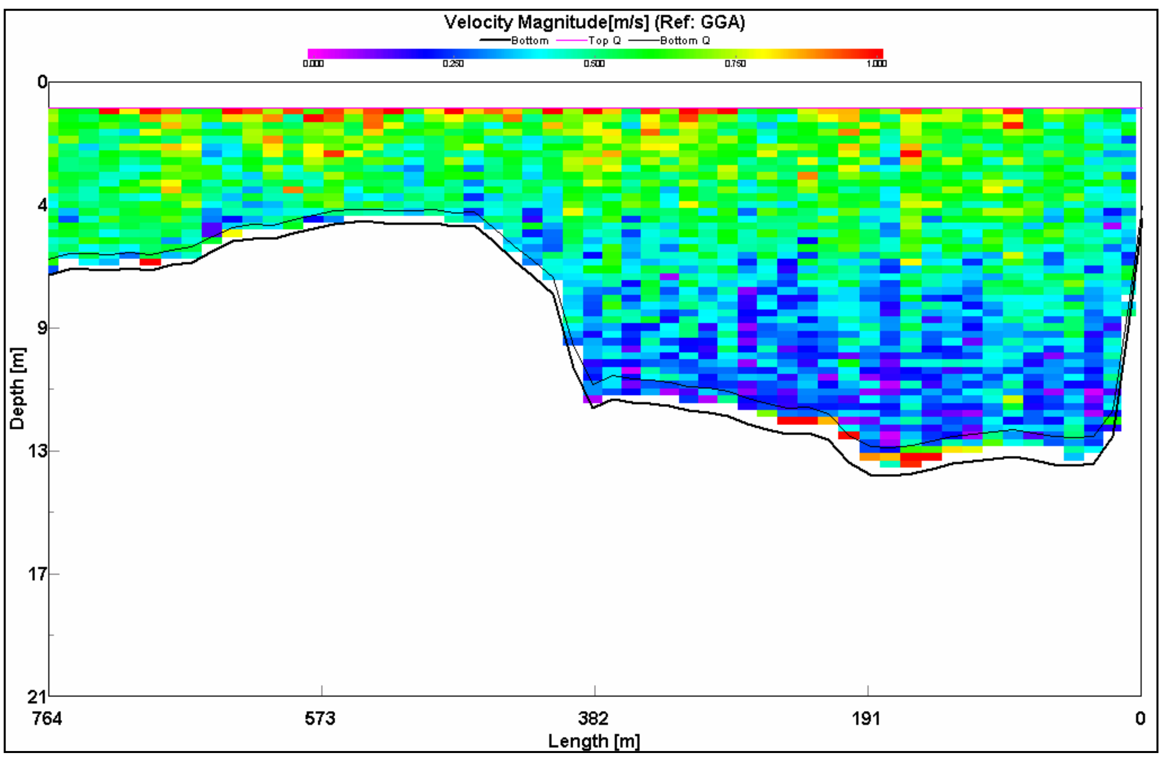


Figure 9. Sample boat mounted ADCP current data transect (full data).

5.0 Model Setup

The modeling effort was basically broken up into three steps which included model setup, model validation, and alternative analysis. The model setup up was performed using both the Surface Modeling System (SMS) and ArcMap GIS software.

The model input files, along with the running of the model was done through the SMS 9.0 interface. The grid and mesh files were generated using the model boundaries discussed in Section 5.2 and the bathymetry data discussed in Section 5.1. The boundaries were converted into densely spaced XYZ point files. The bathymetry data was too dense as provided and it was thinned in SMS. The data within Boston Harbor was kept at a more dense level than further off shore.

5.1 Model Bathymetry

The first step in the model setup was determining the extent of the model necessary to avoid having the ocean/tidal driven boundary conditions too close to the navigation channel. As discussed in Section 5.2.2 it was decided to extend the ocean boundary out to Marble Head, MA on the north side and near Cohasset Harbor on the south side. These two areas were connected by a semicircular/arc and which is shown in Figure 23 (in Section 5.2.2). In order to obtain bathymetry data for such a large area, data was obtained from NOAA's GEODAS data portal, which can be found at the following web site http://map.ngdc.noaa.gov/website/mgg/nos_hydro/viewer.htm. For the more immediate project area, specifically the federal navigation channels, the most recent available bathymetric survey data from the New England District Survey Section was used.

5.1.1 NOAA GEODAS Data

The GEODAS data files contain the digital point data that is used by NOAA to generate the NOAA navigational charts. The advantage of using GEODAS data is that the point density is higher than from digital charts or from digitizing navigational charts and it is already in a digital format. When using the GEODAS interactive viewer, large areas can be selected to retrieve data from. However, it must be realized by the user (at least at the time of this study) that the data was compiled from numerous surveys and individual files that were recorded in two different vertical datums. For the area in this study portions of the data were delivered in the vertical datums of MLW and MLLW. This meant that the entire area could not simply be highlighted and delivered as one large file. Instead the data was sent as individual files and the data was corrected using the proper adjustments from MLLW or MLW to MSL. The corrections were obtained from the Boston Harbor Benchmark Station # 8443970 which can be seen in Table 1. The Boston Harbor station is the control station for all of the prediction tide stations in the area to be modeled. The corrections to the various tide prediction stations within the model domain were checked against the Boston station and the vertical differences between MSL and MLW/MLLW were insignificant. Additionally the bathymetry data was converted from feet to meters.

Table 1. Boston Harbor Benchmark Data – Station # 8443970

Datum	MLLW feet	MTL feet	NGVD29 feet	NAVD88 feet
MEAN HIGHER HIGH WATER (MHHW)	10.27	5.18	5.57	4.77
MEAN HIGH WATER (MHW)	9.83	4.74	5.13	4.32
NORTH AMERICAN VERTICAL DATUM-1988 (NAVD)	5.51	0.42	0.81	0.00
Mean Sea Level (MSL)	5.20	0.11	0.50	-0.31
MEAN TIDE LEVEL (MTL)	5.09	0.00	0.39	-0.42
NGVD29	4.70	-0.39	0.00	-0.81
Mean Low Water (MLW)	0.45	-4.64	-4.25	-5.06
Mean Lower Low Water (MLLW)	0.00	-5.09	-4.70	-5.51

LENGTH OF SERIES: 19 Years
TIME PERIOD: January 1983 - December 2001
TIDAL EPOCH: 1983-2001

The map showing the various NOAA surveys can be seen in Figure 10 and the list of the survey identification numbers is provided in Attachment 1. The data was requested from the GEODAS interactive server in MA State Planes NAD 83 Meters in order to match the State of MA 2001/2003 aerial photography used as a background layer in the SMS interface and ArcMap GIS.

Figures 11 and 12 and have been included to provide the reader an idea of the point density provided by the GEODAS data. The figures show the entire model domain, and include one showing just the inner harbor of Boston.

5.1.2 New England District Survey Data

Since much of the GEODAS data from NOAA was not taken very recently, with several of the surveys being conducted in the 1940's, the more recent survey data collected by the New England District Survey Section was used for the navigation channel bathymetry. The surveys used can be seen in Figure 13. In addition to the data being more recent it was collected at a much higher density, which was necessary to pick of the features of the federal channel and the areas within the Inner Harbor.

The data from the Corps Survey was converted into the horizontal datum of Massachusetts State Plane NAD83 meters in ArcMap GIS/Arc Catalog. This datum was chosen to match the datum of the most recent set of aerial photography taken by MA. These photos were used as a background layer, but more importantly to provide the model shoreline boundary.

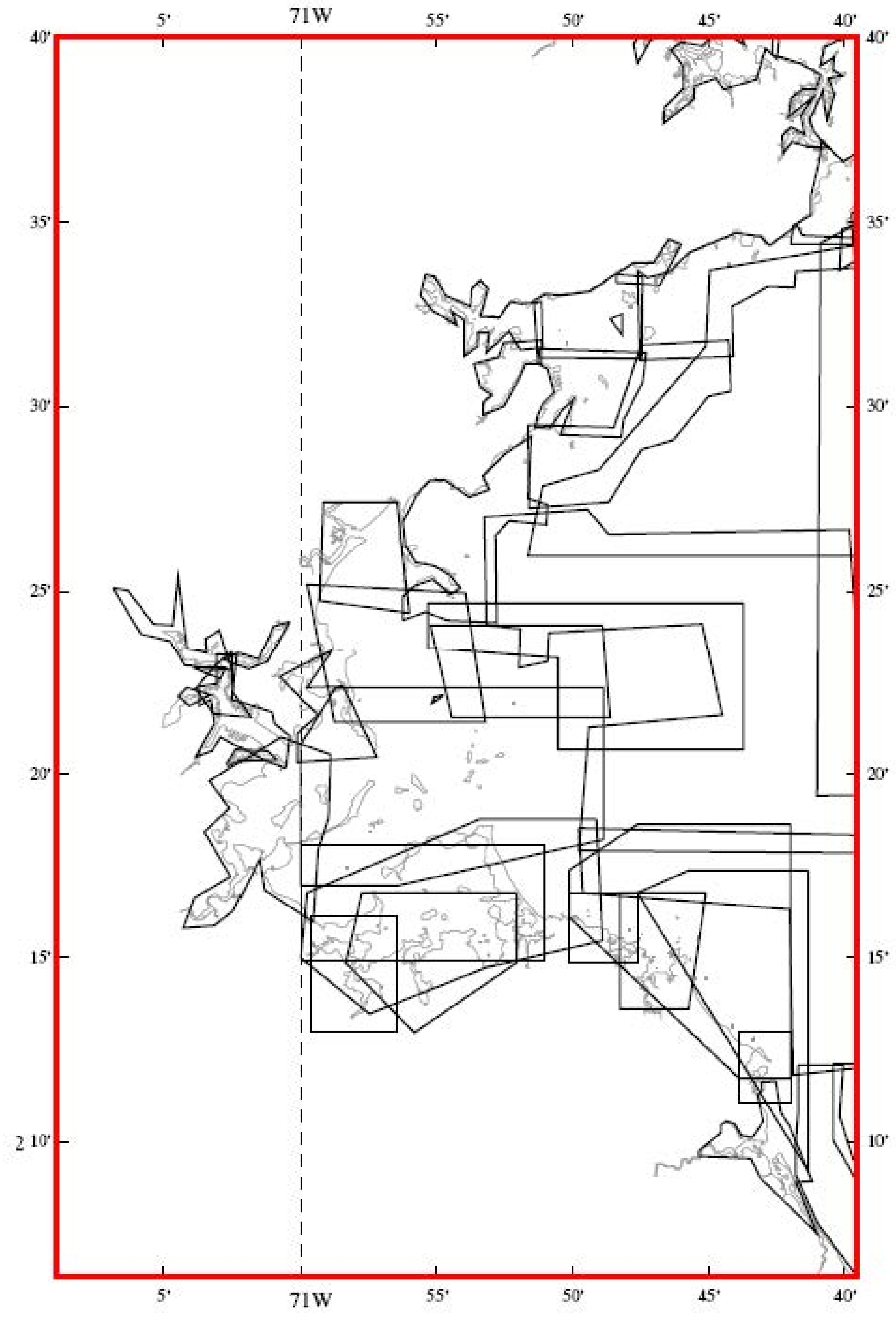


Figure 10. GEODAS surveys used.

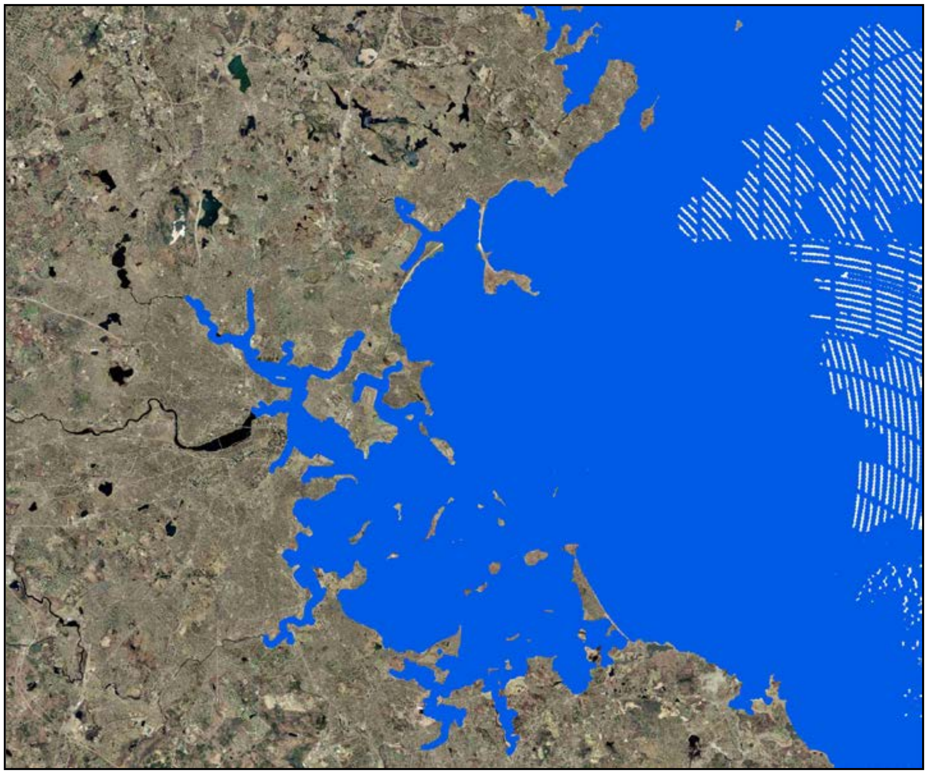


Figure 11. GEODAS data coverage

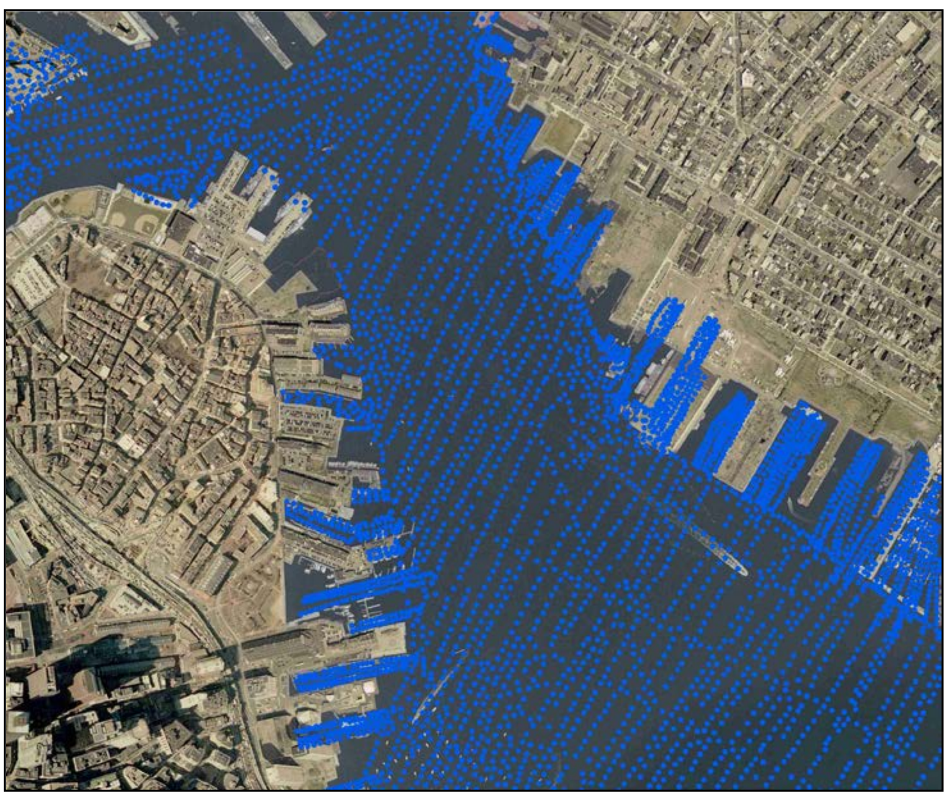


Figure 12. NOAA GEODAS data zoom in of Boston Harbor.

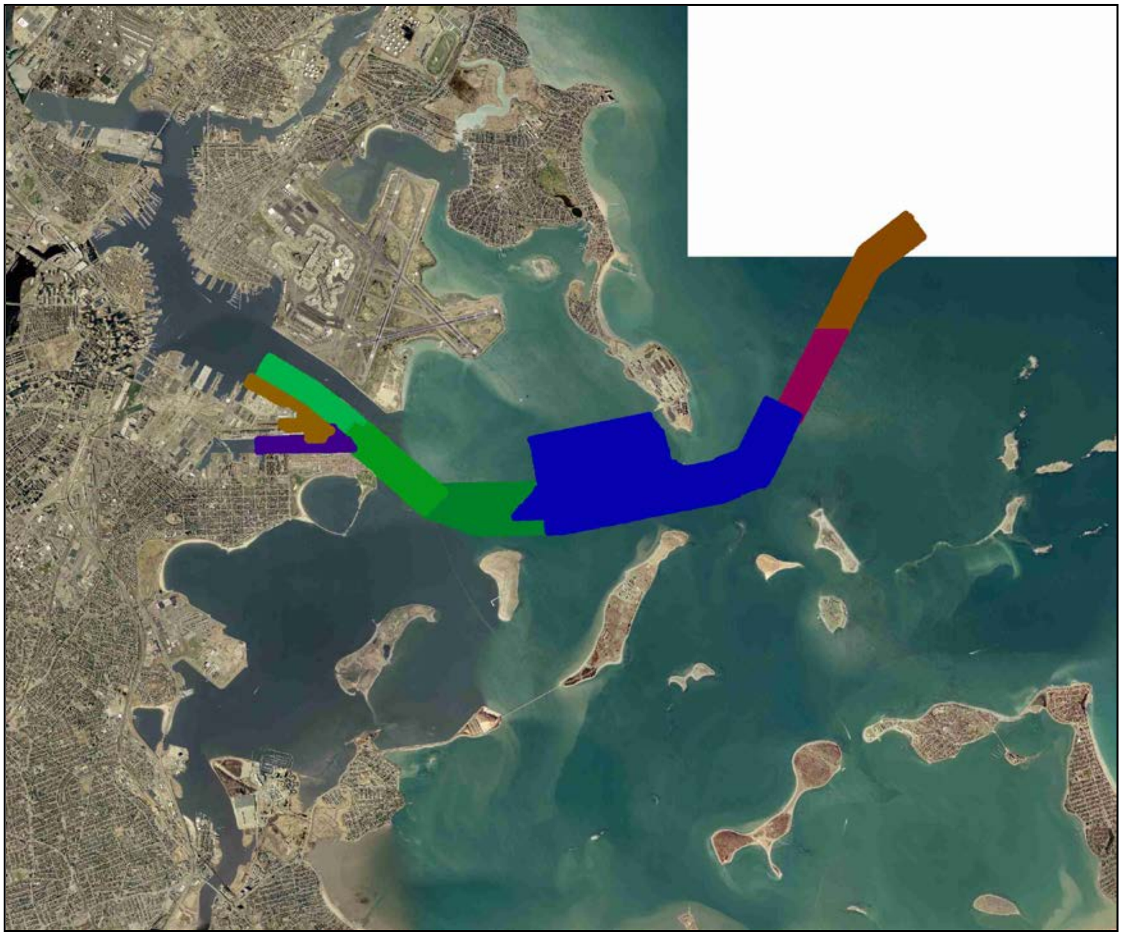


Figure 13. New England District-USACE Survey Data

5.1.3 Existing Condition Model Grid and Model Bathymetry Used

The bathymetry data from both NOAA GEODAS and the New England District were brought into the Corps Surface Modeling System (SMS) version 9.0 to generate the model grid. As previously mentioned, ADCIRC is a finite element model, which allows the grid element size to vary, without grid nesting. The model grid/mesh element sizes can be varied in size depending on the level of accuracy needed in a particular area or for model stability issues (fast current, sharply changing bathymetry, etc.). Due the scale of the model domain, the detailed nature of the Boston Harbor shoreline, and the numerous tidal marsh/channel areas, this was an important feature of the model. The model grid (elements can be seen in Figures 14, 15, and 16. Figure 14 shows the entire model domain, while Figures 15 and 16 provide zoomed in views of the grid to demonstrate the detail of the grid. The largest grid cell size (in deep water) is 518 meters wide, while the finer grid cells are on the order of several meters wide. Figures 17 and 18 show the resultant bathymetry used for the modeling effort and Figure 19 is a zoomed in view of Boston Harbor's Reserve Channel/Turning Basin area. Take note that the vertical scale is different from figure to figure due to the varying elevation ranges in each figure. The shoreline used to define the model grid will be discussed in the next section.

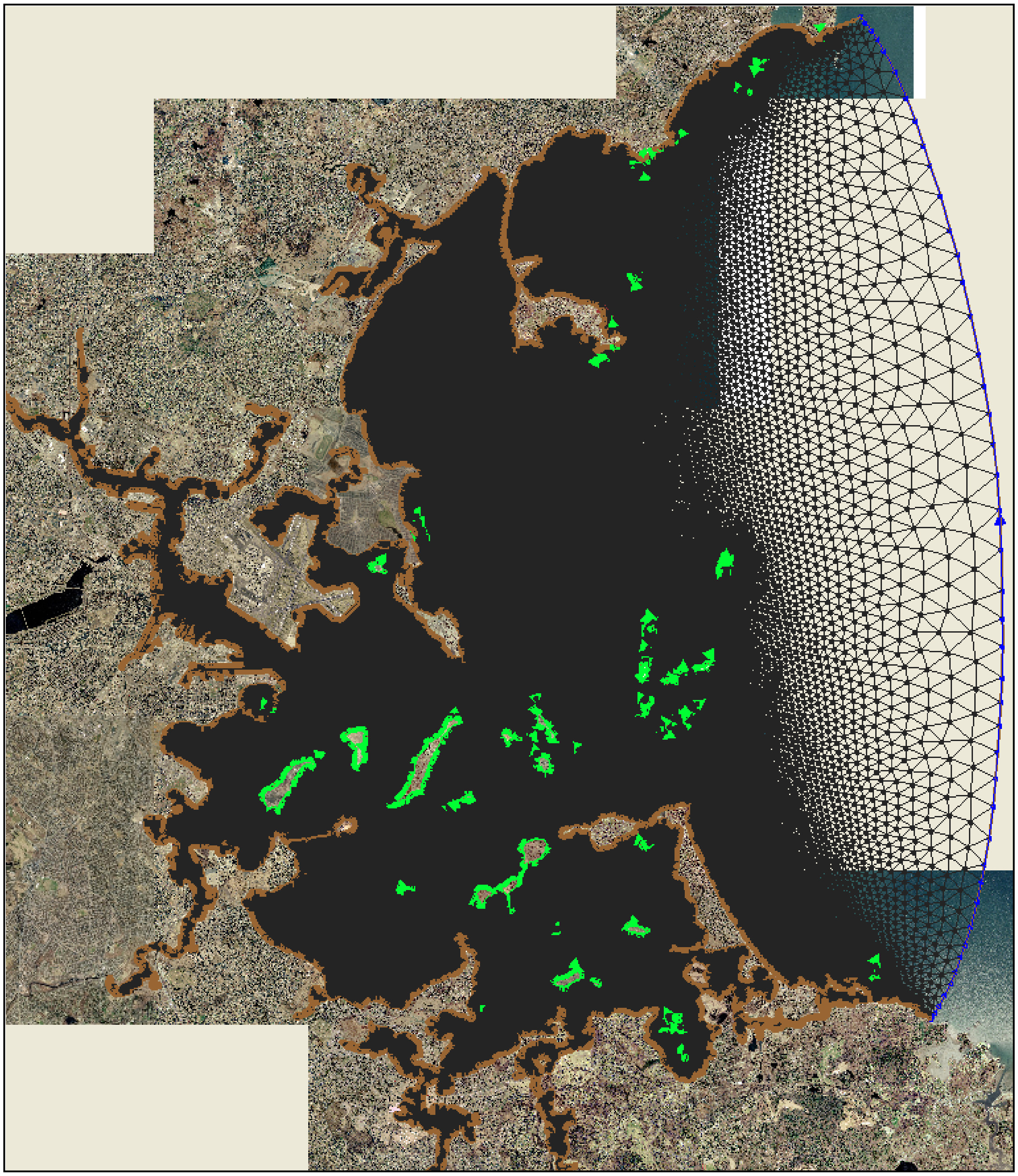


Figure 14. Full mesh for Boston Harbor ADCIRC model.

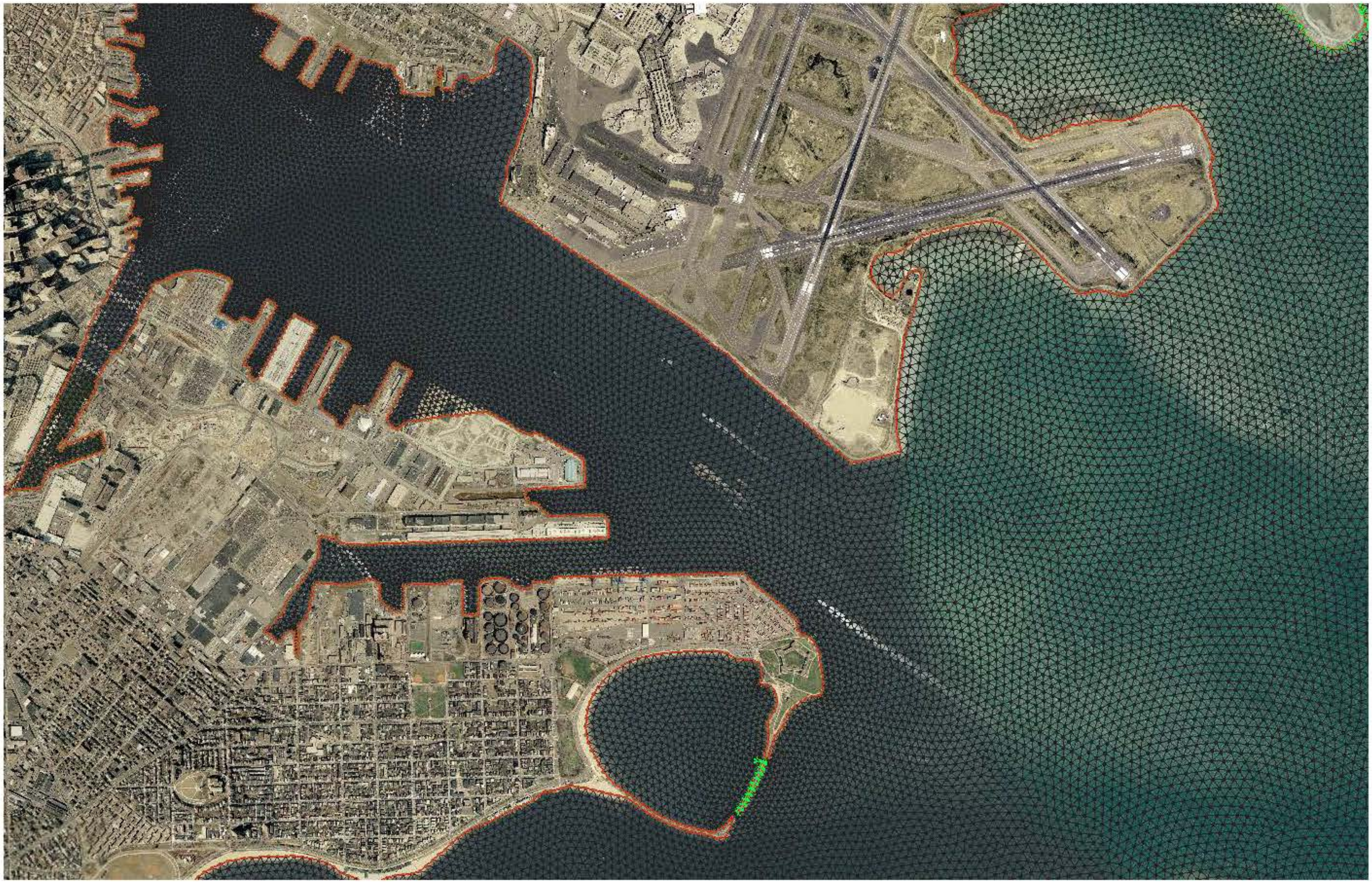


Figure 15. Model mesh zoomed in view.

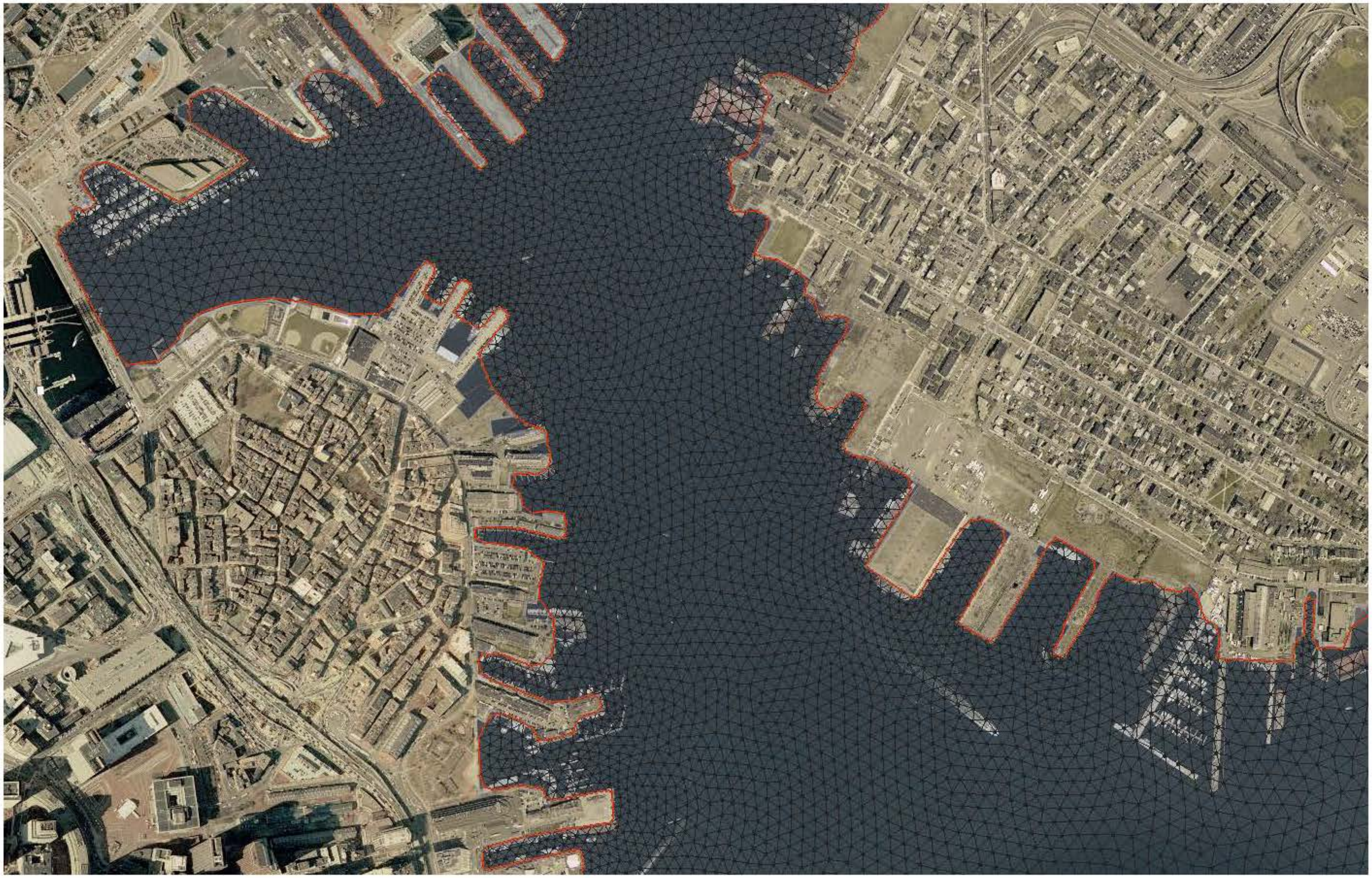


Figure 16. Boston Harbor model mesh – example of mesh detail

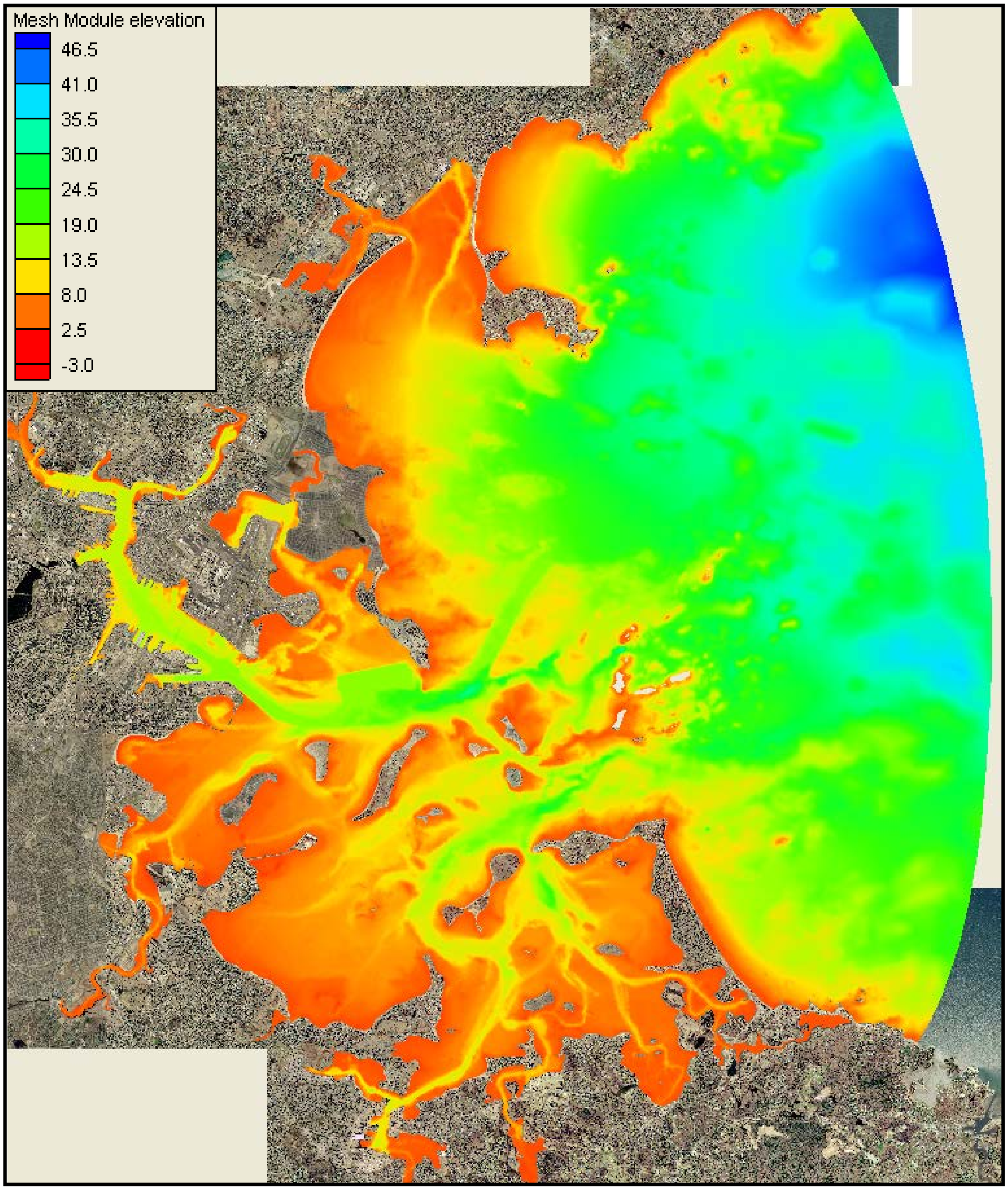


Figure 17. Bathymetry used for existing conditions model (Meters-MSL).

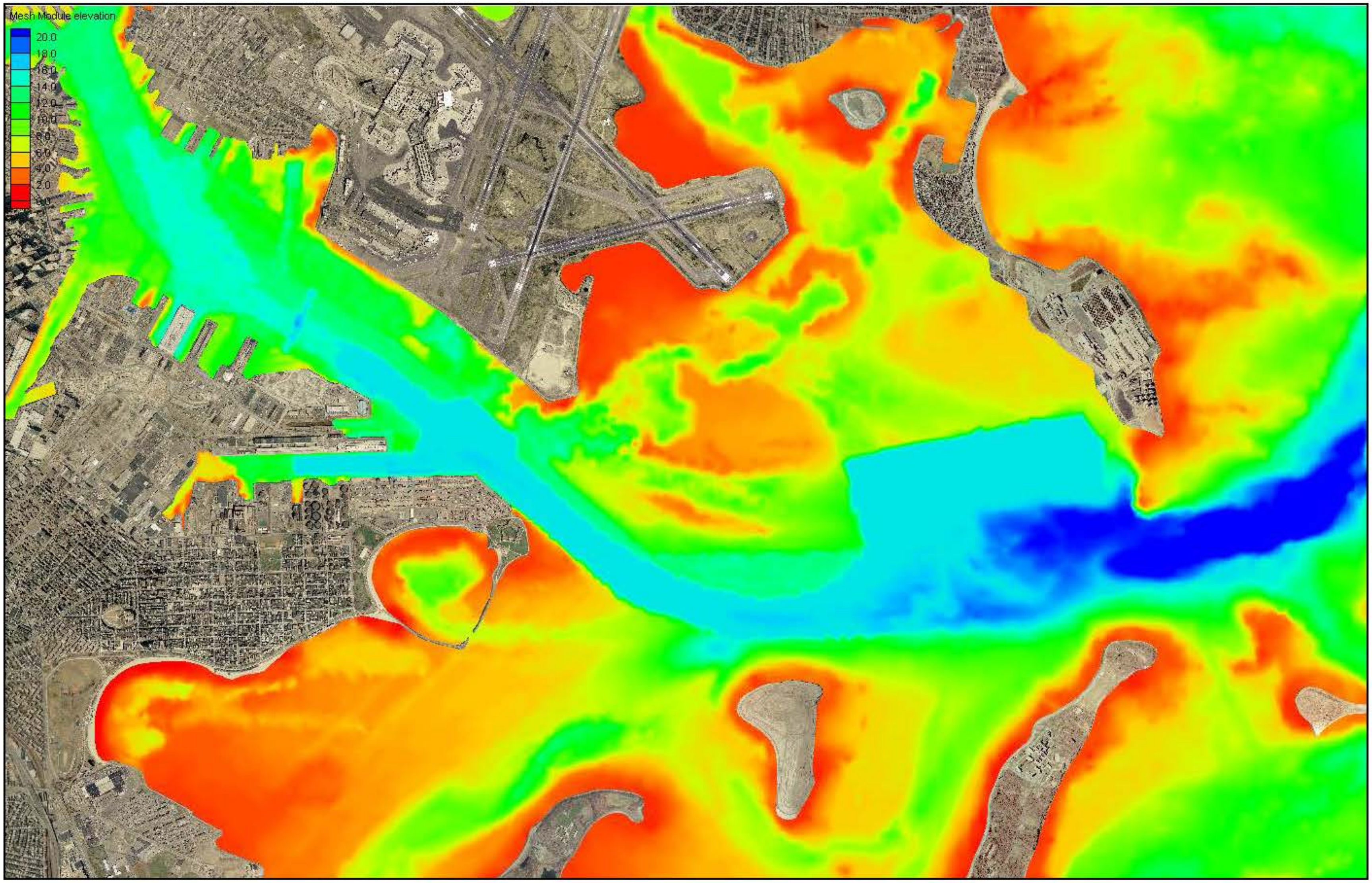


Figure 18. Bathymetry of Boston Inner Harbor used for existing model (Meters-MSL).

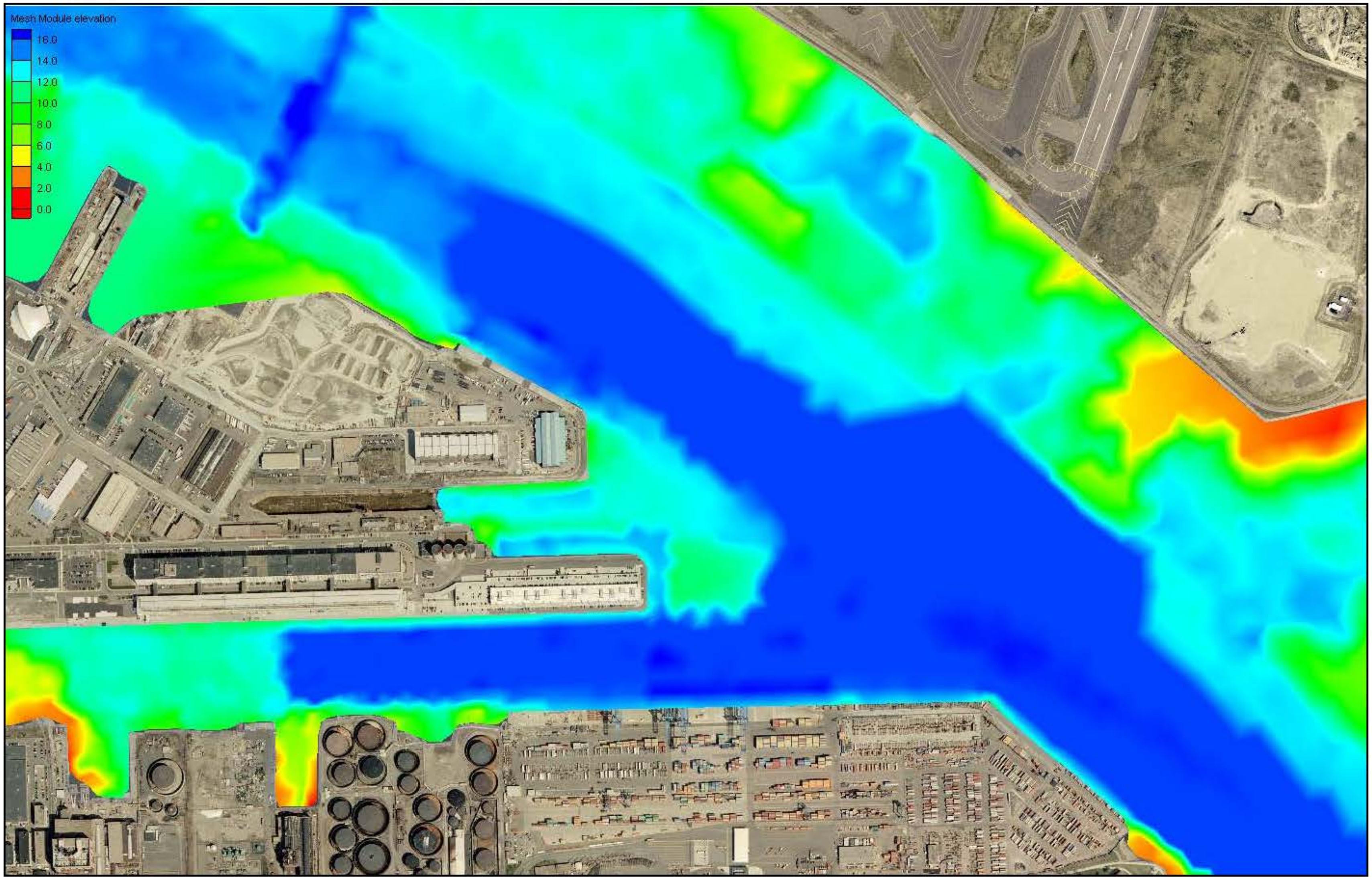


Figure 19. Boston Harbor Reserve Channel and Turning Basin bathymetry for existing conditions model (Meters-MSL)

5.2 Model Boundaries

5.2.1 Model Shoreline Boundary

The shoreline data for the model domain was obtained by meticulously tracing the shoreline from the State of MA 2001/2003 ortho-photos. Both the MA shoreline GIS layer and the NOAA shoreline from the Coastal Services Center were initially planned to be used but after attempting to correct numerous large scale discrepancies it was decided to invest the time and create an accurate shoreline for this modeling effort. From the aerial photos, the shoreline was mapped in ArcMap GIS using approximate beach/shoreline markers such as wetted bound, rock coloration, vegetation lines, channel boundaries in marshes, and hard vertical features such as piers. These features could result in errors on the scale of several meters, but considering the large model domain and the intended purpose of the model it was determined that these errors were insignificant. It is also expected that there are some errors within the inner harbor of Boston Harbor. The pier structures were not ground truthed so it was difficult in some instances to determine if these features were pile mounted features or filled or bulkhead type features. Once again considering the model domain it was anticipated that these issues would not impact the model. The shoreline has been provided in Figures 20 and 21, which show the entire domain shoreline, and a close up to show the reader how it compares to the aerial photos used. In order to use the shoreline in the model the ArcMap based shoreline was converted to a fairly dense point file. The spacing between shoreline points was less than ten meters and can be seen in Figure 22.

5.2.2 Ocean Boundary

The ocean boundary was defined fairly far out from the project area to keep the influences of the boundary condition away from the area of interest. As mentioned the models ocean boundary swept from Marble Head, MA to near Cohasset Harbor, MA on an arc with a roughly 12.5 mile radius from the turning basin at the end of the Reserve Channel in Boston Harbor (Figure 23). The tidal conditions or model driving conditions at the ocean boundary were taken from the Portland, ME tidal recording station. The NOAA tidal station at Portland ME, records and reports tidal elevations every 6 minutes. The data was easy to acquire from NOAA's web page. At first this choice for boundary condition elevations may seem inappropriate, but comparing the Portland, ME Benchmark Station # 8418150 (provided as Table 2) to the Boston Benchmark (Table 1 Section 5.1.1) it can be seen the tidal regimes are very similar. Looking at predicted tidal information from NOAA it can be seen that at the northern end of the ocean boundary the low tides occur at identical times and high tide is only separated by five minutes. At the southern end of the model boundary the discrepancy in time is slightly larger with high tide occurring 12 minutes later than at Portland only 11 minutes later for low tide. The tidal range is only 0.30 feet different as well.

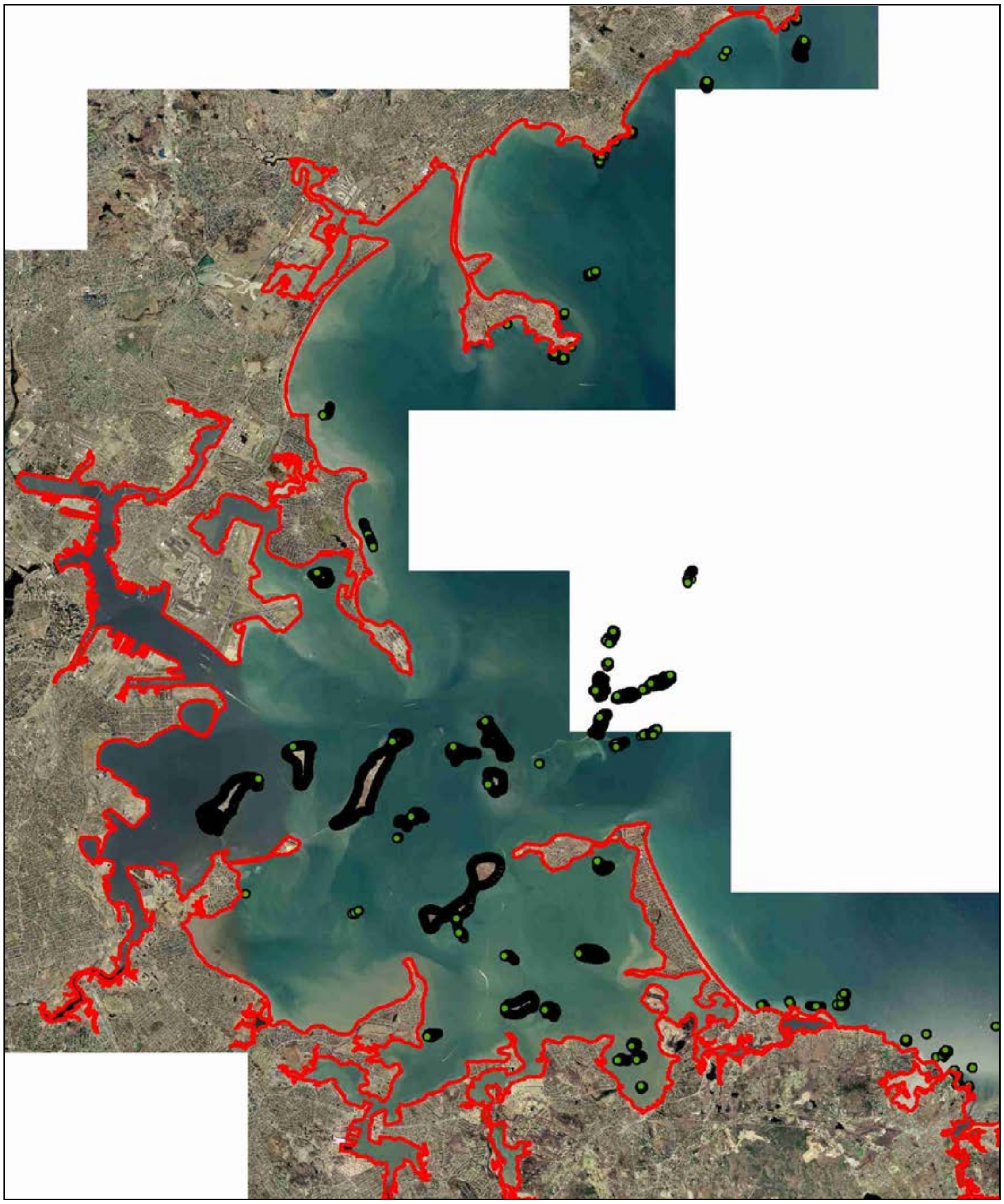


Figure 20. Boston Harbor shoreline map for model domain.

Figure 21. Zoomed in view of Boston Harbor shoreline map.

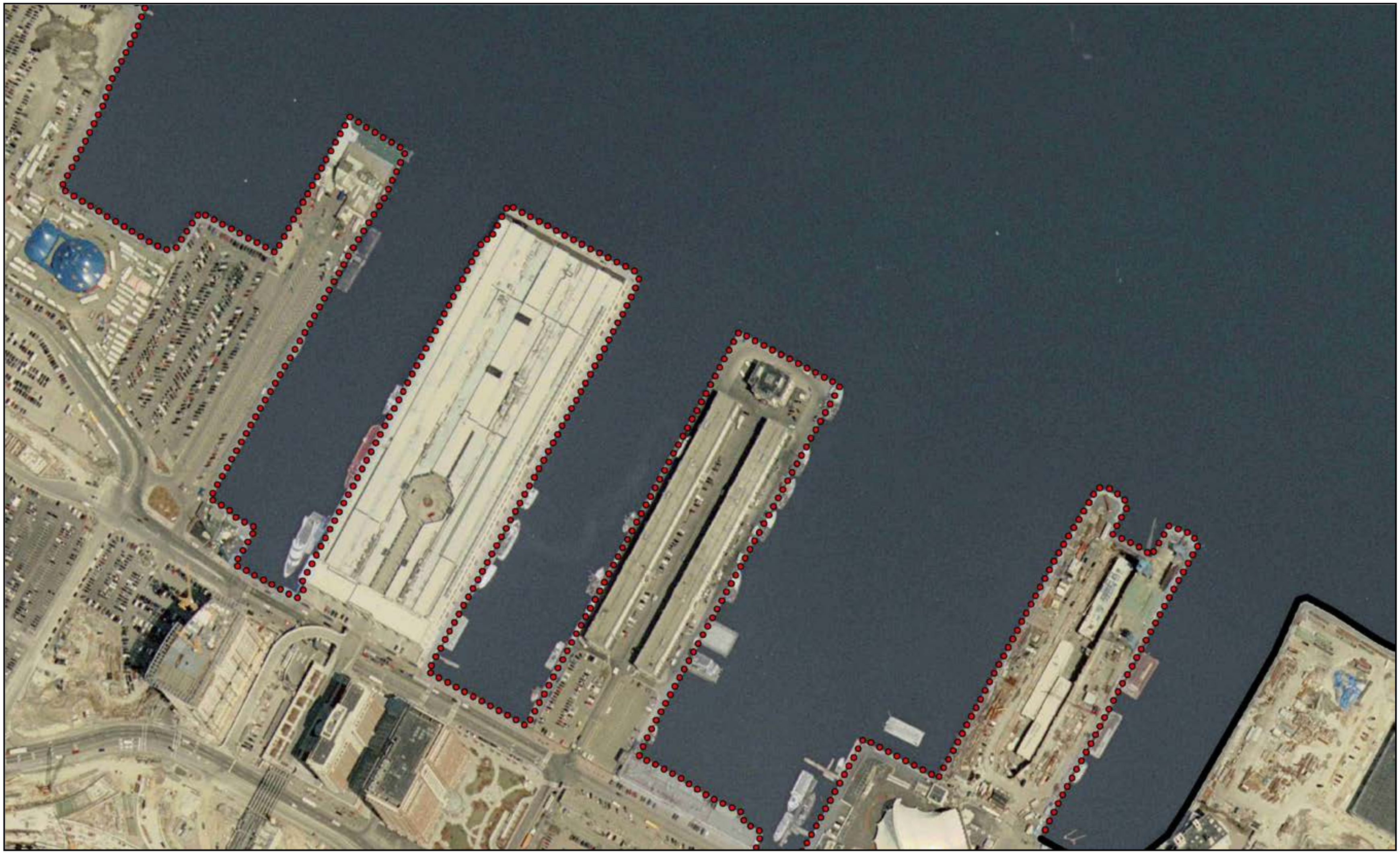


Figure 22. Boston Harbor shoreline converted to points to use in SMS/model mesh

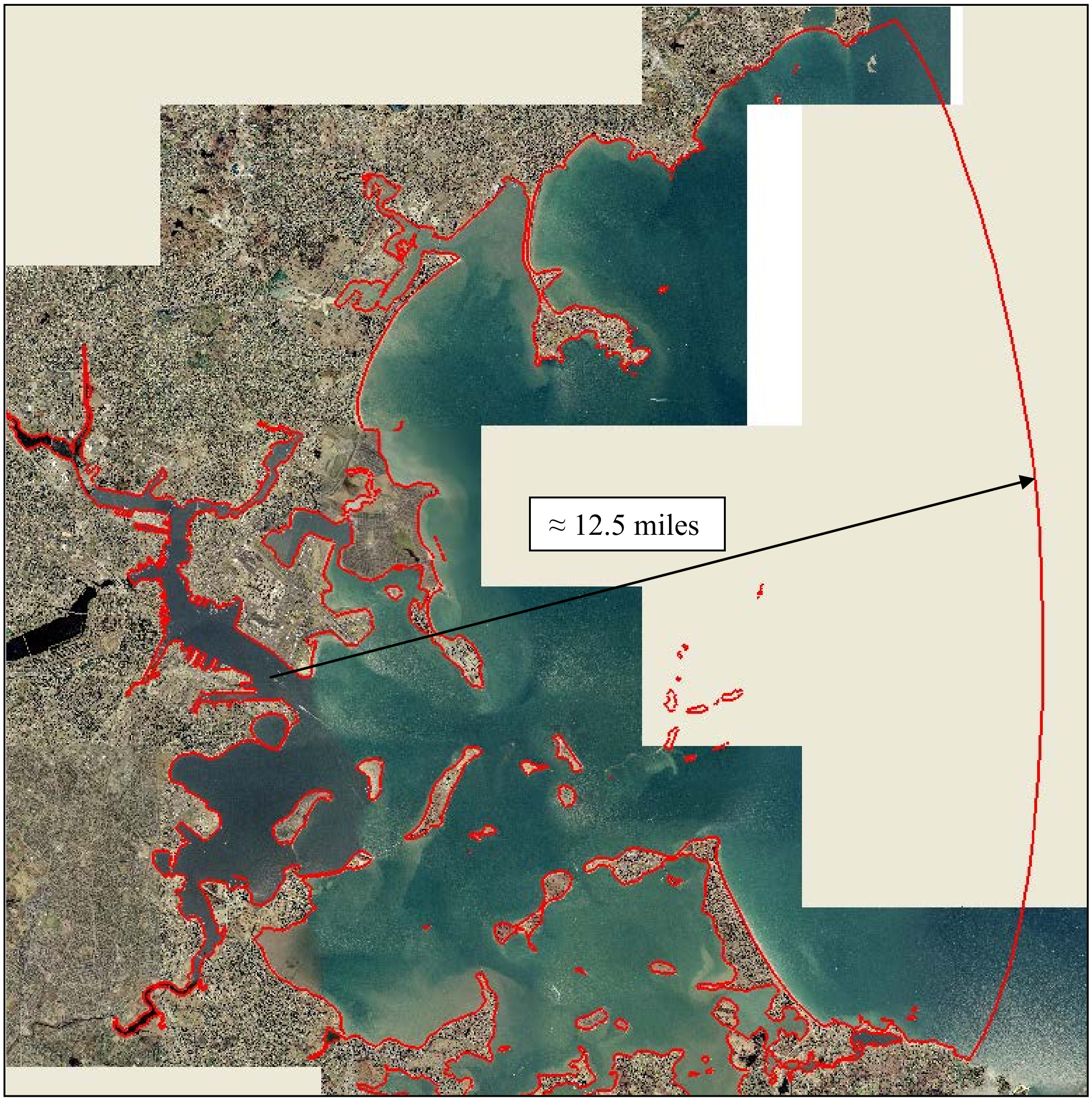


Figure 23. Model boundaries.

Table 2. Portland, ME Benchmark – Station # 8418150

Datum	MLLW feet	MTL feet	NGVD29 feet	NAVD88 feet
MEAN HIGHER HIGH WATER (MHHW)	9.91	5.00	5.39	4.66
MEAN HIGH WATER (MHW)	9.47	4.56	4.95	4.22
NORTH AMERICAN VERTICAL DATUM-1988 (NAVD)	5.25	0.34	0.73	0.00
Mean Sea Level (MSL)	4.94	0.03	0.42	-0.31
MEAN TIDE LEVEL (MTL)	4.91	0.00	0.39	-0.34
NGVD29	4.52	-0.39	0.00	-0.73
Mean Low Water (MLW)	0.34	-4.57	-4.18	-4.91
Mean Lower Low Water (MLLW)	0.00	-4.91	-4.52	-5.25

LENGTH OF SERIES: 19 Years
TIME PERIOD: January 1983 - December 2001
TIDAL EPOCH: 1983-2001

5.3 Frictional Information

The bottom friction, or Manning's "n", coefficients used across the model domain are shown in Figure 24. The main intent of the higher frictional values shown in the figure was to provide model stability. Exact care was not given in these areas and model results in these areas are likely not accurate. The main concern of this effort was the deeper navigation channel areas. If this model is to be used in the future to investigate the wetlands and smaller basins included in this model domain the model will need to be calibrated/validated for these areas.

6.0 Model Validation

In order to validate the ADCIRC model, an extensive field data collection effort was undertaken during the winter of 2004/2005. This effort was discussed in Section 4.0 with the detailed data collection being provided in Attachment 3.

For this effort calibration was not really performed, instead only model validation. Due to the ADIRC model code, there are not many variables to adjust. The model was run for two ten day simulations that covered the dates of February 1st to 10th, of 2005. The first run included wind while the second one did not. Significant differences were not noticed between the two runs. The model validation results can be seen below in three sets of information. The first set (shown in Figure 25), shows the comparison of the water elevation at various locations across the model domain. The points are located at the tide data recording stations from the data collection effort (locations shown in Figure 2). The second type of data used for validation was the current velocity information collected at the CM2 current meter location. This current meter was the eastern most bottom mounted ADCP current meter (location shown in Figure 2). As discussed in Section 4.0 the bottom mounted ADCP located in the inner harbor (CM 1) failed and no data was collected. The depth averaged current velocity data was compared directly to the model data at the ADCP gage coordinates. The results of the comparison are provided graphically in Figure 26. The third set of data/information that was used to validate the model was the boat mounted ADCP transect current data. The comparison between transect data and the model was not as straight forward as comparing the model data to the in situ gage data since the transects were not instantaneous snap shots of the channel current profile. The model output, which was in one hour time steps, was used by using the time step data that straddled the transect time for comparison. SMS and ArcMap GIS were used for the comparison and the results can be seen in Figures 27 to 32.

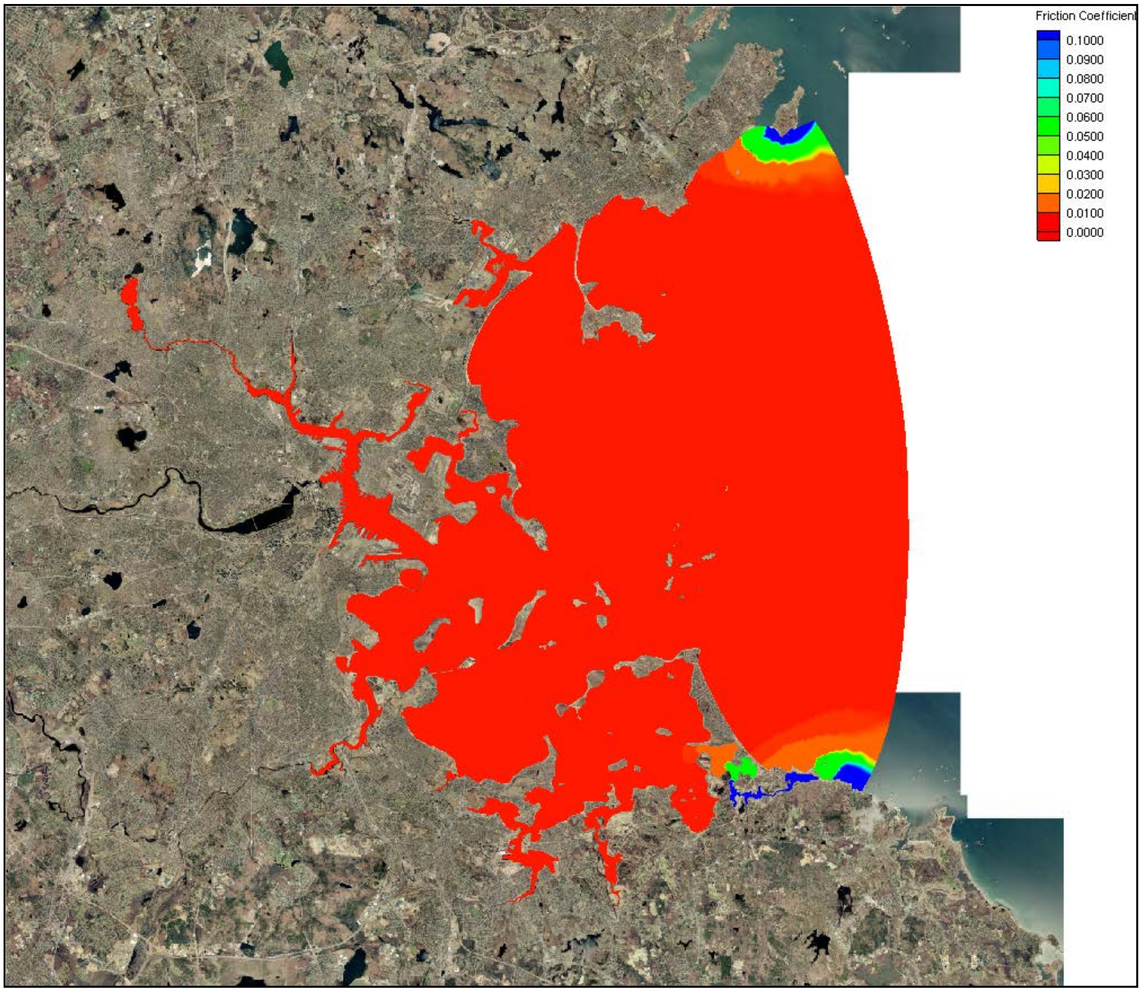


Figure 24. Map of bottom friction values used across model domain.

6.1 Model Validation Discussion

As shown in Figures 25 through 32 the validation run compares very well to the data that was collected. As provided in Attachment 3 the numerical information used to generate the graphics is provided. This information shows that the elevation data is nearly identical and along with the current data at the in situ station with a few exceptions. As shown in Figure 25, later in the 10 day simulation, the tidal phase output from the model elevation data at both CHL3 and 4 begins to lead the recorded data. The elevations are still very close, and the impacts to the model and ship simulator are not important but it is worth noting. Also, as shown in Figure 26, the current magnitude in the East/West direction slightly overestimates the ebb tide speed and slightly underestimates the flood tide speed.

As discussed, due to the issues of comparing the boat mounted ADCP data to model data, comparisons between the two was more difficult. However it can be seen in Figures 27 and 32 that the model output matches the ADCP fairly well. The only exception is shown in Figure 32 in which the two sets of data do not match. It is uncertain what caused this large discrepancy, but based on the quality of the model validation shown in all other figures this was written off as an error in time stamping data, a processing error, or some other type of procedural error.

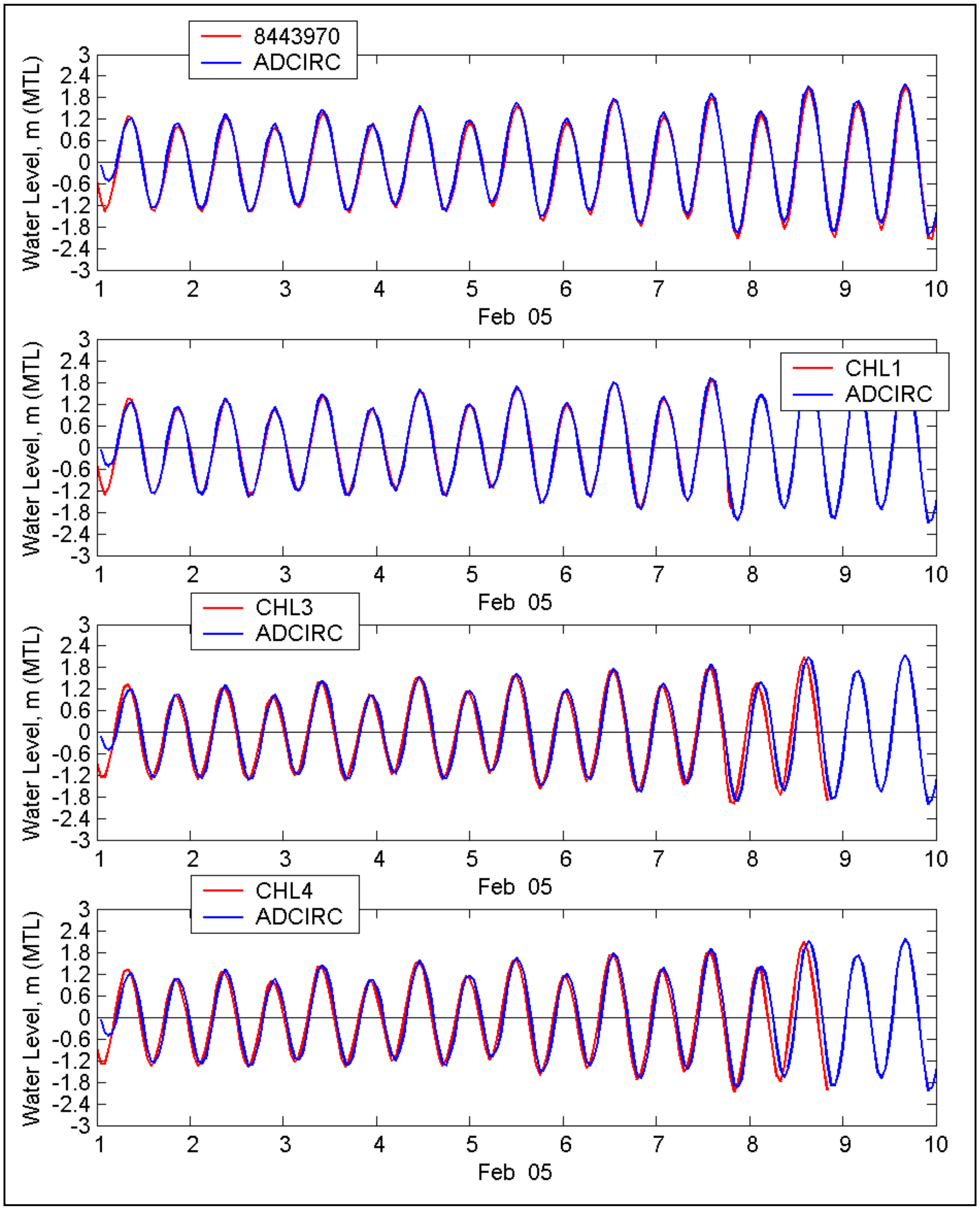


Figure 25. Model output vs. field data collected between 02/01/2005 and 02/08/2005

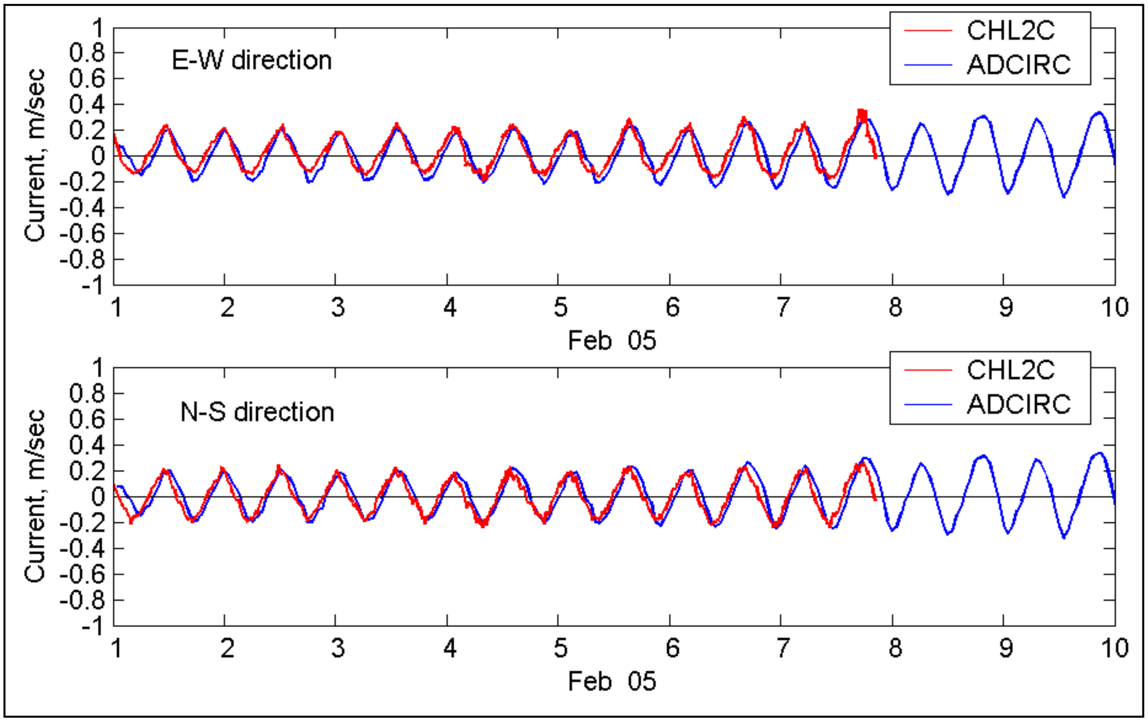
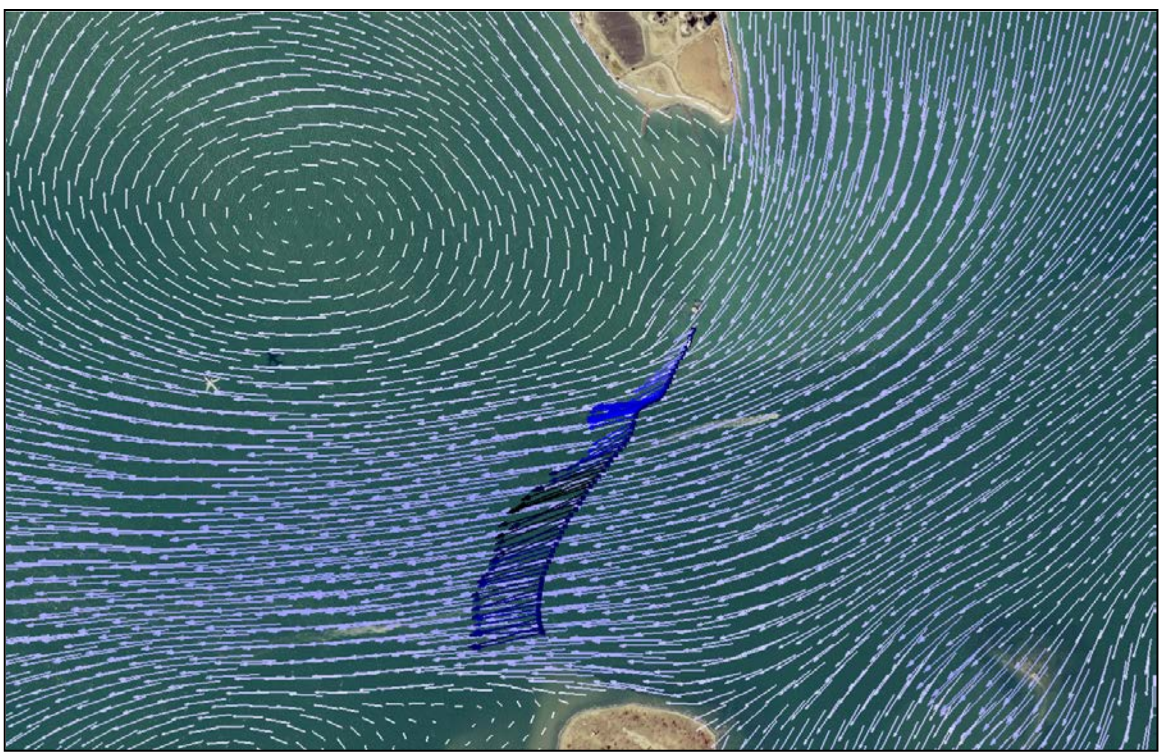


Figure 26. Model output vs. field data collected between 02/01/2005 and 02/08/2005



Figures 27. Boat ADCP data Transect 1 02-08-05 13:41 compared to model data at 14:00.

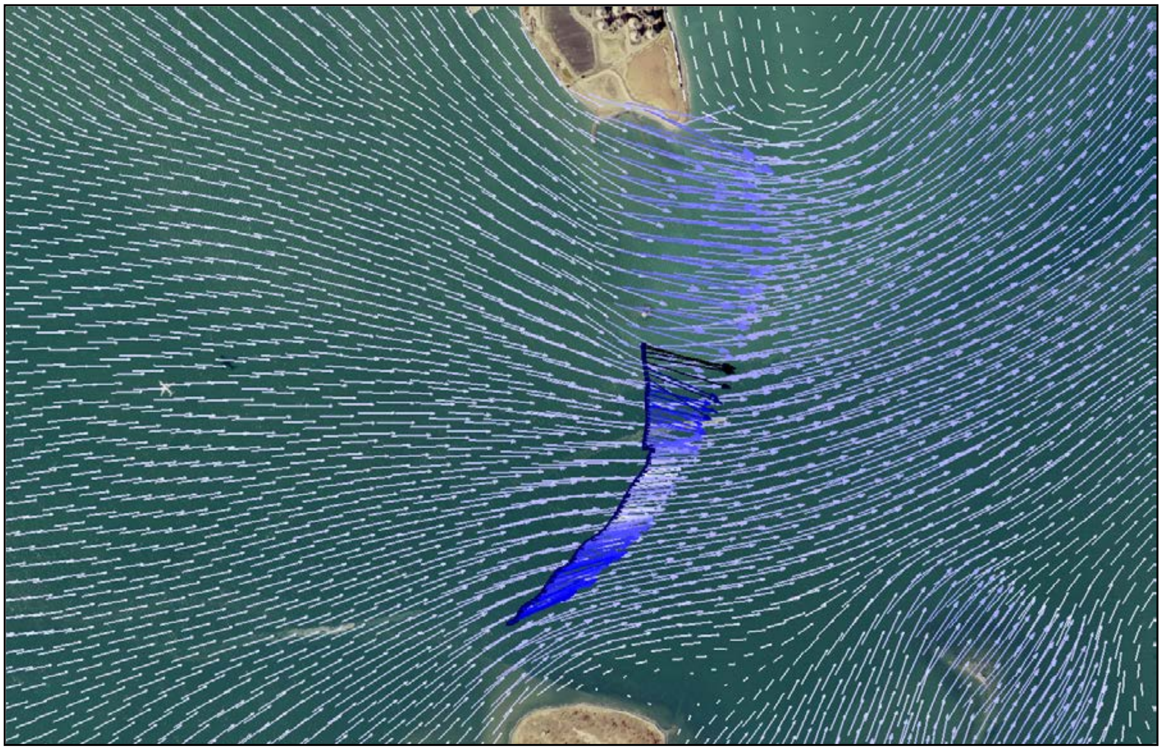


Figure 28. Boat ADCP data Transect 1 02/08/05 18:40 compared to model data at 19:00

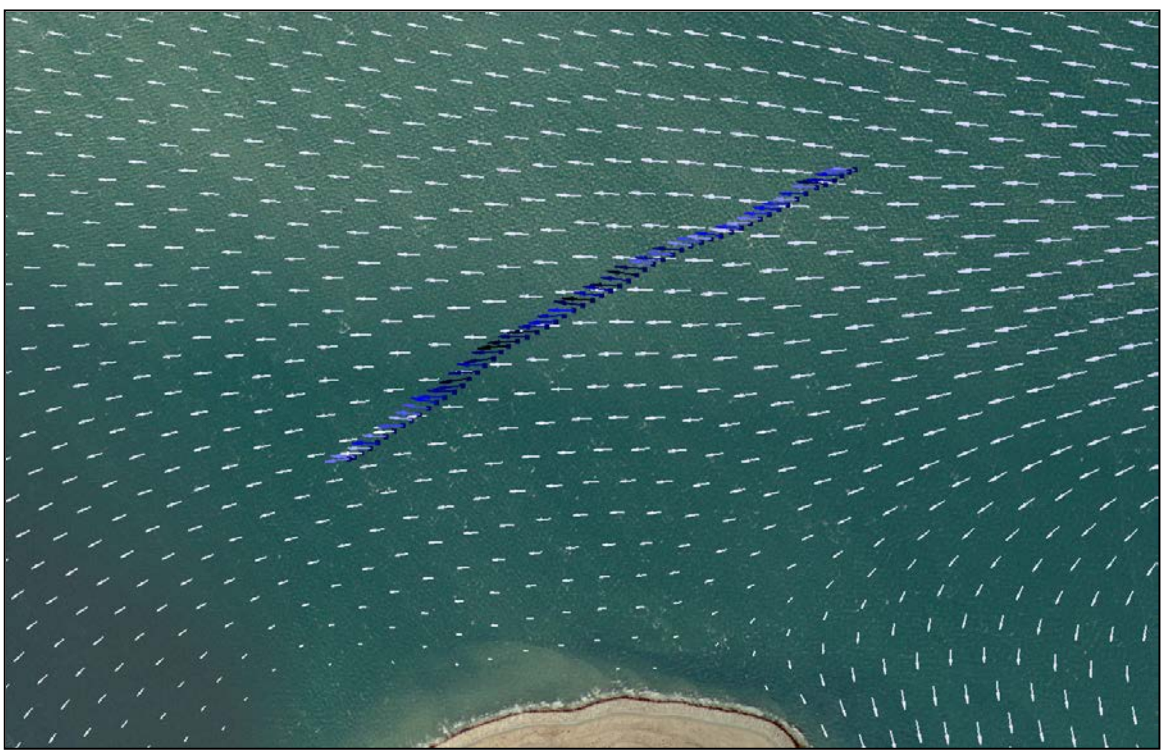


Figure 29. Boat ADCP data Transect 3 02/08/05 15:20 compared to model data at 15:00

Figure 30. Boat ADCP data Transect 3 02/08/05 20:12 compared to model data at 20:00

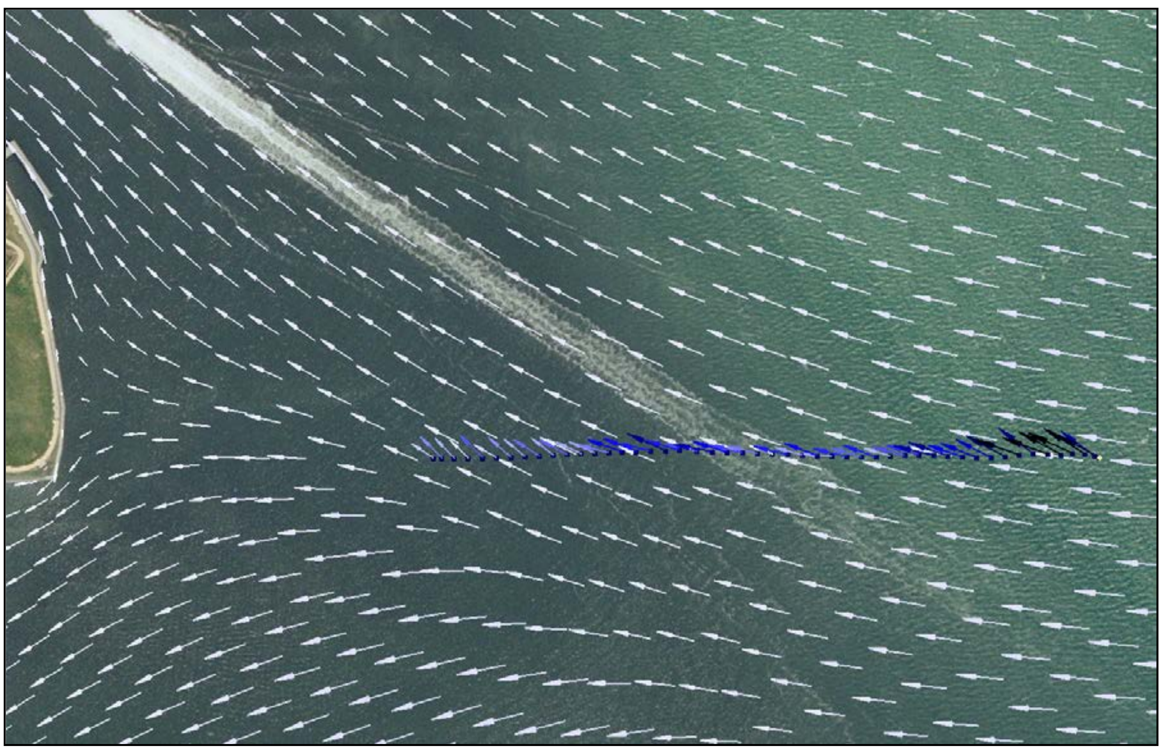


Figure 31. Boat ADCP data Transect 2 02/08/05 14:15 compared to model data at 14:00

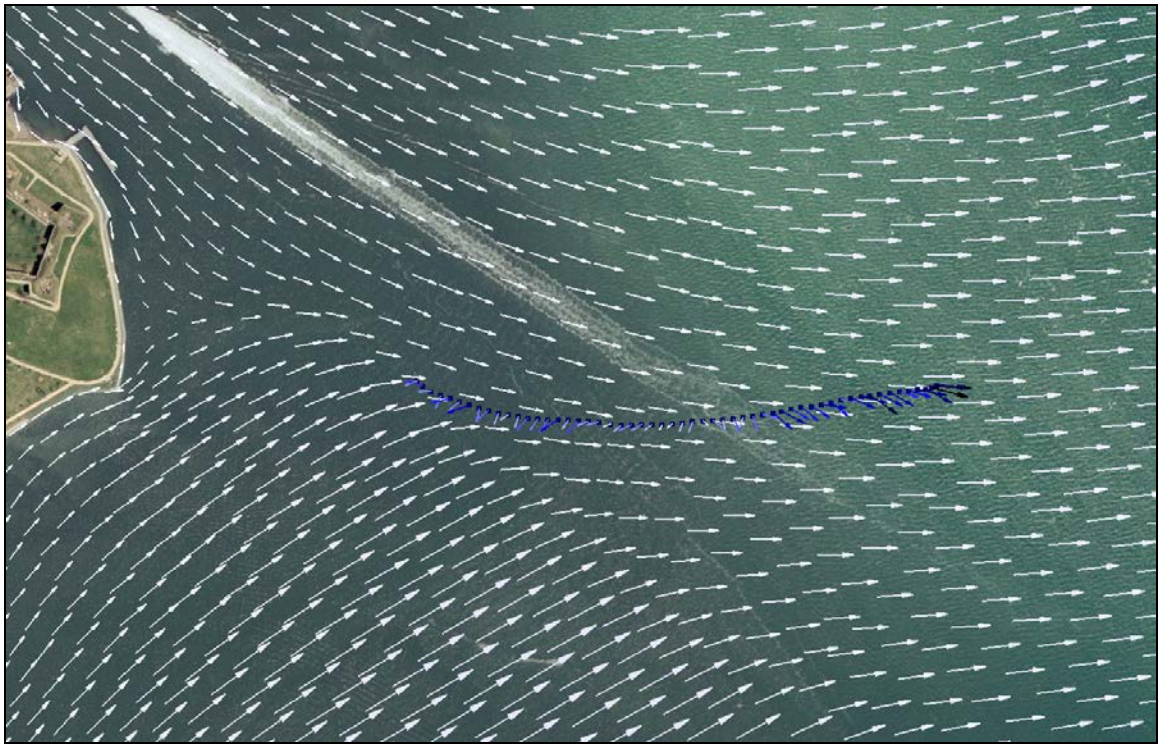


Figure 32. Boat ADCP data Transect 2 02/08/05 18:03 compared to model data at 18:00

7.0 Model Run – Existing Conditions

The existing conditions run is the same as the validation run. The highest current velocity magnitudes occur near the very end of the simulation since this time period was a Spring Tide condition. The peak ebb and flood currents have been provided in Figures 33 through 36. The highest current speeds that occur in the navigation channel are between Long Island and Deer Island. In this area the current speeds exceed 1.25 m/s or 3 mph. Along the rest of the navigation channel current speeds are less than 1.0 m/s or 2.25 mph. These maximum current speed fields were converted to the proper format for the Ship Simulator and provided to Mr. Dennis Webb of ERDC in Vicksburg, MS. Maximum current speed fields were used since these would impact ship handling the most. It was important to have the existing conditions modeled so that it could be verified by the Boston Harbor Bar Pilots that the ship simulator was reasonably representing real world conditions.

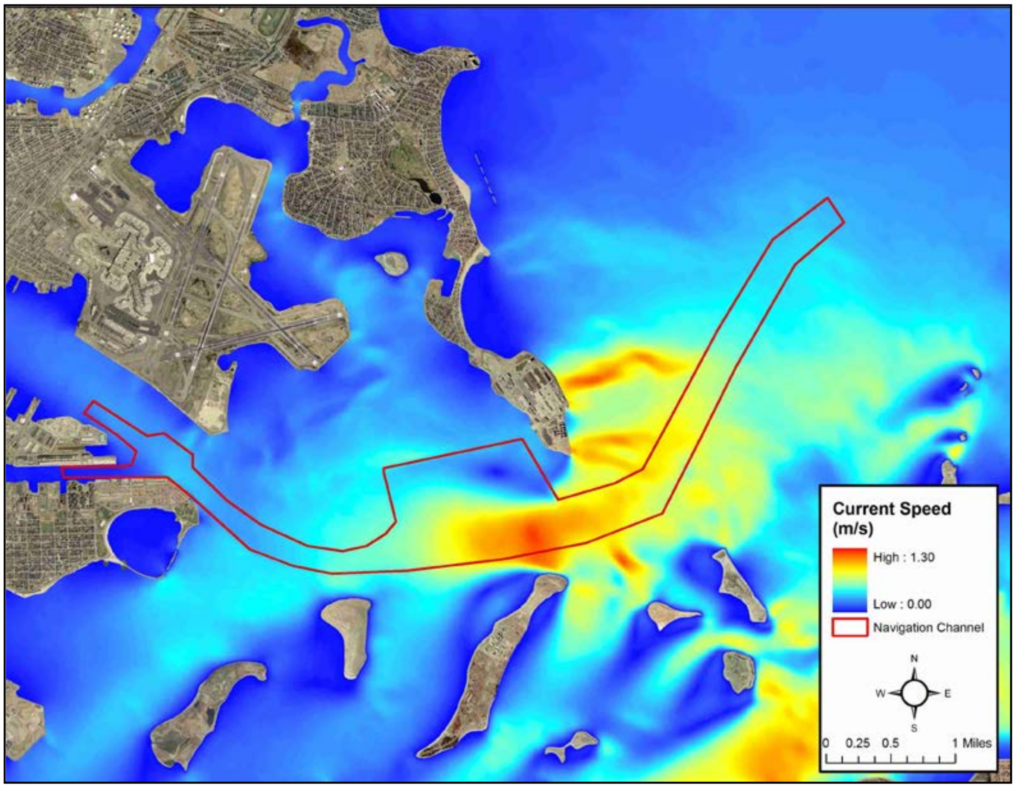


Figure 33. Maximum flood current (hour 123 of simulation)

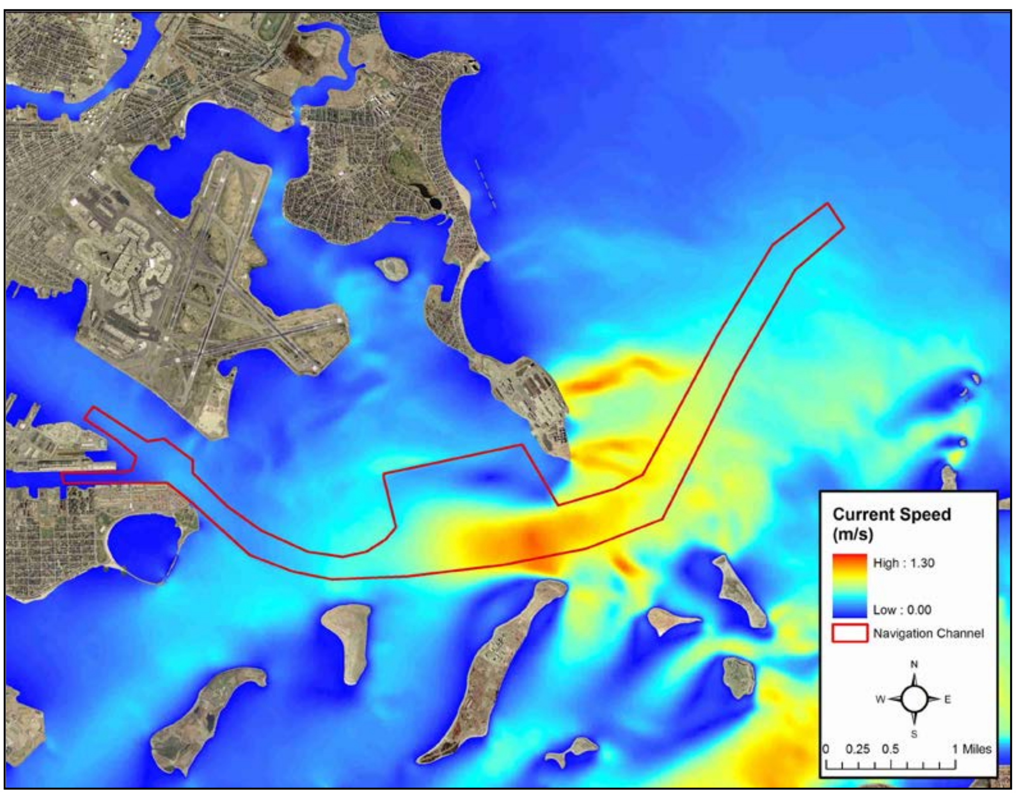


Figure 34. Maximum flood current (hour 135 of simulation)

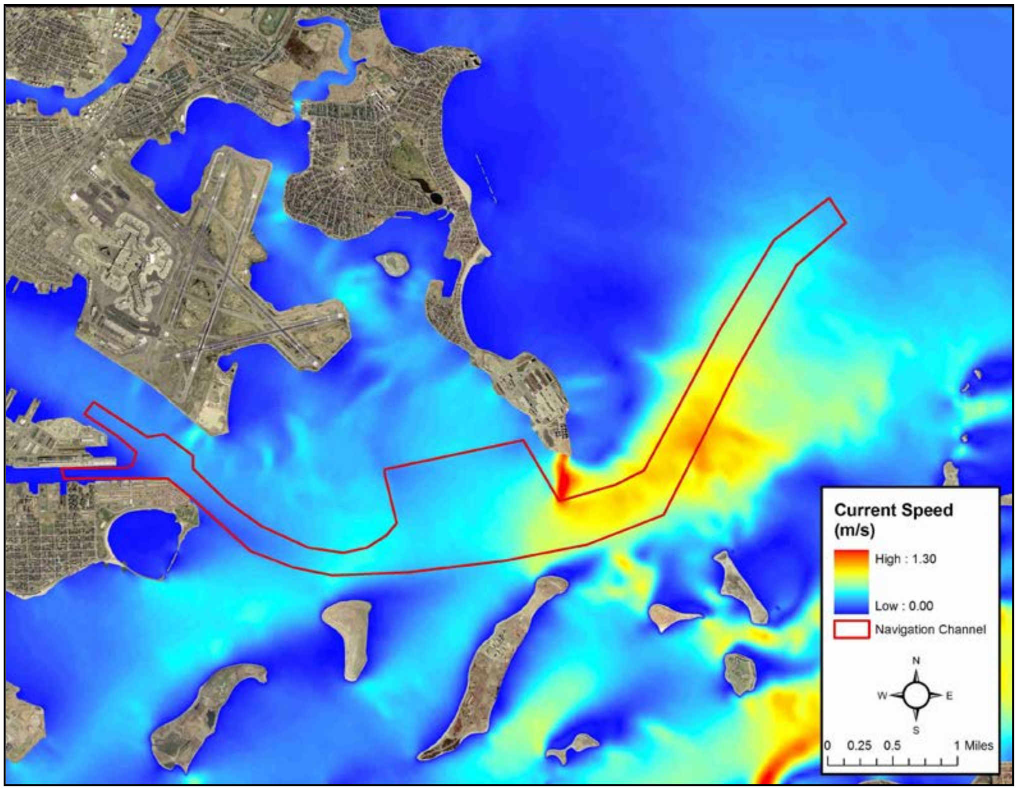


Figure 35. Maximum ebb current (hour 129 of simulation)

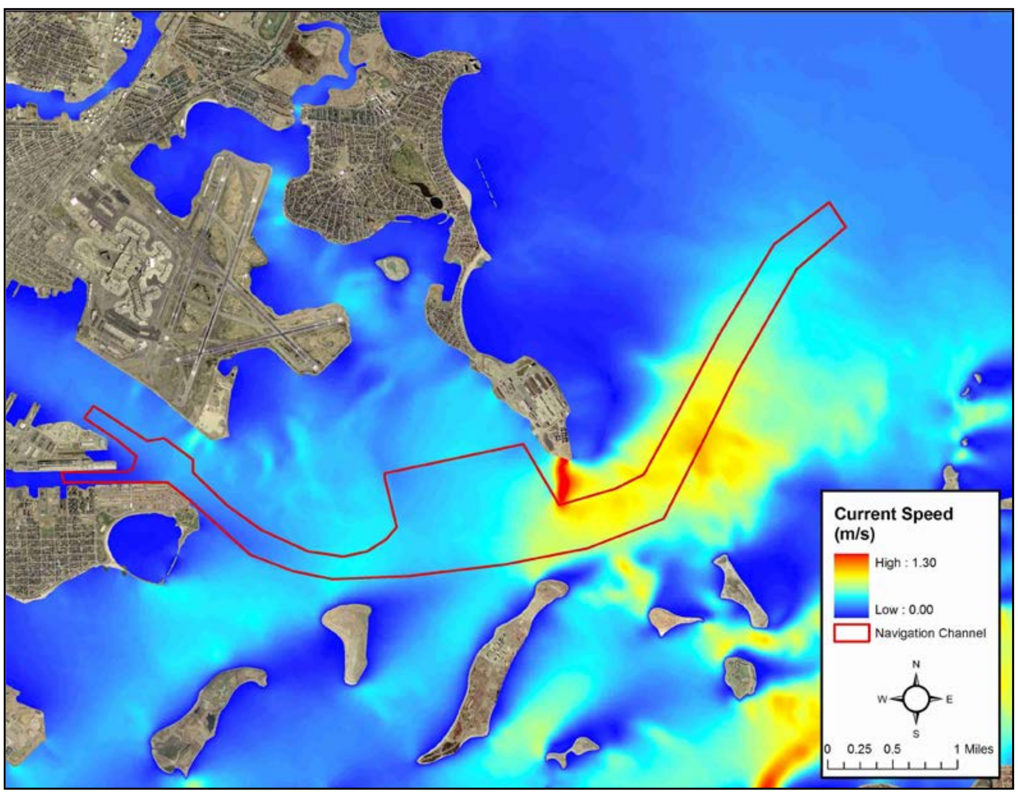


Figure 36. Maximum ebb current (hour 141 of simulation)

8.0 Alternative Model Runs

Alternative model runs were conducted for three different navigation channel depths which were, -44, -45, and -48 feet-MLLW. The existing conditions model mesh was altered by highlighting the nodes in the model that fell within the “deepening” area and changing the depths to the alternative depths. Depths that were already below the alternative depth were not altered. The model mesh was not altered except for the depth. The differences in elevation for alternatives -45 feet and -48 feet compared to the existing condition are shown in Figures 37, 38.

The resulting maximums for the spring flood and ebb currents have been provided below for the -45 foot and -48 foot alternatives (Figures 39, 41, 43, and 45). Also provided in Figures 40, 42, and 44 are the differences between the -45 foot and -48 foot alternatives and the existing condition currents. It can be seen that in the navigation channel area the changes are relatively small with the maximum current speed increase of 0.04 m/s or 0.09 mph for both the -45 foot and -48 foot alternatives. This is less than a 5% increase in current speed.

An additional alternative was looked at during the feasibility study outside of the three alternatives that were modeled. A -50 feet-MLLW channel option was looked at. Based on the very small increase in current speeds seen for the -45 and -48 foot alternatives, it was concluded that the -50 foot alternative would not cause a significant change in current velocity either.

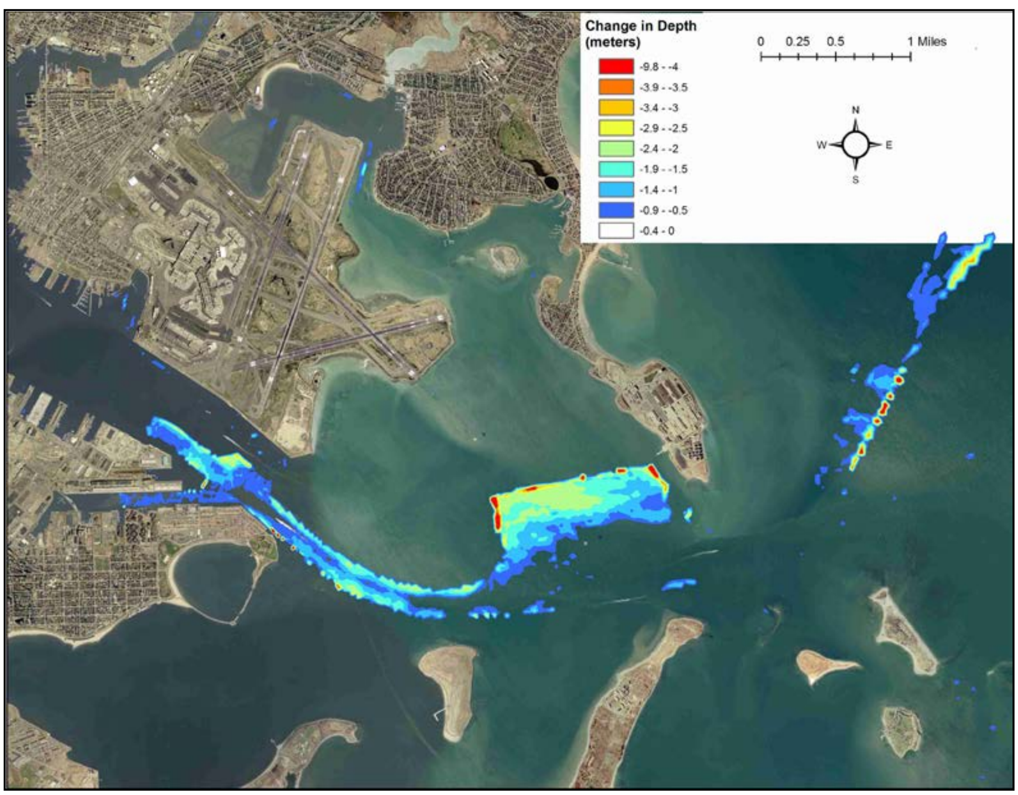


Figure 37. Depth difference between -45 foot-MLW alternative and existing bathymetry.

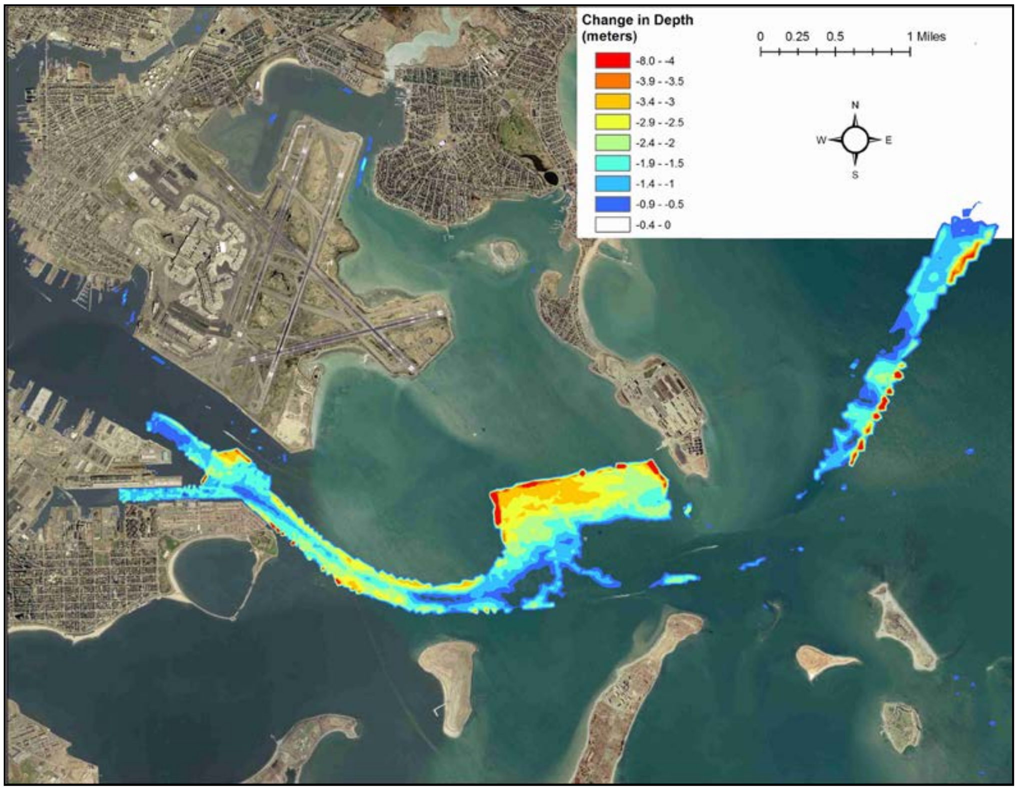


Figure 38. Depth difference between -48 foot-MLW alternative and existing bathymetry.

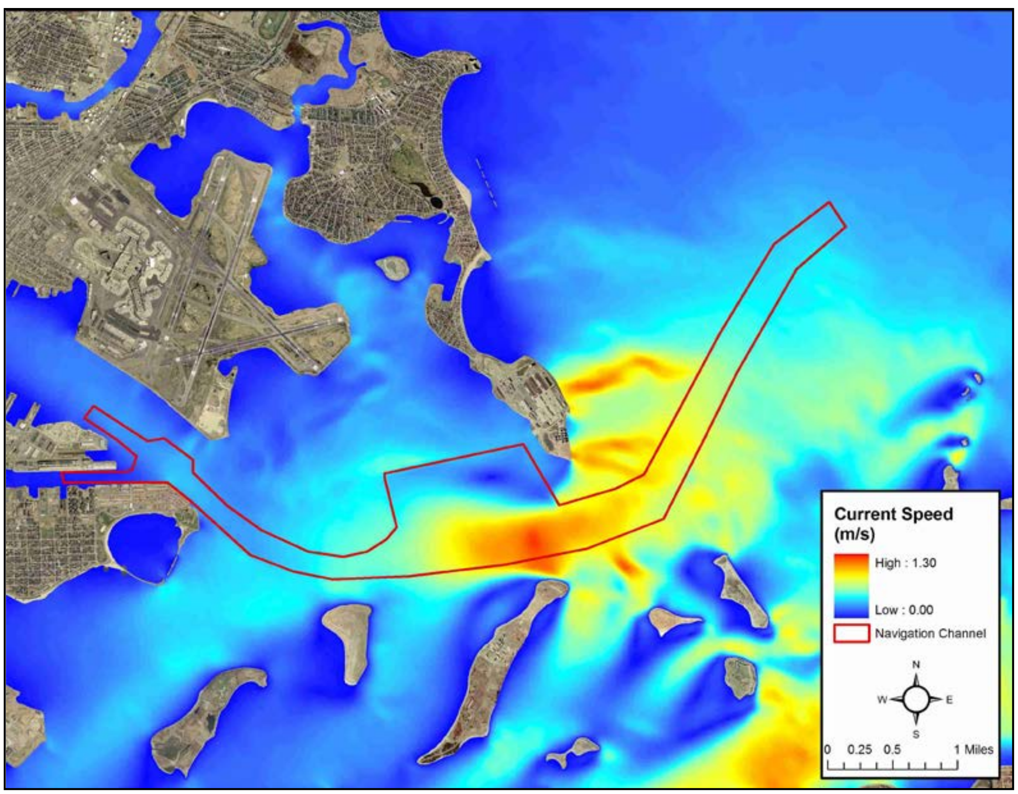


Figure 39. Alternative 45' channel max flood currents at model time of 123.

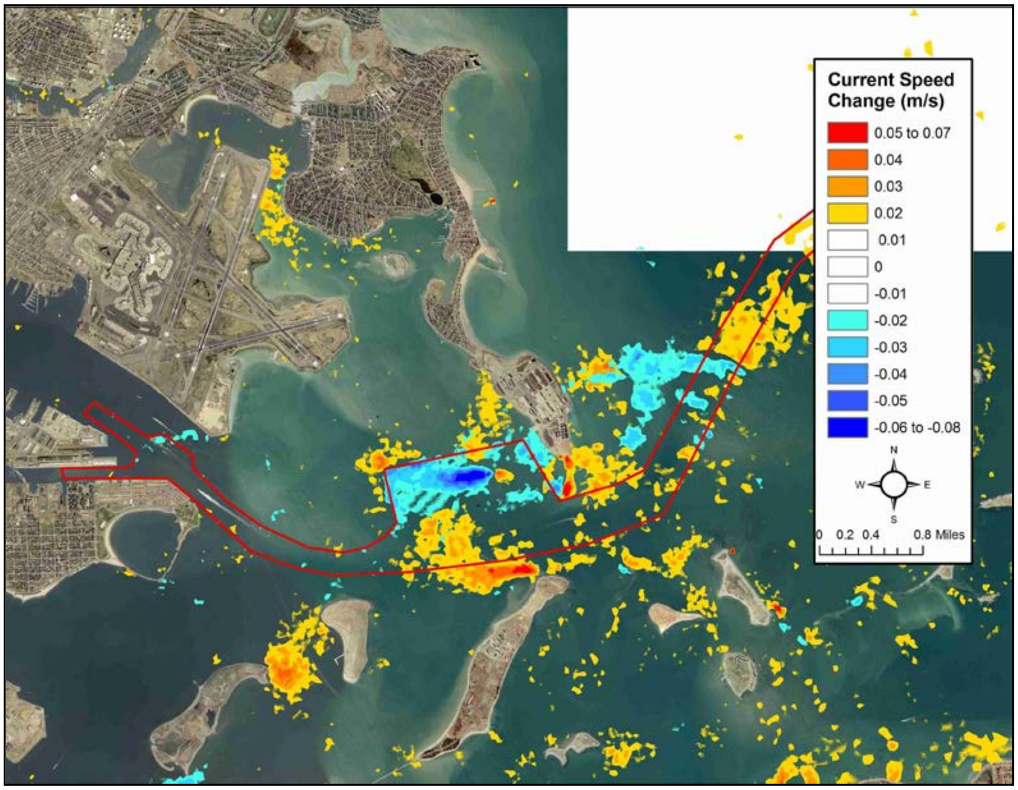


Figure 40. Alternative 45’ channel minus existing conditions currents at model time 123.

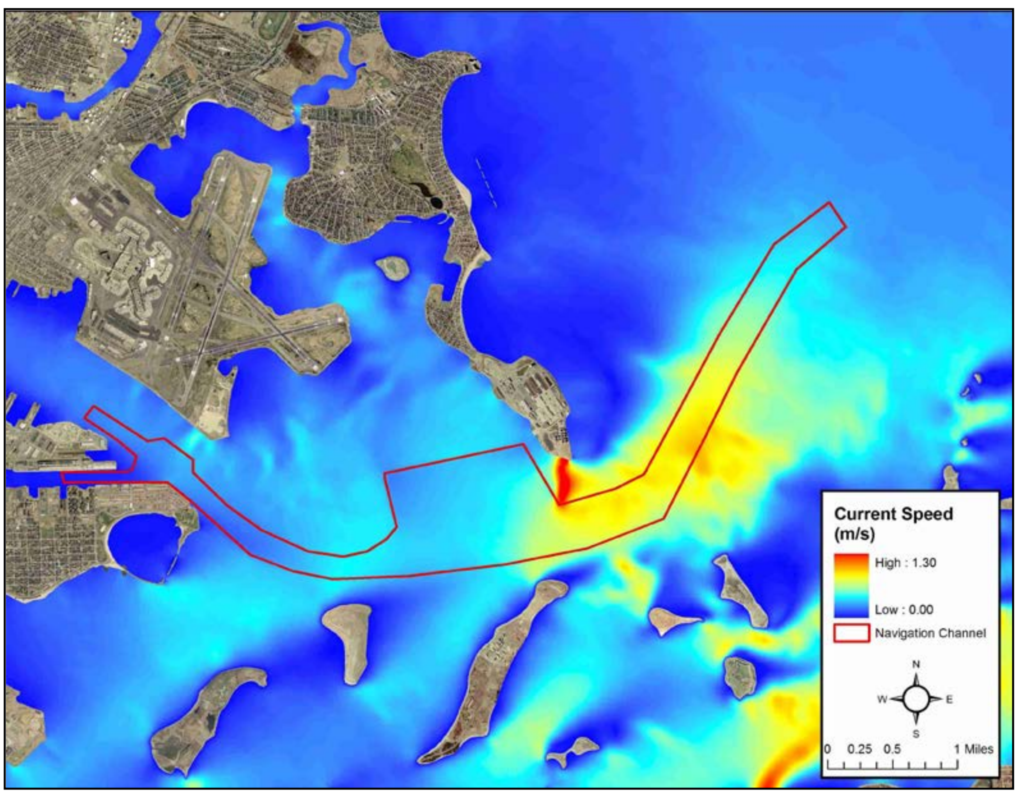


Figure 41. Alternative 45 max ebb currents at model time of 141.

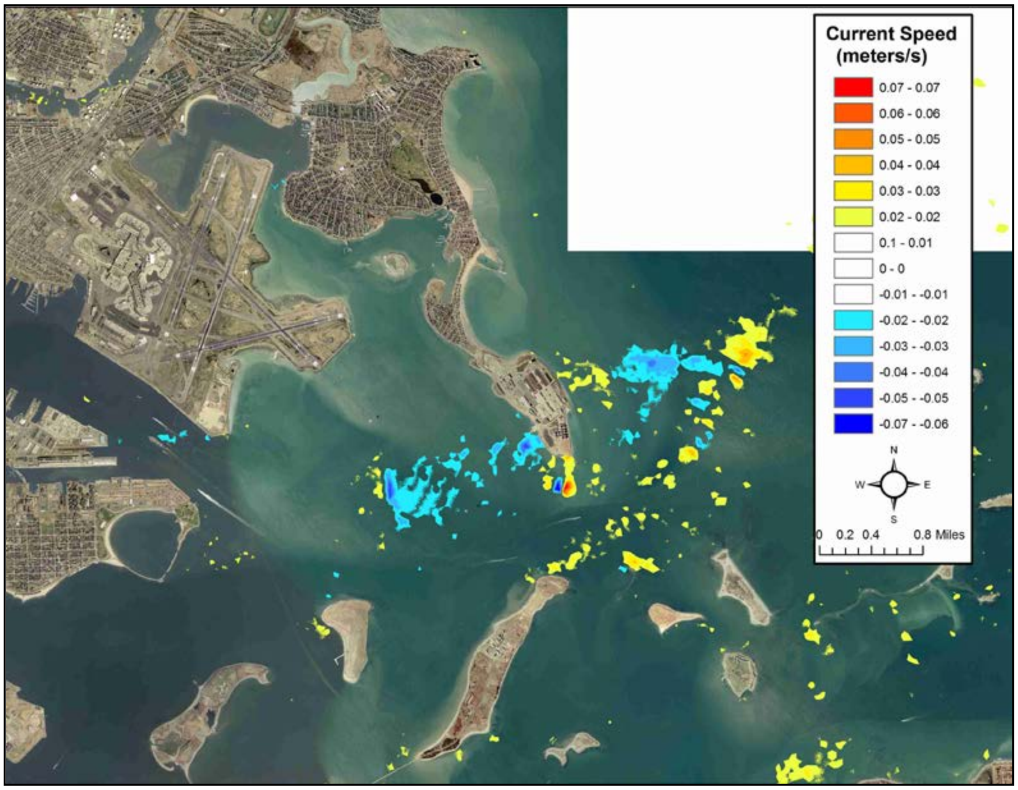


Figure 42. Alternative 45' channel minus existing conditions currents at model time 141.

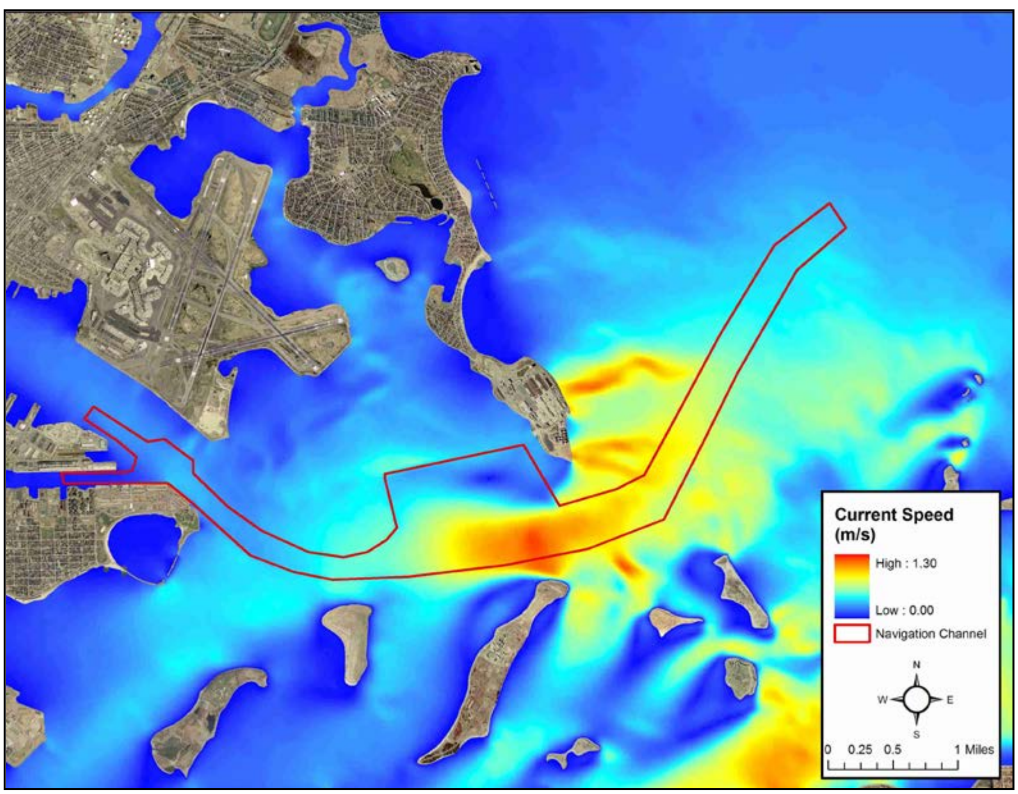


Figure 43. Alternative 48' channel max flood currents model time step 123

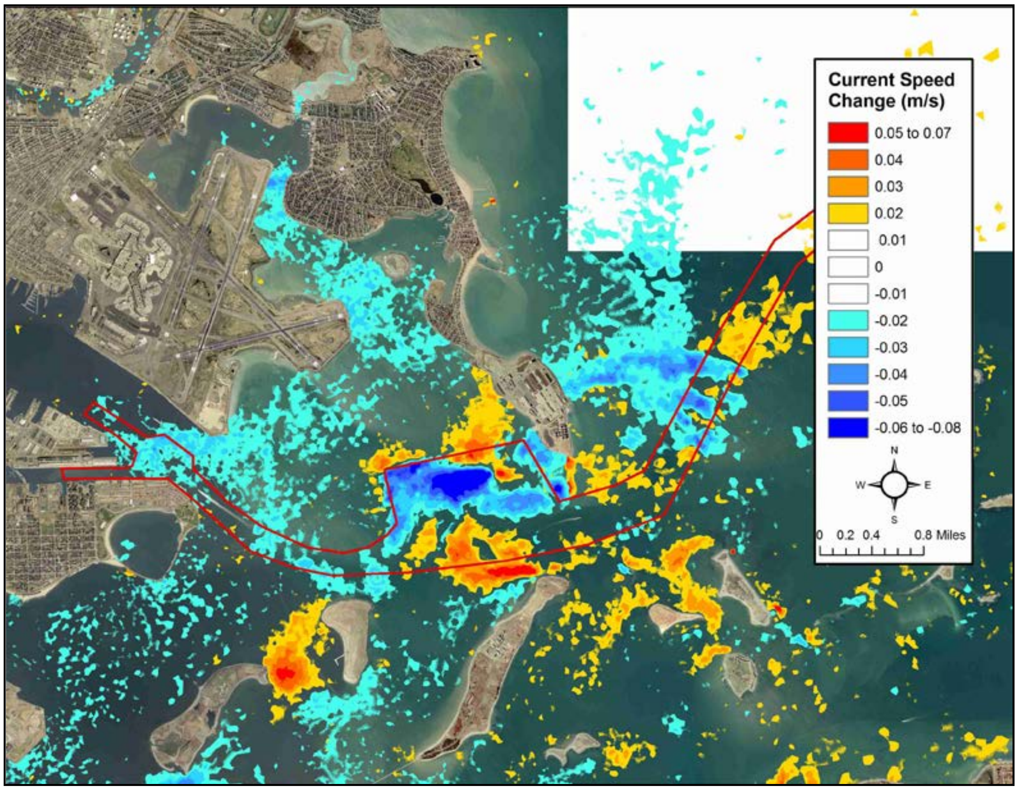


Figure 44. Alternative 48’ channel minus existing conditions currents at model time 123

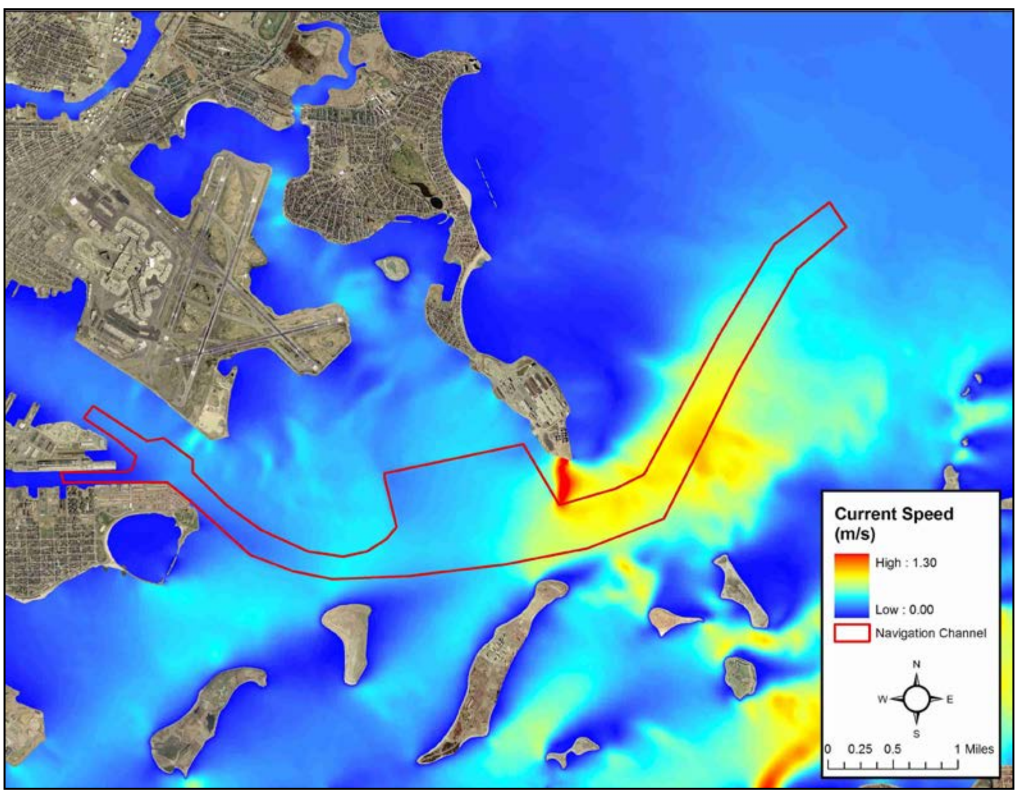


Figure 45. Alternative 48’ channel max ebb currents model time step 141

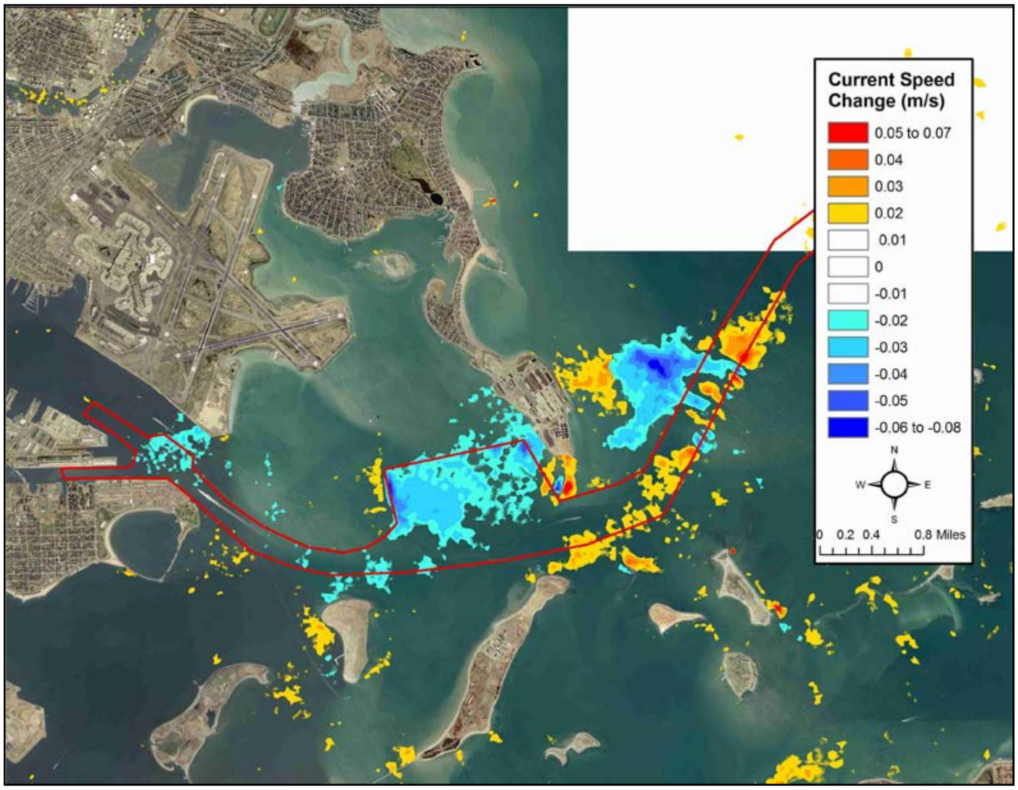


Figure 46. Alternative 48' channel minus existing conditions currents at model time 141

8.1 Alternative Model Runs – Adjusted Reserve Channel Turning Basin

Due to the discovery that the proposed improvements to the turning basin at the end of the reserve channel were directly in line with the flight path of airplanes from Boston Logan Airport, and from the input provided by the Boston Harbor Bar Pilot ship simulation runs, an alternative turning basin layout was designed. Figures 47 to 49 show the different layout of the turning basin. Since the altered turning basin would require significant removal of bank material at the north edge (Figure 49), it was determined that the new bathymetries would have to be modeled. It was thought that the bathymetric changes were significant enough to change the current field in the local area of the turning basin. The altered turning basin alternative was run for the -44 foot, -45 foot, and -48 foot channel depths. The model mesh was changed in the same fashion as the first set of alternatives. Due to the high mesh density the mesh elements did not need to be altered in the turning basin area and only the elevations were changed. The current speed differences between the -45 foot and -48 foot channel alternatives with the altered turning basin were compared to the original -45 foot and -48 foot alternatives. These difference plots are shown in Figures 50 to 53. As shown in the figures the current speed increased where the bathymetry was returned to the existing depth, and dropped where the bathymetry was deepend. The maximum increase was 0.05 m/s or 0.11 mph and the maximum decrease was 0.08 m/s or 0.18 mph. Comparisons to the existing conditions were not made since it was shown in Section 8.0 that the current speed change in this area was very small.

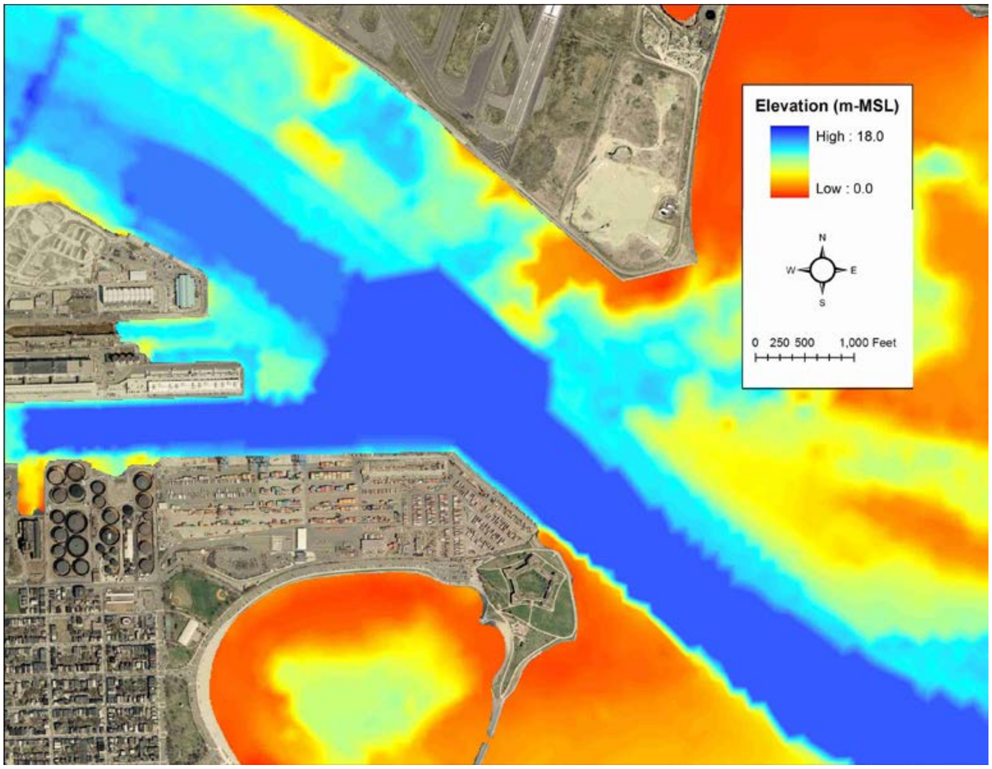


Figure 47. Original Turning Basin

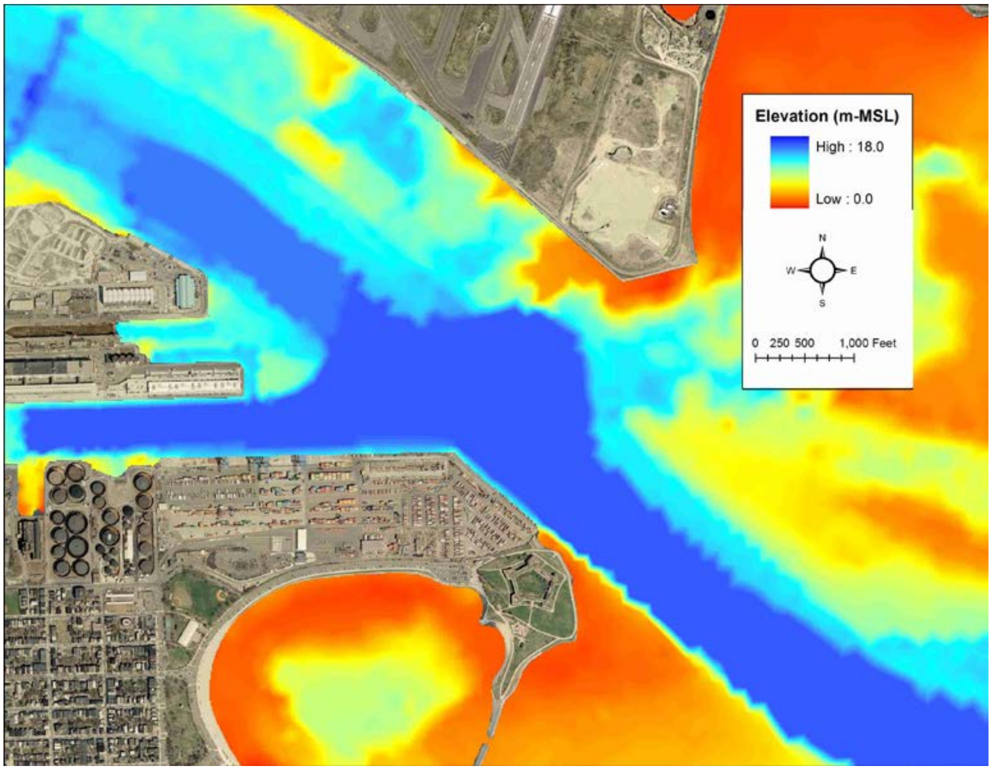


Figure 48. Alternate Turning Basin

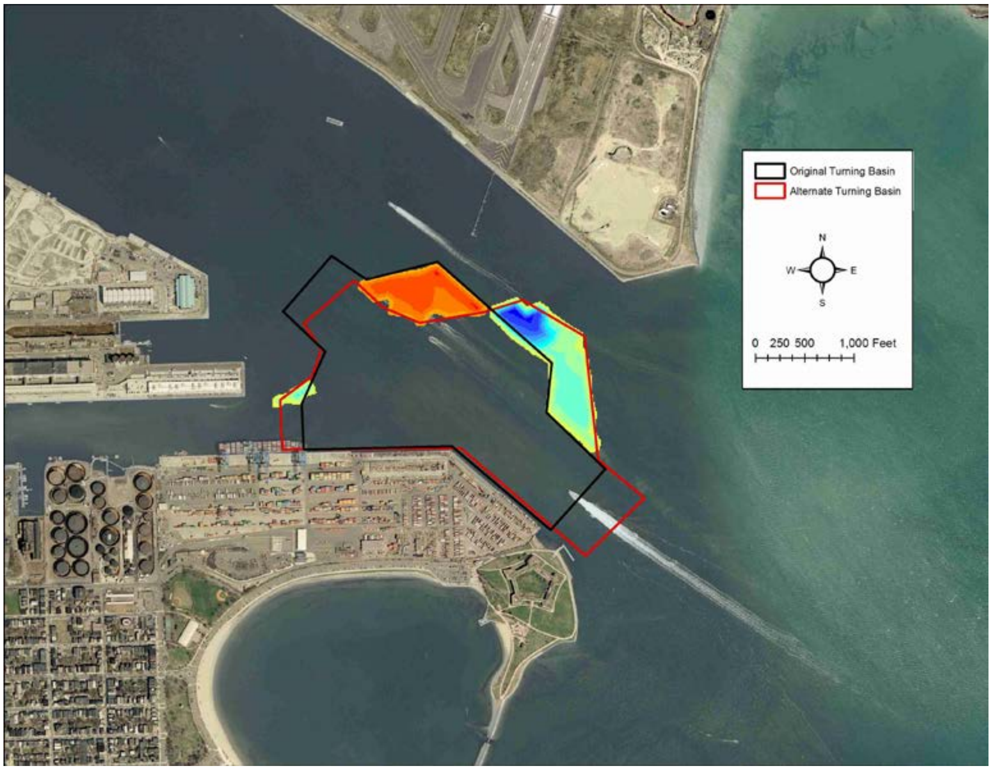


Figure 49. Comparison of original and alternative turning basin (for alt 48).

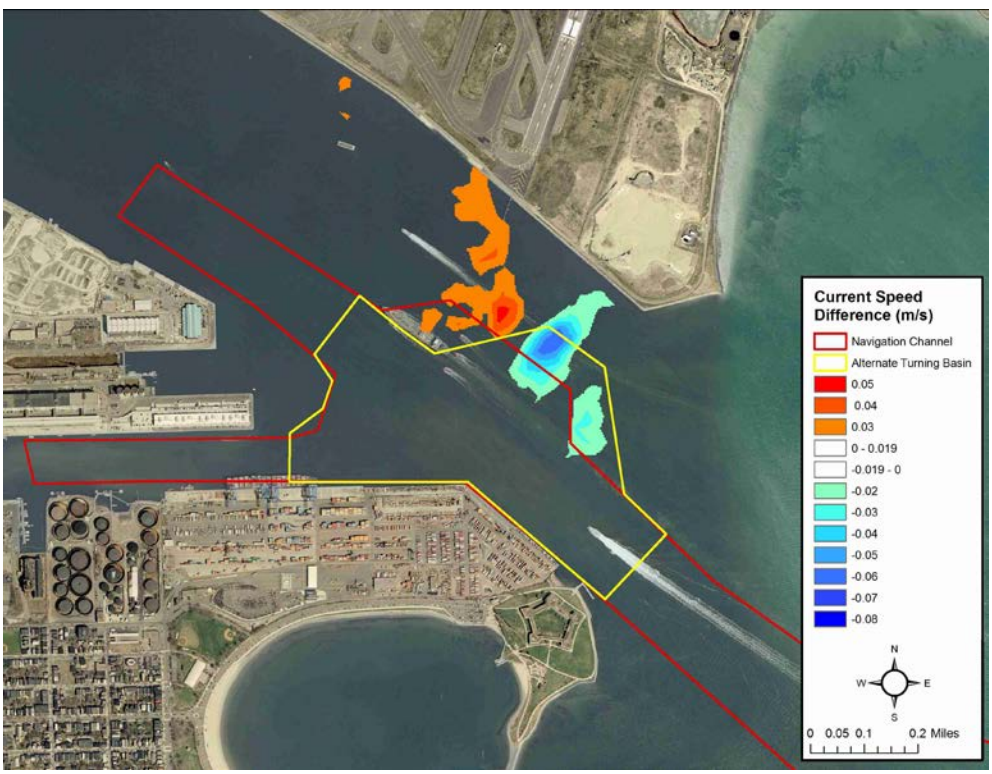


Figure 50. Comparison of original and alternate turning basin model time 123 alt 45.

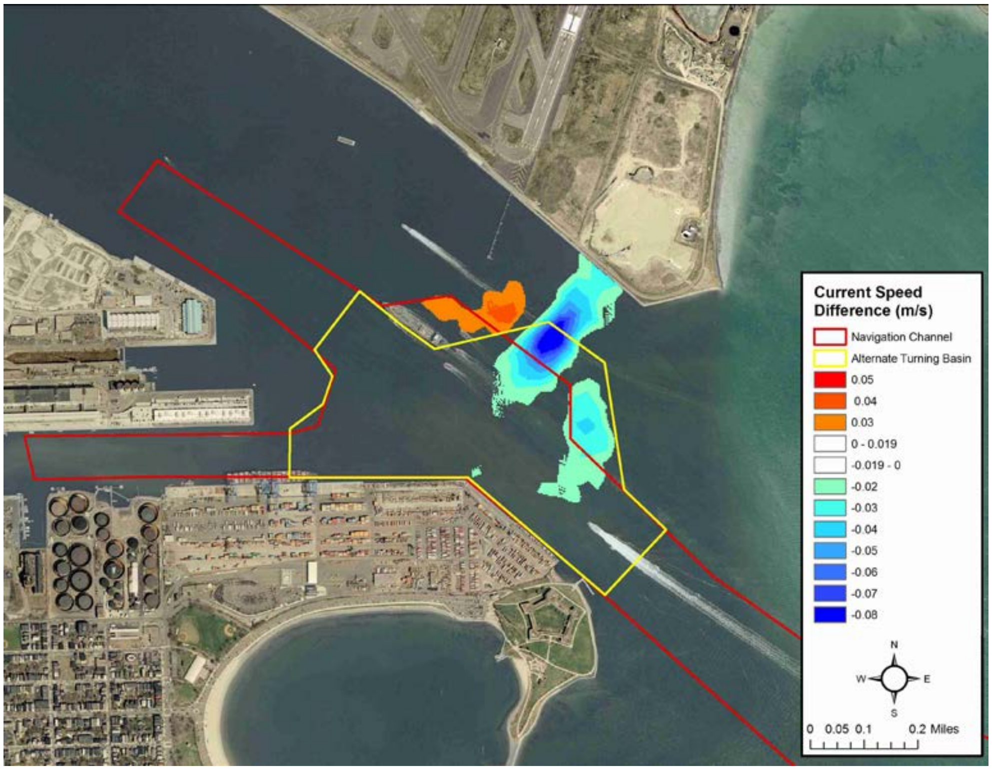


Figure 51. Comparison of original and alternate turning basin model time 141 alt 45.

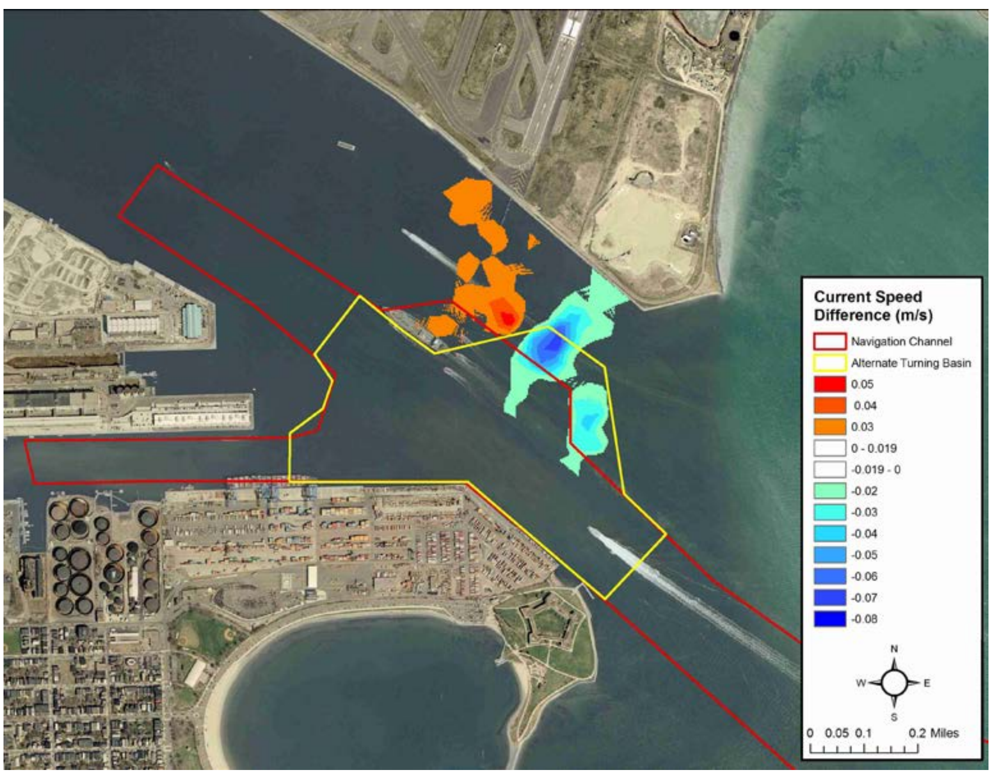


Figure 52. Comparison of original and alternate turning basin model time 123 alt 48.

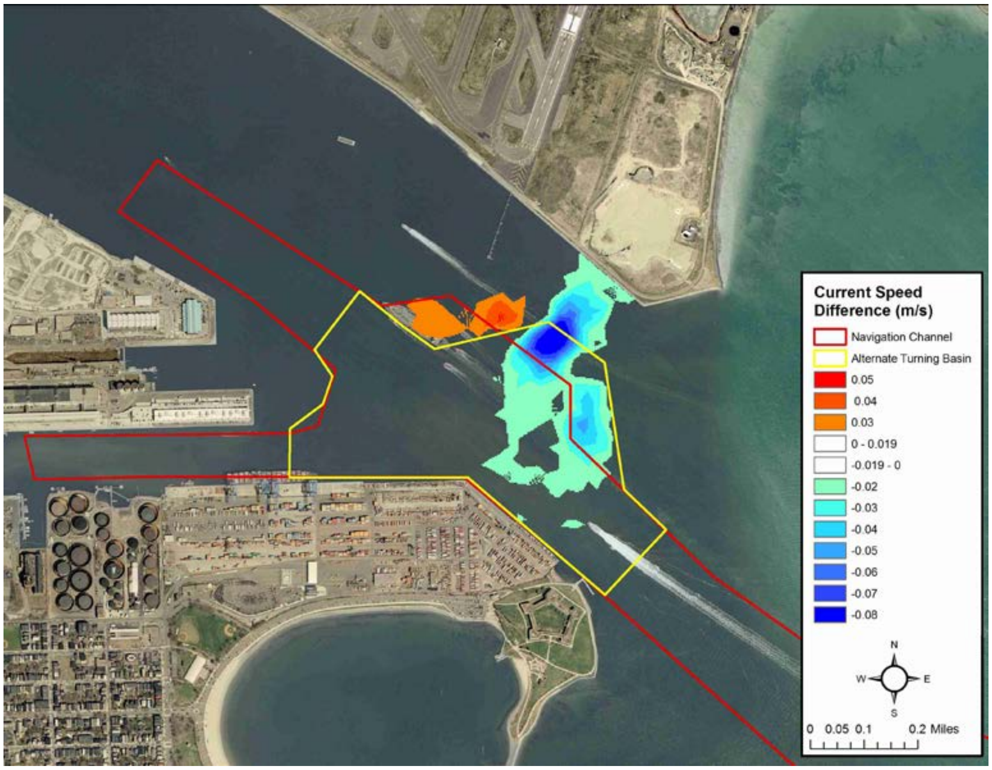


Figure 53. Comparison of original and alternate turning basin model time 141 alt 48

9.0 Conclusions

Based on the validated numerical model and the deepening alternatives modeled, current speeds will not change significantly in the Boston Harbor Navigation Channel and that it is likely that changes in channel layout would have more of an impact on ship handling. The maximum increases were found to be less than 5% which likely falls within modeling error and/or the natural variation in real life currents due to spring and neap tide cycles and wind generated current impacts. While not modeled, the additional alternative of -50 feet-MLLW would not be expected to be noticeably different from the -48 feet-MLLW channel alternative.

10.0 Summary

As part of the Boston Harbor Deep Draft Navigation Study a highly detailed 2-D, depth averaged, hydrodynamic numerical modeling effort was completed. Based on a review of available models, the Corps supported ADCIRC numerical model was chosen. The modeling effort was completed by the New England District, the CHL at ERDC, and the New York District in order to meet schedule deadlines.

Both ArcMap GIS and the SMS 9.0 package were used to develop the model and to run the model. Bathymetric data was taken from the NOAA GEODAS database and from previous navigation channel surveys conducted by USACE New England. The shoreline boundary was mapped using the 2003 Massachusetts aerial photographs and the ocean boundary was set at over a 12 mile radius from the center of the project site in order to avoid model boundary affects in the study area.

A field data collection effort was undertaken in order to provide model validation data. The data collection effort consisted of both collecting both water surface elevation data and current velocity data. Water surface elevation was recorded using submerged pressure transducers and current velocity was collected using acoustic Doppler current profilers (ADCP). The ADCP gages were mounted on the bottom along the navigation channel and also on a boat in order to provide cross channel current velocity transects. Data return was fairly good with only one bottom mounted ADCP gage failing completely. The complete data report has been included as Attachment 3.

The model output compared very well to the collected data and showed the hydrodynamic model data very usable as input for the ship simulator study. The ADCIRC model output was converted into the necessary format for use in the ERDC ship simulator. The validated model's bathymetry was altered to model three different deepening alternatives, and the results showed current speeds only increased by a maximum of 5% over existing current speeds. In addition to the first three alternatives, the turning basin at the end of the Reserve Channel was altered. The model was rerun for the three depth alternatives with the altered turning basin. Once again the change in current speeds was relatively minor with the maximum change between the original alternative and turning basin alternative being 0.08 m/s or 0.18 mph.

Attachment 1
NOAA GEODAS Surveys Used

NGDC-Num	Survey	Navigation	Soundings	Features
03001010	H07724	2177	2087	90
03001030	H07715	17425	16568	857
03001043	F00256	7	7	0
03041028	H06642	12072	11076	996
03041029	H06643	37295	36784	511
03041030	H06644	3647	3632	15
03061204	H08938	17088	17088	0
03061205	H08939	8164	8164	0
03061206	H08940	15137	15137	0
03061207	H08941	8658	8658	0
03061208	H08942	8040	8040	0
03061209	H08943	7952	7952	0
03141004	H09009	6725	6725	0
03141005	H09010	4938	4938	0
03141007	H09012	17207	17207	0
03141010	H09046	15947	15947	0
03141011	H09063	8303	8303	0
03141012	H09064	4346	4346	0
03141013	H09090	8658	8658	0
03141014	H09094	12026	12026	0
03141015	H09095	2931	2931	0
03141071	H09133	9511	9511	0
03141072	H09134	6849	6849	0
03141073	H09150	11412	11412	0
03141074	H09151	6808	6808	0
03141075	H09152	4485	4485	0
03361081	F00465	1076	1075	1
03711002	H07159	2862	2840	22
03A11948	H06995	12401	12385	16
03F11572	H07066	11969	11649	320
03F11683	H07060	4466	4447	19
03F11684	H07061	2105	2057	48
03F11685	H07063	1483	1454	29
03F11740	H06862	4900	4900	0
03F11741	H06863	13383	13223	160
03F11744	H08005	4743	4479	264
03F11745	H08006	1870	1815	55
03F11746	H08007	1686	1652	34
03F11747	H08008	16897	16736	161
03F11748	H08009	8159	7993	166
03F11749	H08010	1619	1506	113
03F11750	H08063	13896	13896	0
03F11753	H08898	2742	2645	97

Attachment 2
ADCIRC Model Control file (Fort 19)

```
Boston Harbor                    ! 32 CHARACTER ALPHANUMERIC RUN DESCRIPTION
 ADCIRC Run                       ! 24 CHARACTER ALPHANUMERIC RUN IDENTIFICATION
 1                          ! NFOVER - NONFATAL ERROR OVERRIDE OPTION
 1                          ! NABOUT - ABREVIATED OUTPUT OPTION PARAMETER
 1                          ! NSCREEN - OUTPUT TO UNIT 6 PARAMETER
 0                          ! IHOT - HOT START OPTION PARAMETER
 1                          ! ICS - COORDINATE SYSTEM OPTION PARAMETER
 0                          ! IM - MODEL RUN TYPE: 0=2DDI, 1=3DL(VS), 2=3DL(DSS)
 1                          ! NOLIBF - NONLINEAR BOTTOM FRICTION OPTION
 2                          ! NOLIFA - OPTION TO INCLUDE FINITE AMPLITUDE TERMS
 1                          ! NOLICA - OPTION TO INCLUDE CONVECTIVE ACCELERATION TERMS
 1                          ! NOLICAT - OPTION TO CONSIDER TIME DERIVATIVE OF CONV ACC TERMS
 0                          ! NWP - VARIABLE BOTTOM FRICTION AND LATERAL VISCOSITY OPTION PARAMETER
 0                          ! NCOR - VARIABLE CORIOLIS IN SPACE OPTION PARAMETER
 0                          ! NTIP - TIDAL POTENTIAL OPTION PARAMETER
 0                          ! NWS - WIND STRESS AND BAROMETRIC PRESSURE OPTION PARAMETER
 1                          ! NRAMP - RAMP FUNCTION OPTION
 9.81000000                     ! G - ACCELERATION DUE TO GRAVITY - DETERMINES UNITS
 0.0100                       ! TAU0 - WEIGHTING FACTOR IN GWCE
 0.500000                     ! DT - TIME STEP (IN SECONDS)
 0.000000                     ! STATIM - STARTING SIMULATION TIME IN DAYS
 0.000                       ! REFTIME - REFERENCE TIME (IN DAYS) FOR NODAL FACTORS AND EQUILIBRIUM ARGS
 10.000000                    ! RNDAY - TOTAL LENGTH OF SIMULATION (IN DAYS)
 0.500                       ! DRAMP - DURATION OF RAMP FUNCTION (IN DAYS)
 0.350 0.300 0.350                ! TIME WEIGHTING FACTORS FOR THE GWCE EQUATION
 0.05 12 12 0.05                 ! H0 - MINIMUM CUTOFF DEPTH
 249512.81 901287.25               ! SLAM0,SFEA0 - CENTER OF CPP PROJECTION (NOT USED IF ICS=1, NTIP=0, NCOR=0)
 0.0025                       ! FFACTOR - HOMOGENEOUS LINEAR OR NONLINEAR BOTTOM FRICTION COEFFICIENT
 5.000                       ! ESL - LATERAL EDDY VISCOSITY COEFFICIENT; IGNORED IF NWP =1
 0.00001                      ! CORI - CORIOLIS PARAMETER - IGNORED IF NCOR = 1
 0                          ! NTIF - TOTAL NUMBER OF TIDAL POTENTIAL CONSTITUENTS BEING FORCED
 0                          ! NBFR - TOTAL NUMBER OF FORCING FREQUENCIES ON OPEN BOUNDARIES
 90.000                       ! ANGINN : INNER ANGLE THRESHOLD
 0 0.000 0.000 0                 ! NOUTE,TOUTSE,TOUTFE,NSPOOLE:ELEV STATION OUTPUT INFO (UNIT 61)
 0                          ! TOTAL NUMBER OF ELEVATION RECORDING STATIONS
 0 0.000 0.000 0                 ! NOUTV,TOUTSV,TOUTFV,NSPOOLV:VEL STATION OUTPUT INFO (UNIT 62)
 0                          ! NSTAV - TOTAL NUMBER OF VELOCITY RECORDING STATIONS
```

```
-1 0.000 10.000 7200                  ! NOUTGE,TOUTSGE,TOUTFGE,NSPOOLGE : GLOBAL ELEVATION OUTPUT INFO (UNIT 63)
-1 0.000 10.000 7200                  ! NOUTGV,TOUTSGV,TOUTFGV,NSPOOLGV : GLOBAL VELOCITY OUTPUT INFO (UNIT 64)
0                                     ! NHARF - NUMBER OF FREQENCIES IN HARMONIC ANALYSIS
0.000 0.000 0 0.000                   ! THAS,THAF,NHAINC,FMV - HARMONIC ANALYSIS PARAMETERS
0 0 0 0                               ! NHASE,NHASV,NHAGE,NHAGV - CONTROL HARMONIC ANALYSIS AND OUTPUT TO UNITS 51,52,53,54
1 144000                              ! NHSTAR,NHSINC - HOT START FILE GENERATION PARAMETERS
1 0 1.000000000E-005 25               ! ITITER, ISLDIA, CONVCR, ITMAX - ALGEBRAIC SOLUTION PARAMETERS
```

BOSTON HARBOR
MASSACHUSETTS

NAVIGATION IMPROVEMENT STUDY

FINAL FEASIBILITY REPORT
AND FINAL SUPPLEMENTAL
ENVIRONMENTAL IMPACT STATEMENT
(AND MASSACHUSETTS FINAL EIR)

APPENDIX H

SHIP SIMULATION STUDY

U.S. ARMY CORPS OF ENGINEERS
ENGINEERING RESEARCH AND
DEVELOPMENT CENTER
VICKSBURG, MISSISSIPPI

This Appendix Unchanged Since 2008 Draft Final Report

ERDC/CHL TR-06-11

Coastal and Hydraulics Laboratory

US Army Corps of Engineers®
Engineer Research and Development Center

Boston Harbor, Massachusetts, Deep-Draft Navigation Improvement Project Feasibility Study

Channel Improvement Investigations

Dennis W. Webb and Mark L. Habel

August 2006

APPENDIX H

SHIP SIMULATION STUDY

ERDC/CHL TR-06-11
August 2006

Boston Harbor, Massachusetts, Deep-Draft Navigation Improvement Project Feasibility Study

Channel Improvement Investigations

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Final report

Prepared for U.S. Army Engineer District, New England
Concord, MA 01742-2751

Abstract: Boston Harbor is located on the eastern shore of the Commonwealth of Massachusetts, on Massachusetts Bay. The Corps of Engineers and the Massachusetts Port Authority (Massport) are evaluating a number of improvements to Boston Harbor. These improvements include deepening and widening portions of the Broad Sound North Entrance Channel, Main Ship Channel, and lower Reserved Channel and its turning area for the benefit of larger container vessels calling on Massport's Conley Terminal. To assist in evaluating these improvements, the U.S. Army Engineer Research and Development Center (ERDC) conducted a ship-simulator-based navigation study. Data for the simulation models were obtained during a site visit to ride ships in the project area. Currents for both the existing and proposed channels were calculated using the ADCIRC computer model in a joint effort between ERDC and the U.S. Army Engineer District, New England. Harbor pilots traveled from Boston to validate and operate the simulations in September 2005.

Contents

Figures

Preface

The model investigation described herein was conducted for the U.S. Army Engineer District, New England, by the U.S. Army Engineer Research and Development Center (ERDC), Vicksburg MS. The simulator experiments were performed during September 2005 by personnel of the Coastal and Hydraulics Laboratory (CHL).

The New England District was informed of the progress of the simulator study through monthly progress reports. Mark Habel, New England District, was in charge of project oversight for the District. The simulation models for the *Cosco Hamburg* and *Delaware Bridge* were developed by Designers and Planners, Inc.

The principal investigator in immediate charge of the navigation portion of the simulator study was Dennis W. Webb, assisted by Peggy Van Norman, Donna Derrick, Danny Marshall, and Gary Lynch, all of the Navigation Branch, CHL, and Ms. Sally Harrison, contractor for Analytical Services, Inc. Mr. Webb and Mr. Habel prepared this report , under the general supervision of Dr. Margaret Rose Kress, Chief, Navigation Division; Dr. William D. Martin, Deputy Director, CHL; and Mr. Thomas W. Richardson, Director, CHL.

Commander and Executive Director of ERDC was COL Richard B. Jenkins. Director was Dr. James R. Houston.

Unit Conversion Factors

Multiply	By	To Obtain
feet	0.3048	meters
knots	0.5144444	meters per second

1 Introduction

Background

Boston Harbor is located on the eastern shore of the Commonwealth of Massachusetts, on Massachusetts Bay (Figure 1). The layout of the existing Federal Navigation Project for Boston Harbor is shown in Figure 2. Deeply loaded commercial traffic uses the Broad Sound North Entrance Channel to access the harbor. Use of the other two entrance channels, the 30-ft Broad Sound South Channel and the 27-ft Narrow Channel, is limited to smaller ships and barges, mainly those in transit between the Port and the Cape Cod Canal to the south. Ships that presently call at Boston Harbor include petroleum tankers, bulk product carriers, containerships, and liquefied natural gas (LNG) tankers. The principal dry bulk cargos include salt and cement imports, and scrap and newsprint exports.

The existing Federal Navigation Project for Boston Harbor consists of the three entrance channels described above, a Main Ship Channel connecting the confluence of the three entrance channels off Deer Island with the lower and upper harbor areas, a deep-draft anchorage in President Roads, and several commercial tributary channels (the Reserved Channel, Fort Point Channel, Charles River, lower Mystic River, and Chelsea River).

Prior to 1930 the North Entrance Channel and Main Ship Channel had depths of –35 ft and widths of 1500 and 1200 ft, respectively. From 1930 to the mid-1950s, a 40-ft channel was constructed from the sea to the inner confluence of the Mystic and Chelsea Rivers, but not to the full channel width. In the North Entrance Channel and the lower reaches of the Main Ship Channel, the deeper 40-ft lane was dredged along the south limit of the channel, 900 ft wide in the entrance and 600 ft wide in the lower main ship channel. Above Commonwealth Pier in South Boston, the 40-ft lane shifted to the north side of the Main Ship Channel, and then shifted back to the northwest side above the Charles River. The intent seems to have been to ensure that the 40-ft depth accessed the several U.S. Navy facilities located on both sides of the harbor. The result today is an asymmetrical layout for the deep-draft channels, as shown in Figure 2.

Figure 1. Boston Harbor location map.

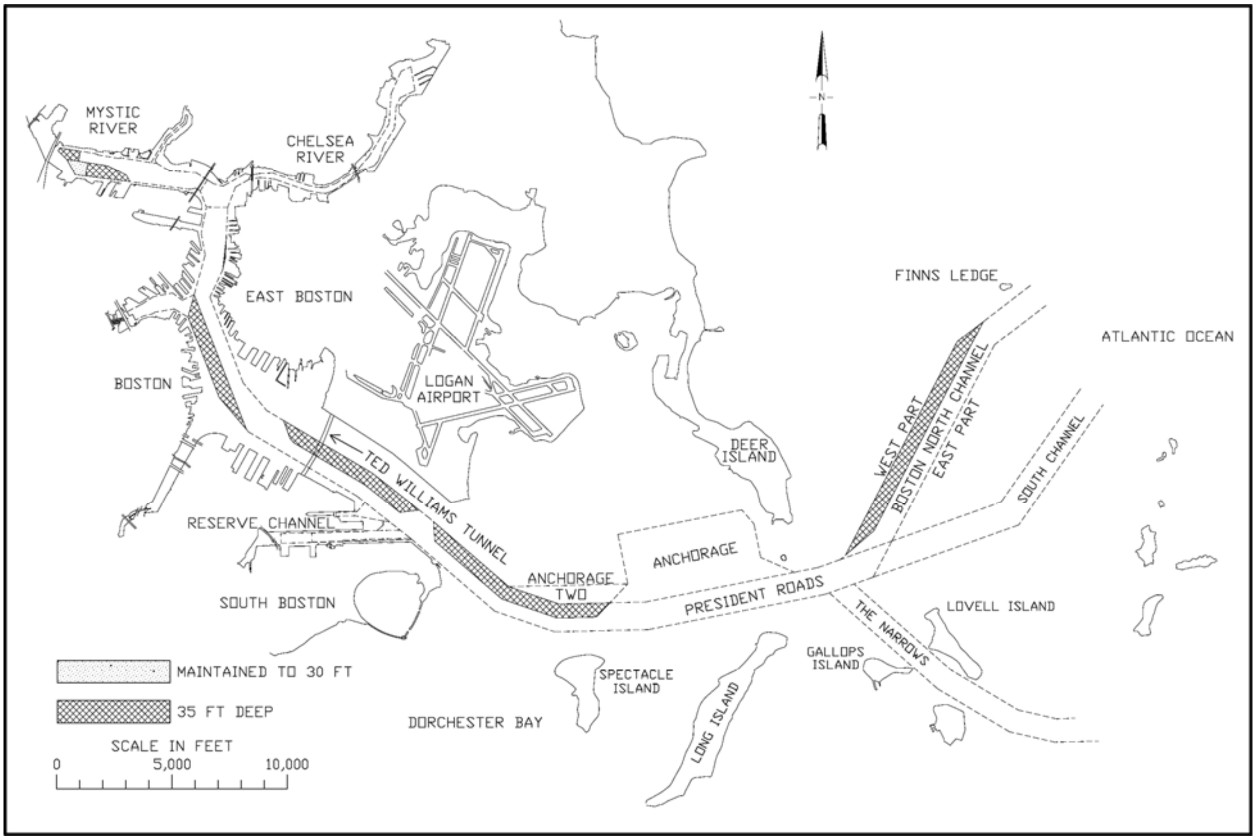

Figure 2. Boston Harbor, existing conditions.

The U.S. Coast Guard marks only the outer limits of the channels, and not the division between the 35- and 40-ft lanes. Consequently, safe navigation of larger vessels relies on the expert knowledge and experience of the harbor pilots and docking masters. Rules of the road regarding the passing of larger vessels rely on local knowledge and communication so that the deeper draft vessel can travel in the 40-ft lane.

The Reserved Channel in South Boston is 40 ft deep in its lower two-thirds along the Conley Terminal on the south shore and the former Army Base, now a dry bulk (cement) terminal on the north shore. Above this area the channel depth is 35 ft to access the upper berths of the Black Falcon Cruise Ship Terminal. The Main Ship Channel, at its confluence with the Reserved Channel, has been deepened to 40 ft for its full 1200-ft width to provide a turning basin for vessels accessing the Reserved Channel.

The 23-ft Fort Point Channel and 35-ft lower Charles River Channel are not included in this study as project dimensions are at least adequate for prospective commerce. The U.S. Coast Guard (USCG) Group Boston is located on the 35-ft Charles River Channel. Smaller visiting U.S. and NATO warships are berthed at the former Navy Yard on the Charles River Channel. Deeper draft vessels such as carriers are berthed at the World Trade Center on the 40-ft Main Ship Channel during port visits.

The deep-draft reaches of the Mystic River Channel between the Tobin and Malden Bridges are divided into 40-, 35-, and 30-ft areas. Most of the channel was deepened to 40 ft under the project of 1990 between 1998 and 2001. The full width of the lower, eastern end of the channel is at 40 ft to access the Boston Autoport and Exxon Terminals. The northern half of most of the upper length of the channel along the Everett shore is also 40 ft. The remaining areas are authorized to 35 ft, with the far upper end of the channel along the southern (Charlestown) shore only maintained to -30 ft. At the time of the 1990 authorization and 1996 design memorandum, the Massachusetts Port Authority (Massport) plans for its Medford Street Terminal, located immediately upstream of the Boston Autoport along the southern shore, were not far enough advanced to permit a favorable economic justification for deepening this area of the channel to 40 ft.

The Chelsea River Channel, from the inner confluence to the head of navigation in Revere, has an authorized depth of 38 ft under the project of 1990. The 38-ft depth was the limit that could be economically justified with increased vessel drafts and capacities without replacement of the Chelsea Street Bridge. With the exception of a small area near the Chelsea Street Bridge that is awaiting utility relocation, the 38-ft deepening project was completed in 2002. As the USCG and City of Boston are proceeding with plans to replace the bridge, deepening this channel to 40 ft is once again being considered.

The Port's only container facility, the Conley Terminal, is located on the 40-ft lower reach of the Reserved Channel in South Boston. This is the Port's seaward most commercial terminal. The Port's only LNG facility, Distrigas, is located on the north side of the 40-ft Mystic River Channel near its head of deep-draft navigation. The Port's major petroleum terminals are located along the 38-ft Chelsea River Channel, with the sole exception of the Exxon Terminal on the Mystic River, below the Distrigas LNG Terminal. Boston Harbor has a mean tidal range of approximately 10 ft and a spring range of about 13.5 ft.

Purpose

The U. S. Army Engineer District, New England, is presently evaluating channel designs to deepen portions of Boston Harbor and widen some of the turns. The primary purpose of these improvements is to allow larger containerships to call at the docks at the Conley Terminal on the Reserved Channel.

The U. S. Army Engineer Research and Development Center (ERDC) conducted a navigation study utilizing real-time ship simulation modeling to evaluate the proposed improvements to Boston Harbor. Model development and online testing occurred at the ERDC Waterways Experiment Station in Vicksburg, MS, during the period April to September 2005.

2 Proposed Improvements

The New England District and Massport are evaluating a number of improvements to Boston Harbor's system of channels and anchorage area. The proposed improvements for Boston Harbor are shown in Figure 3.

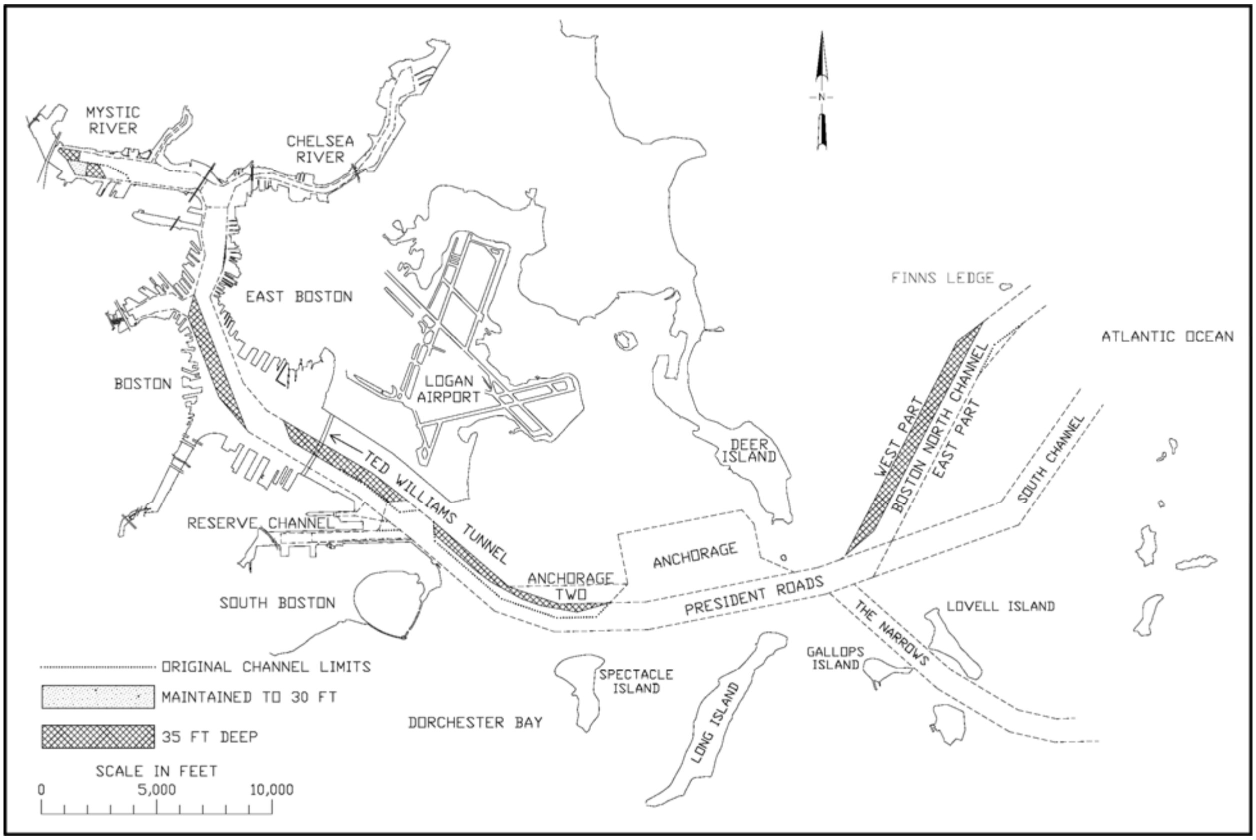

Figure 3. Boston Harbor, proposed conditions.

Entrance and main channel deepening

The first improvement plan would deepen the Broad Sound North Entrance Channel, Main Ship Channel, and the lower Reserved Channel and its turning area for the benefit of larger container vessels calling on Massport's Conley Terminal. A channel depth of –45 ft mean lower low water (MLLW) in the harbor is being considered, with incremental optimization between 42 and 50 ft. This plan includes (1) deepening the 40-ft lane of the Broad Sound North Entrance Channel from Massachusetts Bay to the outer confluence to a depth of –47 ft MLLW (the additional 2 ft in depth to compensate for increased wave and wind action), (2) deepening the Main

Ship Channel from the outer confluence through President Roads and up-harbor to the Reserved Channel to −45 ft, (3) deepening the 40-ft lower reach of the Reserved Channel to 45 ft, (4) deepening the Reserved Channel turning area to 45 ft and expanding it northwesterly up the main channel to accommodate larger vessels, and (5) deepening all or a portion of the President Roads Anchorage to 45 ft.

The deepened entrance channel will retain its 1100-ft entrance reach width and its 900-ft width in its remaining length. The current 35-ft-deep lane would remain unchanged. A bend widener is proposed at the turn where the 1100- and 900-ft-wide reaches join in response to pilots' concerns to have additional maneuvering width opposite Finns Ledge. A closeup of the widener is shown in Figure 4.

The portion of the Main Ship Channel along the south side of President Roads would retain its current 1200-ft width to facilitate safe access and egress from the anchorage and permit recovery of vessel course before entering the turns at Spectacle Island. The deepened channel would be widened to 800 ft by incorporating portions of the existing 35-ft lane. In the turns at Spectacle Island the channel would be widened further to 880 ft to increase the width available for vessel maneuvering through the turns, easing a difficult bend, especially for the larger containerships that are expected to call at Reserved Channel. The transition from the anchorage and the 1200-foot channel width in President Roads into the narrower lower Main Ship Channel would also be flared into the 35-ft lane to ease the approach up-harbor. These improvements are shown in Figure 5.

Main Ship Channel deepening extension to Ted Williams Tunnel

In order to accommodate plans by Massport to develop a new dry bulk terminal at the Massport Marine Terminal in South Boston, extending the proposed deepening of the Main Ship Channel above the Reserved Channel to below the Ted Williams Tunnel is also being considered. Massport's plans for this facility include leases for the receipt or export of cement, aggregates, newsprint, steel, and other bulk products. The clearances over the Ted Williams Tunnel above this terminal limit channel depths in the upper harbor areas to the 40 ft already provided. The reach of the Main Ship Channel to be deepened to 45 ft under this plan would be widened to 650 ft by including a 50-ft-wide strip of the current 35-ft lane.

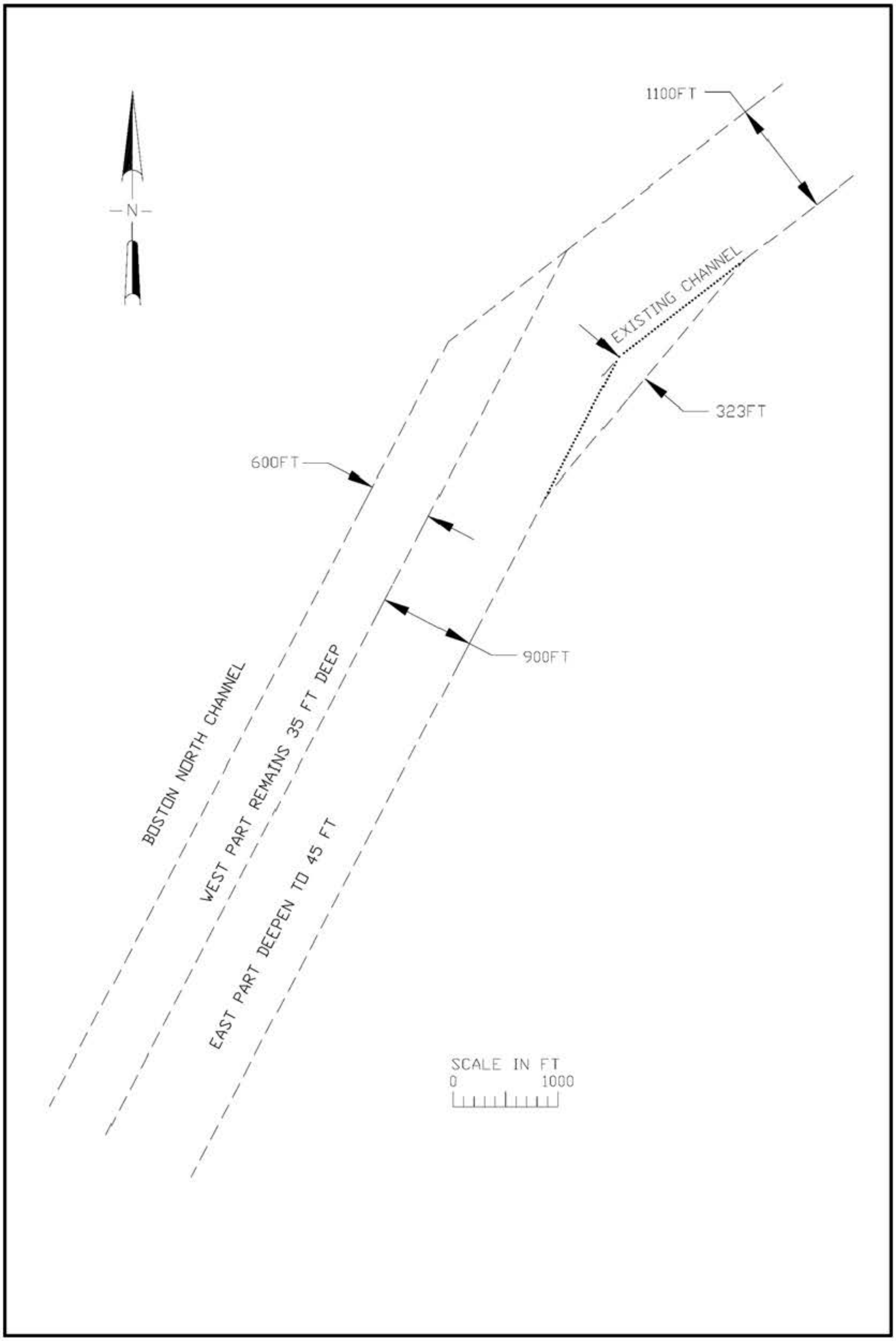

Figure 4. Boston North Channel bend widener.

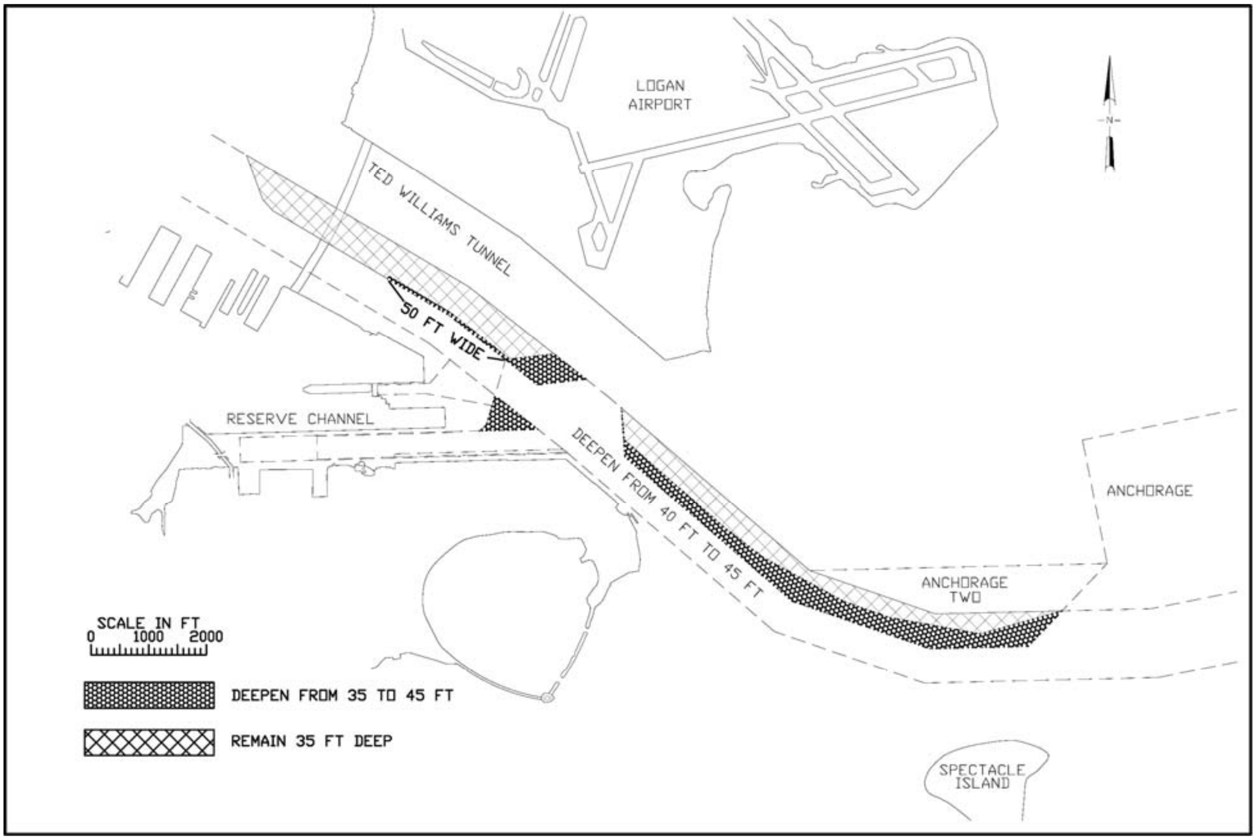

Figure 5. Widening near Reserve Channel.

Ted Williams Tunnel to confluence of Mystic and Chelsea Rivers

No channel improvements are proposed for this section of the harbor, including the Fort Point and Charles River Channel tributaries.

Mystic River

A portion of the existing 35-ft channel will be deepened to 40 ft to permit deeper access to Massport's Medford Street Terminal for bulk cargo vessels. This is shown in Figure 3. This area is located about midway along the southern half of the Mystic Channel above the Boston Autoport. This area was not included in the 1990 project authorization, as plans for this terminal had not yet progressed to the point of decisions on its future use. Massport plans to develop the property as another dry bulk terminal and has already deepened the berths to –40 ft. This will allow large bulk carriers to call without having to wait for tidal advantage. Since there will be no increase in ship size over those now plying this waterway, and currents are negligible throughout the tidal cycle, this improvement did not require being included in this navigation study.

Chelsea River

The Chelsea River is being considered for deepening from 38 ft to 40 ft. The 1990 project only recommended a 38-ft depth for this waterway because the Chelsea Street Bridge limited design vessel dimensions, particularly beam, so greater improvements were impractical with bridge replacement. With the USCG and the City of Boston now pursuing funds for a new bridge, a 40-ft improvement is being reconsidered. This area was included in the 1992 ship simulation study that examined vessels of the classes that would be expected to use the waterway under the 38-ft improvement and also considered a 40-ft improvement without the bridge. That study showed that larger tank ships that would require the 40-ft depth would also require bridge replacement and bend easing. Therefore, Chelsea River is not included in this navigation study.

3 Reconnaissance Trip

The reconnaissance trip for the Boston Harbor study was conducted November 15-19, 2004. The purpose of the trip was to meet with New England District representatives and the Boston Pilots. These meetings primarily took place upon ships transiting the study area so navigation practices could be observed. In addition, ERDC representatives took photographs and video, which was later used for simulation model development. ERDC was represented by Dennis Webb and Peggy Van Norman who traveled to Boston on November 15. Upon arrival in Boston, they contacted Capt. Gregg Farmer of the Boston Pilots and Mr. John Winkelman of the New England District to coordinate.

November 16

Capt. Farmer, Mr. Webb, Ms. Van Norman, and Mr. Winkelman boarded the *MV Allegiance* in the Atlantic Ocean. The *MV Allegiance* is a 612-ft-long Length-Over-All (LOA) tanker with a beam of 90 ft. The *MV Allegiance* was loaded to a draft of 34 ft and was heading inbound to the Global Terminal on Chelsea Creek. During the transit, Capt. Farmer listed several navigation concerns of the existing and future Boston Harbor:

- A wrecked barge was discovered a few years ago. The wreck was marked by a can buoy (Figure 6) and avoided by the pilots. This obstruction has since been removed by New England District under the last contract for maintenance dredging of the outer harbor channels in 2005. Therefore, this is no longer a concern.
- Swell is a serious issue for the approach channels to Boston Harbor. The channels are operational in up to 18-ft swells with tidal assistance.
- Boston Harbor presently has two asymmetric channels, i.e., two lanes of different depths. Capt. Farmer expressed concern that as the one lane was deepened to 50 ft, they would have problems with bank effects caused by the 35-ft lane.
- Flood currents into Dorchester Bay cause the ship to be set to the green buoys in the turns above Spectacle Island.
- There is also a ledge in this area where the channel is not 40 ft MLLW. This ledge is scheduled for removal to at least -42 ft as part of the upcoming inner harbor maintenance operation.

Figure 6. Buoy marking wreck.

Corps employees disembarked the ship onto the pilot boat in downtown Boston. The *MV Allegiance* and Capt. Farmer continued on to the Global Terminal. Corps representatives disembarked early, at Capt. Farmer's recommendation, so they could ride an inbound containership.

The Corps representatives boarded the *MV MSC Jeanne* in the Atlantic Ocean. The pilot was Capt. Frank Morten. The *MV MSC Jeanne* is a 767-ft-long (LOA) containership with a beam of 106 ft. The inbound draft was 41 ft. The *MV MSC Jeanne* was inbound to the container docks on the Reserved Channel. Capt. Morten reiterated Capt. Farmer's concerns about navigation in Boston Harbor. Figure 7 shows the *MV MSC Jeanne* turning into the Reserved Channel.

The Corps representatives boarded the *MV Zephyros* in the President Roads Anchorage. The *MV Zephyros* is a 538-ft-long (LOA) scrap metal ship with a beam of 75 ft. The *MV Zephyros* was loaded to a draft of 25 ft and was inbound to the Prolerized scrap metal dock on the Mystic River. The pilot for this movement was Capt. Richard Stover.

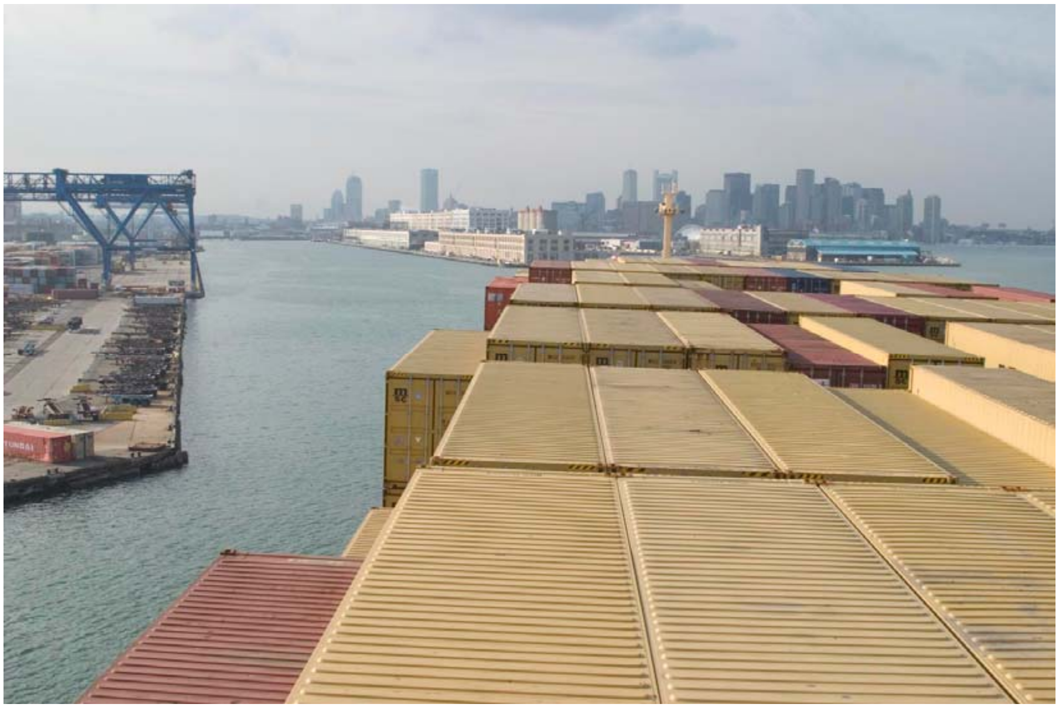

Figure 7. *MV MSC Jeanne* approaching Reserve Channel.

November 17

Mr. Webb and Ms. Van Norman boarded the *MV Delphina*, Capt. Marty McCabe, pilot. During the ride on the pilot boat, Captains McCabe and Chris Hoyt discussed their desired modifications to the President Roads Anchorage (USCG Anchorage #2). They stated that the anchorage was often crowded with three ships and that flood currents pushed the ships toward the northern end of the anchorage. Both pilots felt that angling the western end of the anchorage to incorporate portions of the 35-ft barge anchorage and areas between the two would make it more effective. The pilots' proposed angle is shown in Figure 8.

The *MV Delphina* is a 610-ft-long (LOA) tanker with a beam of 90 ft. The *MV Delphina* was loaded to a draft of 36 ft. During the transit to the Gulf Oil Dock, the 90-ft-wide *MV Delphina* passed through the 93-ft-wide Chelsea Street Bridge (Figure 9). Corps representatives rode back to the pilot station on a tractor tug, which gave them the opportunity to photograph Chelsea Creek from an outbound viewpoint.

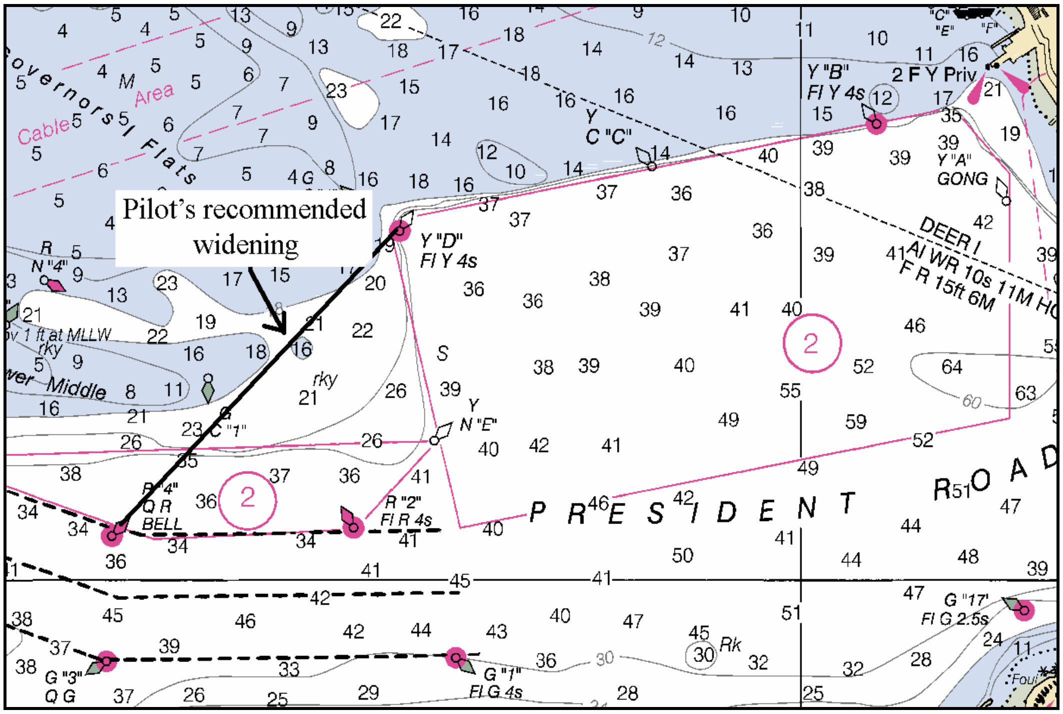

Figure 8. Pilot's recommended widening for anchorage.

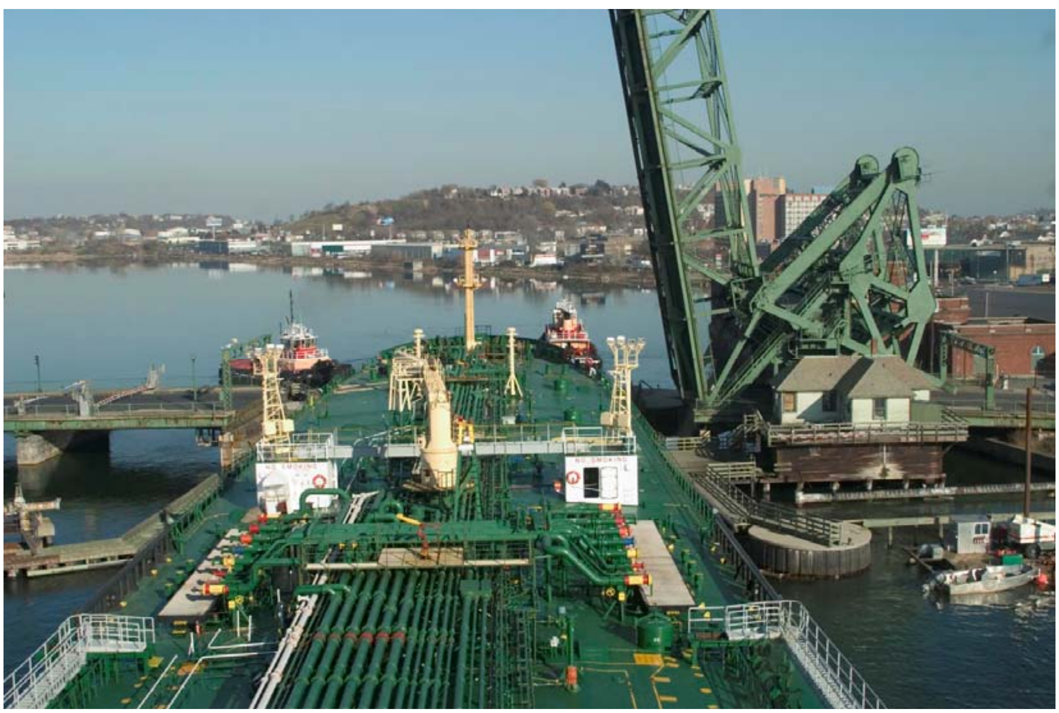

Figure 9. *MV Delphina* passes through Chelsea Street Bridge.

November 18

Mr. Webb and Ms. Van Norman boarded the *MV Hoegh Galleon*, Capt. Gregg Farmer, pilot. The *MV Hoegh Galleon* is an 818-ft-long (LOA) LNG ship with a beam of 131 ft. The ship's draft was approximately 33 ft. The *MV Hoegh Galleon* docked at the Distrigas LNG terminal on the Mystic River, which concluded the reconnaissance trip.

4 Database Development and Validation

Database development

Currents for both the existing and proposed channels were calculated using the ADCIRC model in a joint New England District/ERDC effort (Wilkelman et al., in preparation). Current data for the maximum strength of both the ebb and flood tides were extracted and converted into the format required by the ERDC Ship/Tow Simulator.

Two ship models were developed for the Boston Harbor Navigation Study by Designers & Planners, Inc. (Ankudinov 2005):

- Ship 1. The *COSCO Hamburg*, a 918-ft-long (LOA), 5,618-TEU (TEU = twenty-foot equivalent unit) containership. The ship's beam is 131.2 ft, and the ship is fully loaded to a draft of 45.9 ft.
- Ship 2. The *Delaware Bridge*, a 871.8-ft-long (LOA), 4,713-TEU containership. The ship's beam is 105.6 ft, and the ship is fully loaded to a draft of 43.3 ft.

Both containership models were equipped with bow thrusters.

The visual scene was modified using the photos taken during the reconnaissance trip. Figure 10 shows the visual scene as one of the Boston Pilots operates the simulator. The only adjustment required to the visual scene for the proposed alternative channels was new aids to navigation (ATONS) for the Boston North Channel Bend widener. The buoy marking the wreck was removed, as was buoy G "3". The two new buoys that marked the ends of the widener are shown in Figure 11. The wrecked barge was removed from the approach to Boston Harbor during maintenance dredging during the spring/summer of 2005.

The Electronic Chart Display and Information System (ECDIS) was modified to reflect proposed changes to the channel footprints. Figure 12 shows an ECDIS chart modified to reflect changes at the mouth of the Reserved Channel. It should be noted that the ECDIS editing software does not allow removal of ATONS or modifying contour lines. However, the pilots felt the display showing the proposed channel was adequate.

Figure 10. Boston Ship Pilot turning containership near mouth of Reserve Channel.

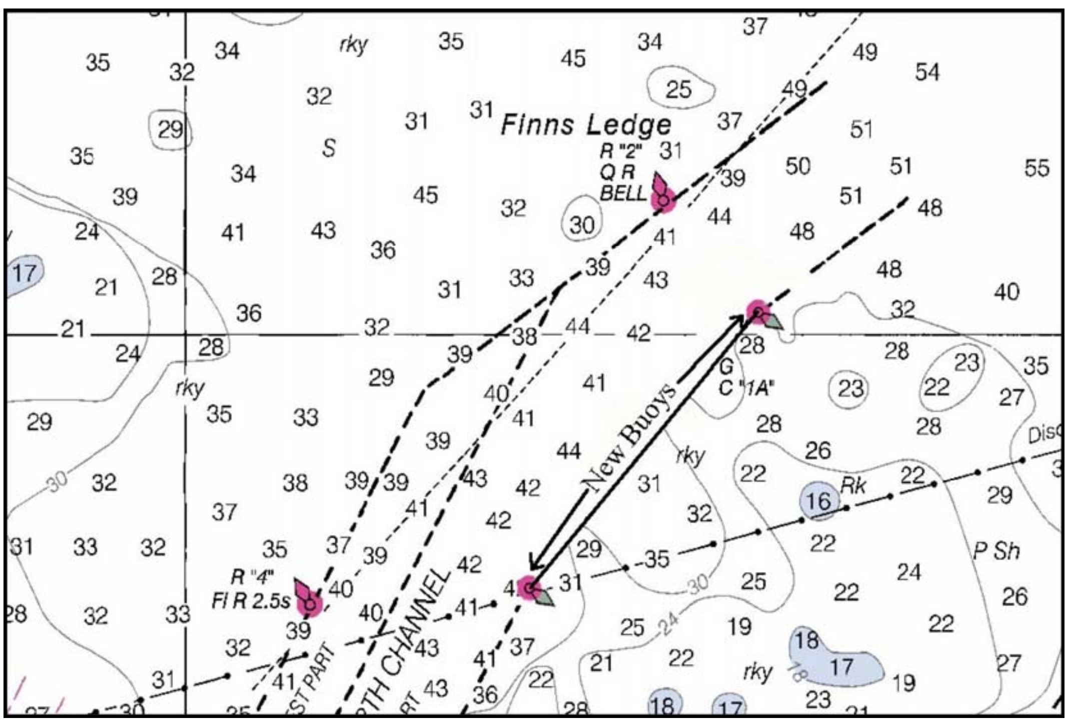

Figure 11. New buoys for bend widener.

Figure 12. ECDIS display modified to show improved turning notch at mouth of Reserve Channel.

Validation

Validation for Boston Harbor was conducted September 6-9, 2005. Two Boston Harbor Pilots participated in the validation effort. A Massport representative also attended. Validation originally scheduled for August 29 – September 2, 2005, was delayed a week due to Hurricane Katrina. Representatives for New England District were scheduled to attend the original validation week but were unable to reschedule.

During validation, the Massport representative voiced concerns over the location of the improved turning notch. He stated that the improvements were directly in line with the low approach runway for Logan Airport. Representatives from New England District, New York District, ERDC, Massport, and the pilots worked together to formulate an alternative turning area configuration. This turning area, Plan 2, is shown in Figure 13. The ADCIRC model was modified to reflect the channel geometry of Plan 2 and currents were calculated. Simulations of the Plan 2 channel were conducted in the final days of the formal testing program.

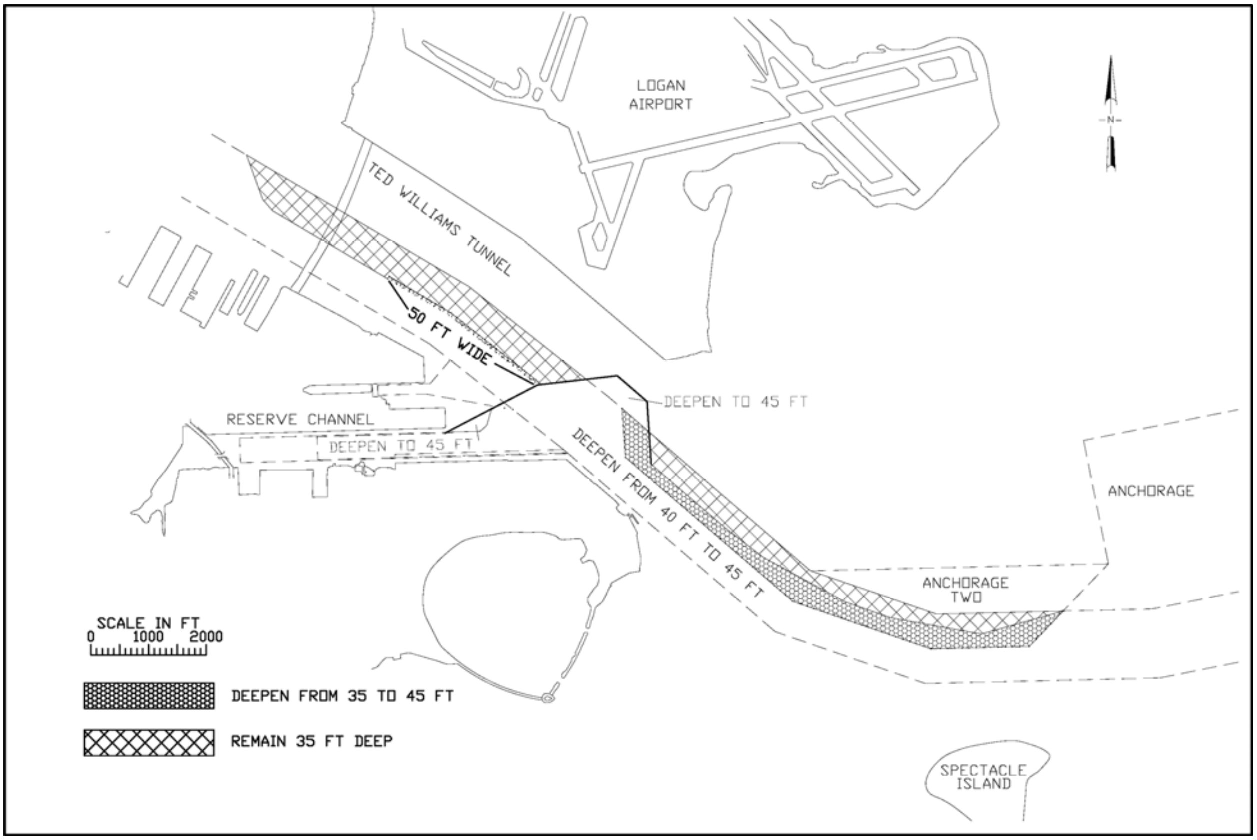

Figure 13. Plan 2 turning notch.

5 Tug Usage

Both containerships were equipped with bow thrusters for the simulations. All but one of the runs were completed with two tractor tugs. That one run used two tractor tugs and one conventional tug.

Tractor tugs are a generation beyond normal harbor tugs. Utilizing propulsion such as the Z Drive, the tractor tug can push or pull with little to no loss of thrust efficiency, eliminating most of the need to change position during the job.

Tug usage in the simulator is accomplished by radio communication between the pilot and the simulator operator. Different pilots use the tugs differently, but for the Boston transits, full ahead and astern commands were common. These commands are not unusual and do not necessarily indicate that changes need to be made.

During inbound runs, as the containerships came through Dorchester Bay (20-30 min before getting to Conley Terminal) the pilot would call the tugs alongside. From this point on the tugs were hooked up in order to be in position to work when needed. This position was typically one tug each on the ship's port bow and stern. Once the vessel started its turn for the backing maneuver into Reserve Channel, the tugs worked almost continuously until the transit and initial docking maneuvers were completed. Tug usage during the inbound runs was about 20–25 min (remembering that the transit stopped before the vessel was fully docked). For outbound runs, usage time increased closer to 40 min since the containerships were maneuvering off the terminal face to enter the federal channel.

6 Results

Testing was conducted September 12–16 and 17–21, 2005. Four Boston Harbor Pilots participated in the testing program. Simulations of the Plan 2 turning notch were conducted only during the last 3 days of the second session. After each test, the pilot was given a chance to provide written comment on the simulation. At the end of each week of testing, the pilots were given a final questionnaire to complete. These questionnaires are included in Appendix A.

Results are presented in the form of composite track plots. Results will be presented first for the Main Ship Channel and Reserved Channel turning notch improvements. These will be followed by the results for the Boston North Channel bend widener.

Main Ship Channel improvements and Plan 1 turning notch

Inbound, flood tide, 30 knots northeast wind, backing into Reserved Channel

Results of the *COSCO Hamburg* inbound through the Main Ship Channel and backing into the Reserved Channel with flood tide and 30 knots of wind from the northeast are shown in Plate 1. Four pilots completed this exercise, with one leaving the northeast end of the turning notch by nearly 260 ft. The other three pilots were able to turn within the notch. Several of the runs left the northeast end of the Reserved Channel. All ships successfully transited the improved Main Ship Channel. One of the four pilots used three tugs to back into the Reserved Channel. The pilot that used three tugs was one of the successful runs.

Results of the *Delaware Bridge* inbound through the Main Ship Channel and backing into the Reserved Channel with flood tide and 30 knots of wind from the northeast are shown in Plate 2. Four pilots completed this scenario. All ships successfully transited the improved Main Ship Channel and successfully turned in the improved notch. One of the runs left the northeast end of the Reserved Channel.

Inbound, flood tide, 30 knots northwest wind, backing into Reserved Channel

Results of the *COSCO Hamburg* inbound through the Main Ship Channel and backing into the Reserved Channel with flood tide and 30 knots of wind from the northwest are shown in Plate 3. Four pilots completed this scenario. All ships successfully transited the improved Main Ship Channel and successfully turned in the improved notch. One of the runs left the northeast end of the Reserved Channel.

Results of the *Delaware Bridge* inbound through the Main Ship Channel and backing into the Reserved Channel with flood tide and 30 knots of wind from the northwest are shown in Plate 4. Four pilots completed this scenario. All ships successfully transited the improved Main Ship Channel and successfully turned in the improved notch.

Inbound, ebb tide, 30 knots northeast wind, backing into Reserved Channel

Results of the *COSCO Hamburg* inbound through the Main Ship Channel and backing into the Reserved Channel with ebb tide and 30 knots of wind from the northeast are shown in Plate 5. Four pilots tested this scenario. One pilot was unable to stop his ship in time to turn in the notch and could not complete the maneuver. Another ship left the northeast side of the turning notch by nearly 260 ft. A third vessel just crossed the channel limits on the north end of the notch. All ships successfully transited the improved Main Ship Channel.

Results of the *Delaware Bridge* inbound through the Main Ship Channel and backing into the Reserved Channel with ebb tide and 30 knots of wind from the northeast are shown in Plate 6. Four pilots completed this scenario. All ships successfully transited the improved Main Ship Channel. One ship left the turning notch by slightly more than 10 ft.

Inbound, ebb tide, 30 knots northwest wind, backing into Reserved Channel

Results of the *COSCO Hamburg* inbound through the Main Ship Channel and backing into the Reserved Channel with ebb tide and 30 knots of wind from the northwest are shown in Plate 7. Four pilots completed this scenario. All ships successfully transited the improved Main Ship Channel.

Two ships left the northeast side of the turning notch, one by approximately 80 ft and the other by approximately 15 ft.

Results of the *Delaware Bridge* inbound through the Main Ship Channel and backing into the Reserved Channel with ebb tide and 30 knots of wind from the northwest are shown in Plate 8. Two pilots successfully completed this scenario. Pilots for the second week of testing did not attempt this exercise in order to complete some scenarios for the Plan 2 notch.

Outbound, flood tide, 30 knots northeast wind, backing out of Reserved Channel

Results of the *COSCO Hamburg* backing out of the Reserved Channel and heading outbound through the Main Ship Channel with flood tide and 30 knots of wind from the northeast are shown in Plate 9. Four pilots completed this exercise. All successfully turned in the improved notch. One ship did leave the southern edge of the improved Main Ship Channel by approximately 75 ft.

Results of the *Delaware Bridge* backing out of the Reserved Channel and heading outbound through the Main Ship Channel with flood tide and 30 knots of wind from the northeast are shown in Plate 10. Four pilots completed this exercise. All successfully turned in the improved notch. One ship did leave the southern edge of the improved Main Ship Channel by approximately 75 ft. The same pilot that left the southern edge of the improved Main Ship Channel with the *COSCO Hamburg* also left the channel with the *Delaware Bridge*, by approximately 60 ft.

Outbound, flood tide, 30 knots northwest wind, backing out of Reserved Channel

Results of the *COSCO Hamburg* backing out of the Reserved Channel and heading outbound through the Main Ship Channel with flood tide and 30 knots of wind from the northwest are shown in Plate 11. Four pilots completed this exercise. All successfully turned in the improved notch. One ship left the northeast corner of the Reserved Channel by about 15 ft.

Results of the *Delaware Bridge* backing out of the Reserved Channel and heading outbound through the Main Ship Channel with flood tide and 30 knots of wind from the northeast are shown in Plate 12. Four pilots successfully completed this exercise.

Outbound, ebb tide, 30 knots northeast wind, backing out of Reserved Channel

Results of the *COSCO Hamburg* backing out of the Reserved Channel and heading outbound through the Main Ship Channel with ebb tide and 30 knots of wind from the northeast are shown in Plate 13. Four pilots completed this exercise. One ship crossed the northeast end of the Reserved Channel while backing into the notch. All ships turned in the improved notch and transited the improved Main Ship Channel successfully.

Results of the *Delaware Bridge* backing out of the Reserved Channel and heading outbound through the Main Ship Channel with ebb tide and 30 knots of wind from the northeast are shown in Plate 14. Four pilots completed this exercise. One ship crossed the northeast end of the Reserved Channel while backing into the notch. All ships turned in the improved notch and transited the improved Main Ship Channel successfully.

Outbound, ebb tide, 30 knots northwest wind, backing out of Reserved Channel

Results of the *COSCO Hamburg* backing out of the Reserved Channel and heading outbound through the Main Ship Channel with ebb tide and 30 knots of wind from the northwest are shown in Plate 15. Two pilots completed this exercise. Both ships turned in the improved notch and transited the improved Main Ship Channel successfully.

Results of the *Delaware Bridge* backing out of the Reserved Channel and heading outbound through the Main Ship Channel with ebb tide and 30 knots of wind from the northwest are shown in Plate 16. Two pilots completed this exercise. One ship crossed the northeast end of the Reserved Channel while backing into the notch. Both ships turned in the improved notch and transited the improved Main Ship Channel successfully.

Inbound, ebb tide, 30 knots northwest wind, backing out of Reserved Channel

At a pilot's request, a scenario of a ship turning bow-in to Reserved Channel was undertaken. The scenario included a ship docked at the outer berth. Results of this exercise with the *COSCO Hamburg* are shown in Plate 17. Only one pilot completed this exercise. The ship entered the 35-ft-deep portion of the Main Ship Channel by about 20 ft while swinging his ship to port. The pilot used two tugs and felt that three would be required in real life.

Plan 2 turning notch

Inbound, ebb tide, 30 knots northwest wind, backing into Reserved Channel

Results of the *COSCO Hamburg* inbound through the Main Ship Channel and backing into the Reserved Channel, using the Plan 2 turning notch, with ebb tide and 30 knots of wind from the northwest are shown in Plate 18. Two pilots completed this scenario. However, both pilots did a repeat run on the scenario. One pilot left the north side of the notch by about 170 ft on his first attempt. The other three runs were successful.

Outbound, ebb tide, 30 knots northwest wind, backing out of Reserved Channel

Results of the *COSCO Hamburg* backing out of the Reserved Channel, turning in the Plan 2 turning notch, and heading outbound through the Main Ship Channel with ebb tide and 30 knots of wind from the northwest are shown in Plate 19. Only one pilot attempted this exercise. It was successfully completed.

Outbound, ebb tide, 30 knots northeast wind, backing out of Reserved Channel

Results of the *COSCO Hamburg* backing out of the Reserved Channel, turning in the Plan 2 turning notch, and heading outbound through the Main Ship Channel with ebb tide and 30 knots of wind from the northeast are shown in Plate 20. Two pilots attempted this exercise, both successfully.

Inbound, flood tide, 30 knots northeast wind, backing into Reserved Channel

Results of the *COSCO Hamburg* inbound through the Main Ship Channel and backing into the Reserved Channel, using the Plan 2 turning notch, with flood tide and 30 knots of wind from the northeast are shown in Plate 21. Two pilots completed this scenario. However, one pilot brought his ship approximately 100 ft out of the north side of the Plan 2 turning notch. Both ships left the northeast end of the Reserved Channel.

Boston North Channel bend widener

Inbound, flood tide, 30 knots northeast wind

Results of the *COSCO Hamburg* inbound through the Boston North Channel bend widener with flood tide and 30 knots of wind from the northeast are shown in Plate 22. Four pilots completed this exercise, all successfully using the bend widener.

Results of the *Delaware Bridge* inbound through the Boston North Channel bend widener with flood tide and 30 knots of wind from the northeast are shown in Plate 23. Four pilots completed this exercise, all successfully using the bend widener.

Outbound, flood tide, 30 knots northeast wind

Results of the *COSCO Hamburg* outbound through the Boston North Channel bend widener with flood tide and 30 knots of wind from the northeast are shown in Plate 24. Four pilots completed this exercise, all successfully using the bend widener.

Results of the *Delaware Bridge* outbound through the Boston North Channel bend widener with flood tide and 30 knots of wind from the northeast are shown in Plate 25. Four pilots completed this exercise, all successfully using the bend widener.

Inbound, flood tide, 30 knots northwest wind

Results of the *COSCO Hamburg* inbound through the Boston North Channel bend widener with flood tide and 30 knots of wind from the northwest are shown in Plate 26. Two pilots completed this exercise, both successfully using the bend widener.

Outbound, flood tide, 30 knots northwest wind

Results of the *COSCO Hamburg* outbound through the Boston North Channel bend widener with flood tide and 30 knots of wind from the northwest are shown in Plate 27. Two pilots completed this exercise, both successfully using the bend widener.

Final questionnaire

At the end of their simulator testing session, the pilots completed a final questionnaire (included as Appendix A). In the questionnaire, the pilots stated their support for the improvements to the both Plans 1 and 2 turning notches, the Main Ship Channel, and the bend widener for the Boston North Channel. The two pilots that had the opportunity to simulate the Plan 2 turning notch felt it was adequate and even superior to the Plan 1 notch.

7 Recommendations

Based upon the simulator results and the pilot's final questionnaires, the following recommendations are made for the Boston Harbor Channel improvements:

a. The Boston North Channel bend widener is recommended without any modifications.

b. The widening of the Main Ship Channel is recommended without any modifications.

c. The Plan 1 turning notch is recommended with the modifications shown in Figure 14. A number of ships left the northeastern edge of the turning notch. This edge should be extended 100 ft. A number of ships also left the northeast end of the Reserved Channel. Modifying the Plan 1 notch to resemble the Plan 2 notch in this area is recommended.

d. The Plan 2 turning notch is recommended without any modifications. Only two pilots were able to test the Plan 2 notch, and they felt the notch was adequate. It is recommended that two additional pilots participate in a 2- or 3-day simulation program to verify these results. The modified Plan 1 turning notch could also be simulated at this time. However, this is not a requirement.

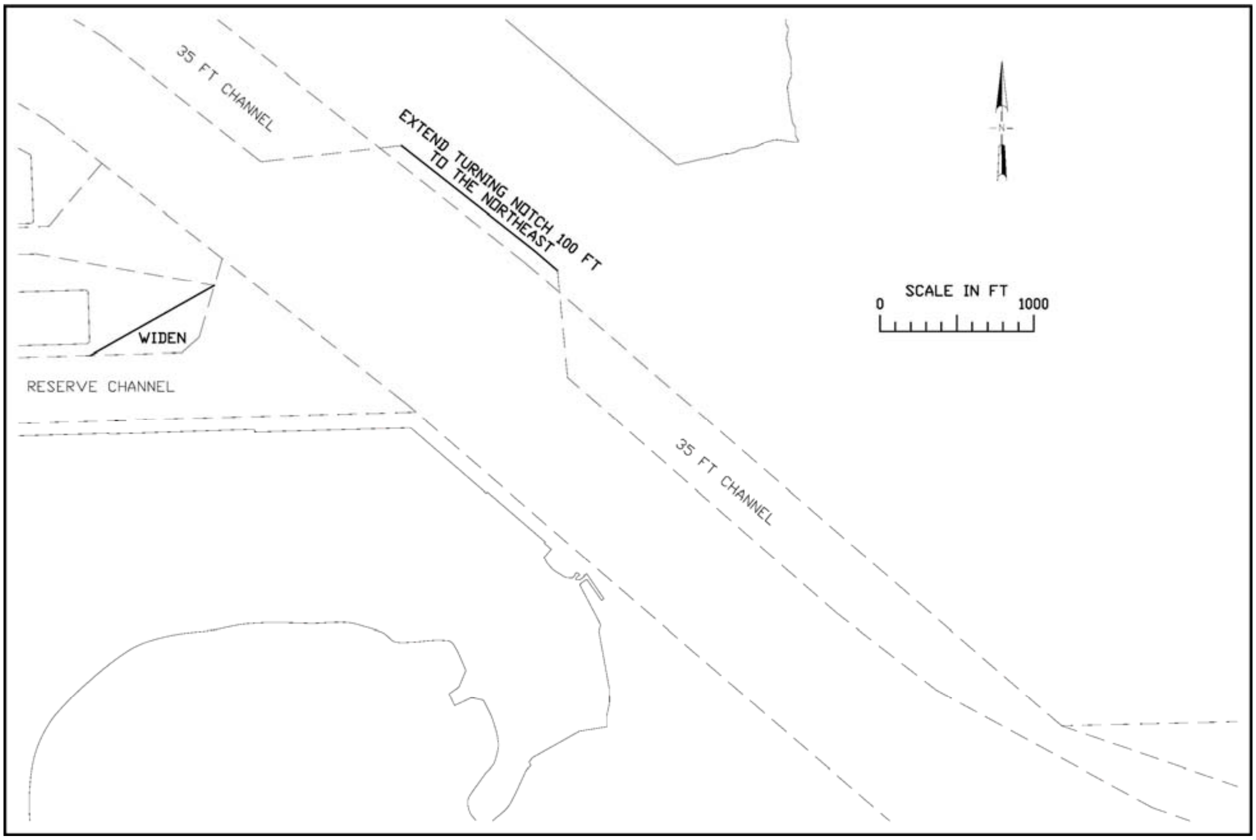

Figure 14. Recommended modifications to the Plan 1 turning notch.

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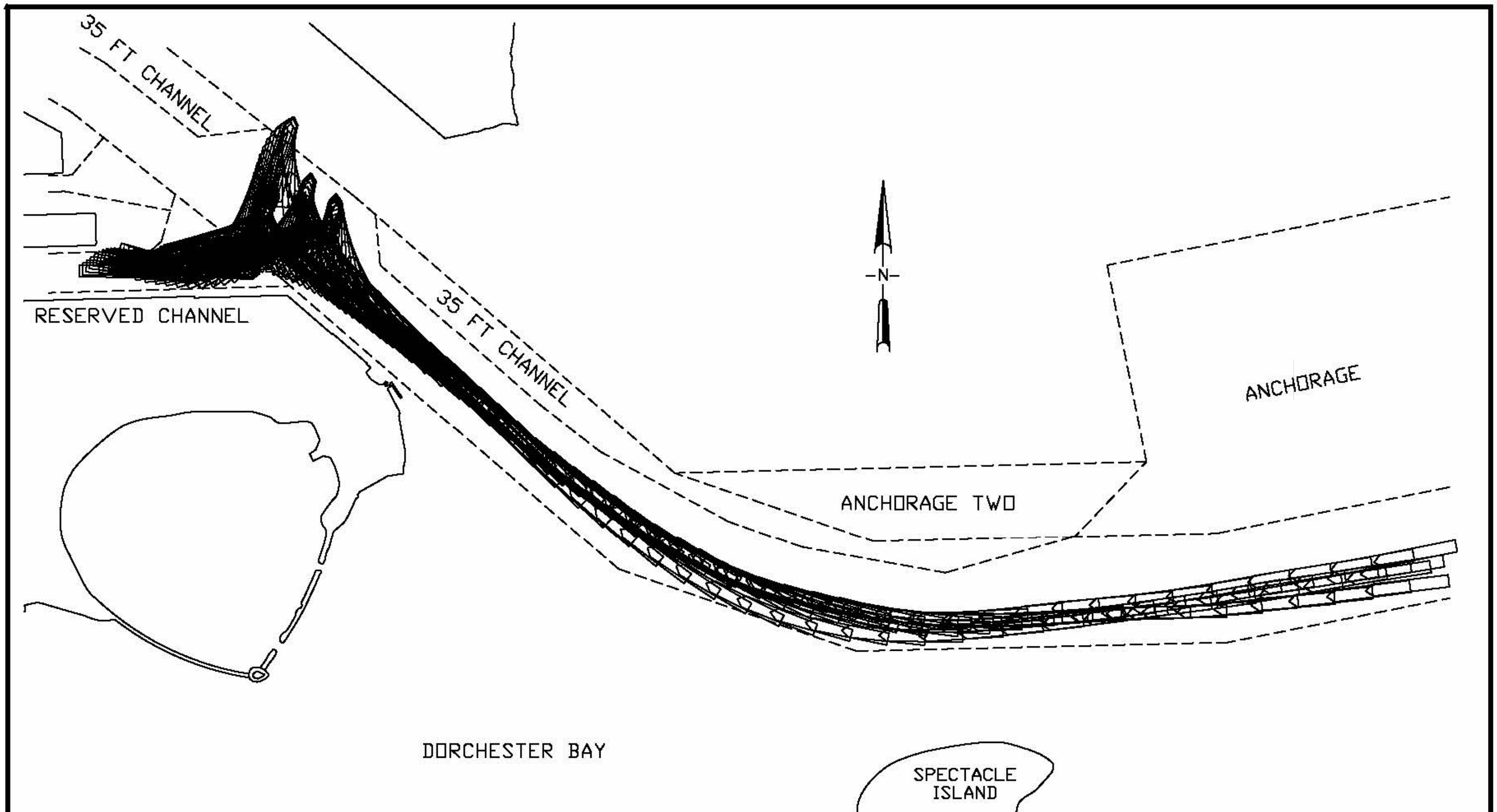
Ankudinov, V. 2005. Development of two hi-fidelity ship models for a ship simulation study of Boston Harbor: "*COSCO Hamburg*", and "*Delaware Bridge*." Arlington, VA: BTM Designers & Planners, Inc.

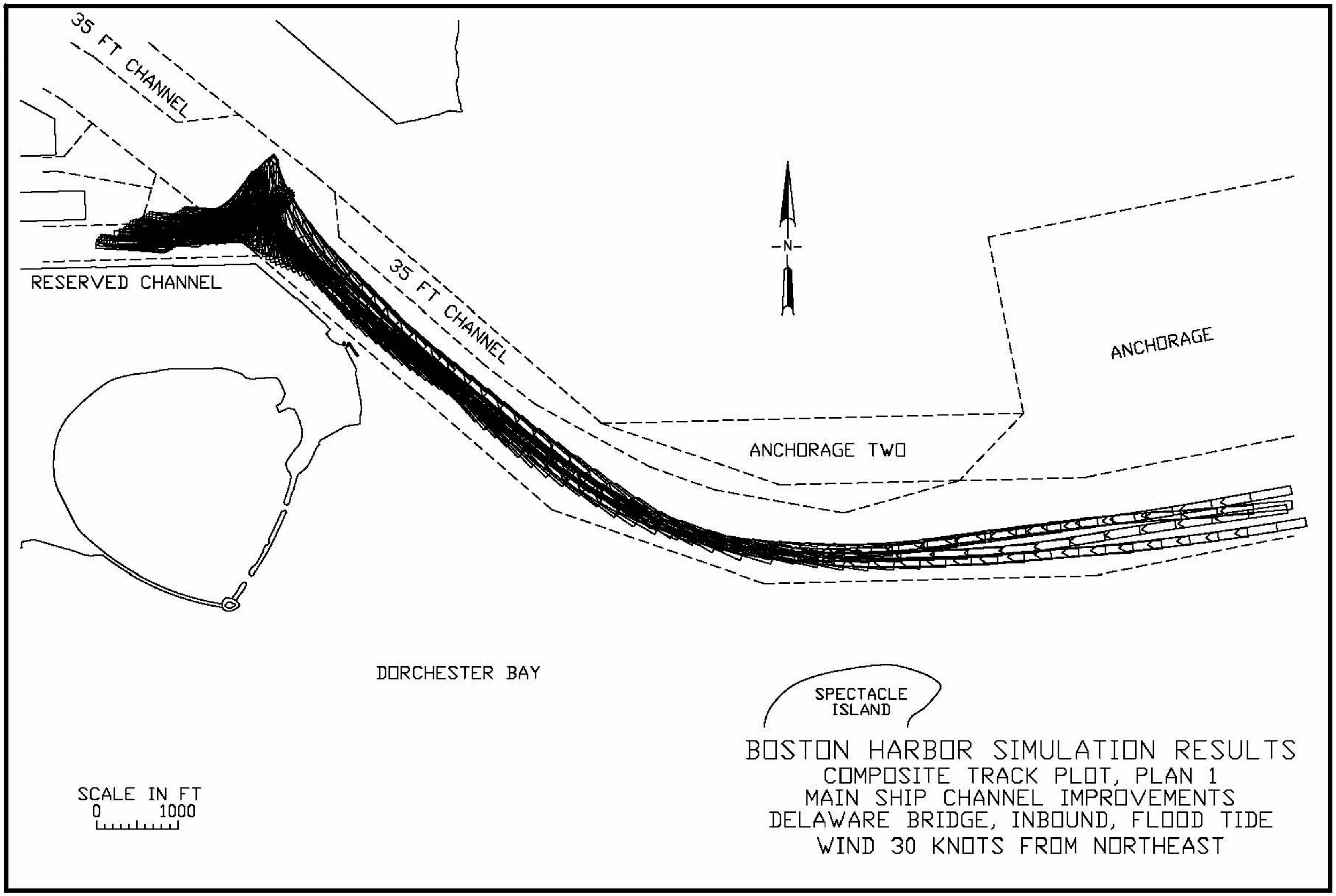
Wilkelman, J., Z. Demirbilek, and L. Lin. *Boston Harbor Deep Draft Navigation Channel Improvement: 2-D Hydraulic Modeling*. In preparation.



BOSTON HARBOR SIMULATION RESULTS
COMPOSITE TRACK PLOT, PLAN 1
MAIN SHIP CHANNEL IMPROVEMENTS
COSCO HAMBURG, INBOUND, FLOOD TIDE
WIND 30 KNOTS FROM NORTHEAST

PLATE 1

PLATE 2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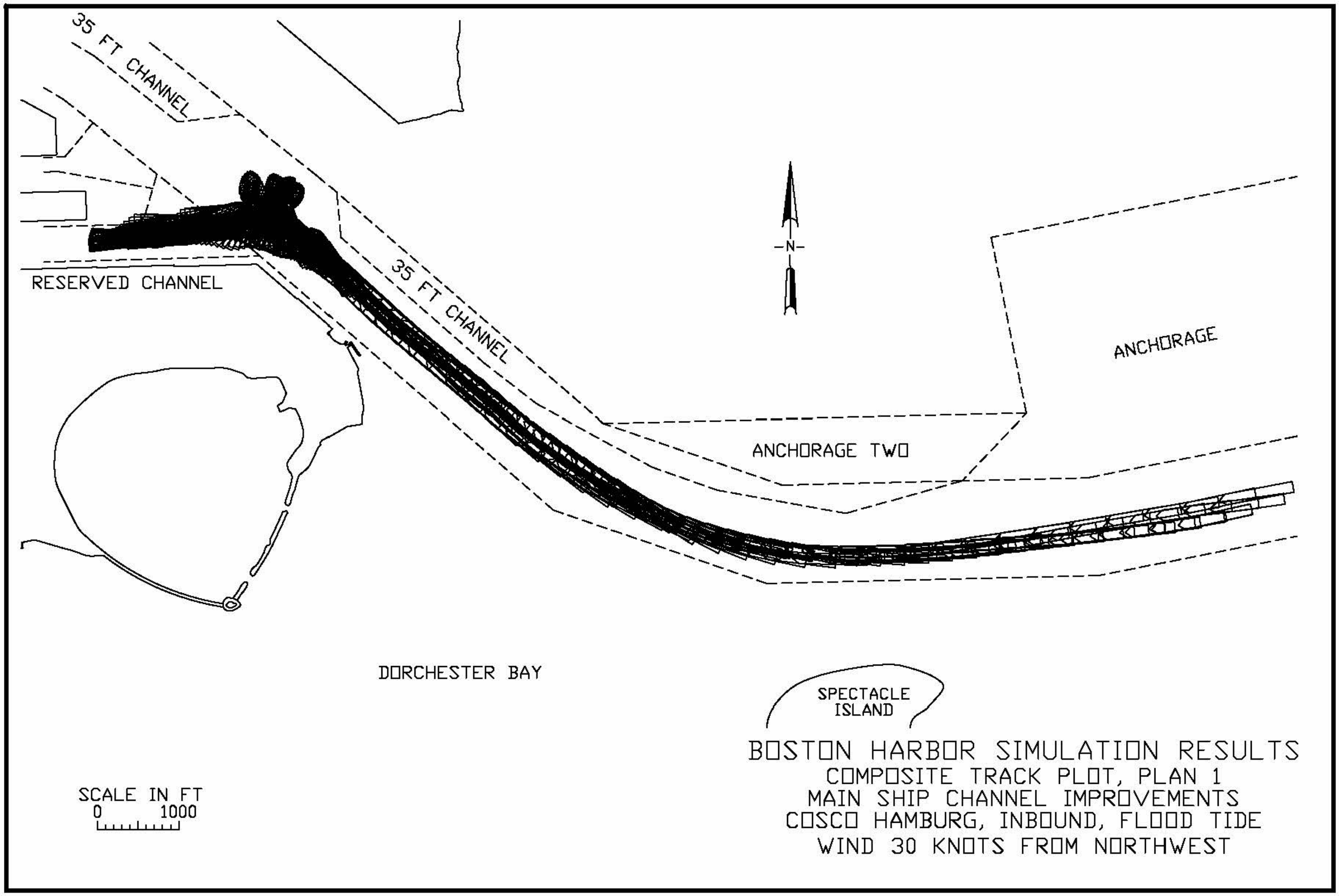
COMPOSITE TRACK PLOT, PLAN 1
MAIN SHIP CHANNEL IMPROVEMENTS
DELAWARE BRIDGE, INBOUND, FLOOD TIDE
WIND 30 KNOTS FROM NORTHEAST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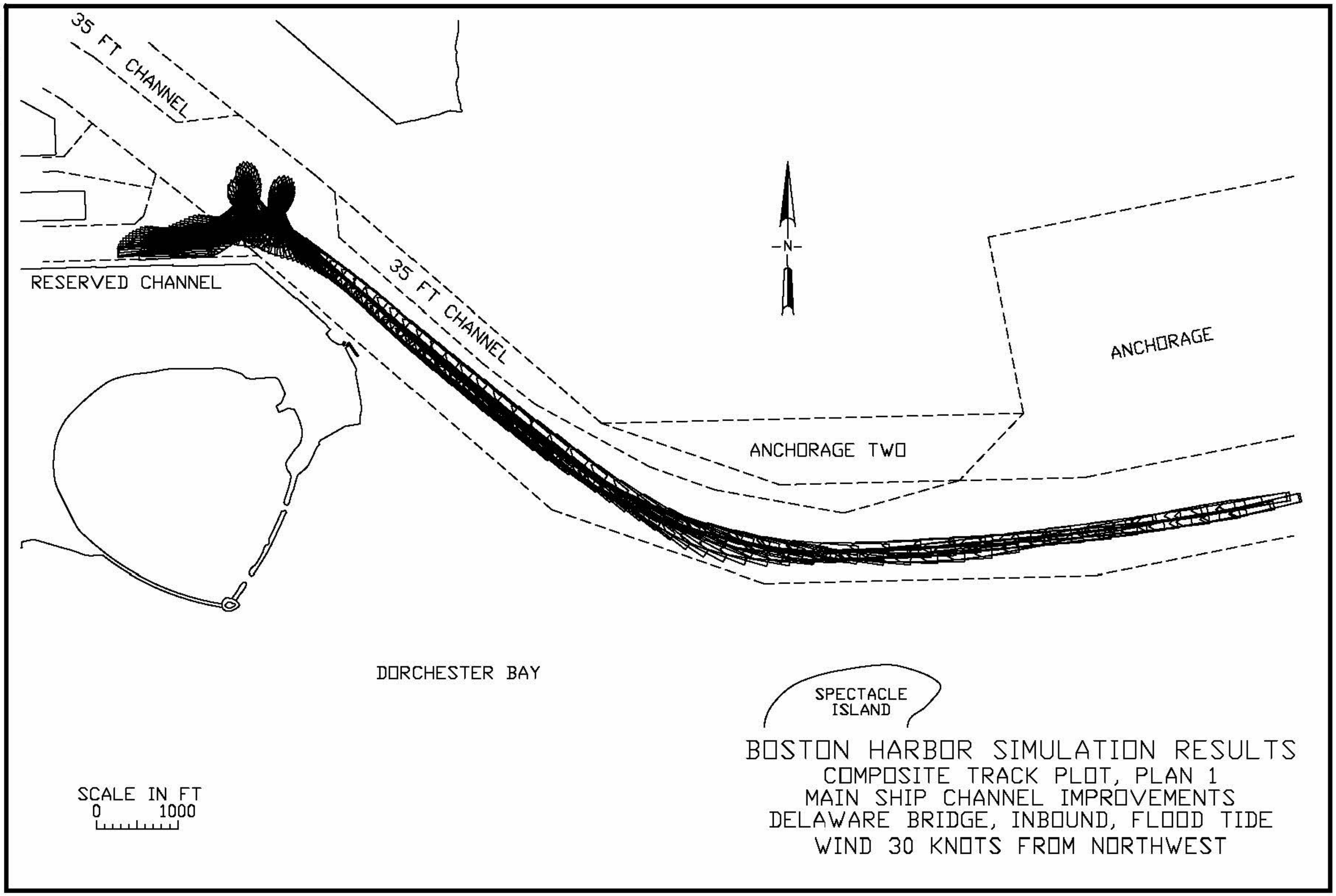
COMPOSITE TRACK PLOT, PLAN 1
MAIN SHIP CHANNEL IMPROVEMENTS
COSCO HAMBURG, INBOUND, FLOOD TIDE
WIND 30 KNOTS FROM NORTHWEST

PLATE 3

PLATE 4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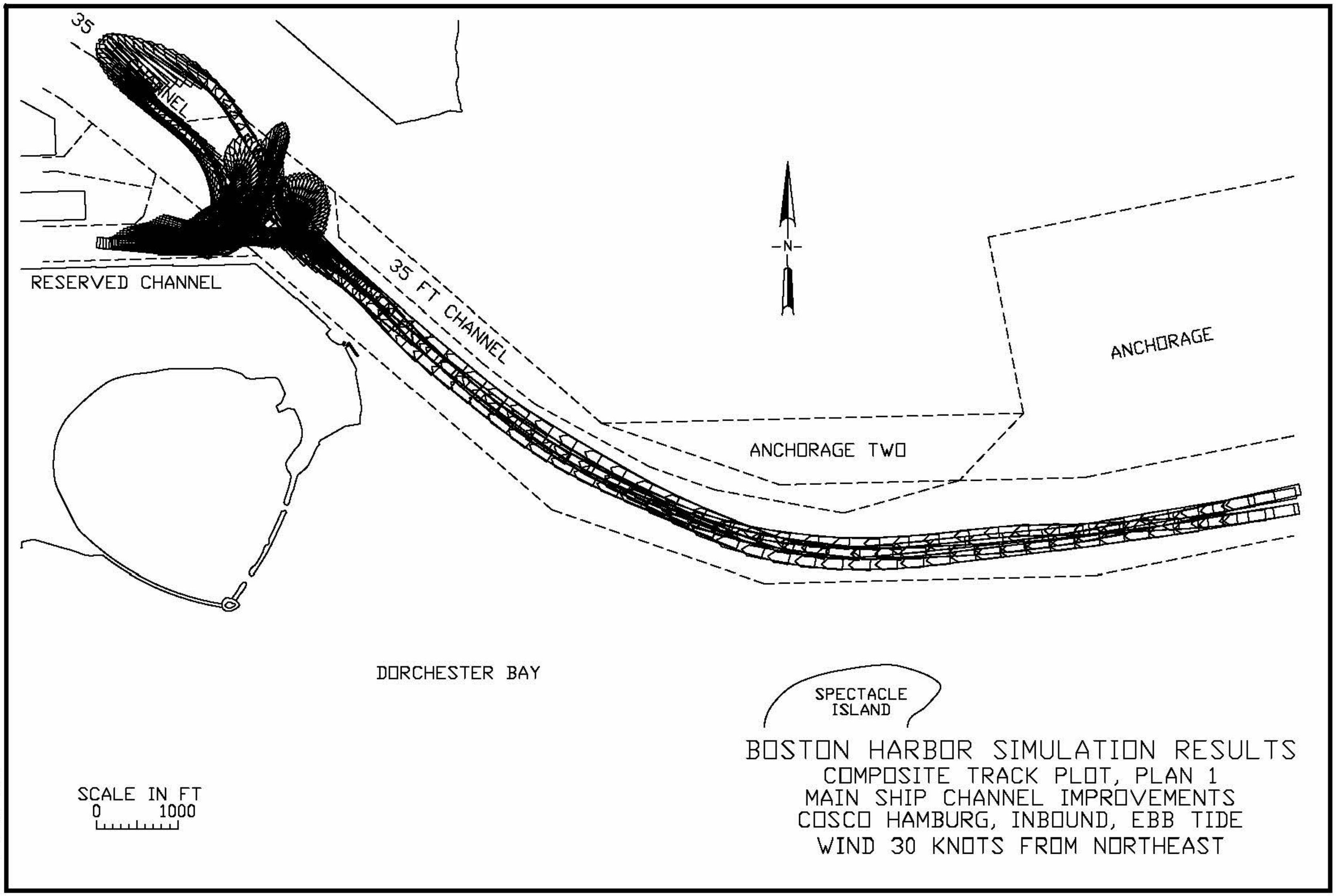
WIND 30 KNOTS FROM NORTHWEST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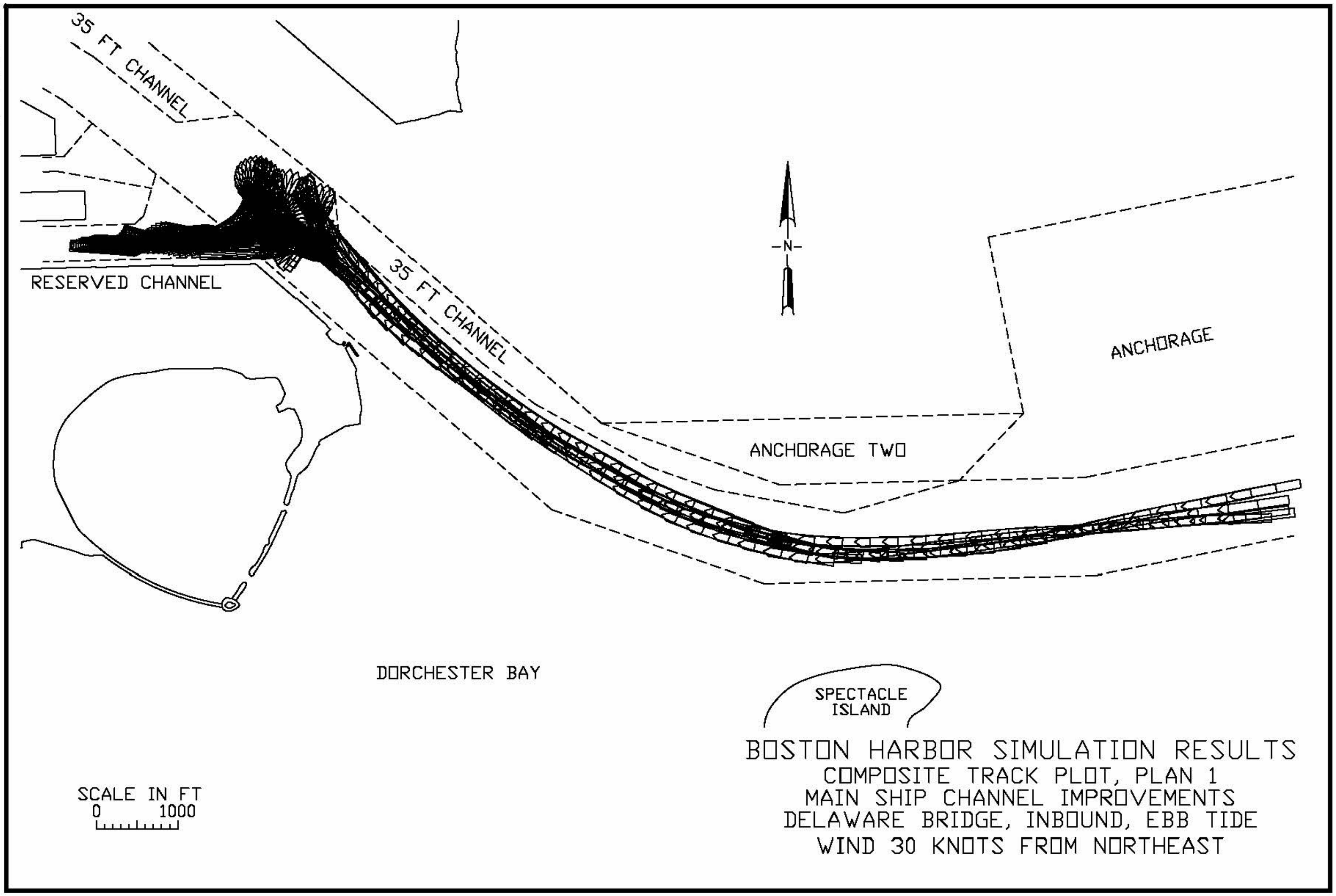
COMPOSITE TRACK PLOT, PLAN 1
MAIN SHIP CHANNEL IMPROVEMENTS
COSCO HAMBURG, INBOUND, EBB TIDE
WIND 30 KNOTS FROM NORTHEAST

PLATE 5

PLATE 6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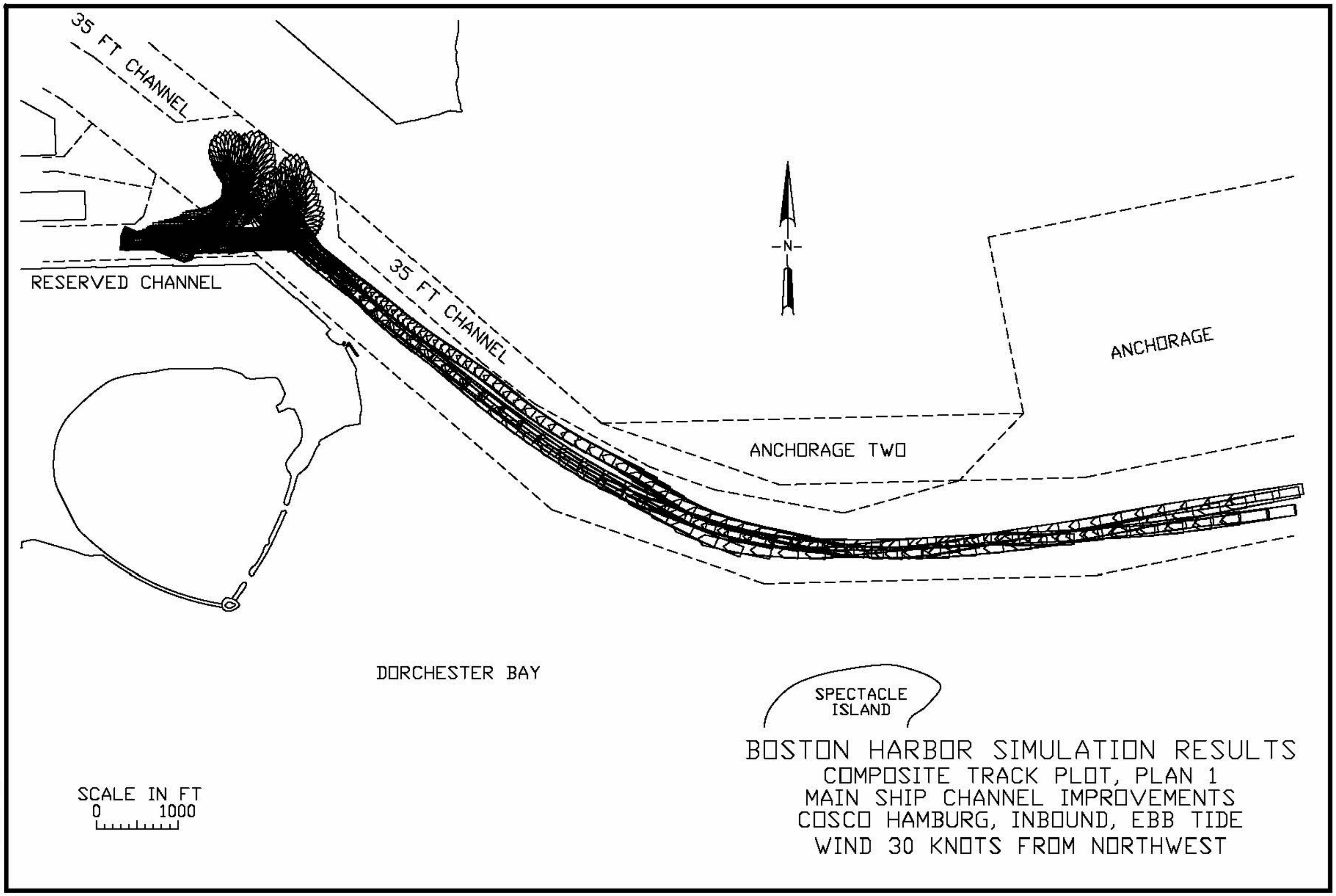
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COSCO HAMBURG, INBOUND, EBB TIDE
WIND 30 KNOTS FROM NORTHWEST
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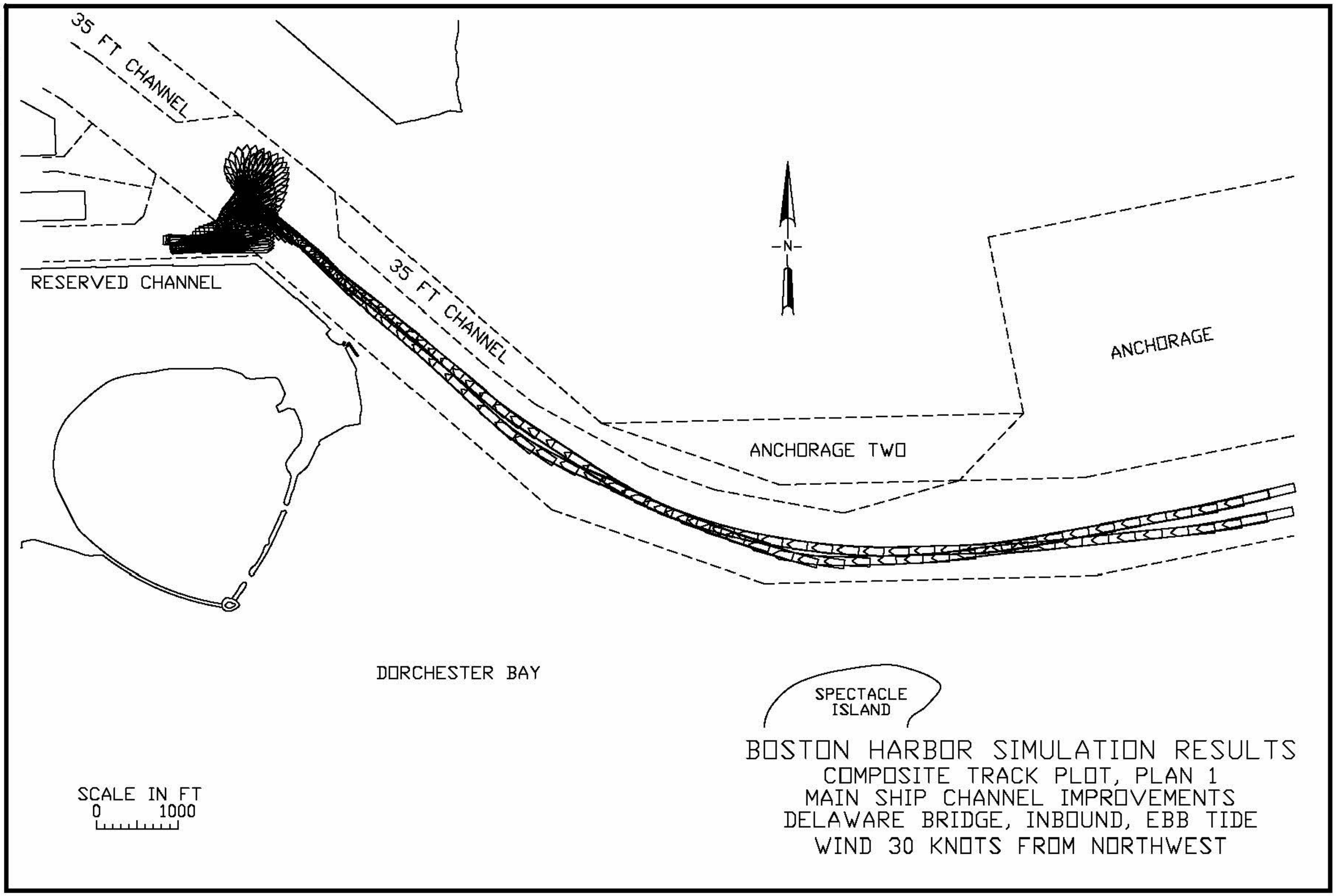
PLATE 7

PLATE 8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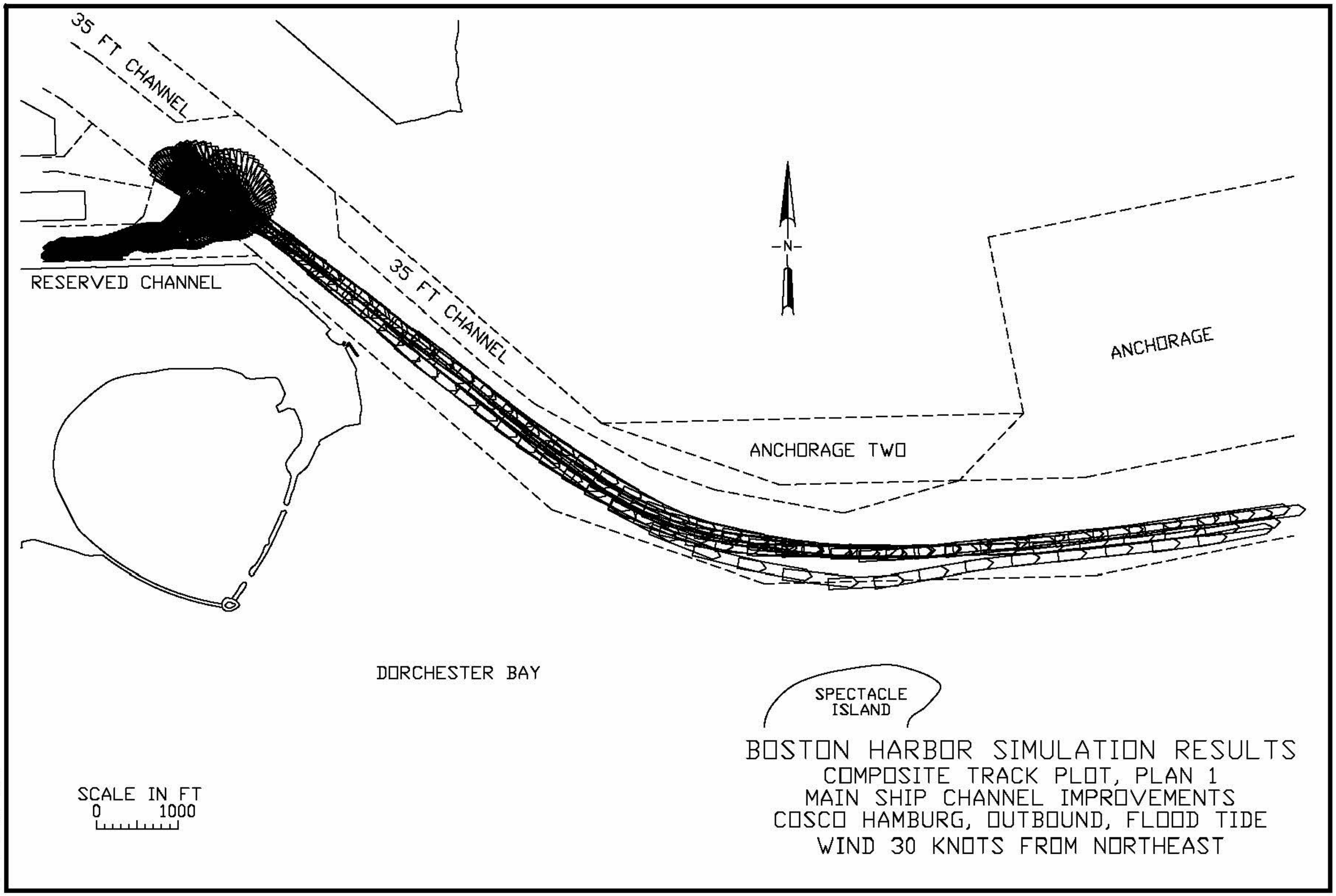
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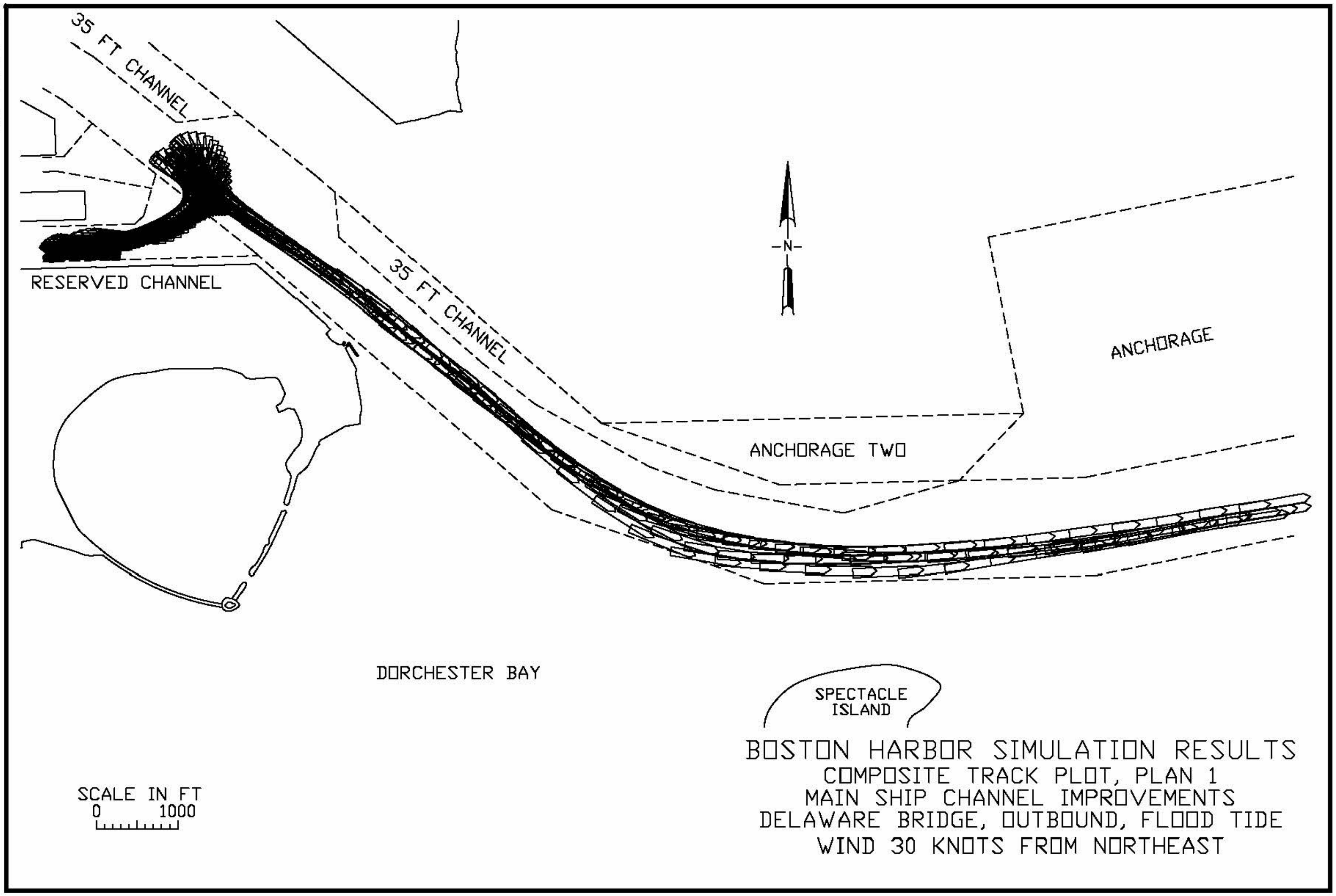
COSCO HAMBURG, OUTBOUND, FLOOD TIDE
WIND 30 KNOTS FROM NORTHEAST

PLATE 9

PLATE 10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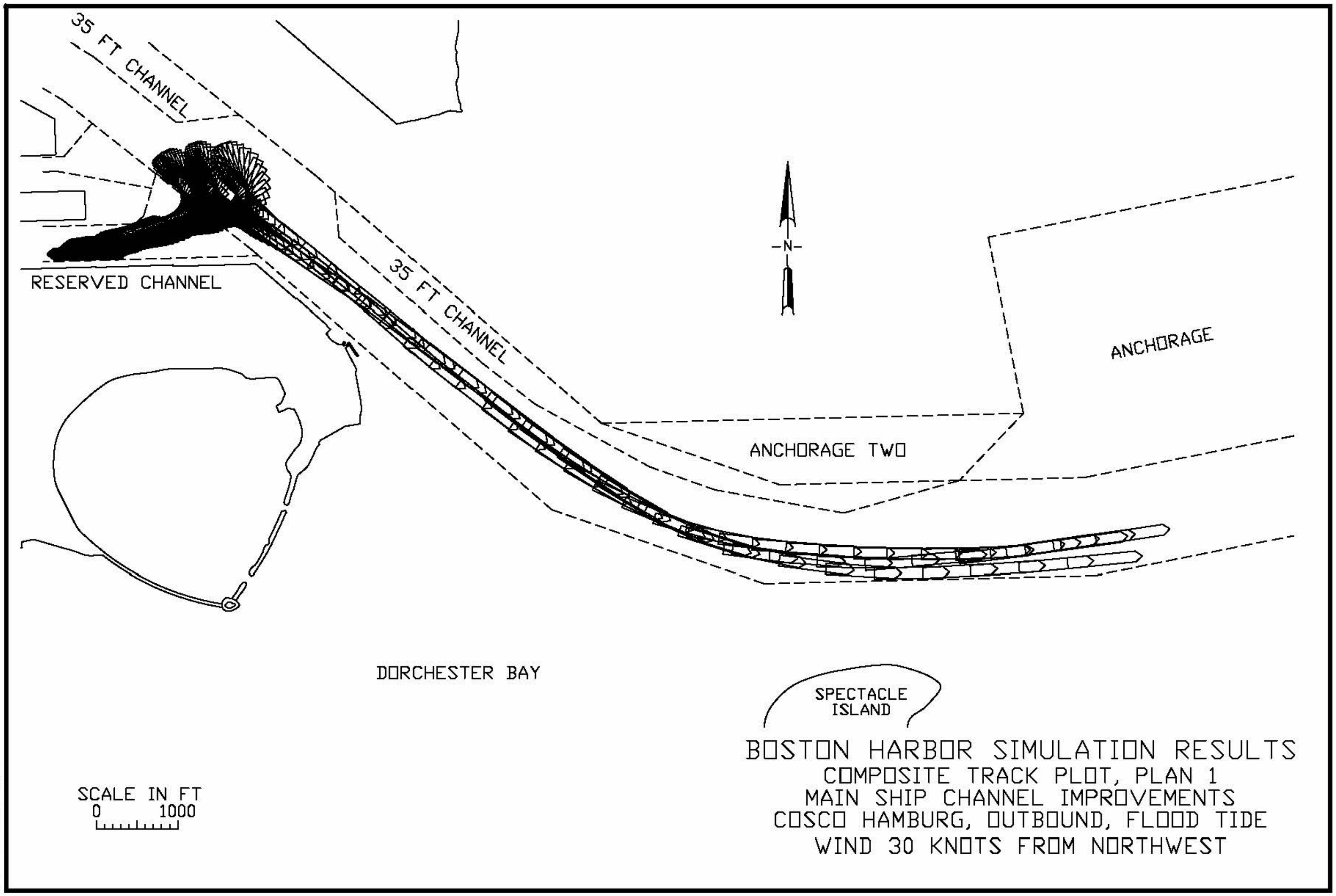
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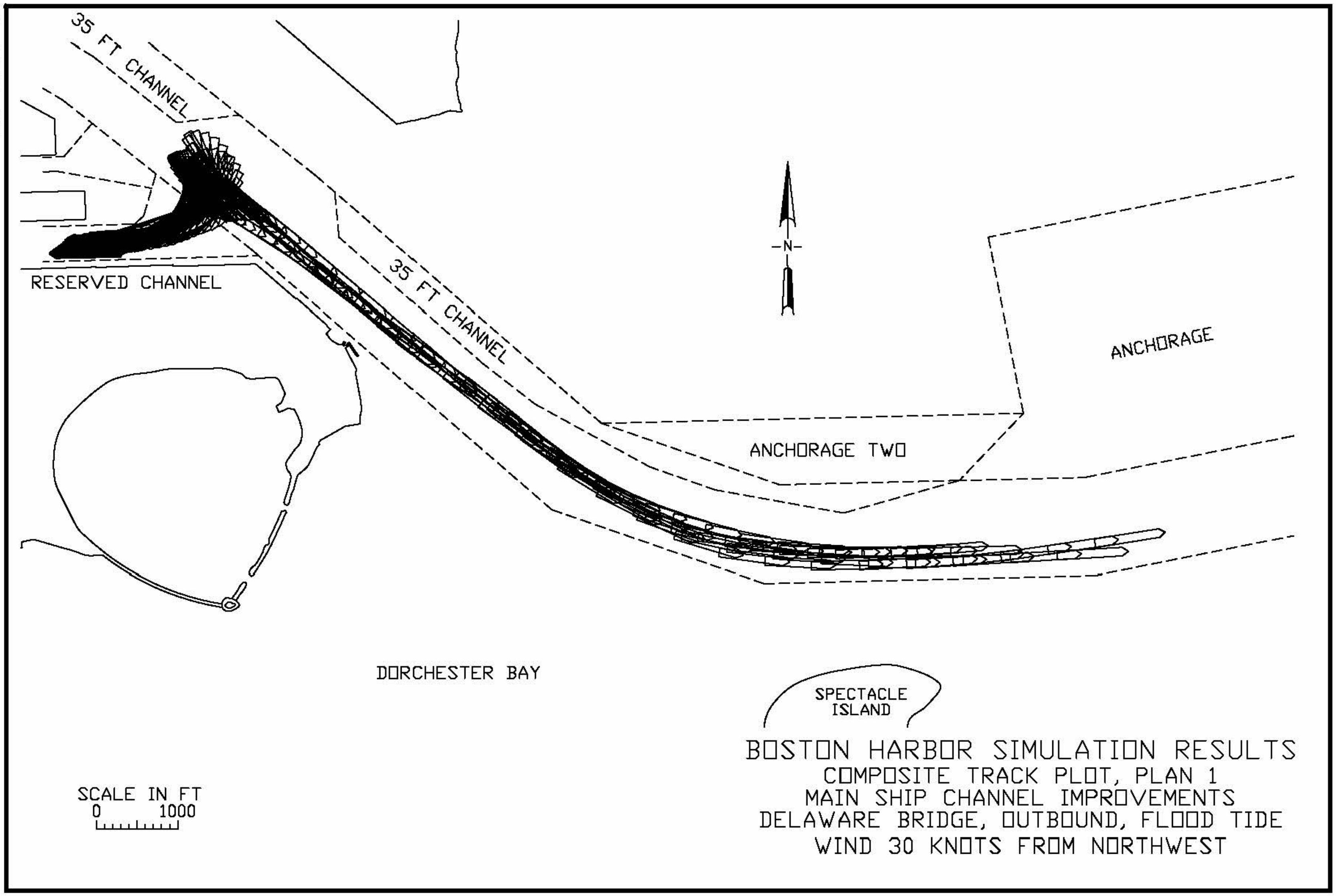
MAIN SHIP CHANNEL IMPROVEMENTS
COSCO HAMBURG, OUTBOUND, FLOOD TIDE
WIND 30 KNOTS FROM NORTHWEST

PLATE 11

PLATE 12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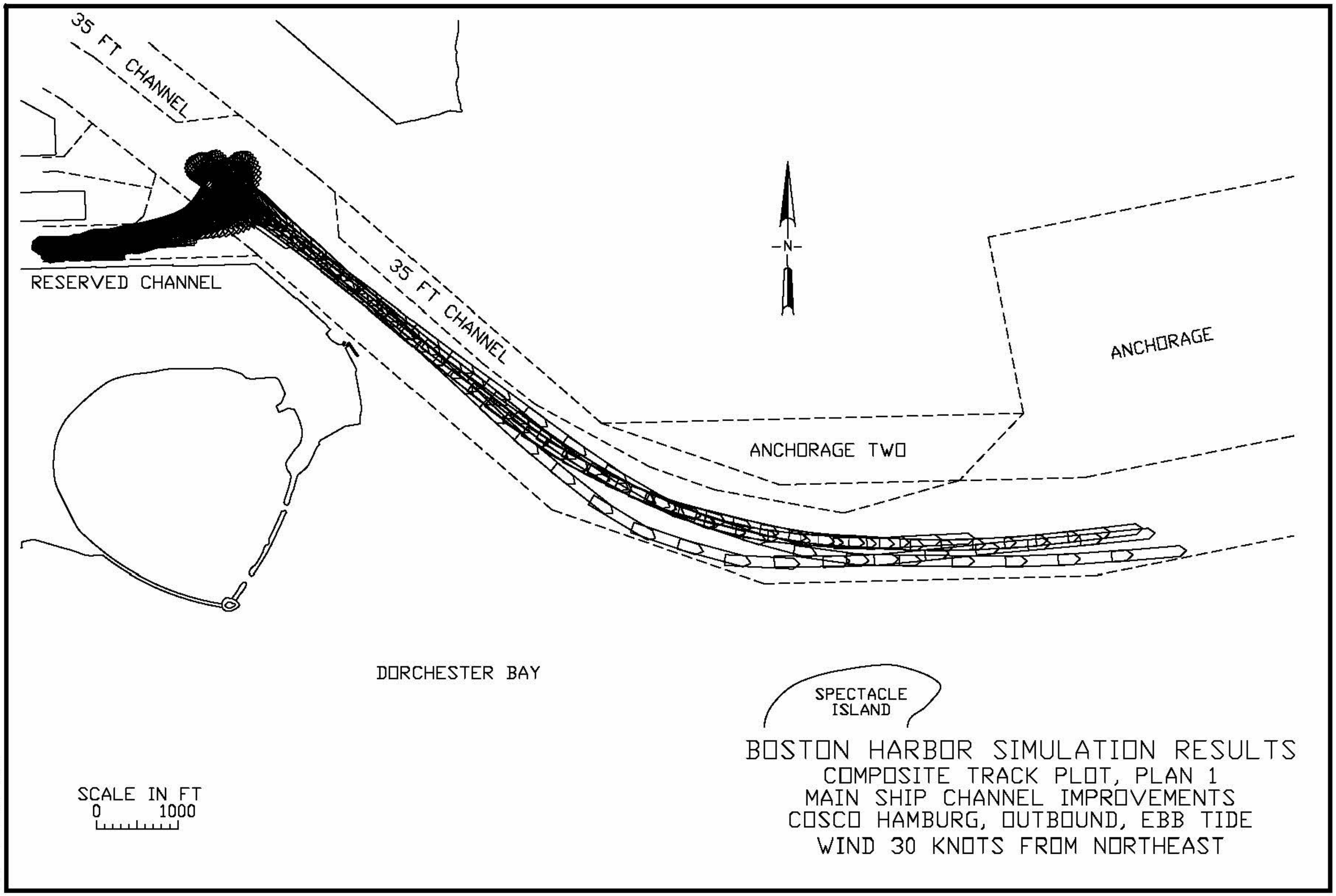
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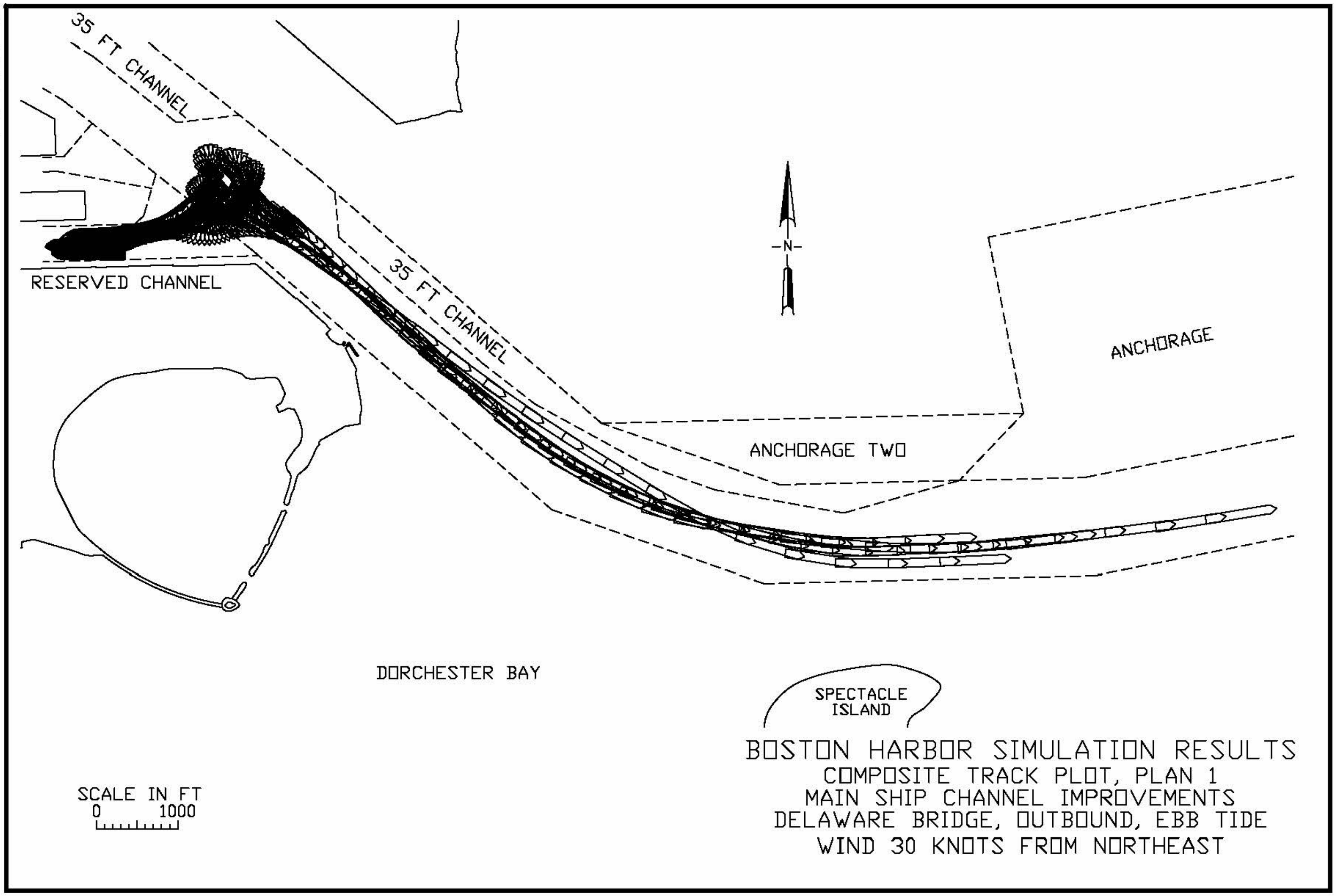
COSCO HAMBURG, OUTBOUND, EBB TIDE
WIND 30 KNOTS FROM NORTHEAST

PLATE 13

PLATE 14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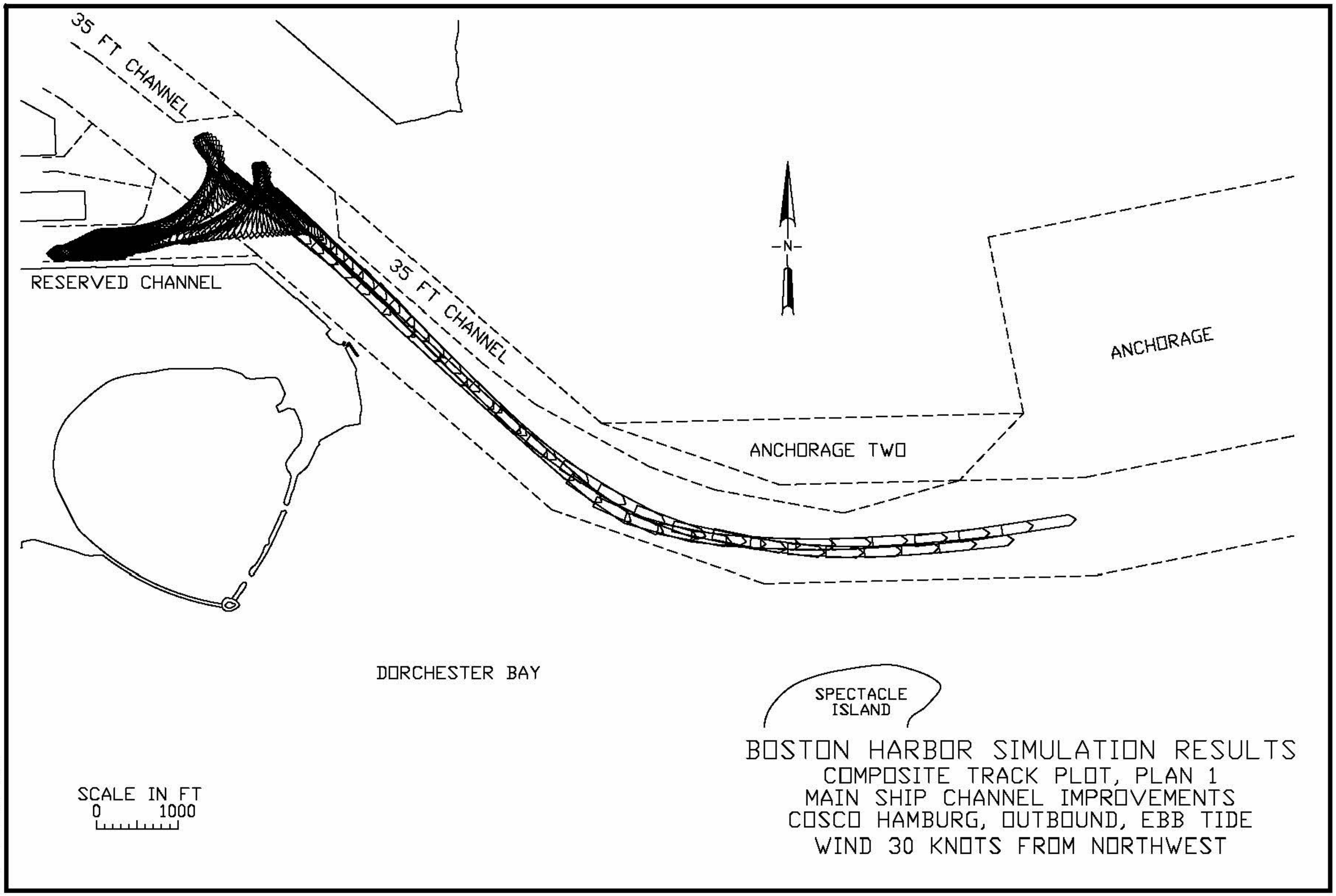
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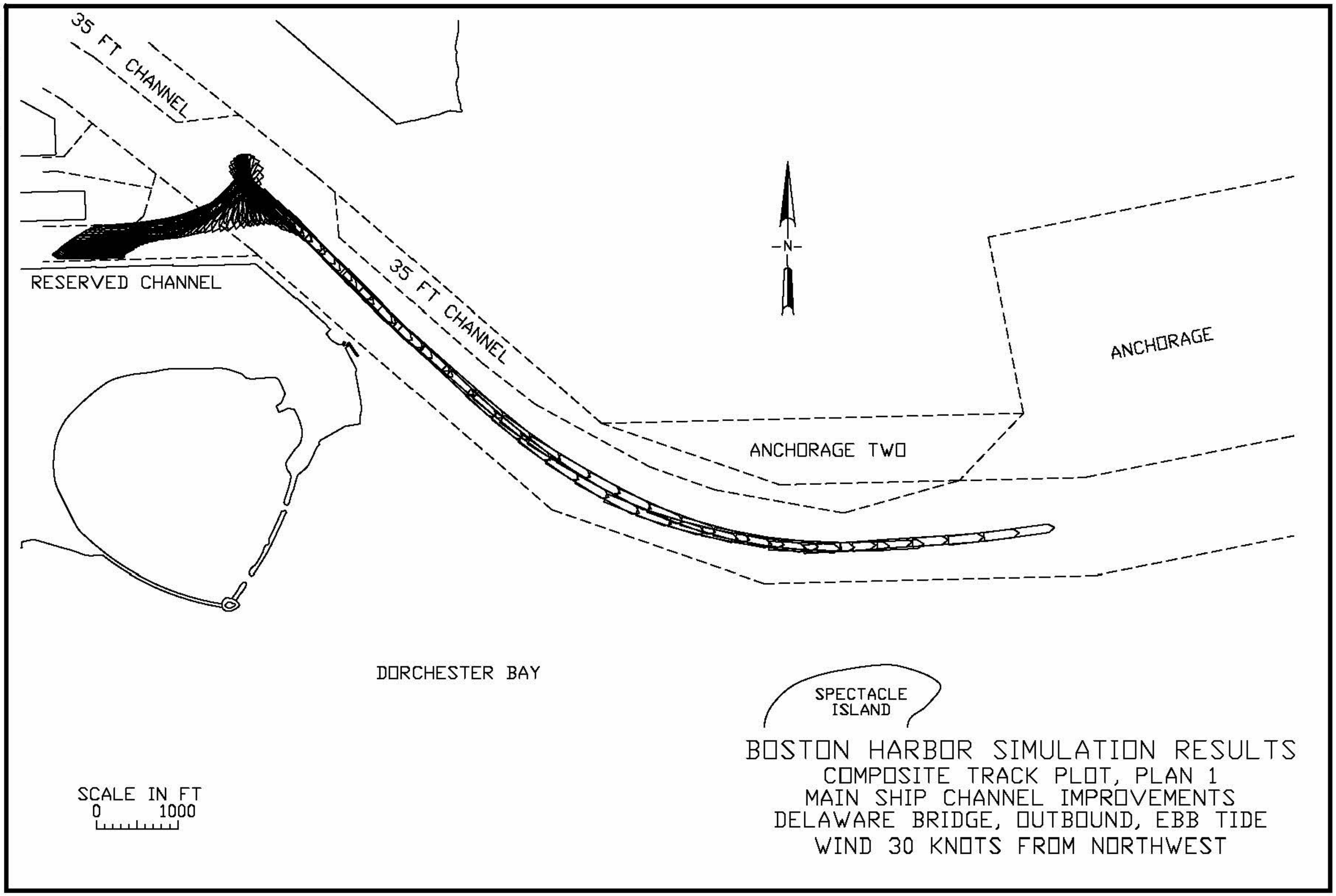
COSCO HAMBURG, OUTBOUND, EBB TIDE
WIND 30 KNOTS FROM NORTHWEST

PLATE 15

PLATE 16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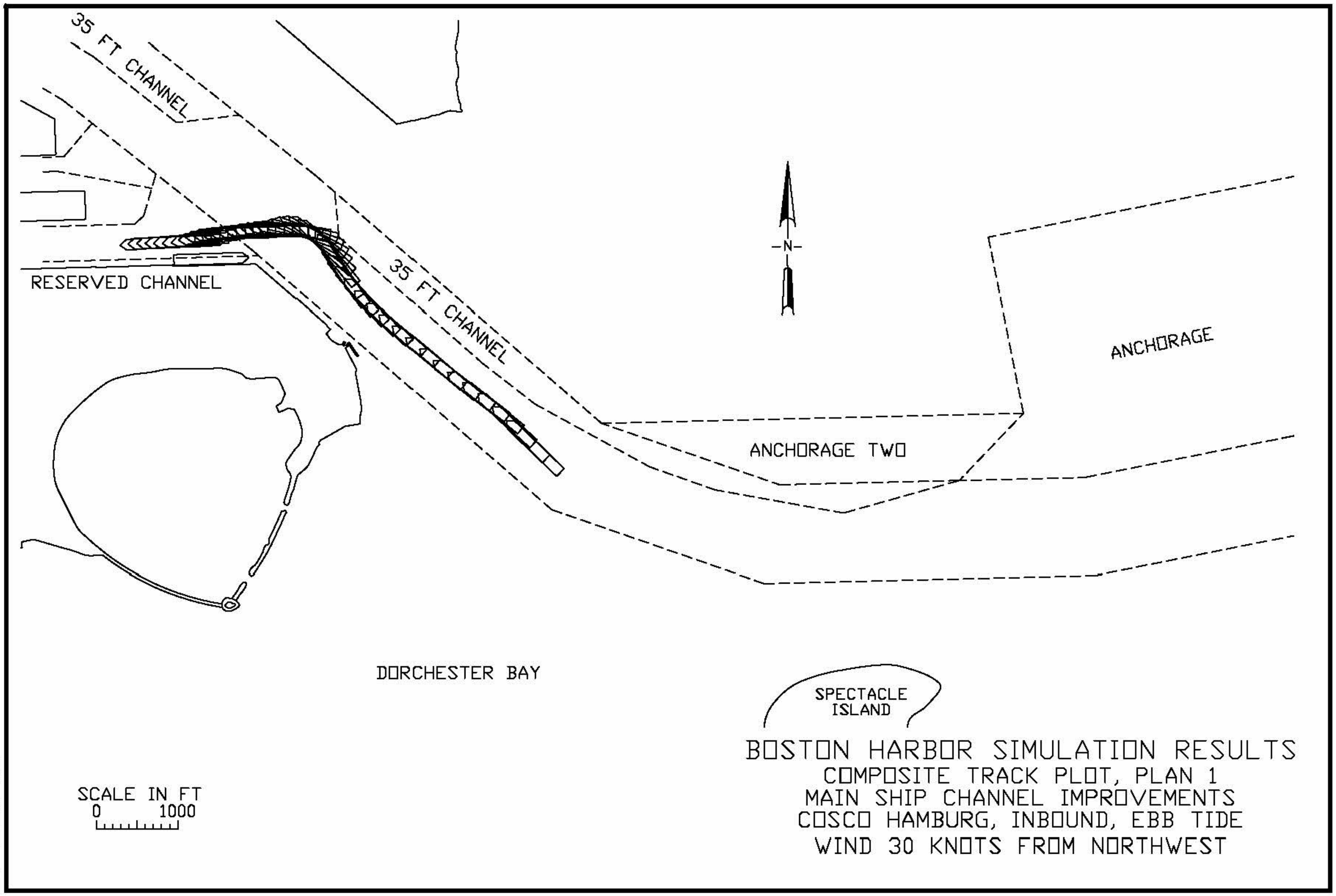
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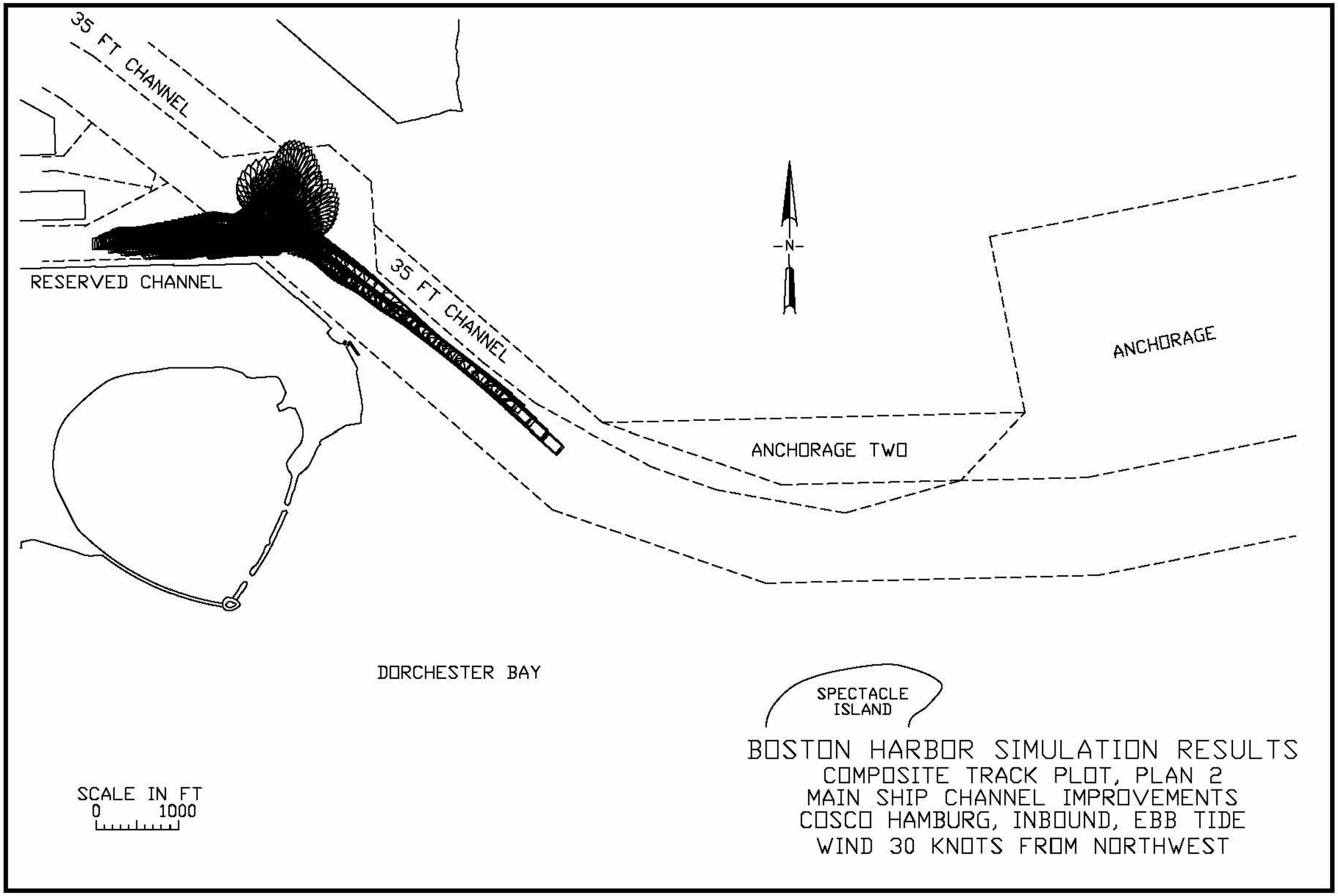
COSCO HAMBURG, INBOUND, EBB TIDE
WIND 30 KNOTS FROM NORTHWEST

PLATE 17

PLATE 18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BOSTON HARBOR SIMULATION RESULTS
COMPOSITE TRACK PLOT, PLAN 2
MAIN SHIP CHANNEL IMPROVEMENTS
COSCO HAMBURG, INBOUND, EBB TIDE
WIND 30 KNOTS FROM NORTHWEST

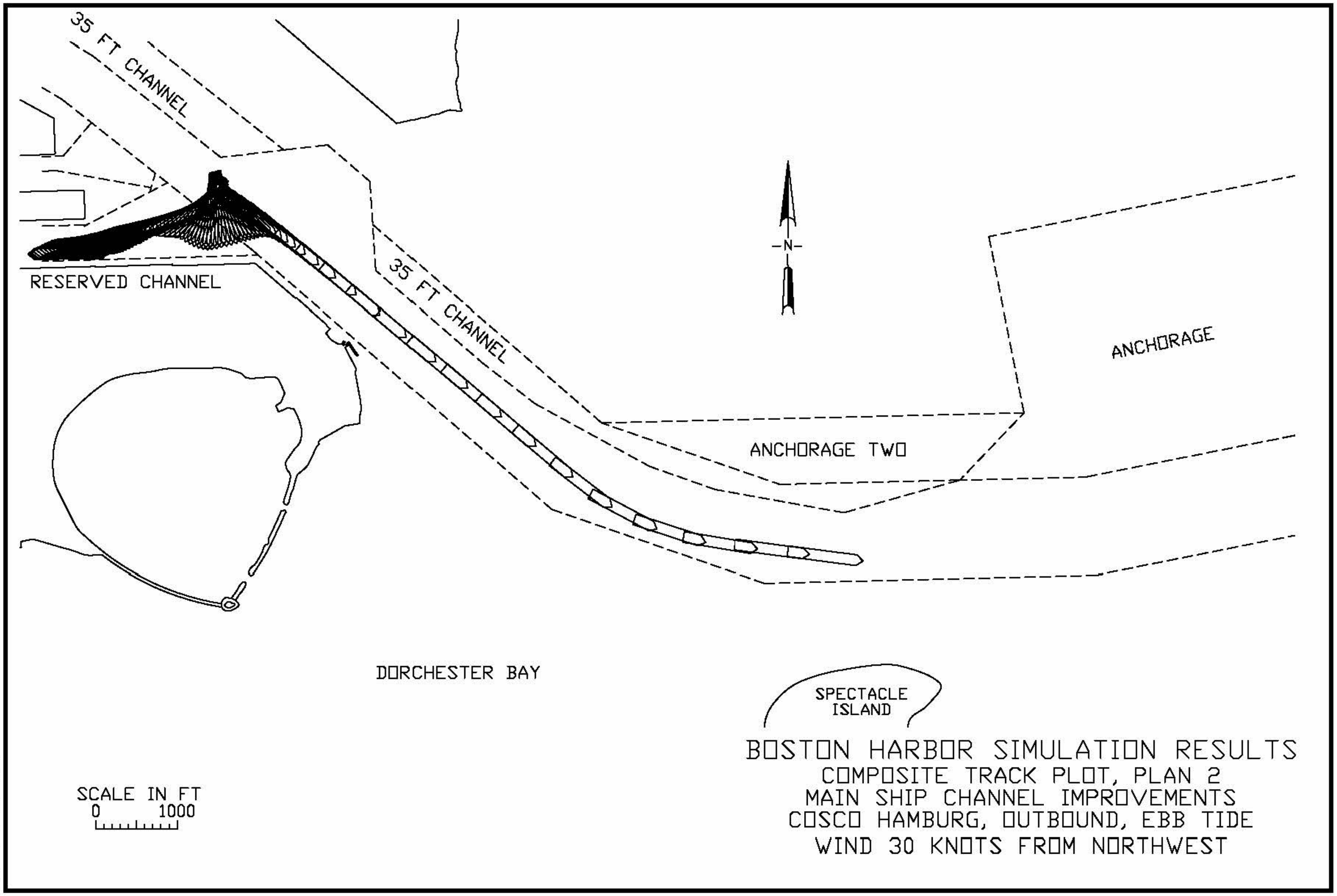
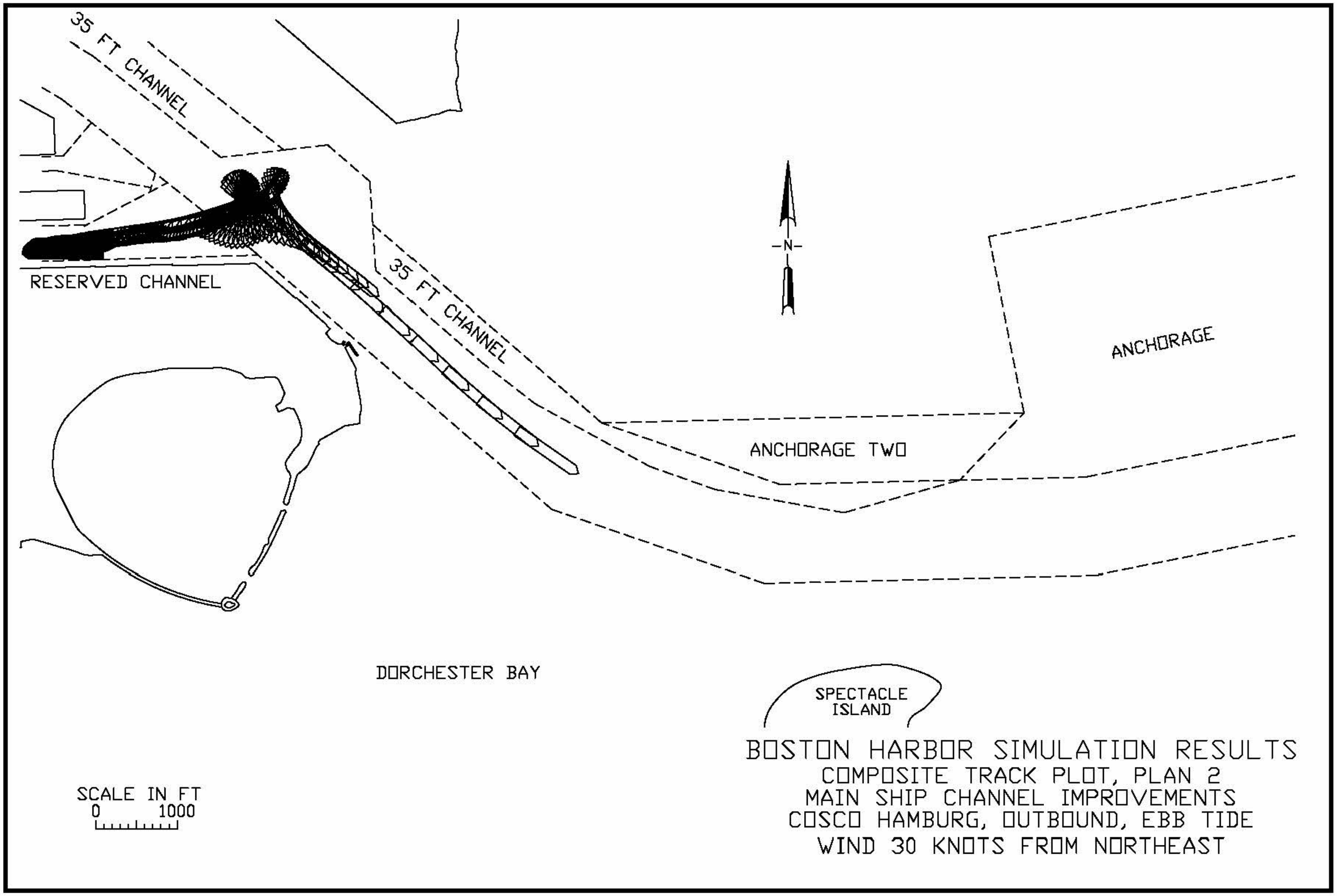

35 FT CHANNEL
35 FT CHANNEL
RESERVED CHANNEL
N
ANCHORAGE
ANCHORAGE TWO
DORCHESTER BAY
SPECTACLE ISLAND
SCALE IN FT
0 1000
BOSTON HARBOR SIMULATION RESULTS
COMPOSITE TRACK PLOT, PLAN 2
MAIN SHIP CHANNEL IMPROVEMENTS
COSCO HAMBURG, OUTBOUND, EBB TIDE
WIND 30 KNOTS FROM NORTHWEST

PLATE 19

PLATE 20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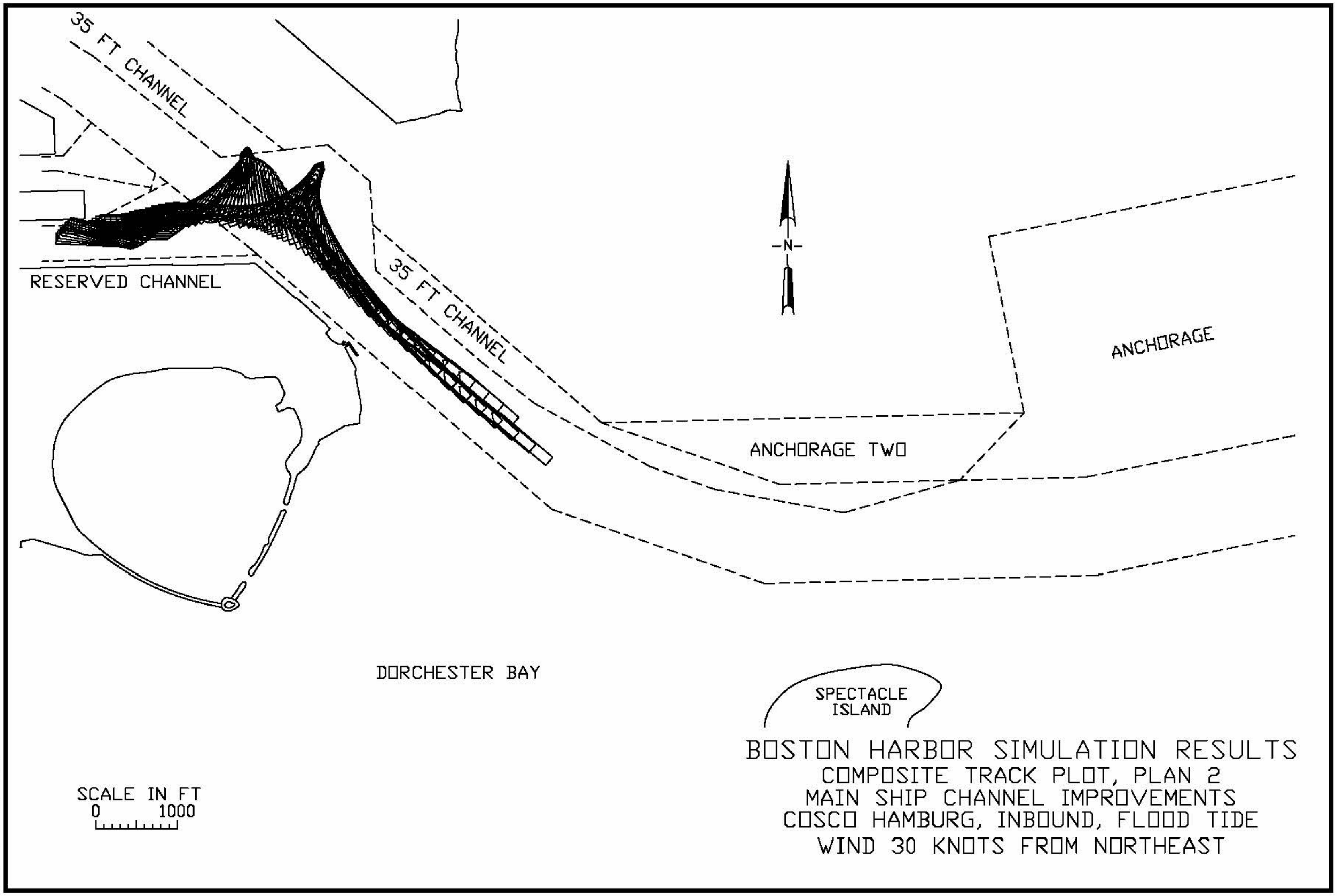
35 FT CHANNEL
RESERVED CHANNEL
N
ANCHORAGE
ANCHORAGE TWO
DORCHESTER BAY
SPECTACLE ISLAND
SCALE IN FT
0 1000
BOSTON HARBOR SIMULATION RESULTS
COMPOSITE TRACK PLOT, PLAN 2
MAIN SHIP CHANNEL IMPROVEMENTS
COSCO HAMBURG, OUTBOUND, EBB TIDE
WIND 30 KNOTS FROM NORTHEAST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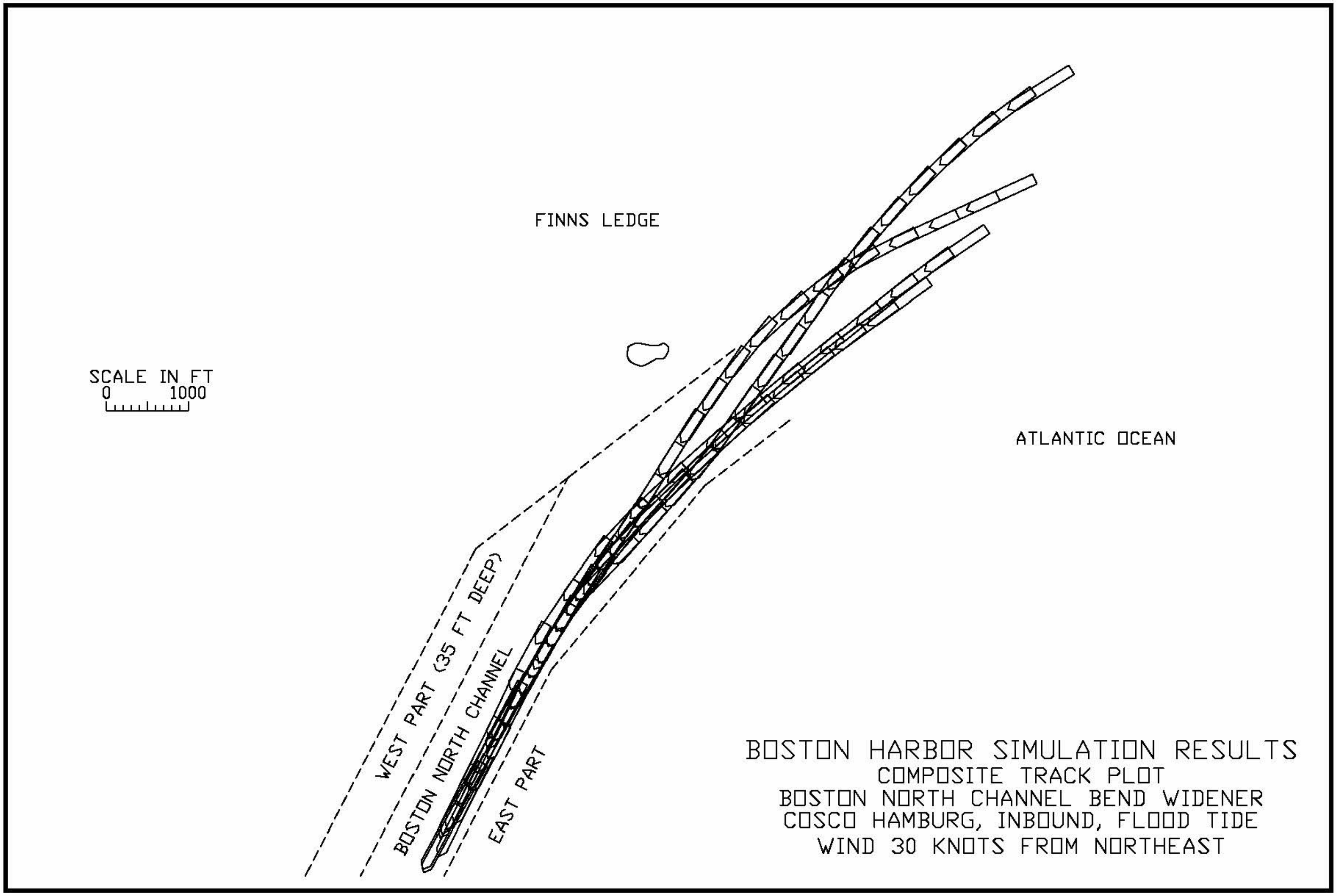
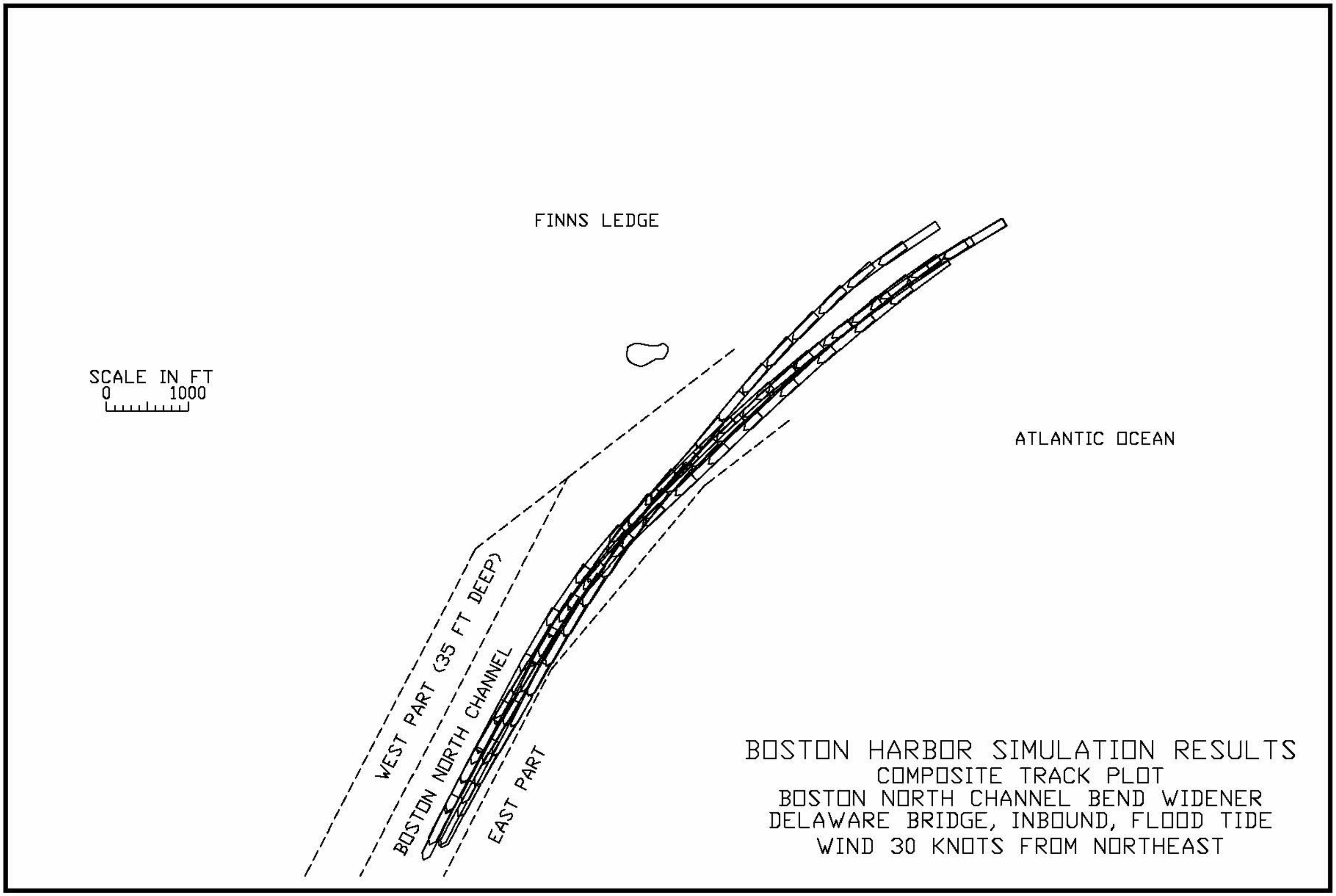
RESERVED CHANNEL
35 FT CHANNEL
N
ANCHORAGE
ANCHORAGE TWO
DORCHESTER BAY
SPECTACLE ISLAND
SCALE IN FT
0 1000
BOSTON HARBOR SIMULATION RESULTS
COMPOSITE TRACK PLOT, PLAN 2
MAIN SHIP CHANNEL IMPROVEMENTS
COSCO HAMBURG, INBOUND, FLOOD TIDE
WIND 30 KNOTS FROM NORTHEAST

PLATE 21

PLATE 22


FINNS LEDGE
SCALE IN FT
0 1000
ATLANTIC OCEAN
WEST PART (35 FT DEEP)
BOSTON NORTH CHANNEL
EAST PART
BOSTON HARBOR SIMULATION RESULTS
COMPOSITE TRACK PLOT
BOSTON NORTH CHANNEL BEND WIDENER
COSCO HAMBURG, INBOUND, FLOOD TIDE
WIND 30 KNOTS FROM NORTHEAST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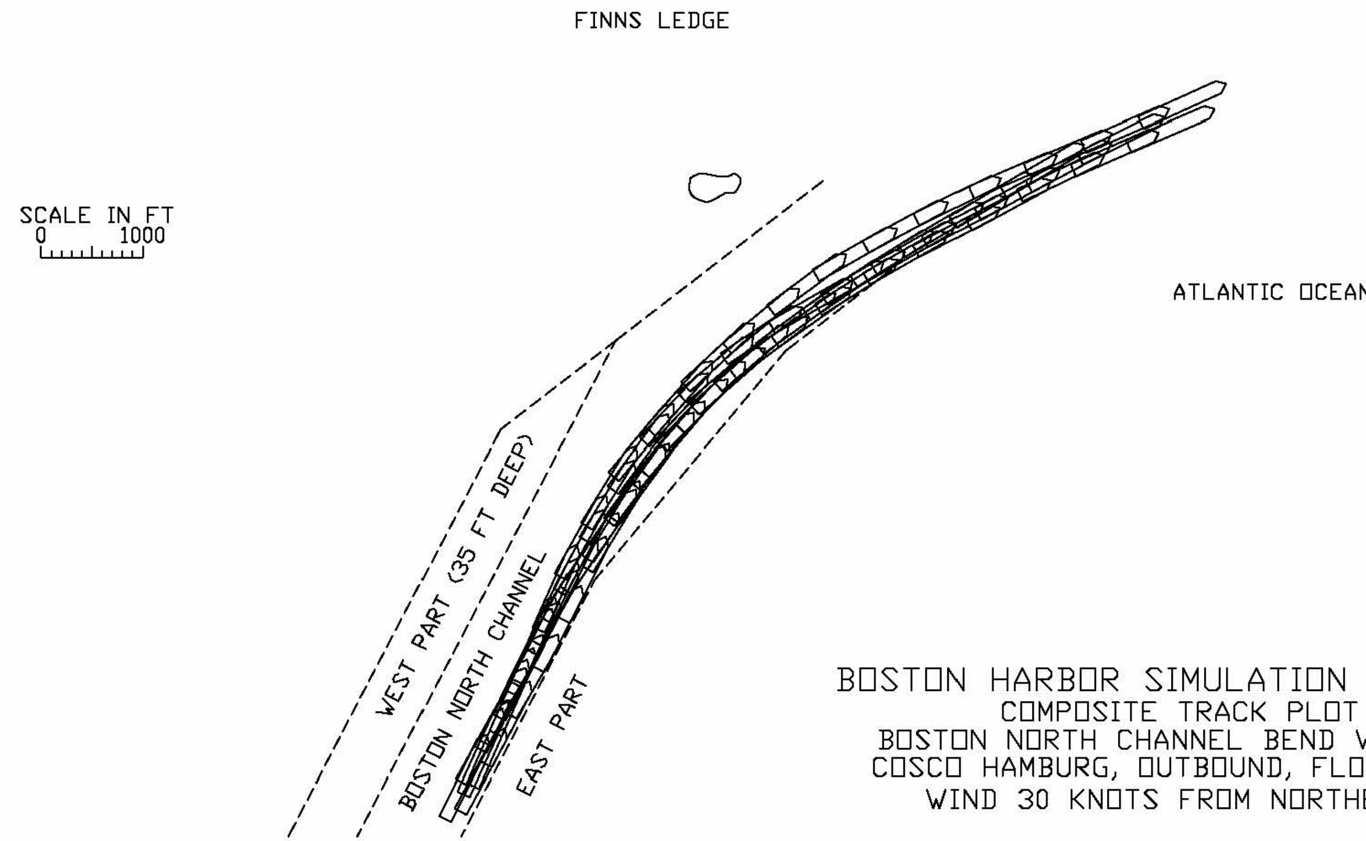
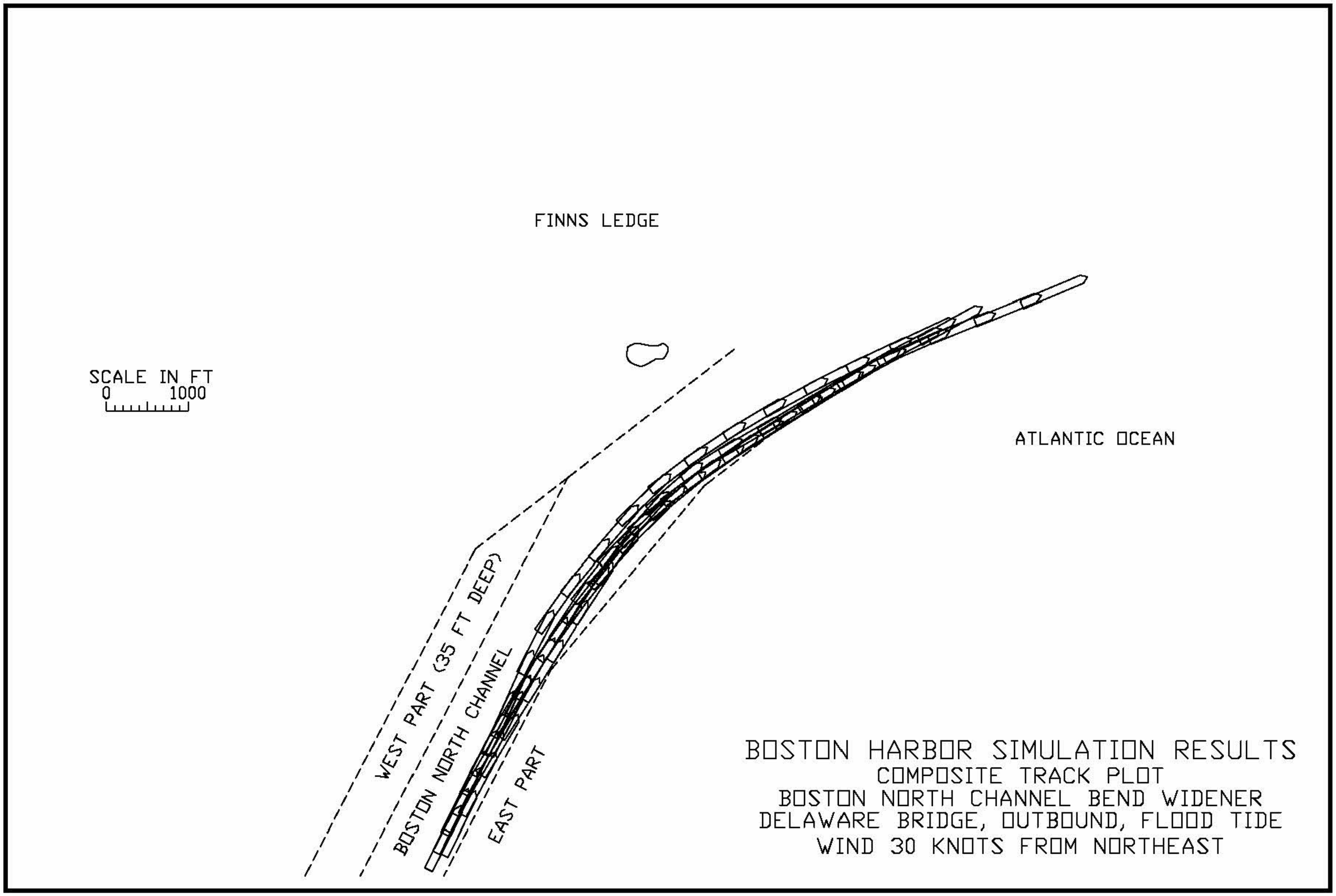
ATLANTIC OCEAN
WEST PART (35 FT DEEP)
BOSTON NORTH CHANNEL
EAST PART
BOSTON HARBOR SIMULATION RESULTS
COMPOSITE TRACK PLOT
BOSTON NORTH CHANNEL BEND WIDENER
DELAWARE BRIDGE, INBOUND, FLOOD TIDE
WIND 30 KNOTS FROM NORTHEAST

PLATE 23



BOSTON HARBOR SIMULATION RESULTS
COMPOSITE TRACK PLOT
BOSTON NORTH CHANNEL BEND WIDENER
COSCO HAMBURG, OUTBOUND, FLOOD TIDE
WIND 30 KNOTS FROM NORTHEAST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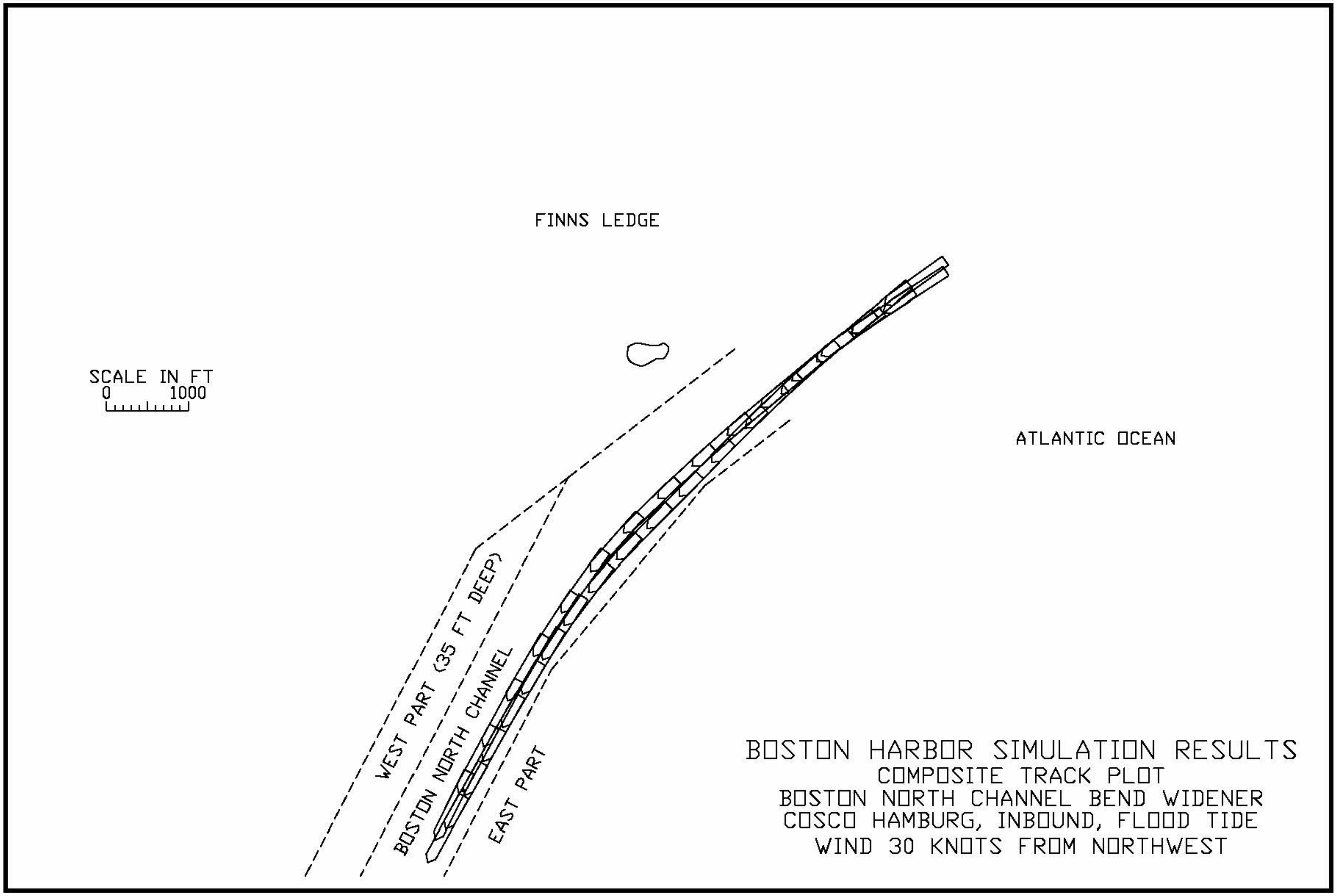
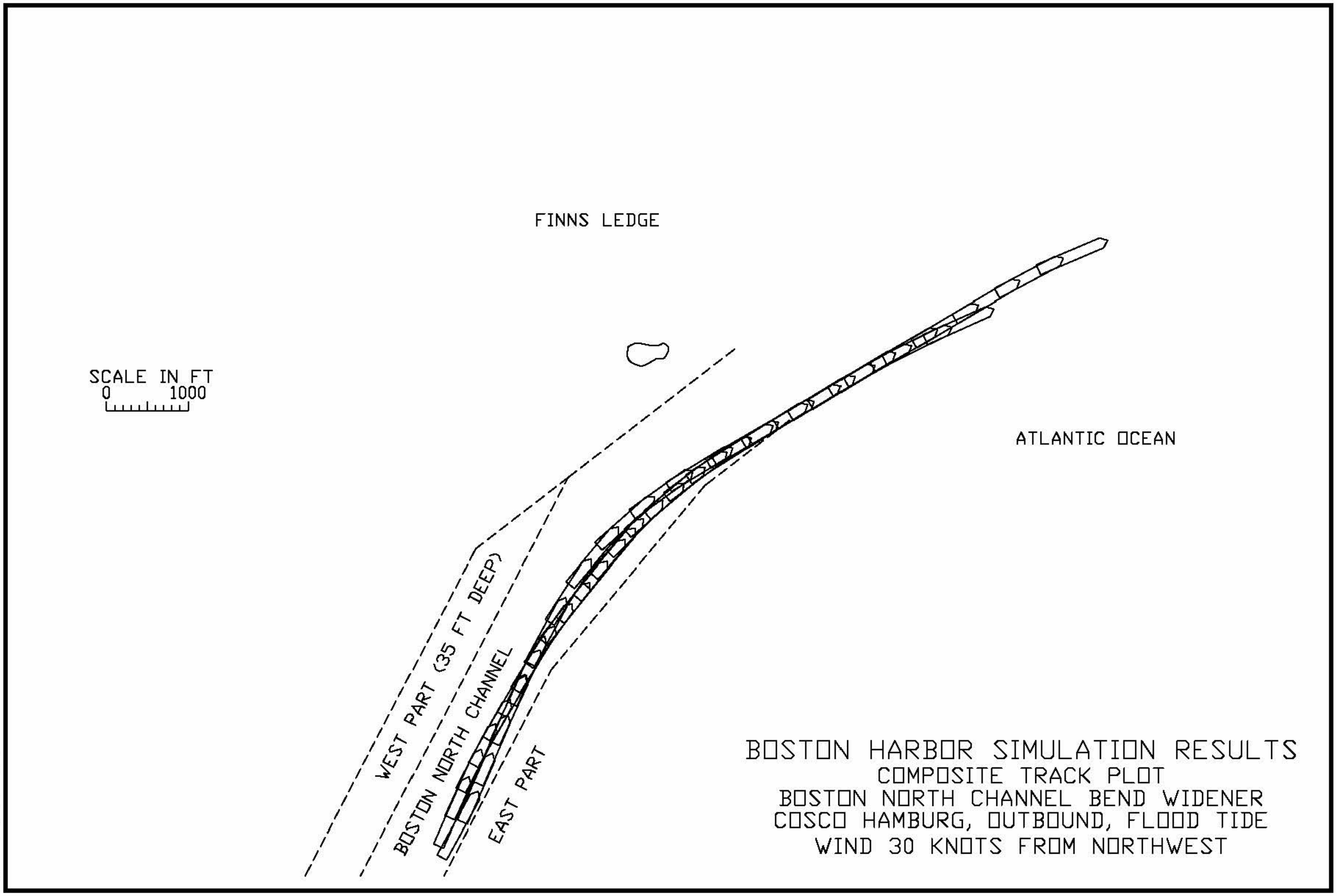
ATLANTIC OCEAN
WEST PART (35 FT DEEP)
BOSTON NORTH CHANNEL
EAST PART
BOSTON HARBOR SIMULATION RESULTS
COMPOSITE TRACK PLOT
BOSTON NORTH CHANNEL BEND WIDENER
DELAWARE BRIDGE, OUTBOUND, FLOOD TIDE
WIND 30 KNOTS FROM NORTHEAST

PLATE 25

PLATE 26


FINNS LEDGE
SCALE IN FT
0
1000
ATLANTIC OCEAN
WEST PART (35 FT DEEP)
BOSTON NORTH CHANNEL
EAST PART
BOSTON HARBOR SIMULATION RESULTS
COMPOSITE TRACK PLOT
BOSTON NORTH CHANNEL BEND WIDENER
COSCO HAMBURG, INBOUND, FLOOD TIDE
WIND 30 KNOTS FROM NORTHWEST


FINNS LEDGE
SCALE IN FT
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ATLANTIC OCEAN
WEST PART (35 FT DEEP)
BOSTON NORTH CHANNEL
EAST PART
BOSTON HARBOR SIMULATION RESULTS
COMPOSITE TRACK PLOT
BOSTON NORTH CHANNEL BEND WIDENER
COSCO HAMBURG, OUTBOUND, FLOOD TIDE
WIND 30 KNOTS FROM NORTHWEST

PLATE 27

Appendix A: Pilot Questionnaires

Boston Harbor Channel Improvements
Final Questionnaire

Captain Dick Coffman

Ships

The *COSCO Hamburg* – 918 - x 131- x –46-ft containership.

The *Delaware Bridge* - 871.8 – 106 – x 43 ft containership.

1. A bend widener (Figure 1) is proposed for the East Part of the Boston North Channel. The purpose of the widener was to provide additional maneuvering room near Finns Ledge.

a. Based upon your simulation runs, do you feel that the widener provided adequate room for both the *COSCO Hamburg* and the *Delaware Bridge*?

Yes

b. Based upon your simulation runs, do you feel that the widener is necessary to bring the *COSCO Hamburg* and the *Delaware Bridge* into and out of Boston Harbor?

Both ships could be brought in with existing channel but the widener would make a hard turn easier and safer. It would also make meeting other ships in to area easier.

c. Will the widener benefit other vessels calling at Boston Harbor? If so, which vessels and in what manner would they benefit.

All ships would benefit as turn could be negociated easier and safer.

d. Should the widener be modified? Feel free to sketch on Figure 1.

Configuration is good. I believe buoys are planned for corners.

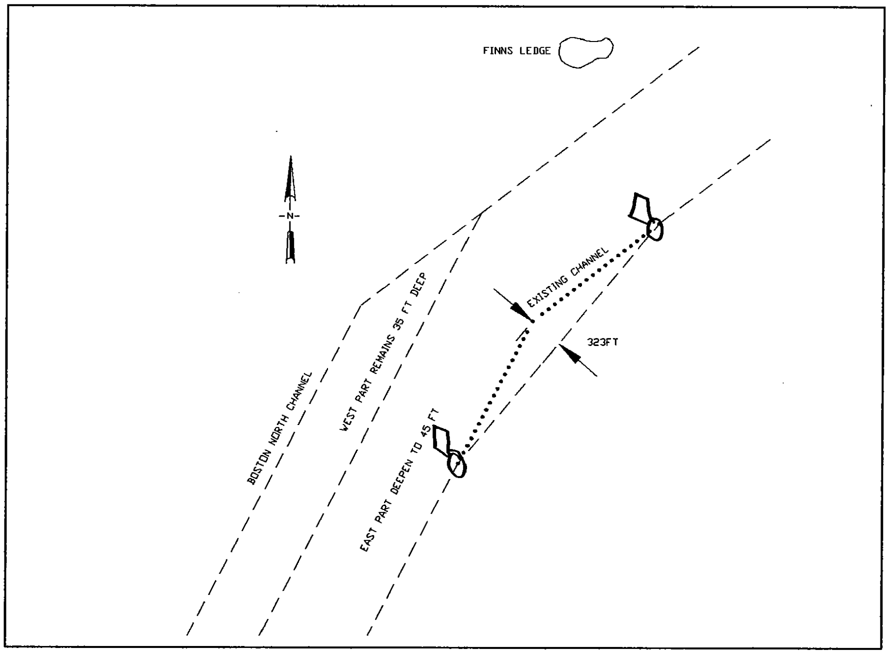

Figure 1. Boston North Channel Bend Widener

2. Widening of the deepened 45 ft channel near Spectacle Island is proposed. The widening will be accomplished by deepening on the south side of the 35 ft channel. The channel width would be increased to 800 feet with 880 feet through the turns. The widening is shown in Figure 2. The purpose of the additional width is permit passage of these larger vessels through this reach of the harbor's Main Ship Channel and to ease passage in the two turns above Spectacle Island.

   a. Based upon your simulation runs, do you feel that the additional width provided adequate room for both the *COSCO Hamburg* and the *Delaware Bridge*?

   yes

   b. Based upon your simulation runs, do you feel that the additional width is necessary to bring the *COSCO Hamburg* and the *Delaware Bridge* to make the turn near Spectacle Island?

   Yes, to bring in vessels of this size in challenging conditions of wind and current at slow speeds required the widening is necessary for safe transit.

   c. Will the widener benefit other vessels calling at Boston Harbor? If so, which vessels and in what manner would they benefit.

   Other deep draft vessels (tankers, bulk scrap or salt, etc) will also benefit greatly.

   d. Should the channel width in the straight sections or in the two turns be modified? Feel free to sketch on Figure 2.

   The proposed wider would be a great improvement. Additional improvements are noted on sketch.

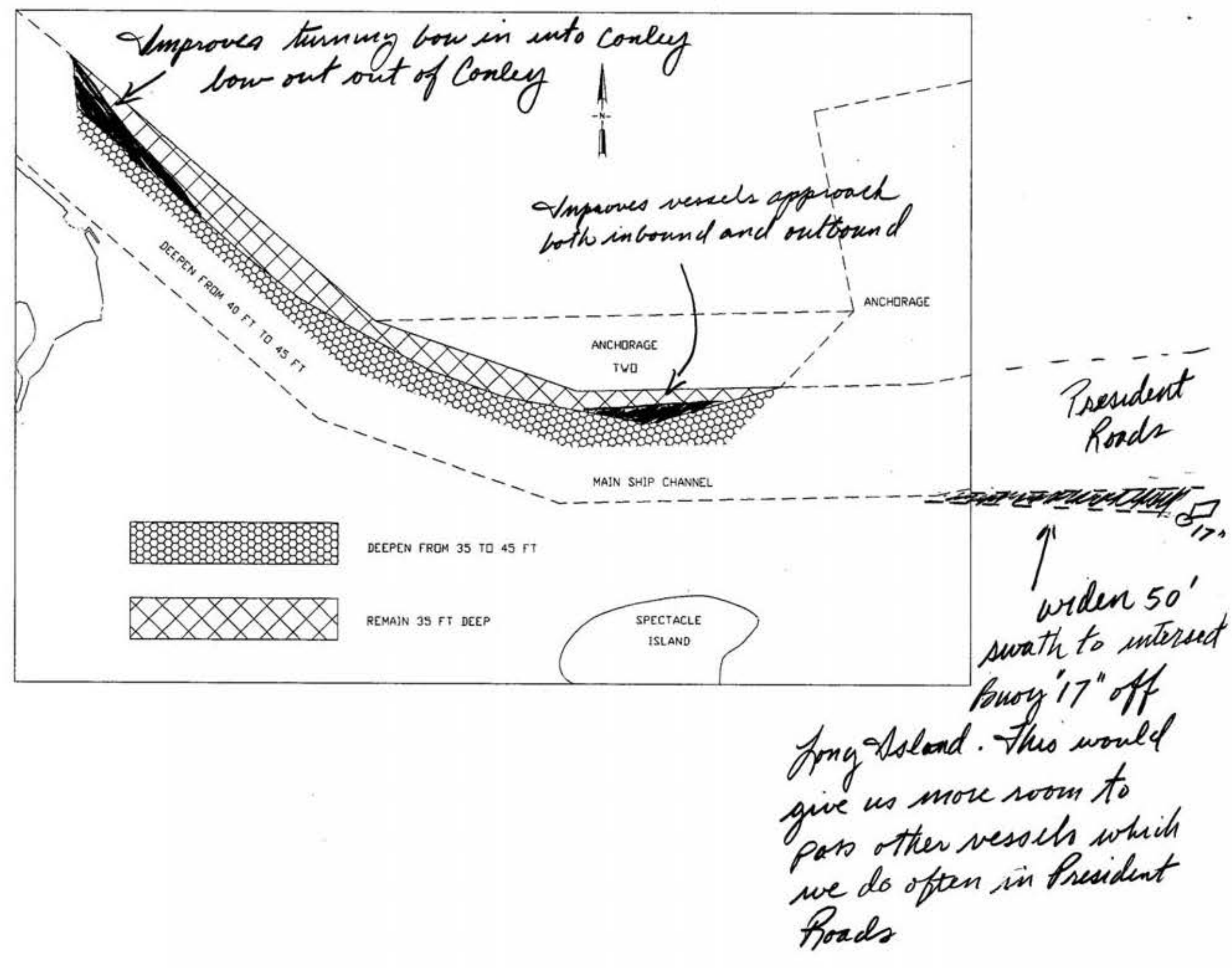

Figure 2. Spectacle Island Widening

3. Widening near the mouth of the Reserved Channel is proposed. The widening will increase the size of the turning area from a radius of 1200 feet to a radius of 1500 feet. and also provide 50 ft additional width for the 45 ft channel north of the turning area. The widening is shown in Figure 3. The turning area is being increased to allow larger containerships access to the Reserve Channel. The additional 50 ft width is to allow more maneuvering room for larger bulk carriers expected to call on the Massport marine Terminal just north of the Reserve Channel.

a. Based upon your simulation runs, do you feel that the enlarged turning area provided adequate room for both the *COSCO Hamburg* and the *Delaware Bridge*?

It can be done, but would benefit from larger area off Army Base

b. Based upon your simulation runs, do you feel that the enlarged turning area is necessary to bring the *COSCO Hamburg* and the *Delaware Bridge* to enter and leave the Reserve Channel?

As mentioned above enlarging the proposed turning basin of the Army Base make it possible to negotiate the turn in and out, bow in and bow out or around another ship at dock

c. Should the enlarged turning area be modified? Feel free to sketch on Figure 3.

Yes, see sketch

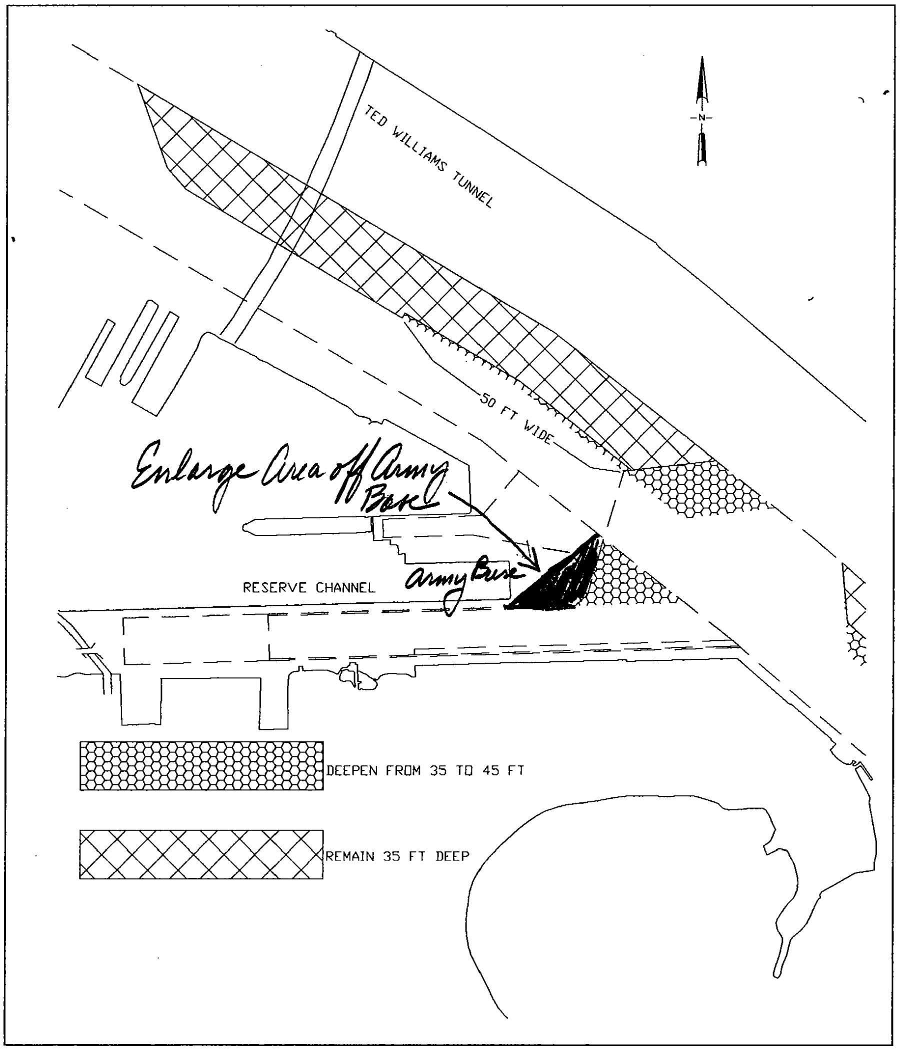

Figure 3. Widening near mouth of Reserve Channel

4. The following questions concern the simulation modeling of Boston Harbor.

a. Was the visual scene realistic, accurate, and adequate for the study?

Yes

b. Do you feel the ships responded correctly to the currents?

In most cases

c. Do you feel the ships responded correctly to the bank forces?

Yes

d. Do you feel the ships responded correctly to the wind?

In most cases

e. Any additional comments regarding the simulation model?

Overall, I had a great expirience. The staff adminestered the simulations in a competent proffesional manner. Thank You for your hard work on this project.

Boston Harbor Channel Improvements
Final Questionnaire

Captain Robert G. Cordes

Ships

The *COSCO Hamburg* – 918 - x 131- x –46-ft containership.

The *Delaware Bridge* - 871.8 – 106 – x 43 ft containership.

1. A bend widener (Figure 1) is proposed for the East Part of the Boston North Channel. The purpose of the widener was to provide additional maneuvering room near Finns Ledge.

a. Based upon your simulation runs, do you feel that the widener provided adequate room for both the *COSCO Hamburg* and the *Delaware Bridge*?

Yes

b. Based upon your simulation runs, do you feel that the widener is necessary to bring the *COSCO Hamburg* and the *Delaware Bridge* into and out of Boston Harbor?

No, But It Gives You The Extra Room Needed In The Event You Meet Another Vessel At This Juncture. It Also Reduces The Degree Of Turn To Maintain Ability To Remain On Green Side Of Channel (Deep Side).

c. Will the widener benefit other vessels calling at Boston Harbor? If so, which vessels and in what manner would they benefit.

Yes, LNG Tankers. It Allows For A Less Radical Turn To Port To Keep On Green (Deep) Side Of North Channel.

d. Should the widener be modified? Feel free to sketch on Figure 1.

See Sketch!

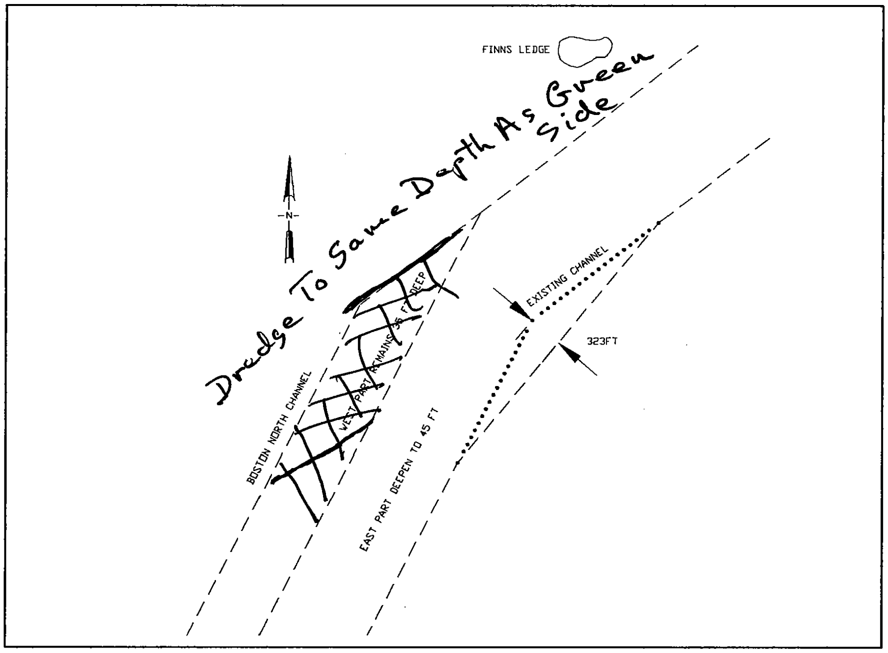

Figure 1. Boston North Channel Bend Widener

2. Widening of the deepened 45 ft channel near Spectacle Island is proposed. The widening will be accomplished by deepening on the south side of the 35 ft channel. The channel width would be increased to 800 feet with 880 feet through the turns. The widening is shown in Figure 2. The purpose of the additional width is permit passage of these larger vessels through this reach of the harbor's Main Ship Channel and to ease passage in the two turns above Spectacle Island.

a. Based upon your simulation runs, do you feel that the additional width provided adequate room for both the *COSCO Hamburg* and the *Delaware Bridge*?

Yes

b. Based upon your simulation runs, do you feel that the additional width is necessary to bring the *COSCO Hamburg* and the *Delaware Bridge* to make the turn near Spectacle Island?

Yes

c. Will the widener benefit other vessels calling at Boston Harbor? If so, which vessels and in what manner would they benefit.

Yes, LNG Tankers, In Sudden High Wind Gusts, And Would Also Allow For Larger LNG's. i.e. Longer & Wider

d. Should the channel width in the straight sections or in the two turns be modified? Feel free to sketch on Figure 2.

See Note On Sketch.

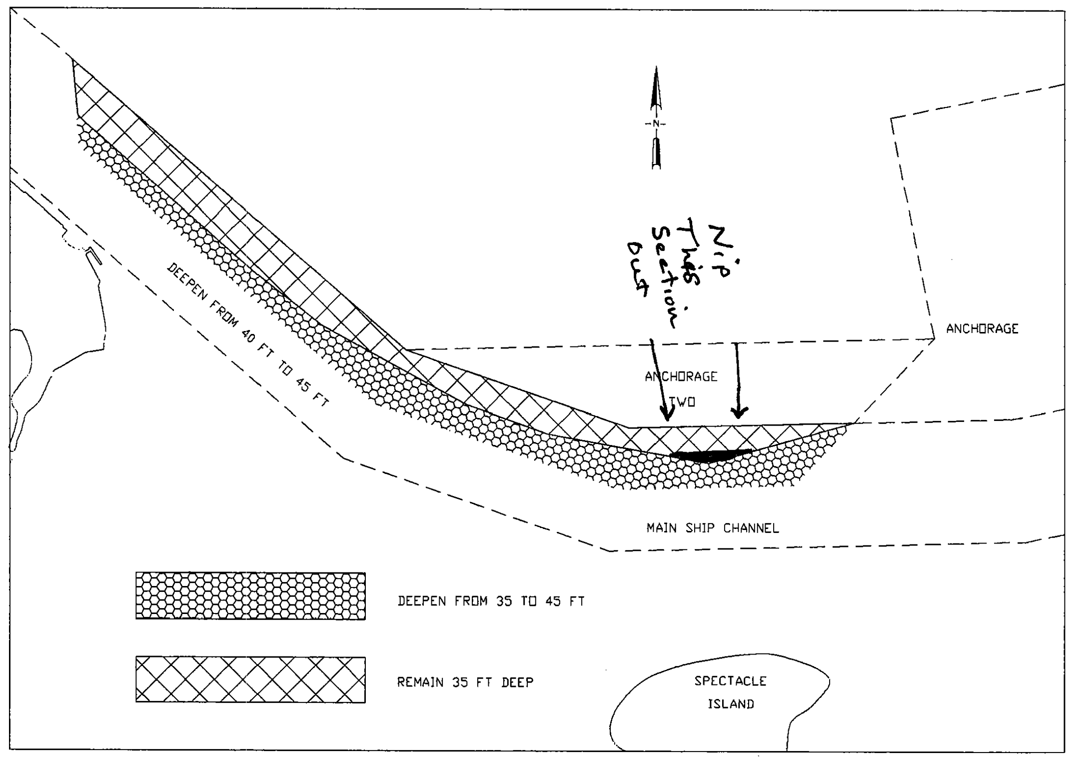

Figure 2. Spectacle Island Widening

3. Widening near the mouth of the Reserved Channel is proposed. The widening will increase the size of the turning area from a radius of 1200 feet to a radius of 1500 feet. and also provide 50 ft additional width for the 45 ft channel north of the turning area. The widening is shown in Figure 3. The turning area is being increased to allow larger containerships access to the Reserve Channel. The additional 50 ft width is to allow more maneuvering room for larger bulk carriers expected to call on the Massport marine Terminal just north of the Reserve Channel.

a. Based upon your simulation runs, do you feel that the enlarged turning area provided adequate room for both the *COSCO Hamburg* and the *Delaware Bridge*?

Yes

b. Based upon your simulation runs, do you feel that the enlarged turning area is necessary to bring the *COSCO Hamburg* and the *Delaware Bridge* to enter and leave the Reserve Channel?

Yes

c. Should the enlarged turning area be modified? Feel free to sketch on Figure 3.

Yes (See Note On Sketch.)

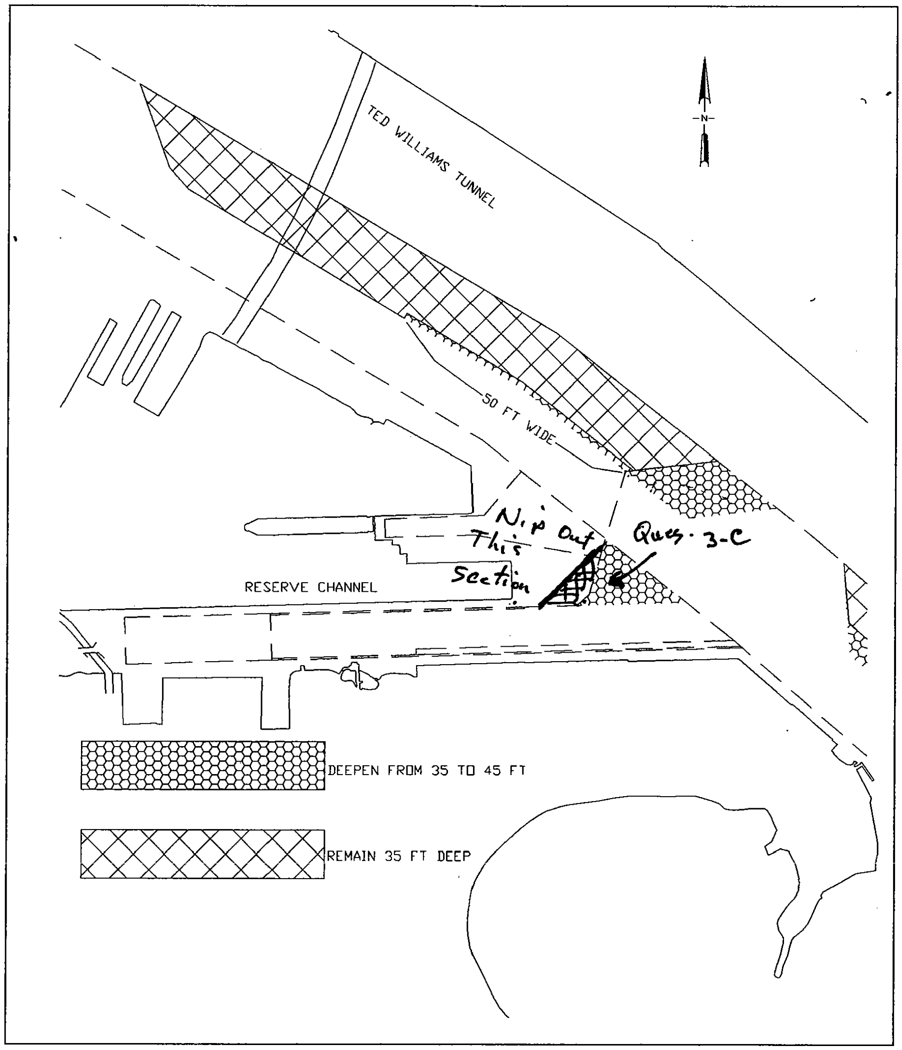

Figure 3. Widening near mouth of Reserve Channel

4. The following questions concern the simulation modeling of Boston Harbor.

   a. Was the visual scene realistic, accurate, and adequate for the study?

      Yes

   b. Do you feel the ships responded correctly to the currents?

      Yes

   c. Do you feel the ships responded correctly to the bank forces?

      Yes

   d. Do you feel the ships responded correctly to the wind?

      Yes

   e. Any additional comments regarding the simulation model?

      No, It Was Quite Satisfactory!

Boston Harbor Channel Improvements
Final Questionnaire

Captain F.R. MORTON

Ships

The *COSCO Hamburg* – 918 - x 131- x –46-ft containership.

The *Delaware Bridge* - 871.8 – 106 – x 43 ft containership.

1. A bend widener (Figure 1) is proposed for the East Part of the Boston North Channel. The purpose of the widener was to provide additional maneuvering room near Finns Ledge.

a. Based upon your simulation runs, do you feel that the widener provided adequate room for both the *COSCO Hamburg* and the *Delaware Bridge*? YES, THE ADDITIONAL ROOM WILL BE A BIG HELP WHEN SHIPS ARE MEETING.

b. Based upon your simulation runs, do you feel that the widener is necessary to bring the *COSCO Hamburg* and the *Delaware Bridge* into and out of Boston Harbor?

YES.

c. Will the widener benefit other vessels calling at Boston Harbor? If so, which vessels and in what manner would they benefit.

THE WIDENER WILL BENEFIT THE TRANSIT OF LNG TANKERS AND CRUISE SHIPS. THESE ARE BOTH GENERALLY BIG VESSELS THAT NEED LONGER TURNING AREAS.

d. Should the widener be modified? Feel free to sketch on Figure 1.

NO. IT IS FINE AS PROPOSED.

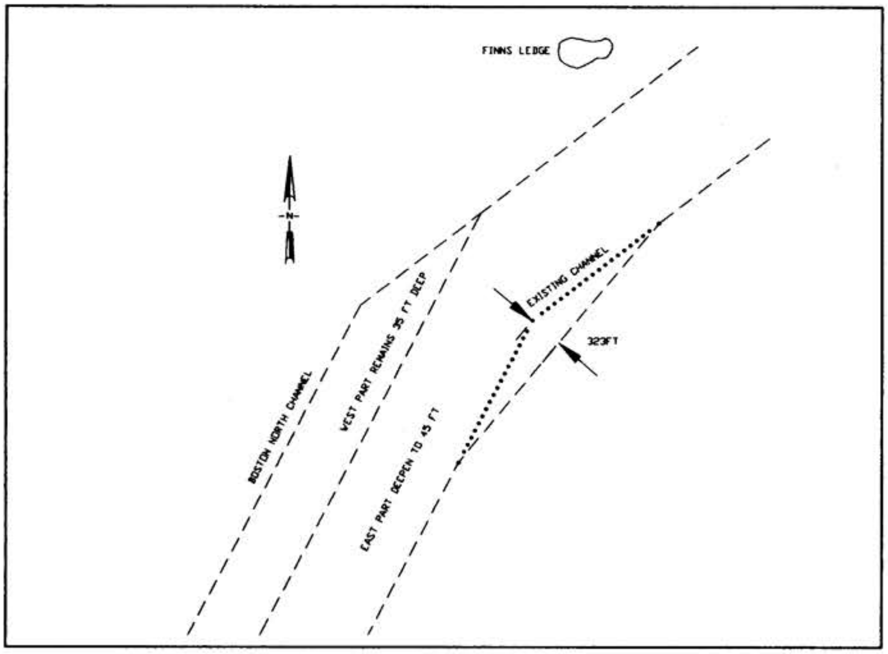

Figure 1. Boston North Channel Bend Widener

2. Widening of the deepened 45 ft channel near Spectacle Island is proposed. The widening will be accomplished by deepening on the south side of the 35 ft channel. The channel width would be increased to 800 feet with 880 feet through the turns. The widening is shown in Figure 2. The purpose of the additional width is permit passage of these larger vessels through this reach of the harbor's Main Ship Channel and to ease passage in the two turns above Spectacle Island.

   a. Based upon your simulation runs, do you feel that the additional width provided adequate room for both the *COSCO Hamburg* and the *Delaware Bridge*? YES.

   b. Based upon your simulation runs, do you feel that the additional width is necessary to bring the *COSCO Hamburg* and the *Delaware Bridge* to make the turn near Spectacle Island? YES

   e. Will the widener benefit other vessels calling at Boston Harbor? If so, which vessels and inwhat manner would they benefit. LNG TANKERS, CRUISE SHIPS, AIRCRAFT CARRIES. ALSO LOADED INBOUND TANKERS WITH A FLOOD TIDE NEED ADDITIONAL ROOM TO MAKE TURNS.

   c. Should the channel width in the straight sections or in the two turns be modified? Feel free to sketch on Figure 2.

   NO. IT IS WELL PLANNED AS IS.

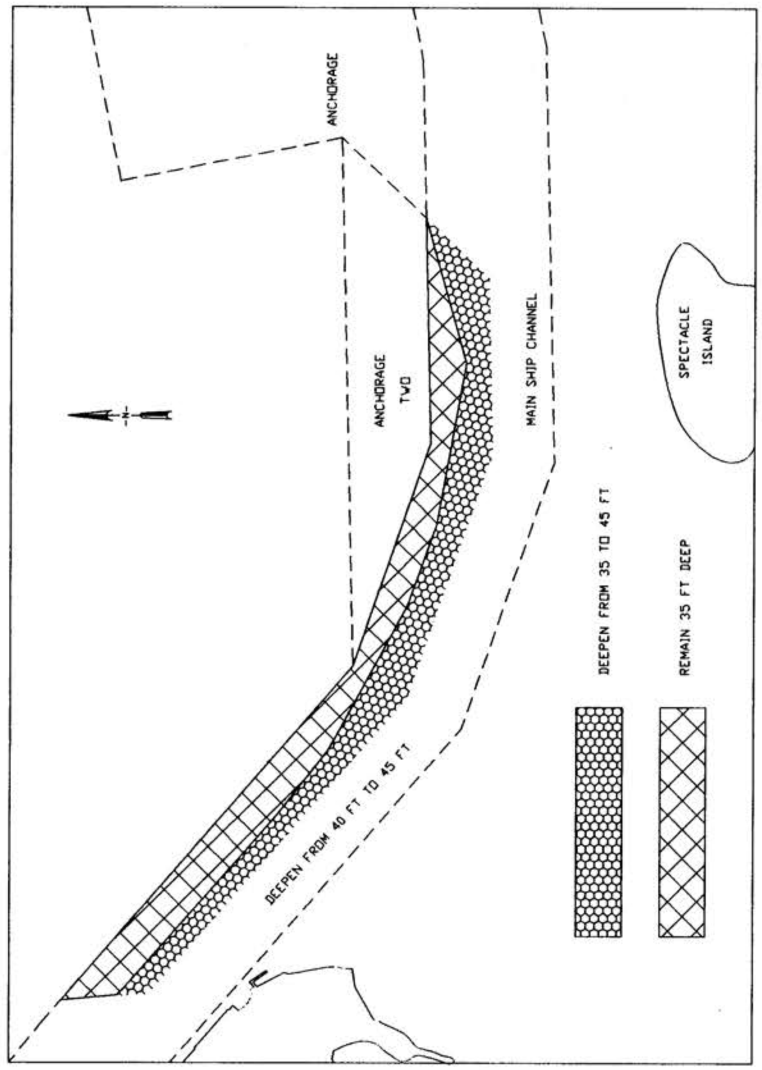

Figure 2. Spectacle Island Widening

3. Widening near the mouth of the Reserved Channel is proposed. The widening will increase the size of the turning area from a radius of 1200 feet to a radius of 1500 feet. and also provide 50 ft additional width for the 45 ft channel north of the turning area. The widening is shown in Figure 3. The turning area is being increased to allow larger containerships access to the Reserve Channel. The additional 50 ft width is to allow more maneuvering room for larger bulk carriers expected to call on the Massport marine Terminal just north of the Reserve Channel.

   a. Based upon your simulation runs, do you feel that the enlarged turning area provided adequate room for both the *COSCO Hamburg* and the *Delaware Bridge*?

   YES.

   b. Based upon your simulation runs, do you feel that the enlarged turning area is necessary to bring the *COSCO Hamburg* and the *Delaware Bridge* to enter and leave the Reserve Channel? YES

   c. Should the enlarged turning area be modified? Feel free to sketch on Figure 3.

   YES. I PREFER THE ALTERNATIVE TURNING NOTCH AS SHOWN IN FIGURE 4. THIS PROVIDED FOR AN EASIER TURN AROUND BOTH INBOUND AND OUTBOUND. IT ALSO KEEPS THE SHIPS AWAY FROM THE AIRPORT RUNWAY.

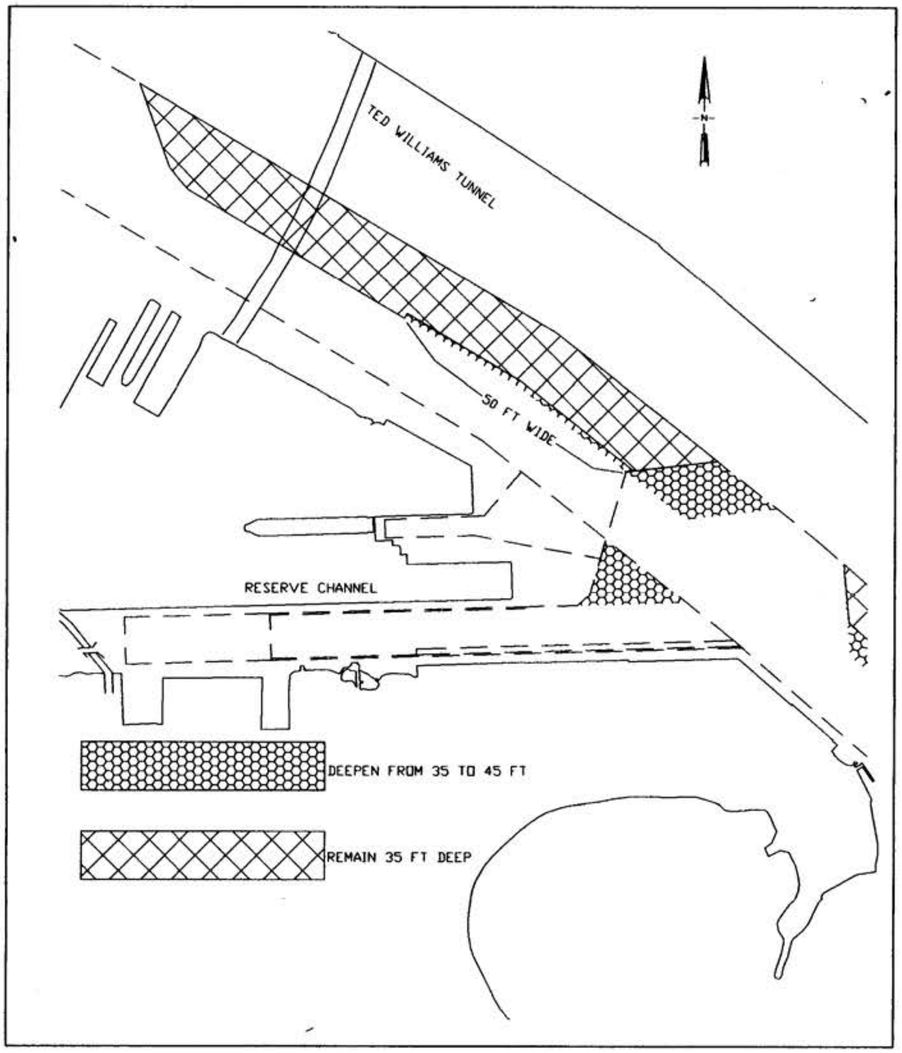

Figure 3. Widening near mouth of Reserve Channel

4. An alternative turning notch was simulated during the final days of the second week of simulations. It is shown in Figure 4.

a. Based upon your simulation runs, do you feel that the enlarged turning area provided adequate room for both the *COSCO Hamburg* and the *Delaware Bridge*?

YES.

b. Based upon your simulation runs, do you feel that the enlarged turning area is necessary to bring the *COSCO Hamburg* and the *Delaware Bridge* to enter and leave the Reserve Channel?

YES.

c. Should the enlarged turning area be modified? Feel free to sketch on Figure 4.

NO. I PREFER THIS TURNING AREA OVER THE OTHER PROPOSAL. IT MAKES FOR MUCH EASIER TURNS.

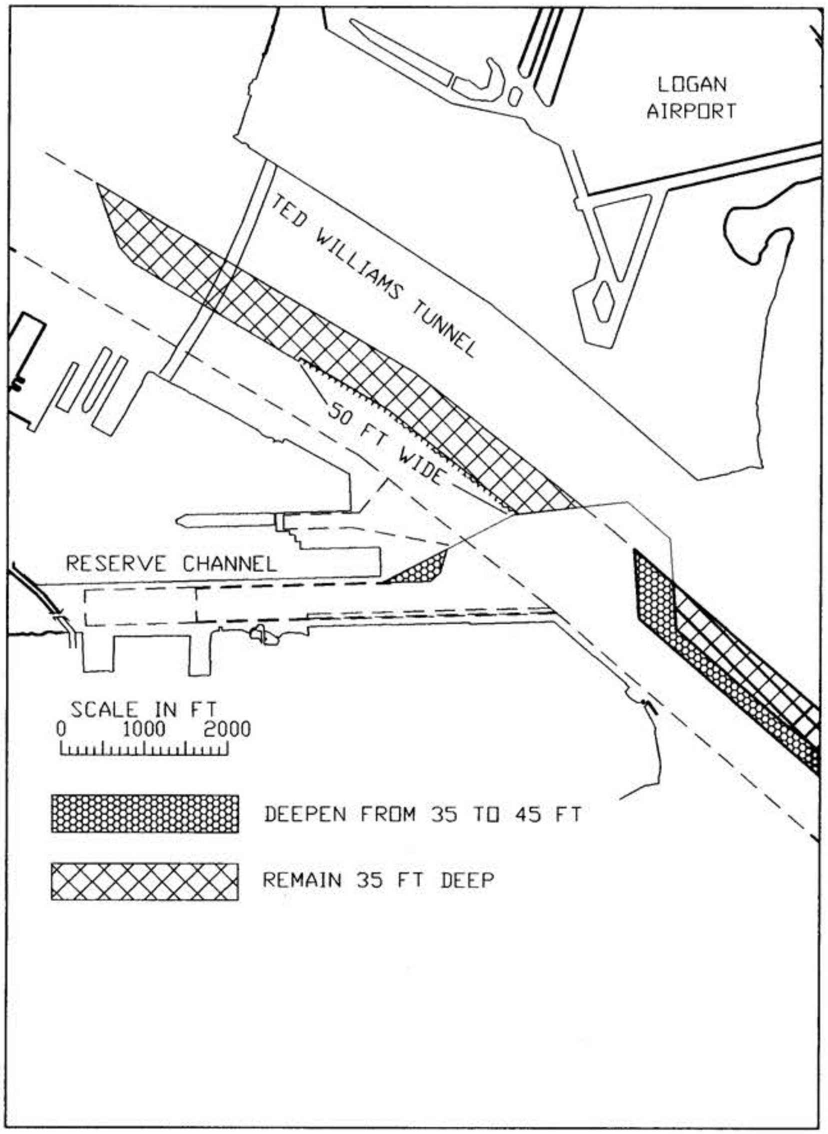

Figure 4. Plan 2 turning notch

5. The following questions concern the simulation modeling of Boston Harbor.

a. Was the visual scene realistic, accurate, and adequate for the study?

YES, VERY MUCH SO.

b. Do you feel the ships responded correctly to the currents?

YES ON THE FLOOD CURRENT. BUT NOT ON THE EBB. THE EBB CURRENT REALLY SLOWS THE SHIPS DOWN IN THE MAIN CHANNEL OF CONLEY TERMINAL.

c. Do you feel the ships responded correctly to the bank forces?

YES.

d. Do you feel the ships responded correctly to the wind?

YES

e. Any additional comments regarding the simulation model?

VERY GOOD SIMULATOR. I ENJOYED WORKING ON IT AND LEARNED A LOT. AN EXCELLENT STAFF TO WORK WITH.

Boston Harbor Channel Improvements
Final Questionnaire

Captain MIKE PEDDLE

Ships

The *COSCO Hamburg* – 918 - x 131- x –46-ft containership.

The *Delaware Bridge* - 871.8 – 106 – x 43 ft containership.

1. A bend widener (Figure 1) is proposed for the East Part of the Boston North Channel. The purpose of the widener was to provide additional maneuvering room near Finns Ledge.

a. Based upon your simulation runs, do you feel that the widener provided adequate room for both the *COSCO Hamburg* and the *Delaware Bridge*? YES. LONGER VESSELS WOULD HAVE NO DIFFICULTY MAKING THAT TURN.
TWO WAY TRAFFIC AT CHANNEL ENTRANCE WOULD BE POSSIBLE

b. Based upon your simulation runs, do you feel that the widener is necessary to bring the *COSCO Hamburg* and the *Delaware Bridge* into and out of Boston Harbor?
WITH THE DRAFT + U.K.C. OF THE COSCO HAMBURG, THE WIDENER PROVIDES A GREATER MARGIN OF SAFETY IN ADVERSE CONDITIONS.

c. Will the widener benefit other vessels calling at Boston Harbor? If so, which vessels and in what manner would they benefit.
TWO WAY PASSING OR OVERTAKING ~~wou~~ COULD BE DONE SAFELY WITH 99% OF VESSELS CALLING.
CURRENTLY ONLY ONE WAY PASSAGE AT FINN'S.

d. Should the widener be modified? Feel free to sketch on Figure 1.
DON'T SEE NEED TO EXPAND CURRENT PROPOSAL.

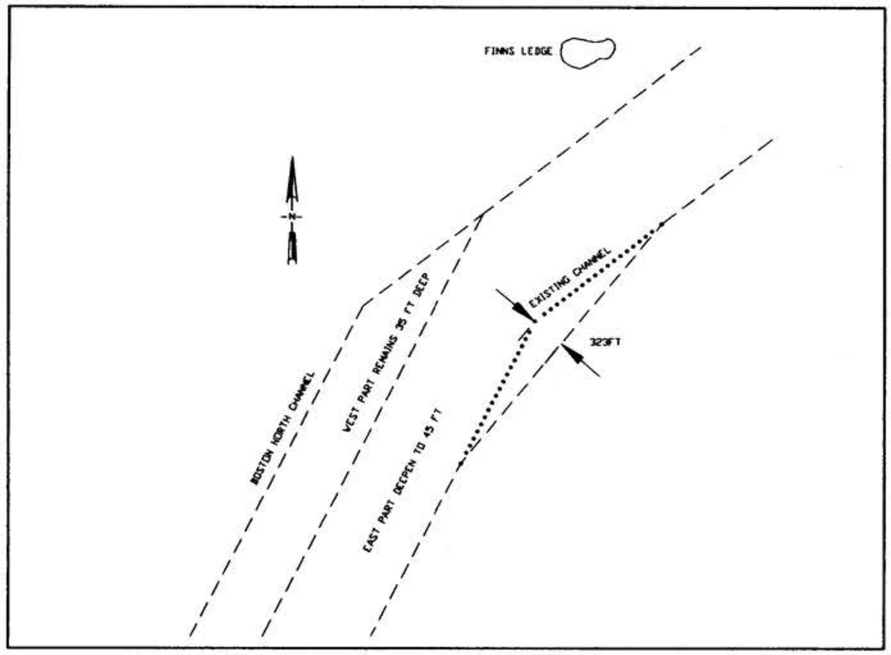

Figure 1. Boston North Channel Bend Widener

2. Widening of the deepened 45 ft channel near Spectacle Island is proposed. The widening will be accomplished by deepening on the south side of the 35 ft channel. The channel width would be increased to 800 feet with 880 feet through the turns. The widening is shown in Figure 2. The purpose of the additional width is permit passage of these larger vessels through this reach of the harbor's Main Ship Channel and to ease passage in the two turns above Spectacle Island.

a. Based upon your simulation runs, do you feel that the additional width provided adequate room for both the *COSCO Hamburg* and the *Delaware Bridge*?

DEFINITELY

b. Based upon your simulation runs, do you feel that the additional width is necessary to bring the *COSCO Hamburg* and the *Delaware Bridge* to make the turn near Spectacle Island?

YES

e. Will the widener benefit other vessels calling at Boston Harbor? If so, which vessels and inwhat manner would they benefit.

TANKER (DEEP DRAFT), BULKER'S (SALT + SCRAP). WOULD BE RESTRICTED ONLY BY DEPTH AT BERTH NOT CHANNEL DEPTH.

c. Should the channel width in the straight sections or in the two turns be modified? Feel free to sketch on Figure 2.

PROPOSAL WORKED FINE.
CHANGES/MODIFICATIONS WOULD BE NIT PICKING.

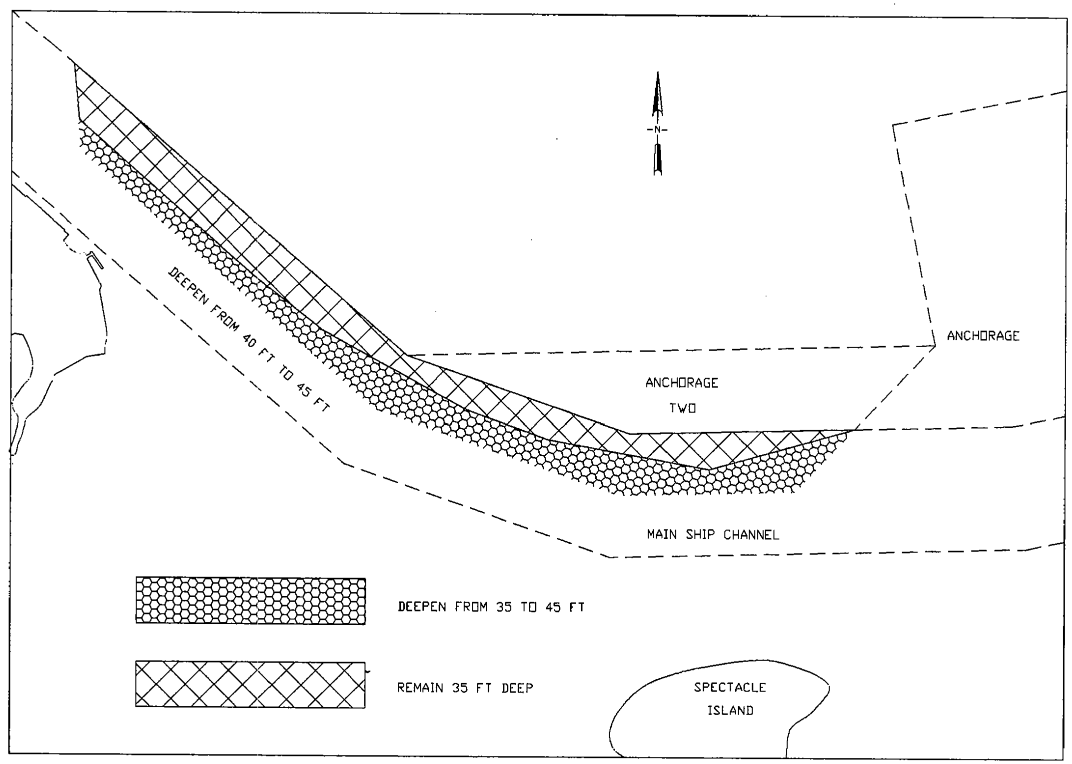

Figure 2. Spectacle Island Widening

3. Widening near the mouth of the Reserved Channel is proposed. The widening will increase the size of the turning area from a radius of 1200 feet to a radius of 1500 feet. and also provide 50 ft additional width for the 45 ft channel north of the turning area. The widening is shown in Figure 3. The turning area is being increased to allow larger containerships access to the Reserve Channel. The additional 50 ft width is to allow more maneuvering room for larger bulk carriers expected to call on the Massport marine Terminal just north of the Reserve Channel.

a. Based upon your simulation runs, do you feel that the enlarged turning area provided adequate room for both the *COSCO Hamburg* and the *Delaware Bridge*?

DEFINITELY

b. Based upon your simulation runs, do you feel that the enlarged turning area is necessary to bring the *COSCO Hamburg* and the *Delaware Bridge* to enter and leave the Reserve Channel?

YES

c. Should the enlarged turning area be modified? Feel free to sketch on Figure 3.

SEE PROPOSAL #2

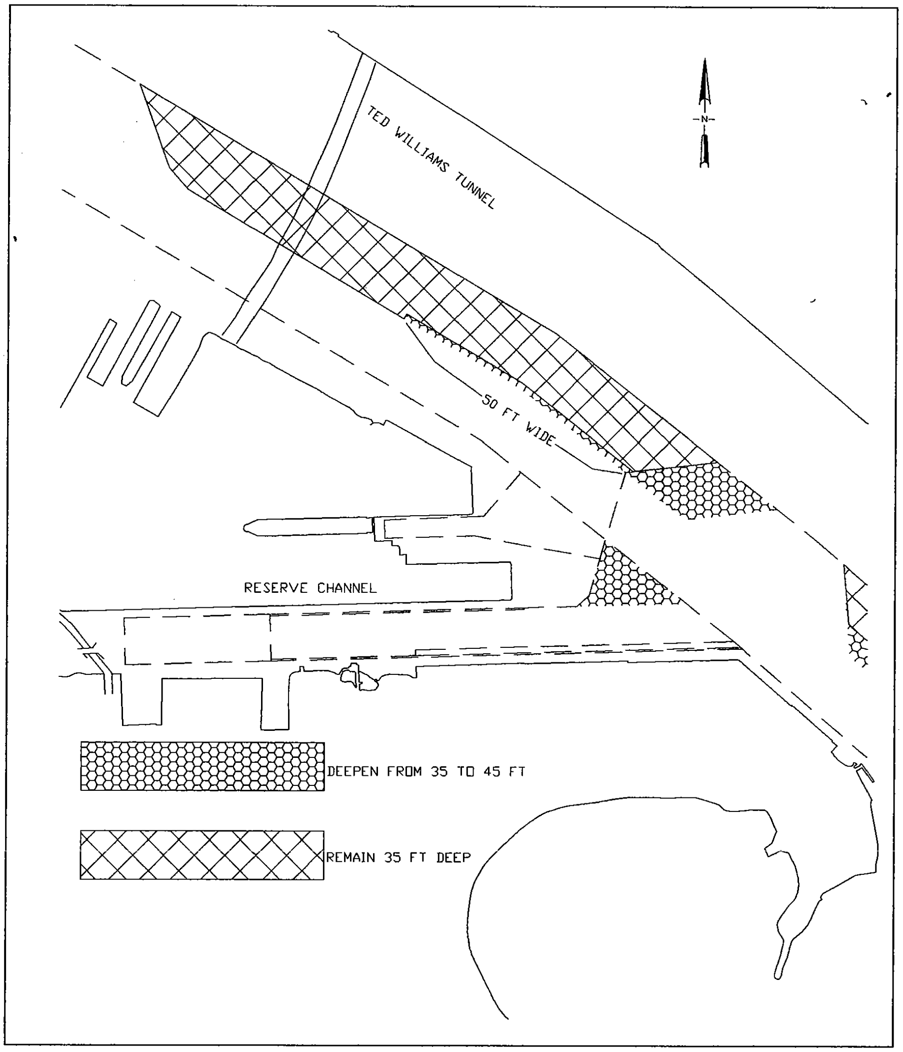

Figure 3. Widening near mouth of Reserve Channel

4. An alternative turning notch was simulated during the final days of the second week of simulations. It is shown in Figure 4.

   a. Based upon your simulation runs, do you feel that the enlarged turning area provided adequate room for both the *COSCO Hamburg* and the *Delaware Bridge*?

      YES

   b. Based upon your simulation runs, do you feel that the enlarged turning area is necessary to bring the *COSCO Hamburg* and the *Delaware Bridge* to enter and leave the Reserve Channel?

      IF INTENT IS TO MINIMIZE IMPACT TO AIR TRAFFIC, THE ALTERNATIVE NOTCH WORKED WELL.

   c. Should the enlarged turning area be modified? Feel free to sketch on Figure 4.

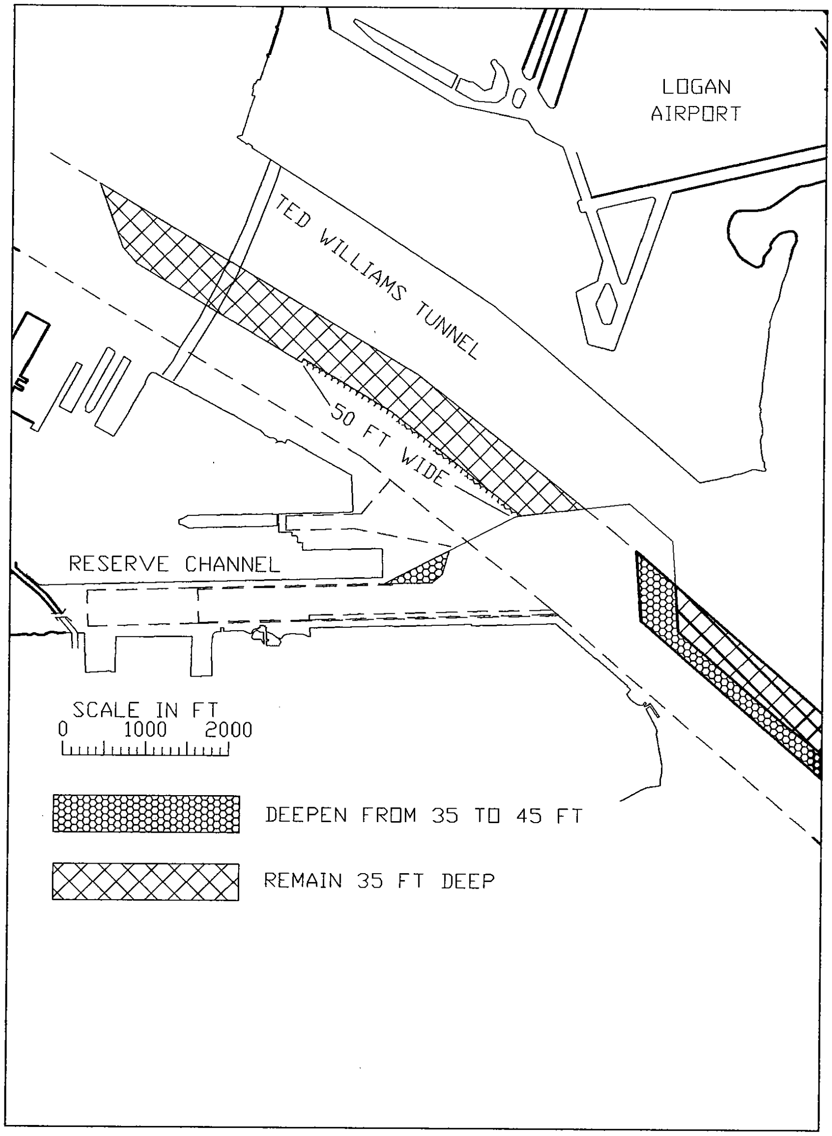

Figure 4. Plan 2 turning notch

5. The following questions concern the simulation modeling of Boston Harbor.

   a. Was the visual scene realistic, accurate, and adequate for the study?

      YES

   b. Do you feel the ships responded correctly to the currents?

      YES

   c. Do you feel the ships responded correctly to the bank forces?

      AS MODELED, THE PROGRAM RESPONDED AS DESIGNED. HOWEVER, SUCTION OCCURED WHERE IT NORMALLY WOULDN'T.

   d. Do you feel the ships responded correctly to the wind?

      GENERALLY, YES

   e. Any additional comments regarding the simulation model?

      TUGS SEEMED A LITTLE WEAKER THAN EXPECTED

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14. ABSTRACT

Boston Harbor is located on the eastern shore of the Commonwealth of Massachusetts, on Massachusetts Bay. The Corps of Engineers and the Massachusetts Port Authority (Massport) are evaluating a number of improvements to Boston Harbor. These improvements include deepening and widening portions of the Broad Sound North Entrance Channel, Main Ship Channel, and lower Reserved Channel and its turning area for the benefit of larger container vessels calling on Massport's Conley Terminal. To assist in evaluating these improvements, the U.S. Army Engineer Research and Development Center (ERDC) conducted a ship-simulator-based navigation study. Data for the simulation models were obtained during a site visit to ride ships in the project area. Currents for both the existing and proposed channels were calculated using the ADCIRC computer model in a joint effort between ERDC and the U.S. Army Engineer District, New England. Harbor pilots traveled from Boston to validate and operate the simulations in September 2005.

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BOSTON HARBOR
MASSACHUSETTS

NAVIGATION IMPROVEMENT STUDY

FINAL FEASIBILITY REPORT
AND FINAL SUPPLEMENTAL
ENVIRONMENTAL IMPACT STATEMENT
(AND MASSACHUSETTS FEIR)

APPENDIX I

GEOLOGY AND GEOTECHNICAL
INVESTIGATIONS

(THIS APPENDIX UNCHANGED FROM 2008 DRAFT)

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BOSTON HARBOR FEASIBILITY STUDY
GEOLOGY AND GEOTECHNICAL STUDIES

INTRODUCTION

Feasibility Study investigations to support proposed navigational improvements of the Boston Harbor Channels were initiated in 2002 and are scheduled for completion in 2008. Explorations have consisted of marine geophysics and subsurface probes and borings for determining sea floor and bedrock topography and composition prior to deepening the channels. This appendix presents the results of current and previous studies and aims to provide sufficient description of the material to be dredged, to support Feasibility-level studies, as well as make recommendations for design phase investigations.

Since the early 1800's navigation in Boston Harbor and its tributaries has been facilitated by constant maintenance and periodic deepening. The current study aims to evaluate the feasibility of various deepening alternatives to allow larger container ships and other marine traffic easier access to Boston Harbor. Since the early 1900's, investigations concerning the surface of the seafloor and the underlying materials have been conducted. As the channels have been deepened, areas of shallow bedrock and dense sediment have taken on larger footprints. With the cost of removing hard material so high, and the scope of the project so large, marine geophysical surveys combined with subsurface explorations provide a cost-effective approach for obtaining information over large areas. This appendix serves to present these results, in context of past findings, and make recommendations for design-phase studies.

Marine geophysical surveys were performed in 2002, followed by probes and borings in 2003 to further confirm and delineate areas having shallow bedrock, and to predict the topography of the bedrock surface, for use in quantifying the required rock removal volumes for the various deepening alternatives. Shallow ledge was confirmed by probes in the Entrance Channel, consistent with historic probe information. Bedrock is not as extensive as predicted by marine geophysics in this area, as a dense till layer may be present, and getting picked up by the seismic survey methods above the actual bedrock surface. While shallow ledge was known to exist in the Entrance Channel, two previously unknown large bands of shallow bedrock were discovered crossing the North Channel off Great and Little Faun Shoals. These ledges were first identified by geophysical surveys, and then confirmed by probes. The existence of another ledge was also confirmed in the western end of the 40-foot President Roads Anchorage and in the 35-foot Anchorage No. 2 (barge anchorage), perhaps an extension of the Lower Middle Ground shoal. Consistent with the historic ledges identified in the 1940s deepening projects, bedrock was determined to be present under large portions of the Reserved Channel and Main Ship Channel, which were cut through areas of shallow bedrock and till, with an undulating bedrock surface and multiple shallow ledges to the east of Castle Island and along the South Boston shore. Smaller areas of rock were also found in sections of the Mystic and Chelsea Rivers. The Cambridge Argillite forms the bedrock underlying most of Boston Harbor and, while rippable in the past using heavy excavators, could be more difficult to remove if encountered in a harder, unweathered state at depth. Granite was encountered in the upper Chelsea River, and has required blasting in the past.

Despite these explorations, data gaps still remain. Seismic data are not available for areas where gaseous organic sediment or coarse bottom sediments prevented signal penetration. Chelsea River and the northern half of the President Roads Anchorage were not included in the geophysical surveys from this study. The topography of the bedrock surface will need to be further refined in the design phase to more accurately predict ledge volumes and rock types, and to distinguish ledge from other hard materials. A series of investigations is recommended to support design, starting with the collection of additional geophysical data; re-processing all geophysical data collected to date using probe data to ground-truth the seismic model; subsurface explorations to probe bedrock elevations and collect physical samples of sediment and rock core for mechanical analysis and strength testing to assess rippability, and a final re-processing of the geophysical data using the new subsurface data.

GEOLOGIC SETTING

Boston Harbor lies within the Boston Basin, a coastal depression bound by east-west trending thrust faults and composed of Proterozoic sedimentary rocks and Cenozoic glacial and marine deposits (see Figure I-1). A few major events led to the creation of the current basin topography. Reactivated fault movement in the late Paleozoic to Mesozoic folded the clastic rocks deposited in the Proterozoic, resulting in a series of easterly plunging anticlines and synclines. Uplift during this period is thought to have eroded a large part of the basin away. In the Tertiary, sea levels fell up to 65 feet (20 meters) and valleys were cut into the bedrock by rivers seeking equilibrium with the coast. Glacial activity in the Pleistocene scoured the bedrock surface and deposited more sediment. Most recently the prehistoric landscape of the basin was flooded as sea levels rose to their present state. The oldest bedrock formation in what remains of the Boston Basin is known as the Boston Bay Group.

The Boston Bay Group is a clastic wedge believed to have formed by a retrograding coastal sequence. Ages for the Boston Bay Group vary, but recent studies have established an estimated Proterozoic age from between 620 and 570 million years ago (mya) (Kaye and Zartman, 1980; Zartman and Naylor, 1984; Thompson and Bowring, 2000). The different units within the group are interconnected facies of the coastal environment and represent changing conditions across time and space (Billings and Tierney, 1964). As the basin subsided the coastline migrated inward towards the south-southwest and became deeper towards the north due to increased subsidence in the basin center (Billings, 1976). The higher basement rock to the south served as source material which was carried into the basin by rivers flowing north and east. This basement rock is composed of felsic volcanics and granites. Overlying the suite of basement rocks is the Cambridge and Roxbury Formations of the Boston Bay Group. The Cambridge Formation and the more recent sediments above it are most likely to be encountered in future dredging operations.

The Cambridge Formation, or Cambridge Argillite, represents the upper and more distal (deposited distant from shore) segment of the Boston Bay Group. The unit is almost exclusively comprised of gray argillite, a typically hard and well indurated siltstone, and has only 2-3% sandstone with little-to-no conglomerate (Billings, 1976). A possible member of the Cambridge Formation is the Milton Quartzite, a coarse white quartzite found near the southern edge of the harbor (Billings, 1976). Deposition of the Cambridge Argillite occurred in the deeper portion of the basin where mainly finer grained silt and clay particles would be carried. Common sedimentary structures include very thin bedding, ripples, slumps, and folds. There are also numerous storm beds, or turbidites, that carried some coarser grained sand and silt further into the basin.

The Cambridge Argillite forms the bedrock under most of the harbor and associated rivers and channels involved in this improvement project. In other previous studies by the Corps, where limited probe and boring explorations were implemented, argillite was shown to form several significant high points (USACE, 1996). In earlier dredging the argillite had exhibited a highly weathered and broken up surface which proved to be rippable by heavy excavators. Even if the current surface has been cleared down to fresh exposures the higher clay content of the rock may still allow for separation along the bedding; a point confirmed during the excavation of the Main Drainage Tunnel in 1957-58. At depths of over 300 feet the argillite in the tunnel still had in many cases a “flaggy parting” associated with bedding and laminations (Rahm, 1962). However, new explorations into the condition of the bedrock surface should be done to confirm this. Also mentioned in the tunnel investigations are numerous dikes and sills of fresh to weathered diabase. Weathered diabase could make rock removal easier, but is potentially harder than the argillite in an unweathered state. Although most are smaller the largest diabase structure is 120 feet thick, and could pose a problem if the surface is fresh. Covering much of this bedrock surface is a series of Quaternary sedimentary deposits.

The majority of material overlying the Boston Bay Group is the result of Pleistocene glacial activity. Directly atop the Cambridge Argillite, and forming much of the harbor islands, is the drumlin till. Thought to be pre-Wisconsinan in age it is made of dense, highly weathered, surface-oxidized till with lesser amounts of stratified silt, sand, and gravel. The highly compacted nature of the till and its coarse texture, including boulders, sometimes results in the till surface being identified as the dominant reflector in marine seismic surveys, rather than the underlying bedrock. The next unit, known as the surface till, was formed during the retreat of the Wisconsin glacier. It is separated from the underlying drumlin till by an unconformity and consists of various till, outwash, and ice-contact sediments. A thick sequence of marine silts and clays called the Boston Blue Clay is the last of the glacial deposits. Meltwater released from the continuing glacial withdrawal is believed to have carried fine particles trapped beneath the ice out into the sea, and ice rafting may explain the few lenses of coarser sediment. Deposition also appears to have been quick and undisturbed, a theory supported by the clay’s layered and draping nature (Ocean Surveys, 2003).

Of particular interest to dredging is the compact drumlin till found on the harbor islands. The islands are considered to be submerged drumlins, and it is possible that more of these hills have been eroded down or covered by the ocean (Mulholland, et al., 2003). Geophysical surveys of the Mystic and Chelsea Rivers, and the Inner Confluence discovered till formed the bottom surface in some areas (WES, 1994), such as the vicinity of the Chelsea Street Bridge. More of the sea floor, especially in areas not already dredged or blasted for channel deepening, may be formed by this till.

Younger Holocene sediments form the remaining part of the harbor stratigraphy. The soils contain unconsolidated alluvial and estuarine sand and silt deposits. The most recent of these is rich in organic matter, so much so that the breakdown of organics has produced enough methane gas for portions of the sea bed to be masked in seismic surveys of the harbor due to poor signal penetration (Ocean Surveys, 2003).

Past geophysical surveys and explorations by the Corps and its contractors have identified the likely presence of ledge within the proposed dredge limits, but limited sampling has been performed to date. In order to determine the necessary rock removal methods, additional sampling to characterize the rock type and strength properties is required. Strength data can be used indirectly to assess rippability. As discussed above the material largely defining the topography of Boston Harbor's sea floor, is the Cambridge Argillite and glacial till. In the event that dredging will take place in very hard argillites, diabase dikes, or compact tills, blasting may be required. However, these areas are likely to be limited, and scoop or shovel operations should be sufficient if the current surface is weathered and rippable as it was in the past.

PREVIOUS INVESTIGATIONS

The US Army Corps of Engineers (USACE) carried out several studies exploring the sea floor and underlying bedrock of Boston Harbor for previous channel improvements dating back to the late 1930's. These investigations serve as good background information regarding the location and identity of materials beneath the harbor. The data is sometimes insufficient because explorations for past improvements were concerned only with material at dredge depths required for those projects. However, in some cases the extent of sample gathering covered much more area than more recent studies could allow.

ARCHIVES

In 1936 and 1937 the 40-foot Boston Harbor Channel was surveyed from President Roads to Commonwealth Pier No. 1. The probes and soundings taken of the channel were for the purpose of future dredging and, in all, 19 areas of ledge were identified (see Figure I-2). In maps based off this information separate 40-foot contours for the ledge surface and the overlying sediments were labeled. Focus was placed only upon the depth and placement of these ledges, however, and no data concerning the underlying materials was recorded.

A second set of depth measurements was made, along with 26 borings, between 1944 and 1945. This series of explorations dealt with the proposed 35 and 40-foot anchorage areas that were to be created at President Roads. Most of the borings show silt or sand over blue clays and only two encountered refusals. One boring along the western edge of the 40-foot President Roads Anchorage encountered shallow refusal at – 44 feet Mean Low Water (MLW) in cemented sand, gravel, and clay. The other boring, situated on the northwestern edge of the 35-foot anchorage, encountered refusal at -38.9 feet MLW in hard sand. Most, if not all, of these borings are now less relevant given that they do not extend deep enough for the requirements of the future project.

USACE NAVIGATION IMPROVEMENT STUDY, GENERAL DESIGN MEMORANDUM, 1996

Plans from the 1996 Corps General Design Memorandum represent the most recent phase of channel deepening and improvement. Rock removal in the Reserved and Chelsea River resulting from this previous design phase is roughly mapped in Figures I-3 and I-4. Most areas were dredged to -40 feet Mean Lower Low Water (MLLW), and down to -43 feet MLLW for overdepth.

In 1992 the US Army Engineer Waterways Experiment Station (WES) carried out seismic reflection and side scan sonar surveys of the Mystic and Chelsea Rivers, Reserved Channel, and the Inner Confluence. Results were published as a separate document in 1994 and in the 1996 General Design Memo. Information gathered determined density and soil type of the sea bed to a depth of -42 feet MLLW and was used to support investigations into deepening the major tributaries of Boston Harbor. Survey lines varied from 1,000 to 6,000 feet in length and were spaced 150 to 200 feet apart. Analysis of 15 borings from the USACE, detailed in the 1996 Navigation Improvement Study, Design Memorandum, and an additional 6 borings made by WES, was used in comparison with the subbottom sediment surveys. The WES study allowed for some interpretation of the location of ledges in this portion of the harbor channel, finding 9 areas of rock, gravel, or till outcrops in the survey area. A number of these ledges within the Reserved Channel and Chelsea River, along with trackline and boring locations, can be seen in Figures 5 and 6. However, spacing was not close enough to provide sufficient detail of these structures for future projects.

In addition to the WES survey 54 machine probes and 15 borings, including drive samples and rock cores, were drilled in 1993. These investigations were used to better characterize the materials in areas where no prior dredging had occurred or where hard rock and till existed within the desired dredge depth. Although the 1993 sampling excluded President Roads and the North Channel it provided some of the only data that accurately describes bedrock near the surface. Bedrock is noted as having been discovered at dredge depth in and around the Reserved Channel and Mystic River. The graphic logs show argillite was collected at -42 to -42.5 feet MLLW in the Reserved Channel area and up to -45.3 feet MLLW in the Mystic River Channel.

CURRENT INVESTIGATIONS

Investigations in support of the Feasibility Study of proposed navigation improvements have been carried out between 2002 and 2003, and consist of marine geophysics (2002) and driven probes and borings (2003). Based on proposed improvements, -55 feet Mean Lower Low Water (MLLW) was considered the maximum depth of interest for these studies.

2002 GEOPHYSICS

Introduction

Between September 2002 and February 2003 marine geophysical surveys were conducted in Boston Harbor for the US Army Corps of Engineers. The investigation was performed by Ocean Surveys, Inc. (OSI) and the University of Massachusetts (UMass) Archaeological Services, under a joint contract to Battelle Memorial Institute. The areas analyzed included a portion of the Mystic River as well as the channel and anchorages from Pier 6 just west of the Reserved Channel to the eastern end of the North Channel at Finns Ledge. Side scan sonar, subbottom profiles, and marine magnetometer surveys were combined with sediment grab samples to map surface and underlying sediments and materials of Boston Harbor.

The purpose of the marine geophysics was twofold. Of primary concern was the determination of where removal of rock will be required. A second concern was the identification of any potential archaeological resources that may be present in areas of the seafloor that have never been dredged, but would be encountered during deepening. UMass used the marine geophysics data to provide an assessment of the potential for archeological discoveries in Boston Harbor's seabed, which was released in 2003 with the title "Remote Sensing Archaeological Survey and Geological Interpretation" under the Boston Harbor Navigation Improvement Study. Further discussion of the archaeological investigations and findings is provided in the Cultural Resources Appendix.

Methods

For the 2002 OSI geophysical survey approximately 200 nautical miles of trackline at 50-foot spacing was traveled with quality control cross tie lines every 2,000 feet. Data was collected on every line for magnetic intensity and along every cross tie and third line for side scan sonar imagery and subbottom profiles.

Ground truthing for the side scan sonar data was based on grab samples taken of the bottom sediments. Only 4 samples were collected spread across the survey area to provide a limited control.

Horizontal control was established using a Trimble DMS 212 Differential Global Positioning System. This equipment is capable of providing coordinates referenced to WGS-84 and NAD 83. Using Coastal Oceanographic's HYPACK navigation computer and software crew could record and convert these coordinates, which were ultimately provided in the Massachusetts State Plane Coordinate System, NAD 27 within the OSI report. Navigation checks with the Trimble GPS were taken every day from point OSI "NAV" on a floating dock at Crystal Cove Marina in Winthrop, MA.

- **Subbottom Profiles**

Subbottom profiles are made with seismic reflection. It is a method which uses acoustic waves emitted by a tow vehicle. As this equipment is dragged through the water the acoustic waves travel down and are bounced back by any objects they encounter, such as shipwrecks, rocks, and sediment. Materials of different densities reflect these waves differently. Hard rock or bedding planes more easily reflect the acoustic waves, while soft sediment will let it pass through. The method is not perfect, however, as different materials can sometimes return the same kind of reflection. Compact till may return as strong a reflection as solid argillite because an abundance of dense cobbles and boulders is present. Images of trackline profiles are created as the reflected waves are measured by the tow vehicle and are electronically processed on ship.

Subbottom profiles were created by using an EdgeTech GeoStar "Chirp" Profiler recording on every third trackline (150-foot line spacing) and every cross tie line. The EdgeTech has a frequency range between 2-16 kHz and can penetrate subbottom sediments, such as clays, up to 260 feet (80 meters). The high-frequency "Chirp" system was considered most appropriate, in that it provides greater resolution, while low frequency profilers provide greater depth penetration, but less detailed resolution. Since the depth of interest was relatively shallow, the "Chirp" profiler was selected.

- **Side Scan Sonar**

Side scan sonar is another method of seismic reflection, which also uses reflecting acoustic waves to create an image. Generally in side scan very few waves penetrate into the subbottom sediments. The reflected signals produce a high resolution "picture" of the sea floor, detailing objects and topography across the surface.

Sonar imagery was collected by a DataSonics SIS1500 along every third trackline (150-foot line spacing) and all cross tie lines, using a 164-foot sweep range, and operating at a swept frequency of 200 kHz.

- **Marine Magnetometer**

Marine magnetometers, when involved in geophysical surveys, are utilized to detect metals on and beneath the sea floor. The magnetometer in the OSI survey used cesium vapor to operate. A photon emitter calibrates the instrument by exciting the electrons in the cesium atoms to specific energy levels. At this point any outside emissions or magnetic activity impacting the cesium atoms can affect their energy state. It is this change that is recorded by a photon detector and translated into a visual readout.

A Geometrics G-881 Magnetometer was used for the survey. Its range of operation is 20,000-100,000 nT and has a sensitivity of <0.01 nT/√Hz RMS.

The marine magnetometer surveys were carried out primarily for the archaeological portion of the study. Readings showing the presence of ferrous metals taken with the instrument were compared with side scan sonar imagery to better evaluate objects with potential historical significance, particularly shipwrecks. However, there is geologic value as bedrock and till with high ferrous content could also create a positive reading. Accurate detection of underwater power cables and tunnels also serves an important purpose when considering the safety of dredging operations.

- **Sediment Grab Samples**

Grab samples are simply samples of material collected from the sea bed. A WildCo Ponor 9-inch grab sampler was used to collect unconsolidated marine sediments from the study area. The instrument has a bucket that is split in half and opened on either side of a set of cables. When the trigger mechanism hits bottom the two halves close together providing a relatively undisturbed sample. The grab sampler bucket has a sampling area of 9 in x 12 in x 6 in.

Results

Subbottom profiles provide an estimate of where till and bedrock may be present at depths above -55 feet MLLW. This methodology identifies the depth at which there is a sharp change in density (acoustic velocity) of subsurface materials, resulting in a well-defined reflection observed in the subbottom profiles. This reflector represents a material change in acoustic properties, and is referred to as the "acoustic basement." Signal penetration below this depth is weak and reflection imaging is negligible. Based on prior experience in the Boston area, the acoustic basement usually represents the contact between marine/glacial deposits and the underlying bedrock. However, strong contrasts in density within glacial till deposits can also generate a strong reflection. Therefore, the acoustic basement topography should not be interpreted definitively as bedrock surface topography without additional ground truthing efforts (outcrop observations, boring data).

OSI interpreted the data and generated a preliminary figure showing the areas where acoustic basement was detected above -55 feet MLLW (see Figures I-7 and I-8). Results are presented in the "Final Report – Geophysical Explorations: Remote Sensing Archaeological Survey and Geologic Interpretation, Boston Harbor Navigation Improvement Study, Boston, MA," prepared by Ocean Surveys, Inc., dated 21 May 2003 (OSI Report No. 02ES066).

OSI also plotted the areas where reflectors could not be identified, and the depth to the acoustic basement could not be determined. The lack of reflectors could be due to either a lack of signal penetration (typically caused by gas bubbles entrained in organic sediments, but also sometimes related to coarse textured material – cobbles and gravel – on the seafloor), or the presence of very deep bedrock, beyond the depth of signal penetration.

USACE subsequently tasked OSI with developing additional figures, contouring the acoustic basement (1-foot contour interval) where it was identified at depths shallower than – 55 feet MLLW. The results of this effort are documented in the "Addendum to Final Report," dated May 2003 (OSI Report No. 02ES066-A). The additional figures are provided in Attachment E-1. The contouring is subject to numerous uncertainties, both geological (variability in seismic velocity) as well as inherent in the data collection program (data density, spacing of cross tie lines, depth variability of the towed sonde, survey accuracy, tidal effects), ultimately affecting the accuracy of the elevations shown. For example, a constant seismic velocity of 5,200 foot per second (fps) was used in all profiles to convert return time data into depth data. Based on a sensitivity analysis of the seismic velocity used in interpretation, velocity variations in subsurface materials may account for as much as a 2-foot difference, plus or minus, in the actual acoustic basement surface. However, the general shape of the acoustic basement is likely valid.

The side scan sonar and magnetic intensity provided less information about the bedrock surface than the subbottom profiling. However, the sonar images gave a detailed view of sediment at the immediate surface, which is often missing or poorly detected in the deeper penetrating subbottom profiles. Shore structures in the inner channel, as well as fishing gear, lobster pots, and other anthropogenic influences clouded much of the magnetic survey, although some areas of shallow bedrock and till may have been detected. OSI included a discussion of how the geophysical data may possibly be used to identify man made objects (such as utilities, tunnels, and debris) that could be hazardous to dredging operations.

Results are divided by area, including: the North Entrance Channel, President Roads, Main Ship Channel, Reserved Channel, the Mystic River, and the Chelsea River. See figures in Attachment 1.

- **Road Sound North Entrance Channel**

The subbottom profiles showed shallow acoustic basement in two main areas of the North Entrance Channel, associated with Finn's Ledge at the outermost mouth of the entrance channel, and east-northeast of Great and Little Faun Shoals. Almost the entire southern half of the channel in this area had poor signal penetration, which was likely related to the coarse textured sediment on the seafloor bottom. As a result, however, there is a large area where subbottom profile data are not available.

The topography of the acoustic basement near Finn's Ledge is highly irregular, with interspersed peaks and valleys. Shallow bedrock would be anticipated near Finn's Ledge, based on historic probes conducted in this area (see Figure 9). However, the topography of the acoustic basement does not corroborate very well with the historic probe refusals. Shallow acoustic basement is indicated where historic probes have extended to depths greater than -55 feet MLLW.

The acoustic basement surface off Great and Little Faun Shoals manifests itself as two broad bands crossing the navigation channel. Ledge removal has not been required in this area in the past, but based on geophysical data, bedrock likely occurs at or just below the seafloor surface in this area. The bathymetry of the seafloor as shown on the nautical charts also hints at the east-northeast extension of these rocky shoals towards the navigation channel.

Side scan imagery revealed areas of coarse sediments at the surface in the section of the North Channel from Finns Ledge to Deer Island Light, just east of President Roads. Strong currents around Deer Island Light and shallow bedrock shoals identified in subbottom profiles are said to be likely reasons for a hard, rocky seafloor.

- **President Roads Anchorage and Channel Reach**

The majority of the subbottom material within the channel and anchorage that is above dredge depth is composed of unconsolidated sediment. A poorly sorted sample of clay, sand, gravel, and cobble was retrieved from some of this sediment in the middle of the President Roads Anchorage. Only several relatively small areas in President Roads showed evidence of acoustic basement above -55 feet MLLW.

The OSI surveys only investigated the southern half of the President Roads Anchorage. The northern half may still have significant sections of shallow bedrock and should be included in future explorations. During maintenance dredging operations in 2004-2005 six small areas of ledge with top elevations shallower than -40 feet MLLW were discovered near the western boundary of the northern part of the Anchorage. These ledge areas were removed in December 2007 as part of the Inner Harbor maintenance operation. The presence of these small ledges will require further exploration.

Side scan sonar showed limited areas of coarse sediment on the sea floor in the anchorages and channels east of Castle Island, which may be attributed to highs of bedrock and till as seen in the subbottom profiles.

- **Reserved Channel, Turning Area and Main Ship Channel**

The channel between Castle Island and President Roads has significant areas of acoustic basement within the proposed dredge depth. Bedrock and/or till form an undulating surface that becomes shallower towards Castle Island. Gaseous organic materials limited the collection of data along the southwestern edge of the channel. This was confirmed by the presence of odorous black silt and clay in grab samples.

Subbottom profiles show acoustic basement sloping up to less than -55 ft MLLW from the mouth of the Reserved Channel to the east and northeast. Much of this basement is formed by an undulating surface. However, most of the Reserved Channel appears to have been previously dredged down into the basement. Black clay with a strong odor, similar to that found near Castle Island, was collected from a location in the Main Ship Channel which corresponds with small area of poor sea floor penetration by the sonar.

Side scan images show coarse sediments forming the sea bed in addition to organic clays, till, and bedrock.

- **Lower Mystic River**

Only a small part of the lower Mystic River Channel is being considered for deepening, and therefore the geophysical surveys were limited to this area. Nearly this entire small portion that was surveyed had no seismic penetration. Undredged organic clays and petroleum byproducts are believed to have blocked the acoustic waves. An acoustics basement reflector was detected, sloping up to the riverbed in the northeast corner of the survey area. However, the shallowest estimated bedrock elevation was -45 feet in this area, below the maximum dredge depth of -42 feet for the Mystic River.

- **Chelsea River Channel**

No subsurface profile data was collected for the Chelsea River Channel. Reliance on prior subsurface exploration programs performed for the 38-foot deepening project of 1998-2001 was determined sufficient to define conditions.

2003 EXPLORATIONS

Introduction

In late 2003 GEI Consultants, Inc. (GEI) was tasked with conducting subsurface explorations for the Boston Harbor Navigation Improvement Study, including the Chelsea River. The work carried out included 97 machine probes, 1 bedrock boring, and 10 vibracores. Geologic–Earth Explorations, Inc. (Geologic) and TG&B Marine Services, Inc. were sub-contracted by GEI to perform the probes and boring, and vibracores, respectively. The areas covered by these explorations included the North Channel and President Roads to the Reserved Channel in the west, as well as portions of the Mystic and Chelsea Rivers. USACE selected probe and boring locations based on the 2002 geophysical data collected by OSI, as well as other existing historical information. Probe and boring locations are also plotted on the figures in Attachment I-1. Generally, probes were located along geophysical (subbottom profile) tracklines, and at the intersection of tracklines with cross tie lines when possible.

The purpose of these explorations was to determine where refusal (assumed to represent either bedrock or very dense glacial till deposits) occurs above -55 feet MLLW, and obtain general information regarding the density of overlying sediments. Due to funding constraints, with the exception of one core boring in Chelsea River to characterize rock type, no samples were collected as part of this program, which consisted entirely of probes. As a result, material types can not be characterized definitively. The rock core at Chelsea River was collected in order to classify the rock type present in that area, where ledge removal has been necessary as part of prior dredging operations (see Figure I-4).

Vibracore samples of soft sediments were sent to UMass Archaeological Services for analysis of potential cultural sites or artifacts, but played little role in determining bedrock surface. Results from the UMass study were presented in the 2004 document, “Archaeological Subsurface Testing for the Boston Harbor Navigation Improvement Study,” and are discussed in more detail in the Cultural Resources Appendix.

Methods

The field work for the GEI explorations consisted of on-water barge based drilling. A skid-mounted drilling rig was loaded onto an approximately 40-foot by 110-foot spud barge owned by Boston Towing and Transport (BT&T). The barge was moved onto locations by a 55-foot tugboat tied to the barge. A 23-foot scow was also used. Once on position, the barge’s three spuds were lowered by the barge crane. Drilling was conducted in water depths ranging from about 33 feet to 53 feet, depending on the tide. To accommodate drilling in these water depths, the spuds had to be lengthened prior to start of work.

To account for fluctuating sea level and tides the contractors needed a way to establish proper vertical controls. Field measurements were made using the tide gauges installed by its survey subcontractor (BSC) at Castle Island, South Boston and Shrafft’s Center, Charlestown. Geologic established a barge reference point as the steel plate on the drill rig wash tub, located 7.5 feet above the water line. The elevation of the reference point was determined in the field by taking a water level measurement from the closest tide gauge. Prior to drilling each location, they driller measured the distance from the reference point to the mudline, using a 6-inch diameter flat plate at the end of a ¾-inch steel rod. All measurements during drilling were referenced to the barge reference point. Ultimately, GEI determined that NOAA water level data for the various Boston and Boston Light water level stations were more accurate for the Inner and Outer Harbors, and so these elevations were used in calculating the final elevations of the probes and borings.

The majority of locations were drilled within 25 feet of the specified coordinate locations; due to barge movements, three locations were actually drilled 31 feet from the proposed locations. Horizontal surveying was controlled by Differential Global Positioning Systems (DGPS). A Trimble GeoXT GPS CE handheld unit was used to record probe, boring, and probe positions in the Massachusetts State Plane Coordinate System, NAD 27 datum. Corrections were made using Federal Aviation Administration (FAA) Wide Area Augmentation (WAA) satellites.

Probes and borings were numbered based on their location within the harbor:

Reach:	Number	Series	Probe Numbers
Finn's Ledge	10	100-Series	FP-03-101 through FP-03-110
Faun Ledges	8	200-Series	FP-03-201 through FP-03-208
President Roads	8	300-Series	FP-03-301 through FP-03-308
Main Ship Channel	40	400-Series	FP-03-401 through FP-03-440
Reserved Channel	8	500-Series	FP-03-501 through FP-03-508
Mystic River	8	600-Series	FP-03-601 through FP-03-608
Chelsea River	16	700-Series	Boring FD-03-701 Probes FP-03-702 through FP-03-716

- **Probes**

Gathering data using probes involves recording the number of blows it takes to drive a drill rod through a foot of sediment. Some assumptions about the type of sediment the rod is in can be made depending on how many times a hammer must be dropped for it to advance. Various size rods and hammers can be used, which can affect the interpretation of the underlying soils based on these numbers. When the probe cannot be advanced any further, or exceeds a specified number of hammer drops per depth of penetration, it has reached refusal. Refusal may indicate that the probe has reached bedrock, but can also be caused by encountering boulders (glacial erratics) or some other densely compacted sediment.

Probes were driven using open-ended NW drill rods and a 300-lb hammer falling from a height of 30 inches. Probes were driven to -45 feet MLLW in the Mystic and Chelsea Rivers and to -55 feet MLLW in the rest of the harbor, or to refusal, whichever was shallower. Refusal was established as 20 blows for less than an inch of penetration, or bouncing refusal.

- **Borings**

Borings provide a means for collecting physical samples of sediments and rock from beneath the sea floor. Many different methods are used for borings. In one way or another borings consist of a hollow pipe that is driven or drilled into the subsurface to retrieve samples through the opening. To sample rocks special hollow casings with cutting edges at the end can be used to allow a core to be retrieved from the borehole.

Geologic, the drilling subcontractor, actually drilled two separate locations to collect the required rock core from the Chelsea River location. In their first attempt, they drilled using the drive-and-wash technique, using a 300-lb hammer to advance the casing (4-inch diameter). Drive samples were collected with a 2.5-inch inside diameter split spoon sampler and blows per foot recorded (300-lb hammer). They collected a 5-foot rock core on their second attempt, after roller-bitting to refusal

- **Vibracores**

TG&B Marine Services, Inc. used a pneumatically-driven vibratory core system to collect the 10-ft long vibracores. This method can carefully retrieve soft sediment samples by using high frequency, low amplitude vibrations to advance a hollow casing into the subsurface. A 6-in diameter vibrating pneumatic piston, actuated with a 125 cubic feet per minute air compressor, was driven into a core pipe. Within the core pipe the piston would impact a 10-ft long, 2 5/8in inner diameter polycarbonate core tube. The cores were not opened in the field, but were transported to GEI's office for evaluation in concert with the UMass archaeology staff.

Results

Of the explorations performed or administered by GEI the probes and borings are of most value to this study. Vibracores were done specifically for the 2004 UMass archaeology study, and are of little use because of their shallow penetration. GEI probe and boring results are summarized in Tables I-1 and I-2.

Data gathered during probing is not always accurate, and conditions between sample points may vary considerably. However, adding probe refusals to the acoustic basement mapped in geophysical surveys provides a great deal of information for estimating the composition and contouring of sediments and bedrock. Probe data relative to the acoustic basement at each location is summarized in Table I-3.

- **Broad Sound North Entrance Channel**

Two portions of the North Entrance Channel were specifically targeted for probing explorations, including Finn's ledge at the mouth of the Entrance Channel and the two broad bands of acoustic basement crossing the North Channel off Great and Little Faun Shoals.

<u>Finn's Ledge</u>: A total of 10 probes were drilled at Finn's Ledge, primarily focusing on peaks in the acoustic basement surface. Of these probes, only 3 encountered refusal above -55 feet MLLW. The location with the shallowest refusal, FP-03-102 (refusal at -46.3 feet MLLW) is located on one of the geophysical peaks, and is located near a finger of ledge that was interpreted to exist based in historic probes. The other refusal locations, FP-03-101 (-52.8) and FP-03-103 (-52.6), are also located near this finger, although actual refusals were

significantly deeper than predicted by the acoustic basement. The remainder of the probes in this area showed poor correlation with the geophysical acoustic basement surface; in all cases the probes extended deeper than the interpreted acoustic basement surface. Based on drilling observations, overburden materials likely consisted of cobbles and boulders, with clayey sand and gravel.

Faun Ledges: A total of 8 probes were drilled at the Faun Ledges, 5 at or near the northern band and 3 at the southern band. Three probes were drilled on the northern area to confirm elevations on the large flat plateau areas (FP-03-201, FP-03-204 and FP-03-205); all 3 encountered shallow refusal (-43.5 to -46.3 feet MLLW). The 3 probes on the southern band (FP-03-206 through FP-03-207) also encountered shallow refusal (-43.3 to –49.8 feet MLLW), again confirming the likely presence of shallow ledge within proposed dredge depths.

The purpose of the other two probes at the northern area was to determine whether shallow bedrock was present in an area of poor signal penetration (FP-03-202), and to investigate the possibility of shallow ledge along the south side of the channel, approximately 1,000 feet downstream of the north plateau (FP-03-203). Although historic probes showed some shallow ledge in this area, just outside the navigation channel, probe FP-03-203 extended to -58 feet MLLW without encountering refusal. Probe FP-03-02 encountered refusal at -53 feet MLLW, consistent with the shape of the suspected ledge in that area.

Based on drilling observations, the soils at the Faun ledges were interpreted to be predominantly clayey sand and sandy gravel.

- **President Roads Anchorage and Channel Reach**

The northern portion of the anchorage was not included in the 2002 subbottom profiling effort, as it was not being considered for deepening at that time. No probes were done in this area as part of the 2003 program. Without geophysical data, the likelihood of identifying ledge areas through a limited number of probes in this area is exceedingly small. Given the cost of marine explorations, a phase of geophysics prior to collecting probe data in this area is warranted. Historic borings (circa 1945) conducted in the northern anchorage extended to elevations of -46 to -49 feet MLLW without encountering refusal.

Very few areas were identified by subbottom profiling in the southern portion of the Anchorage and President Roads as having the potential for shallow bedrock above -55 feet MLLW. As a result, only 8 probes were drilled in this area. Three probes (FP-03-301 through FP-03-303) were located in the vicinity of historic boring No. 21 (circa 1945) at the far west edge of the anchorage where refusal was reported at elevation -44 feet MLW in "cemented sand, gravel and clay." Of these 3 probes, FP-03-302 (located approximately 100 feet east of Boring 21) was the only probe to encounter shallow refusal (-43.2 feet MLLW). The presence of ledge in this area may be related to the Lower Middle Ground shoal (ledge) area, which is located just north of the Main Ship Channel, and extends roughly east-west. The tip of this shoal may extend into the anchorage area. While the recent probe data confirms presence of ledge in this area, additional phases of work will be required to delineate ledge in this area for more accurate estimates of rock removal. The subbottom profiler (using the high resolution "Chirp" high frequency source) was unable to get signal penetration here, and based on drilling observations by GEI, there appears to be a thick layer of organic sediment in this area. Other geophysical methods may be required in this area.

The remaining 7 probes were located where potentially shallow ledge was indicated, and driven to elevations deeper than -55 feet MLLW without encountering refusal.

- **Main Ship Channel**

Ledge areas were identified in the Main Ship Channel during design work for the 1940s deepening project. These historic ledge areas are shown in Figure I-2. The 2002 subbottom profiling also identified large sections of the Main Ship Channel, particularly east of Castle Island and North of the Reserved Channel, having bedrock and/or till within dredging depths. A total of 40 probes were drilled in the Main Ship Channel. Most of the probes confirmed the presence of shallow ledges, although at somewhat deeper elevations typically than what was indicated by the acoustic basement surface. Along the western side of the channel, to the southeast of Castle Island, probes were also able to detect shallow rock and sediment beneath gaseous organics that had masked previous seismic surveys by OSI.

Many different soil types were encountered in the Main Ship Channel including cobbles and boulders, clayey gravel, clay, and organic sediment. Twenty-nine of 40 probes were driven to refusal, and in several cases hard bottom was at or near the surface. Probes reached depths ranging from -36.1 feet to -57.8 feet MLLW.

- **Reserved Channel**

Seven out of the 8 probes drilled in the Reserved Channel encountered shallow refusal, with half of them reaching refusal shallower than -50 feet MLLW. The probe results help verify what prior seismic surveys had shown, that most of the channel has shallow acoustic basement. Ledge removal has been conducted in the Reserved Channel, and near the Notch, as part of recent improvements (reference Figure I-3). Based on drilling observations, sediment was largely organic, with occasional gravel or cobbles.

- **Lower Mystic River**

Probes were driven through gaseous organic sediment in the Mystic River Channel that seismic surveys by OSI could not penetrate. All 8 probes reached a depth of about -48 feet MLLW without encountering refusal. Organic sediment was the only soil type noted according to the blows per foot on the probes and descriptions made from material captured in the open-ended drill rods.

- **Chelsea River Channel**

Past channel dredging in the Chelsea River has required blasting in certain areas to get through the underlying material (reference Figure I-4). While it is know that bedrock is likely to be present in portions of Chelsea River, samples of the rock were not collected previously for geologic examination. One boring was specified in the area of prior rock removal in order to retrieve a core sample of the bedrock. The sediment overlying the bedrock surface included a thin layer of organic sediment and 5 feet of glacial till. A 5-foot rock core was collected and identified as a very hard, slightly weathered to unweathered, pink granite. It is possible that this is a high point in the bedrock surface on which the Boston Bay Group was subsequently deposited, that has been re-exposed since the basin uplifted and eroded.

A total of 15 probes were drilled in Chelsea River, in addition to the boring, but none of them encountered refusal above the -45 feet MLLW dredge depth of interest. Three of the probes were driven to refusal, 2 of which were near the boring location.

BEDROCK SURFACE

Based on the results of subsurface explorations, a crude ground-truthing of the geophysical acoustic basement was performed by USACE staff, and the elevation of the surface adjusted as deemed appropriate, based on the assumption that the general shape of the acoustic basement is likely valid, but the elevation may need to be adjusted to more closely reflect conditions encountered in the probes. In general, most of the surfaces were dropped down. This move is supported by the fact that in many cases, the acoustic basement included elevations above the known mudline elevation of the harbor bottom. A more rigorous re-interpretation and re-processing of the subbottom profile datasets (modifying seismic velocities) is recommended as part of the design phase.

Once it was determined how to adjust the acoustic basement surface, an arithmetic function was applied to the xyz file, to reduce the z elevation by the specified amount. The adjusted xyz file was then provided to the project team for use in estimating ledge volumes for the various proposed navigation improvement plans. A discussion of the adjustments determined for each area is provided below.

- **Broad Sound North Entrance Channel**

<u>Finn's Ledge</u>: Because of the lack of correlation between the acoustic basement and probe data, the acoustic basement surface was not modified or used in estimating ledge removal volumes. Rather, the combination of historical probes and recent probes provide the best data currently to estimate the bedrock surface.

<u>Faun Ledges</u>: The 3 probes targeting the northern plateau all encountered shallow refusal, but somewhat deeper (-43.5 to -46.3 feet MLLW) than predicted by the acoustic basement. As a result, the acoustic basement surface was lowered 5.0 feet. The three probes targeting the southern plateau also confirmed presence of shallow bedrock, but again somewhat deeper than predicted by geophysics (-43.3 to –49.8 feet MLLW), and so the acoustic basement surface in this area was dropped 5.5 feet.

- **President Roads Anchorage and Channel Reach**

There is an area of shallow ledge indicated at the western edge of the anchorage, near the tip of the Lower Middle Ground shoal (ledge), based on historic boring No. 21 and probe FP-03-302. However, subbottom profiling was unable to generate an acoustic basement surface in this area due to organic sediments blocking signal penetration. With only two data points in this area, it is difficult to generate a bedrock surface or predict rock removal quantities with any accuracy. Additional explorations will be needed in this area, as well as the entire northern portion of the anchorage that was not included in the 2002 geophysics program. Recent USACE surveys have identified isolated outcrops of what appears to be ledge in the western portion of the anchorage, and are scheduled to be removed in 2006. Information from this removal program should also be considered in the development of design phase exploration programs.

- **Main Ship Channel**

Comparison of probe data to the acoustic basement contours resulted in lowering the acoustic basement surface by varying values, depending on the area. With the exception of the area just off the Army Base and Turning Basin (“Notch”) where the acoustic basement was lowered by 18 feet, the acoustic basement was lowered by 2 feet to 8 feet, and in most cases on the order of 2 to 5 feet. Areas where signal penetration was prevented by organic-rich sediments have been determined to have some shallow bedrock, based on probe data. Additional investigations will be required to estimate required rock removal volumes in these areas.

- **Reserved Channel**

Probes FP-03-501 through 503 encountered refusal significantly deeper than predicted by geophysics. Therefore the acoustic basement was lowered 12 feet at the west end of the Reserved Channel. The remaining probes encountered refusal somewhat deeper than predicted by geophysics, and so the acoustic basement in the remainder of the Reserved Channel was lowered 6 feet.

- **Lower Mystic River Channel**

Geophysical results were inconclusive due to lack of signal penetration (organic sediments), and probes extended to depths of -48 feet MLLW without reaching refusal. While it appears that a large mass of shallow bedrock is unlikely to be present, isolated bedrock highs cannot be ruled out. Additional investigations would improve the confidence level.

- **Chelsea River Channel**

Although shallow bedrock was not encountered during these investigations, its presence cannot be ruled out, given that rock removal has been required in certain areas during past deepening activities. Bedrock may occur as isolated pinnacles that will be more difficult to detect using either geophysics (limited by line spacing) or probes. It may be more difficult to identify and quantify the amount of rock requiring removal if it occurs as irregular and isolated pinnacles. Based on the granitic rock type, though, it will more likely require blasting to remove it.

DESIGN PHASE RECOMMENDATIONS

During the design phase it is recommended that further analysis of the conditions within the Boston Harbor Channel be performed. The need for continued study is evident in examining the existing data for the channel. Dated sources originating from previous channel deepening were mostly concerned with depths shallower than in the current project, and provide little information on the materials making up the ledges. Although more recent explorations have helped to expand USACE knowledge of subsurface conditions, data gaps still exist.

In most cases, probes confirmed the likely presence of bedrock where it has been identified historically and by recent geophysical investigations. There are still several areas with significant data gaps concerning bedrock elevation and characteristics:

- Areas where the acoustic signal was unable to penetrate the subsurface, either due to organics or coarse-grained surface sediments (President Roads, near historic boring No. 21 and probe FP-03-302; several areas in the Main Ship Channel, and Mystic River).
- The northern portion of President Roads Anchorage. A limited number of explorations were made here as part of the 2003 explorations, given that this area was not included as part of the 2002 geophysical work, as it was not being considered for deepening at that time.
- The nature of the overburden sediments and rock type has not been characterized, as the 2003 exploration program did not include sampling.

The elevation of the bedrock surface will also need to be further refined to more accurately predict ledge volumes in design phase. The following activities are recommended for design phase work:

- Collect additional subbottom profiling data where it is lacking, and to fill in the current subbottom dataset with lines at a 50-foot line spacing in areas where ledge is indicated. Where the high-resolution high-frequency CHIRP profiling system was unable to get signal penetration, the low frequency "Boomer" source should be tried.
- Re-process the previous subbottom profiling dataset and additional data collected, using the 2003 probe data to ground-truth the seismic velocity model and re-generate the acoustic basement surface.
- Employ resistivity methods where seismic methods have provided inconclusive results.
- Conduct explorations (probes and borings) to further characterize both the bedrock surface elevation and nature of subsurface materials. Collect samples of soil and rock
- Test rock core samples to evaluate strength and, indirectly, rippability.
- Test soil samples to characterize grain size distribution as needed to support re-use or disposal.
- Re-process the geophysical data again, using new subsurface exploration data, to update the acoustic basement surface.

A combination of geophysics and intrusive explorations is considered the most cost-effective method of characterizing the bedrock surface. While probes and borings provide very accurate elevations and actual material samples, they reflect the conditions only at that location, and they are very expensive. Geophysical methods allow for cost-effective data collection over large areas. However, as a remote sensing technique, geophysics requires interpretation and ground-truthing.

STEP 1: COLLECT ADDITIONAL GEOPHYSICAL DATA

To aid in the analysis and refinement of existing geophysical data, and prior to conducting additional subsurface explorations, another phase of marine geophysical surveys (sidescan sonar, magnetometer, and subbottom profiling) is recommended. Prior seismic surveys encountered difficulties when attempting to penetrate through gaseous organic materials or get reflections from deep bedrock. Another seismic technique, called the boomer method, could potentially obtain suitable data in this environment. The boomer method uses a lower frequency acoustic source, resulting in greater penetration than the high-frequency “Chirp” source used in the previous investigation. The signal could potentially penetrate the organics and allow imaging of the acoustic basement surface. The disadvantage of the boomer method is a loss of resolution, which may or may not matter for this study. In the event that the boomer method fails to penetrate organics, the seismic surveys could still be useful for resurveying areas with poor detail, or no previous data.

- Data should be collected in the following areas where marine geophysical data were not collected previously:
    - Northern portion of the President Roads Anchorage
    - Chelsea River Channel

- In addition, where shallow bedrock has been identified in the project areas in the past, recommend filling in the line spacing, such that a 50-foot line spacing results. Given that the dominant bedrock structure in the Main Ship Channel is oriented east-west, recommend that lines in this area be run primarily north-south (perpendicular to structure, and to the channel).

- Both the high-resolution “Chirp” source and the “boomer” source (capable of deeper penetration) should be mobilized. The lower frequency “boomer” source should be tried at new areas where signal penetration is affected by organics or surface sediment type, as well as at areas from the 2002 investigation where signal penetration was blocked:
    - Finn’s Ledge Area
    - Faun Ledges
    - President Roads Anchorage, west end
    - Main Ship Channel
    - Mystic River

- As part of this mobilization, a boat reconnaissance should be made of any bedrock areas associated with Finn’s Ledge and Great and Little Faun Shoals that are exposed and accessible during low tide. Such observations could provide supplemental information regarding rock types present in the area.

If seismic results are still inconclusive for large areas, and significant data gaps remain, then a third method could be used, that would not be affected by gaseous sediments. This alternative method analyzes resistivity, and could be used to survey both previous and additional areas. Resistivity measures not acoustic waves, but electrical conductivity of the subbottom sediments. Salt water, being highly conductive, may skew results which could complicate interpretation. Additional literature searches and consultation would need to be conducted before making any recommendation on the applicability of this method to this site.

STEP 2: REPROCESS GEOPHYSICAL DATA

The newly collected geophysical data plus the prior geophysical datasets from seismic surveys carried out by OSI should be reprocessed, using subsurface exploration data to ground-truth the seismic velocity models used to generate the acoustic basement surface. Changing the velocities the acoustic waves are assumed to have been traveling at through sediments would adjust the bedrock surface plot. If the assumed wave velocities were too fast or too slow, the depth of the acoustic basement and other reflectors in the subsurface may have been incorrectly interpreted. The current acoustic basement determined from seismic data does not match up exactly with probes taken in the same areas, and in general the acoustic basement surfaces appeared to be on the order of about 5 feet higher than the bedrock surface, as identified in probes. Figures showing revised acoustic basement contouring would be the final product of this effort, and could be used in selecting the next phase of exploration locations. This re-processing effort could also identify areas where there is greater uncertainty in the interpretation, where additional explorations would be most helpful in resolving the interpretation. Re-contouring would also show more detail of the ledges and high points throughout the channel.

STEP 3: EXPLORATIONS

A final round of probes and borings is recommended to identify the materials likely to be encountered during dredging of hard material within the project boundaries. Subsurface explorations would be used to further delineate the extent of shallow bedrock and to collect physical samples of the overburden soil and bedrock for testing to characterize overburden material for re-use or disposal, and to assess rippability of the bedrock. These new explorations should be done after the above geophysical tasks are complete, and the extent and topography of ledges will be more defined. Placement of probes and borings carried out after reprocessing of the geophysics would be based on an up-to-date map of the acoustic basement contours.

Laboratory tests that should be performed on samples from these explorations include grain size for the overburden soils, and unconfined compressive strength (qu), point load, acoustic velocity, and resistivity for rock cores. Qu, point load tests and seismic velocity can be used to assess rippability, and evaluate the need for blasting. Resistivity and acoustic velocity values can be used to refine results from geophysics.

STEP 4: FINAL GEOPHYSICS REPROCESSING

A final stage of data re-processing (ground-truthing) is recommended to integrate the new exploration data with the prior geophysical datasets, to generate a final, improved contouring of the acoustic basement surface that can be used in calculating estimated rock removal quantities required for the selected alternative, and to determine the likely best methods of rock removal for various areas for cost-estimating, work sequencing and specifications purposes.

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TABLE I-1
BOSTON HARBOR FEASIBILITY STUDY
Geotechnical Probes and Borings in Boston Harbor and the Mississippi River

Taken from GEI Consultants, Inc. 2003 Geophysics Report

Area	Exploration ID	As-Drilled Location Northing (feet)[1]	As-Drilled Location Easting (feet)[1]	Date	Start Time	End Time	Tide Gage Reading Time	Initial Water Level Elevation[2]	Barge Reference[3] Elevation[2]	Final Water Level Elevation[2]	Barge Reference[3] Elevation[2]	Mud Line Depth[4] (feet)	Mud Line Elevation[2]	Bottom of Probe Depth[4] (feet)	Bottom of Probe Elevation[2]	Probe Penetration (feet)	Blows Per Foot[5] [6]	Comments[7]
Finn's Ledge	FP03-101	499,229.10	756,928.00	09/10/03	0922	0950	NA	5.6	13.1	6.7	14.2	57.7	-44.6	67.0	-52.8	8.2	WOR/1.4'-13/1.9'-10-27-17-14-110-20/<1"	*Cobbles/Boulders at bottom;* Drill rods bouncing, REFUSAL
Finn's Ledge	FP03-102	499,050.04	757,147.66	09/10/03	1024	1036	NA	7.9	15.4	8.2	15.7	59.0	-43.6	62.0	-46.3	2.7	10/1.5'-12-55/0.5'-20/<1"	*Cobbles/Boulders at bottom;* Irregular bottom; Drill rods bouncing, REFUSAL
Finn's Ledge	FP03-103	498,767.97	757,510.33	09/10/03	1110	1136	NA	8.9	16.4	9.2	16.7	58.3	-41.9	69.3	-52.6	10.7	WOR/2.3'-9/0.4'-19-27-33-40-24-24-32-40-13/0.3'-20/<1"	*Cobbles/Boulders at bottom;* Drill rods bouncing, REFUSAL
Finn's Ledge	FP03-104	498,079.19	756,850.49	09/10/03	1218	1252	NA	9.3	16.8	8.9	16.4	50.1	-33.3	75.2	-58.8	25.5	WOR/0.9'-14-17-23-26-20-25-37-31-14-24-23-22-21-28-42-23-40-36-30-24-22-28-26-35/1.2'	*Hard bottom*
Finn's Ledge	FP03-105	497,849.04	756,607.51	09/10/03	1315	1340	NA	8.4	15.9	7.7	15.2	51.7	-35.9	73.5	-58.3	22.5	WOR/0.1'-15/2.2'-72-35-40-38-26-23-22-19-19-18-20-16-26-37-25-36-46-42-36-29/0.5'	*Hard bottom*
Finn's Ledge	FP03-106	497,988.76	756,499.63	09/10/03	1417	1433	NA	6.5	14.0	6.0	13.5	56.5	-42.5	71.9	-58.4	16.0	11/1.5'-23-15-19-13-18-10-17-16-21-23-19-21-19-25/0.9'	*Hard bottom*
Finn's Ledge	FP03-107	498,479.46	755,676.56	09/11/03	0940	1011	NA	5.0	12.5	6.3	13.8	53.2	-40.7	72.0	-58.2	17.6	WOH/1.4'-5-7-10-8-10-11-14-20-19-18-16-15-16-17-20-20-23-14	*Clayey sand and gravel* hard bottom;* Irregular bottom
Finn's Ledge	FP03-108	498,337.51	755,996.46	09/11/03	0842	0900	NA	2.8	10.3	3.5	11.0	54.6	-44.3	68.5	-57.5	13.3	WOR/0.4'-10-7-14-19-13-18-17-12-15-10-12-17-10-10/0.5'	*Clayey sand and gravel hard bottom*
Finn's Ledge	FP03-109	498,776.73	756,098.27	09/10/03	1641	1658	NA	1.1	8.6	0.6	8.1	52.5	-43.9	65.8	-57.7	13.8	17/0.5'-20-20-31-14-16-10-11-10-15-10-19-19-18-15/0.8'	*Clayey sand and gravel hard bottom; Cobbles/Boulders;* Irregular bottom
Finn's Ledge	FP03-110	498,502.57	756,432.43	09/10/03	1529	1548	NA	3.7	11.2	3.0	10.5	55.6	-44.4	69.3	-58.9	14.5	WOR/2'-8/2.4'-17-15-25-23-37-60-42-47-66/1.3'	*Hard bottom*
Faun Ledges	FP03-201	494,081.26	753,320.99	09/11/03	1400	1413	NA	8.7	16.2	8.3	15.8	55.6	-39.4	60.8	-45.0	5.6	2/0.4'-34-39-50-50-30/0.8'-20/<1"	*Clayey sand and gravel hard bottom;* Drill rods bouncing, REFUSAL
Faun Ledges	FP03-202	494,272.11	753,830.93	09/11/03	1256	1317	NA	9.8	17.3	9.6	17.1	60.1	-42.8	70.1	-53.0	10.2	WOR/0.9'-2-12/2'-7-12-42-19-28-52-51-37/0.1'-20/<1"	*Clayey sand and gravel hard bottom* ; Drill rods bouncing, REFUSAL
Faun Ledges	FP03-203	495,230.79	755,045.93	09/11/03	1125	1146	NA	8.8	16.3	9.3	16.8	59.1	-42.8	74.8	-58.0	15.2	WOR/1.5'-7/1.4'-5-7-9-9-14-10-7-7-16-20-25-22-14/0.8'	*Clayey sand and gravel hard bottom*
Faun Ledges	FP03-204	493,729.45	754,049.18	09/15/03	0823	0833	NA	1.1	8.6	1.0	8.5	51.5	-43.0	52.0	-43.5	0.5	23/0.5'-20/<1"	*Clayey bottom; Sandy gravel;* Drill rods bouncing, REFUSAL
Faun Ledges	FP03-205	493,127.38	753,916.84	09/15/03	0856	0902	NA	1.0	8.5	1.0	8.5	50.8	-42.3	54.8	-46.3	4.0	WOR/1.2'/WOH/0.3'-9/0.7'-29-20/0.8'-20/<1"	*Clayey bottom; Sandy gravel;* Drill rods bouncing, REFUSAL
Faun Ledges	FP03-206	491,970.97	753,127.54	09/15/03	0933	0948	NA	1.3	8.8	1.5	9.0	50.5	-41.5	58.8	-49.8	8.3	WOR/0.5'-WOH/0.1'-13/0.9'-26-17-55-36-105-85-113/0.8'-20/<1"	*Sandy gravel* Drill rods bouncing, REFUSAL
Faun Ledges	FP03-207	492,510.25	752,603.34	09/15/03	1014	1023	NA	2.1	9.6	2.3	9.8	50.0	-40.2	53.1	-43.3	3.1	WOR/0.5'-28/1.5'-35-10/0.1'-20/<1"	*Clayey bottom; Sandy gravel* Drill rods bouncing, REFUSAL
Faun Ledges	FP03-208	493,223.40	752,942.55	09/15/03	1058	1108	NA	3.2	10.7	3.5	11.0	55.5	-44.5	59.2	-48.2	3.7	25/0.5'-60-45-50-5/0.2'-20/<1"	*Hard bottom;* Drill rods bouncing, REFUSAL
President Roads & Anchorage Area	FP03-301	488,259.57	740,562.75	09/15/03	1302	1316	NA	7.4	14.9	7.9	15.4	53.7	-38.8	73.0	-57.6	18.8	WOR/4.3'-WOH-6-12-15-17-17-18-19-21-19-21-23-21-18-20	*Clay; Organic Sediment*
President Roads & Anchorage Area	FP03-302	488,207.98	740,690.37	09/15/03	1236	1243	NA	6.6	14.1	6.8	14.3	53.6	-39.5	57.5	-43.2	3.7	WOR-3.5'-WOH/0.2'-15/0.2'-20/<1"	*Clay; Organic Sediment;* Drill rods bouncing, REFUSAL
President Roads & Anchorage Area	FP03-303	488,052.38	740,589.71	09/15/03	1200	1210	NA	5.4	12.9	5.7	13.2	52.6	-39.7	70.9	-57.7	18.0	WOR/3.7'-WOH/1.5'-6/1.2'-5-7-8-14-10-13-12-16-19-20-19-21-18/0.9'	*Clay; Organic Sediment*
President Roads & Anchorage Area	FP03-304	487,745.10	741,086.65	09/12/03	1326	1337	NA	9.9	17.4	9.8	17.3	59.8	-42.4	74.5	-57.2	14.8	WOR/4.8'-18/1.4'-25-20-24-20-23-25-21-19-15/0.5'	*Clay**
President Roads & Anchorage Area	FP03-305	487,813.55	741,518.58	09/12/03	1238	1255	NA	9.7	17.2	9.8	17.3	59.9	-42.7	75.4	-58.1	15.4	WOR/1.9'-WOH/1.9'-7/1.3'-11-13-18-14-18-18-22-22-23-33/1.4'	*Clay*
President Roads & Anchorage Area	FP03-306	487,970.39	741,642.51	09/11/03	1512	1522	NA	6.8	14.3	6.5	14.0	55.6	-41.3	71.1	-57.1	15.9	WOR/2.5'-WOH/1.9'-10-10-10-10-9-10-16-15-16-17-19/1.1'	*Organic Sediment*
President Roads & Anchorage Area	FP03-307	488,923.86	745,543.16	09/12/03	1034	1045	NA	5.8	13.3	6.2	13.7	54.1	-40.8	71.5	-57.8	17.0	WOR/1.4'-WOH/2.2'-7/1.3'-5-6-12-10-9-9-8-16-14-16-19-23-8/0.5	*Clay; Organic Sediment*
President Roads & Anchorage Area	FP03-308	489,059.55	746,130.41	09/12/03	0958	1010	NA	4.4	11.9	4.9	12.4	52.5	-40.6	70.2	-57.8	17.2	WOR/1.3'-WOH/5.7'-6/2.5'-14-15-13-13-8-13-10-14-14/1.2'	*Clay; Organic Sediment*

TABLE I-1
BOSTON HARBOR FEASIBILITY STUDY
Geotechnical Probes and Borings in Boston Harbor and the Mystic River

Taken from GEI Consultants, Inc. 2003 Geophysics Report

	Exploration ID	As-Drilled Location Northing (feet)[1]	As-Drilled Location Easting (feet)[1]	Date	Start Time	End Time	Tide Gage Reading Time	Initial Water Level Elevation[2]	Barge Reference[3] Elevation[2]	Final Water Level Elevation[2]	Barge Reference[3] Elevation[2]	Mud Line Depth[4] (feet)	Mud Line Elevation[2]	Bottom of Probe Depth[4] (feet)	Bottom of Probe Elevation[2]	Probe Penetration (feet)	Blows Per Foot[5] [6]	Comments[7]
Main Ship Channel	FP03-401	493,121.12	727,593.63	09/17/03	0733	0738	NA	5.1	12.6	5.0	12.5	48.3	-35.7	51.8	-39.4	3.6	WOR/3.1'-2/0.4'-20/<1"	*Organic sediment;* Drill rods bouncing, REFUSAL
Main Ship Channel	FP03-402	492,018.65	727,403.32	09/17/03	0821	0829	NA	3.8	11.3	3.6	11.1	40.1	-28.8	47.2	-36.1	7.3	WOR/6.5'-22/0.4'-5/0.2'-20/<1"	*Organic sediment;* Drill rods bouncing, REFUSAL
Main Ship Channel	FP03-403	492,031.17	728,113.07	09/17/03	0900	0905	NA	2.8	10.3	2.7	10.2	52.4	-42.1	55.8	-45.6	3.5	WOR/1.5'-WOH/0.1'-29-11/0.8'-20/<1"	*Organic sediment;* Drill rods bouncing, REFUSAL
Main Ship Channel	FP03-404	491,829.64	728,832.79	09/17/03	0945	0953	NA	2.2	9.7	2.1	9.6	52.5	-42.8	59.6	-50.0	7.2	WOR/0.8'-3/0.7'-2-4-10-24-15-20/0.6'-20/<1"	*Cobbles/Boulders at bottom;* Drill rods bouncing, REFUSAL
Main Ship Channel	FP03-405	491,702.32	729,568.18	09/17/03	1028	1033	NA	2.2	9.7	2.2	9.7	44.8	-35.2	49.7	-40.0	4.9	WOR/4.6'-6/0.3'-20/<1"	*Organic sediment;* Spud penetrated harbor bottom ~5' after barge was stationed; Irregular bottom; Drill rods bouncing, REFUSAL
Main Ship Channel	FP03-406	491,076.27	730,002.21	09/12/03	0822	0831	NA	1.1	8.6	1.3	8.8	50.8	-42.2	54.6	-45.8	3.6	WOR/1.2'-10-22-30/0.6'-20/<1"	*Clay; Organic Sediment;* Drill rods bouncing, REFUSAL
Main Ship Channel	FP03-407	490,597.57	729,885.80	09/08/03	0813	0831	NA	7.0	14.5	7.7	15.2	54.3	-39.8	71.8	-56.6	16.8	WOR/3.7'-WOH-5-4-6-8-8-10-11-11-16-10-8-9-5/0.8'	*Organic Sediment to Clay*
Main Ship Channel	FP03-408	490,876.85	729,292.73	09/08/03	1244	1300	NA	6.9	14.4	6.4	13.9	50.5	-36.1	65.5	-51.6	15.5	WOR/8.2'-8/1.3'-45-60-44-35-66-26/0.5'-20/<1"	*Organic Sediment;* Drill rods bouncing, REFUSAL
Main Ship Channel	FP03-409	490,709.02	729,547.64	09/08/03	1153	1214	NA	8.5	16.0	7.9	15.4	51.8	-35.8	73.0	-57.6	21.8	WOR/6'-WOH-10/1.2'-8-8-6-8-8-8-13-17-25-29-17-25-80-20/<1"	*Organic Sediment;* Drill rods bouncing, REFUSAL
Main Ship Channel	FP03-410	490,497.43	729,725.20	09/08/03	0903	0920	NA	8.8	16.3	9.2	16.7	53.6	-37.3	73.1	-56.4	19.1	WOR/6.3'-WOH/1.1'-9/2'-7-10-10-8-15-14-17-12-15-26/1.1'	*Organic Sediment*
Main Ship Channel	FP03-411	490,535.93	729,285.07	09/08/03	1053	1108	NA	9.6	17.1	9.4	16.9	50.1	-33.0	74.1	-57.2	24.2	WOR/13'-WOH/1.9'-5-6-9-11-11-15-15-18-19/1.1'	*Organic Sediment*
Main Ship Channel	FP03-412	490,182.09	729,330.50	09/08/03	0950	1012	NA	9.7	17.2	9.8	17.3	44.2	-27.0	68.7	-51.4	24.4	WOR/10.1'-WOH/0.5'-9/1.2'-10-9-16-9-10-27-30-29-33-39-36-40-17/0.7'-20/<1"	*Organic Sediment;* Drill rods bouncing, REFUSAL
Main Ship Channel	FP03-413	490,196.06	729,623.52	09/08/03	1342	1405	NA	5.0	12.5	4.1	11.6	41.5	-29.0	66.5	-54.9	25.9	WOR/6.5'-5-7-6-8-6-9-8-13-12-12-16-30-50-32-43-19-35-50-90/0.5'-20/<1"	*Organic Sediment;* Drill rods bouncing, REFUSAL
Main Ship Channel	FP03-414	490,052.47	730,183.38	09/18/03	1008	1017	NA	2.8	10.3	2.7	10.2	53.1	-42.8	57.6	-47.4	4.5	WOR/0.3'-WOH/0.8'-3/0.8'-16-26-16/0.6'-20/<1"	*Cobbles/Boulders at bottom;* Drill rods bouncing, REFUSAL
Main Ship Channel	FP03-415	490,523.34	730,475.08	09/15/03	1400	1408	NA	9.1	16.6	9.3	16.8	59.8	-43.2	64.7	-47.9	4.8	WOR/1.2'-WOH/0.8'-7/0.2'-40-62-40/0.7'-20/<1"	*Clayey Gravel*;* Drill rods bouncing, REFUSAL
Main Ship Channel	FP03-416	490,584.25	730,809.94	09/09/03	0817	0845	NA	5.3	12.8	6.5	14.0	55.5	-42.7	68.5	-54.6	11.8	WOR/0.2'-12/1.2'-12-14-15-29-31-54-20-20-71-135-110-50/0.5'-20/<1"	*Cobbles/Boulders at bottom;* Drill rods bouncing, REFUSAL
Main Ship Channel	FP03-417	490,442.57	731,042.30	09/04/03	1355	1425	NA	3.3	10.8	4.2	11.7	54.0	-43.2	67.5	-55.8	12.7	WOR/0.2'-WOH/0.3'-7/0.5'-26-35-24-29-27-41-45-29-54-71-60-82-33/0.5'	*Clay bottom; Organic Sediment;* Terminated to protect drill rods
Main Ship Channel	FP03-418	490,476.29	731,182.93	09/04/03	1255	1320	NA	1.8	9.3	2.5	10.0	54.1	-44.8	62.4	-52.5	7.7	WOR/0.8'-WOH-11/1.1'-15-12-33/2'-29-23/0.3'-20/<1"	*Clay bottom; Organic Sediment;* Drill rods bouncing, REFUSAL
Main Ship Channel	FP03-419	490,550.18	731,558.25	09/04/03	1200	1225	NA	1.2	8.7	1.3	8.8	52.0	-43.3	59.4	-50.6	7.3	WOR-WOH/1.2'-6/0.8'-23-13-21-44-5/0.4'-20/<1"	*Clay bottom; Organic Sediment;* Drill rods bouncing, REFUSAL
Main Ship Channel	FP03-420	489,313.78	732,443.56	09/18/03	0912	0920	NA	3.8	11.3	3.6	11.1	49.0	-37.7	51.7	-40.6	2.9	WOR/0.4'-WOH/1.1'-24/0.5'-40/0.7'-20/<1"	*Cobbles/Boulders at bottom;* Drill rods bouncing, REFUSAL

TABLE I-1
BOSTON HARBOR FEASIBILITY STUDY
Geotechnical Probes and Borings in Boston Harbor and the Mystic River

Taken from GEI Consultants, Inc. 2003 Geophysics Report

	Exploration ID	As-Drilled Location		Date	Start Time	End Time	Tide Gage Reading Time	Initial Water Level Elevation[2]	Barge Reference[3] Elevation[2]	Final Water Level Elevation[2]	Barge Reference[3] Elevation[2]	Mud Line		Bottom of Probe		Probe Penetration (feet)	Blows Per Foot[5] [6]	Comments[7]
		Northing (feet)[1]	Easting (feet)[1]									Depth[4] (feet)	Elevation[2]	Depth[4] (feet)	Elevation[2]			
Main Ship Channel (Cont.)	FP03-421	489,269.74	732,630.76	09/17/03	1314	1320	NA	5.4	12.9	5.6	13.1	51.3	-38.4	52.7	-39.7	1.2	WOR/0.9'-4/0.5'-20/<1"	*Cobbles/Boulders at bottom;* Drill rods bouncing, REFUSAL
	FP03-422	488,829.90	732,768.95	09/17/03	1248	1252	NA	4.6	12.1	4.7	12.2	50.9	-38.8	54.4	-42.2	3.4	WOR/3.1'-2/0.4'-20/<1"	*Cobbles/Boulders at bottom;* Irregular bottom; Drill rods bouncing, REFUSAL
	FP03-423	488,157.06	734,087.22	08/29/03	0835	0910	NA	1.6	9.1	2.8	10.3	48.9	-39.8	51.1	-40.8	1.0	WOR-3/1.1'-25/<1"	*Clay initially* ; Drill rods bouncing, REFUSAL
	FP03-424	487,787.76	734,418.04	09/02/03	0835	0840	NA	2.0	9.5	1.8	9.3	48.2	-38.8	50.5	-41.2	2.5	3/0.6'-4-13-25/<1"	*Hard bottom; Clayey Gravel* ; Drill rods bouncing, REFUSAL
	FP03-425	487,449.75	734,798.30	09/02/03	0910	0915	NA	0.9	8.4	0.8	8.3	45.2	-36.8	45.9	-37.6	0.8	3/0.6'-20/<1"	*Hard bottom; Clayey Gravel* ; Drill rods bouncing, REFUSAL
	FP03-426	488,157.02	732,848.71	09/03/03	1405	1415	NA	5.3	12.8	5.6	13.1	54.8	-42.0	59.1	-46.0	4.0	WOR/3.2'-85-20/<1"	*Clay bottom;* Drill rods bouncing, REFUSAL
	FP03-427	487,676.71	733,655.25	09/03/03	1330	1340	NA	4.1	11.6	4.5	12.0	52.0	-40.4	61.6	-49.6	9.2	WOR/3.5'-WOH/0.2'-3/0.8'-8-35-23-24-26-20<1"	*Clay bottom;* Drill rods bouncing, REFUSAL
	FP03-428	487,551.83	733,985.67	09/03/03	1130	1150	NA	0.9	8.4	1.1	8.6	50.4	-42.0	63.4	-54.8	12.7	WOR/2'-7-4-4-7-17-23-38-29-44-36-23-20/<1"	*Clay bottom;* Drill rods bouncing, REFUSAL
	FP03-429	487,457.86	733,815.41	09/03/03	1230	1250	NA	2.2	9.7	2.8	10.3	51.7	-42.0	64.3	-54.1	12.0	WOR/2.1'-WOH/1.7'-2/0.5'-2-4-5-7-6-8-9-10-20/0.3'	*Clay bottom;* Hard driving at end
	FP03-430	487,402.36	734,067.00	09/03/03	1045	1100	NA	0.8	8.3	0.8	8.3	49.6	-41.3	64.3	-56.0	14.8	WOR/3.9'-WOH/1.7'-3/0.8'-2-7-8-10-8-12-14-10-9/0.3'	*Clay bottom*
	FP03-431	487,422.28	734,227.83	09/03/03	1015	1030	NA	1.3	8.8	1.0	8.5	51.2	-42.5	52.0	-43.5	1.1	WOR/0.3'-5/0.4'-20/<1"	*Cobbles/Boulders at bottom;* Drill rods bouncing, REFUSAL
	FP03-432	487,399.46	734,427.06	09/03/03	0905	0935	NA	3.4	10.9	2.3	9.8	53.4	-42.6	53.5	-43.7	1.2	20/<1"	*Hard bottom;* Drill rods bouncing, REFUSAL
	FP03-433	487,238.07	733,916.27	09/04/03	1100	1110	NA	2.3	9.8	2.1	9.6	52.4	-42.6	66.8	-57.2	14.6	WOR/3.5'-WOH/0.8'-4/1.3'-4-9-7-10-13-14-16-17-8/0.8'	*Clay; Organic Sediment*
	FP03-434	486,944.45	734,613.43	09/03/03	0820	0840	NA	5.0	12.5	4.3	11.8	52.1	-39.6	57.0	-45.2	5.6	WOR/4.5'-18/0.3'-20/<1"	*Organic Sediment;* Drill rods bouncing, REFUSAL
	FP03-435	486,942.59	735,088.89	09/02/03	0950	1000	NA	0.3	7.8	0.2	7.7	50.3	-42.5	56.8	-49.1	6.6	WOR/0.7'-WOR-WOR-WOH/1.5'-1/0.5'-2-4/0.7'-20/<1"	*Clay bottom; Clayey Gravel*
	FP03-436	486,387.83	734,826.82	09/04/03	1000	1020	NA	4.0	11.5	3.3	10.8	54.9	-43.4	67.0	-56.3	12.8	WOR/3.8'-WOH/1.3'-6-4-4-13-8-12-12	*Clay; Organic Sediment*
	FP03-437	486,662.38	735,228.93	09/02/03	1215	1225	NA	3.0	10.5	3.3	10.8	51.2	-40.7	54.7	-43.9	3.2	WOR/0.5'-WOR-WOR-WOR-8/0.9'-20/<1"	*Clay; Organic Sediment* ; Drill rods bouncing, REFUSAL
	FP03-438	486,758.81	735,472.16	09/02/03	1040	1050	NA	0.4	7.9	0.5	8.0	52.1	-44.2	56.5	-48.5	4.3	WOR/0.6'-WOR-WOH/0.7'-11-8-20/<1"	*Clay bottom; Clayey Gravel* ; Drill rods bouncing, REFUSAL
	FP03-439	486,504.84	736,518.10	09/04/03	0855	0920	NA	6.3	13.8	5.5	13.0	54.5	-40.7	69.8	-56.8	16.1	WOR/1.2'-WOH/0.3'-17-16-27-23-40-48-86/3'-49-67-72-67-67/0.8'	*Clay; Organic Sediment*
	FP03-440	487,154.55	734,342.42	09/17/03	1158	1208	NA	3.4	10.9	3.6	11.1	50.8	-39.9	68.9	-57.8	17.9	WOR/4.9'-WOH-6/1.3'-5-6-6-11-9-11-10-11-15-14-12/0.9'	*Organic sediment*

TABLE I-1
BOSTON HARBOR FEASIBILITY STUDY
Geotechnical Probes and Borings in Boston Harbor and the Mystic River

Taken from GEI Consultants, Inc. 2003 Geophysics Report

	Exploration ID	As-Drilled Location Northing (feet)[1]	As-Drilled Location Easting (feet)[1]	Date	Start Time	End Time	Tide Gage Reading Time	Initial Water Level Elevation[2]	Barge Reference[3] Elevation[2]	Final Water Level Elevation[2]	Barge Reference[3] Elevation[2]	Mud Line Depth[4] (feet)	Mud Line Elevation[2]	Bottom of Probe Depth[4] (feet)	Bottom of Probe Elevation[2]	Probe Penetration (feet)	Blows Per Foot[5] [6]	Comments[7]
Reserved Channel	FP03-501	489,739.31	727,158.30	09/25/03	0951	1007	NA	9.3	16.8	9.8	17.3	59.8	-43.0	74.4	-57.2	14.2	WOR/0.2'-6-8-16-10-11-13-29-22-21-27-54-69-71 77-26/0.4'	*Organic sediment with gravel**
	FP03-502	489,650.35	727,316.64	09/22/03	1247	1301	NA	4.2	11.7	3.8	11.3	55.7	-44.0	67.3	-56.0	12.0	WOR/0.9'-WOH/0.2'-1/0.2'-5-15-9-6-12-12-13-16-20-64-29/0.3'-20/<1"	*Organic sediment;* Drill rods bouncing, REFUSAL
	FP03-503	489,743.61	727,517.67	09/25/03	0904	0925	NA	7.5	15.0	8.4	15.9	59.0	-44.0	72.3	-56.4	12.4	WOR/1.6'-WOH/0.9'-4/0.5'-15-14-17-48-100-84-117-58-66-125-68/0.3'-20/<1"	*Organic sediment with gravel;* Drill rods bouncing, REFUSAL
	FP03-504	489,682.28	728,003.95	09/22/03	1157	1205	NA	5.7	13.2	5.5	13.0	57.0	-43.8	61.0	-48.1	4.3	WOR/1.7'-7/0.3'-52-80-23/<1"	*Organic sediment;* Drill rods bouncing, REFUSAL
	FP03-505	489,830.70	728,233.31	09/25/03	0817	0837	NA	5.5	13.0	6.5	14.0	49.4	-36.4	57.1	-43.1	6.7	WOR/0.6'-10-35-39-36-28-37-80/1.1'-20/<1"	*Cobbles;* Drill rods bouncing, REFUSAL
	FP03-506	489,681.84	728,242.05	09/22/03	1042	1054	NA	7.6	15.1	7.3	14.8	56.9	-41.8	63.6	-48.8	7.0	WOR/0.7'-WOH/0.4'-12-30-35-62-41-40/0.6'-20/<1"	*Organic sediment;* Drill rods bouncing, REFUSAL
	FP03-507	489,718.13	728,709.60	09/22/03	0945	1007	NA	8.6	16.1	8.2	15.7	58.7	-42.6	73.6	-57.9	15.2	WOR/1.2'-WOH/0.1'-5/2'-25-24-25-41-47-20-45-82-57-42-56-18/0.6'-20/>1"	*Organic sediment;* Drill rods bouncing, REFUSAL
	FP03-508	489,857.09	729,009.94	09/22/03	0853	0907	NA	8.9	16.4	8.9	16.4	55.8	-39.4	60.6	-44.2	4.8	WOR/1.8'-WOH/0.4'-7-14-7/0.6'-28<1"	*Organic sediment;* Drill rods bouncing, REFUSAL
Mystic River	FP03-601	505,457.47	718,223.84	09/16/03	0954	1002	0942	1.7	9.2	NA	NA	45.1	-35.9	57.2	-48.0	12.1	WOR/4.6'-WOH/0.9'-8/1.4'-4-5-5-7-6/1.2'	*Organic Sediment**
	FP03-602	505,428.35	718,454.13	09/16/03	1024	1029	1018	2.0	9.5	NA	NA	46.4	-36.9	57.5	-48.0	11.1	WOR/4.4'-WOH-5/1.2'-5-6-6-7-3/0.5'	*Organic Sediment**
	FP03-603	505,296.89	718,353.02	09/16/03	1128	1133	1125	3.5	11.0	NA	NA	46.0	-35.0	59.0	-48.0	13.0	WOR/5'-WOH-3-4-4-5-6-9-9	*Organic Sediment**
	FP03-604	505,305.36	718,492.71	09/16/03	1105	1111	1100	2.9	10.4	NA	NA	46.1	-35.7	58.4	-48.0	12.3	WOR/3.9'-WOH-5-5-7-8-7-8-4/0.4'	*Organic Sediment**
	FP03-605	505,277.49	718,795.52	09/16/03	1355	1359	1350	7.9	15.4	NA	NA	51.0	-35.6	63.4	-48.0	12.4	WOR/6.7'-WOH/1.3'-3-4-4-5-3/0.4'	*Organic Sediment**
	FP03-606	505,152.98	718,566.41	09/16/03	1339	1343	1334	7.3	14.8	NA	NA	50.4	-35.6	62.8	-48.0	12.4	WOR/5.5'-WOH/1.7'-4/1.4'-2-4-4-5/0.8'	*Organic Sediment**
	FP03-607	505,140.04	718,841.93	09/16/03	1412	1417	1411	8.3	15.8	NA	NA	50.3	-34.5	63.8	-48.0	13.5	WOR/7.3'-WOH/1.4'-2-3-6-5-4/0.8'	*Organic Sediment**
	FP03-608	505,163.16	718,211.92	09/16/03	1316	1323	1310	6.5	14.0	NA	NA	48.8	-34.8	62.1	-48.1	13.3	WOR/6'-WOH/0.7'-5/1.5'-4-6-6-7-10/1.1'	*Organic Sediment**

Notes:
(1) Coordinates are given in U.S. State Plane, Massachusetts Mainland 2001, NAD 1927, U.S. Survey foot.
(2) Elevations are in feet referenced to Mean Lower Low Water (MLLW).
Boston Light Station was referenced for Series 100 and 200 explorations & VC03-101 through 104.
Boston Harbor U.S. Coast Guard Station was referenced for Series 300, 400, and 500 explorations & VC03-105 through 109.
Shrafft's Center tide gage was referenced for Series 600 explorations.
(3) Freeboard is about 7.5 feet (Distance from water to Barge Reference Point).
(4) Probe and Boring depths are measured from the Barge Reference Point.
(5) Example: 10-18-20/<1" corresponds to 10 blows for the first foot of penetration, 18 blows for the second foot of penetration, and 20 blows for the next 1 inch or less of penetration.
(6) WOR = weight of rods for 1 foot of penetration or other depth as noted by "/"; WOH = weight of hammer with rods for 1 foot of penetration or other depth as noted by "/".
(7) Driller's observations are italicized.
"NA" - Not Applicable.
"*" - Indicates a soil description made from soils directly observed in the open-end of drill rod.
GPS coordinates were post-processed and differentially corrected using the Acushnet, Massachusetts CORS.

Legend:
100 Series - Finn's Ledge
200 Series - Faun Ledges
300 Series - President Roads
400 Series - Main Ship Channel
500 Series - Reserved Channel
600 Series - Mystic River

TABLE I-2
BOSTON HARBOR FASIBILITY STUDY
Geotechnical Probes and Borings in the Chelsea River

Taken from GEI Consultants, Inc. 2003 Geophysics Report

	Exploration ID	As-Drilled Location Northing (feet)[1]	Easting (feet)[1]	Date	Start Time	End Time	Tide Gage Reading Time	Initial Water Level Elevation[2]	Barge Reference[3] Elevation[2]	Mud Line Depth[4] (feet)	Mud Line Elevation[2]	Bottom of Probe/Boring Depth[4] (feet)	Bottom of Probe/Boring Elevation[2]	Probe/Boring Penetration (feet)	Blows Per Foot[5] [6]	Comments[7]
Borings	FD03-701	508,552.13	730,601.03	09/24/03	1150	1312	1150	8.8	16.3	59.8	-43.5	65.0	-48.7	5.2		*Hard bottom* ; Borehole; Sample REFUSAL at ; Gravelly Clay, Till
	FD03-701A	508,562.69	730,597.26	09/25/03	1203	1432	1206	10.3	17.8	61.6	-43.8	74.7	-56.9	13.1		*Hard bottom* ; Borehole; Roller-bit REFUSAL at El -51.9 MLLW; 5-foot rock core run of Pink Granite
Probes	FP03-702	507,762.44	730,485.19	09/26/03	0910	0916	0903	5.9	13.4	54.0	-40.6	61.5	-48.1	7.5	WOR-WOH/0.7'-3/1.3'-4-5-6-6-4/0.5'	*Organic sediment;* *Gravelly Clay* in drill rod tip, Till*
	FP03-703	508,283.39	730,302.80	09/26/03	0833	0842	0825	4.3	11.8	52.2	-40.4	59.5	-47.7	7.3	WOR/0.9'-WOH/0.2'-25/0.7'-45-38-51-38-52-22/0.5'	*Organic sediment;* *Gravelly Clay* in drill rod tip, Till*
	FP03-704	508,258.63	730,542.45	09/26/03	0740	0809	0732	2.1	9.6	49.3	-39.7	58.0	-48.4	8.7	WOR/1.5'-WOH/0.2'-30-31-40-54-88-Tide/0.5'-82/0.5'-27	*Organic sediment;* *Gravelly Clay* in drill rod tip, Till*
	FP03-705	508,340.85	730,487.20	09/24/03	1005	1018	0957	9.8	17.3	56.4	-39.1	65.0	-47.7	8.6	WOR/0.6'-WOH/0.1'-52/0.9'-69-62-25-37-41-32-42	*Organic sediment**
	FP03-706	508,447.52	730,507.96	09/23/03	1356	1408	1345	4.0	11.5	51.8	-40.3	59.2	-47.7	7.4	WOR-2/0.2'-34-50-45-105-69-46-6/0.2'	*Hard bottom, Cobbles/Boulders;* *Clayey Gravel*, Till*
	FP03-707	508,507.01	730,503.99	09/23/03	1311	1328	1300	5.6	13.1	52.6	-39.5	59.6	-46.5	7.0	WOR/0.4'-17-21-33-64-98-174-45/0.6'-20/<1"	*Hard bottom, Cobbles/Boulders* Drill rods bouncing, REFUSAL
	FP03-708	508,694.87	730,565.02	09/24/03	0832	0843	0823	7.2	14.7	58.0	-43.3	63.0	-48.3	5.0	WOR/1.3'-14/0.7'-36-96-51	*Cobbles/Boulders at bottom;* Drill rods dropped 57.6' to 58.9' to 59.3' under WOR; Irregular bottom; Drill rods bouncing, REFUSAL
	FP03-709	508,749.14	730,617.77	09/24/03	0750	0806	0735	5.5	13.0	52.9	-39.9	60.7	-47.7	7.8	WOR/0.5'-WOH/0.1'-17/0.5'-43-30-35-32-46-45-67/0.7'	*Organic sediment*
	FP03-710	508,776.70	730,511.03	09/23/03	1227	1239	1217	6.9	14.4	54.6	-40.2	62.2	-47.8	7.6	WOR/0.2'-WOH/0.2'-24-33-21-13-24-30-47/1.2'	*Hard bottom, Cobbles/Boulders*
	FP03-711	508,773.83	730,885.37	09/23/03	1102	1115	1050	9.0	16.5	56.6	-40.1	64.2	-47.7	7.6	WOR/1.4'-WOH/0.3'-30/0.7'-39-36-41-47-62/1.2'	*Organic sediment*
	FP03-712	508,907.88	730,921.57	09/23/03	1017	1029	1008	9.6	17.1	56.9	-39.8	63.4	-46.3	6.5	WOR/1.1'-WOH/0.1'-60/0.9'-50-28-42-83-20/0.4'-20/<1"	*Organic sediment* Drill rods bouncing, REFUSAL
	FP03-713	509,490.28	730,898.16	09/23/03	0901	0907	0856	9.2	16.7	56.8	-40.1	65.0	-48.3	8.2	WOR/3.1'-WOH/0.1'-11-18-9-14-9	*Organic sediment*
	FP03-714	509,481.55	731,031.22	09/23/03	0832	0837	0824	8.6	16.1	56.3	-40.2	64.0	-47.9	7.7	WOR/2.2'-WOH/0.1'-2/0.4'-6-11-12-7-8	*Organic sediment*
	FP03-715	509,071.58	731,239.31	09/23/03	0941	0947	0932	9.6	17.1	57.6	-40.5	65.0	-47.9	7.4	WOR/1.4'-WOH/0.2'-6/0.8'-9-13-15-14-14	*Organic sediment*
	FP03-716	509,579.57	731,192.39	09/23/03	0757	0809	0748	7.6	15.1	55.8	-40.7	63.0	-47.9	7.2	WOR/1.2'-WOH/0.2'-57/0.8'-6-8-4-5-5	*Organic sediment* Obstruction from 57.2' to 58.0'

Notes:
(1) Coordinates are given in U.S. State Plane, Massachusetts Mainland 2001, NAD 1927, U.S. Survey foot.
(2) Elevations are in feet referenced to Mean Lower Low Water (MLLW).
Chelsea Street Bridge tide gage was referenced for Series 700 explorations.
(3) Freeboard is about 7.5 feet (Distance from water to Barge Reference Point).
(4) Probe and Boring depths are measured from the Barge Reference Point.
(5) Example: 10-18-20/<1" corresponds to 10 blows for the first foot of penetration, 18 blows for the second foot of penetration, and 20 blows for the next 1 inch or less of penetration.
(6) WOR = weight of rods for 1 foot of penetration or other depth as noted by "/"; WOH = weight of hammer with rods for 1 foot of penetration or other depth as noted by "/".
(7) Driller's observations are italicized.
"NA" - Not Applicable.
"*" - Indicates a soil description made from soils directly observed in the open-end of drill rod.
GPS coordinates were post-processed and differentially corrected using the Acushnet, Massachusetts CORS.
Tide gage readings for 700-series probes and borings are corrected based on the NOAA 10/07/2003 published change in the Chelsea Street Bridge Tidal Benchmark (2.7-foot difference).

Legend:
100 Series - Finn's Ledge
200 Series - Faun Ledges
300 Series - President Roads
400 Series - Main Ship Channel
500 Series - Reserved Channel
600 Series - Mystic River
700 Series - Chelsea River

Table I-3
BOSTON HARBOR FEASIBILITY STUDY
Probes vs. Geophysical Acoustic Basement

Sample ID	Easting	Northing	Estimated Harbor Bottom Elevation (FT MLLW)	Acoustic Basement Elevation (FT MLLW)	Estimated Depth to Basement	Probe Data: Hard Zone Elevation	Probe Data: Refusal Elevation	Comments
FP03-101	756928	499229	-42.1	-41.7	-0.4	-51.9	-52.8	Bouncing refusal
FP03-102	757148	499050	-41.0	-41.8	0.9	-46.1	-46.3	Bouncing refusal
FP03-103	757510	498768	-41.6	Organic Material	NA	-46.6	-52.6	Bouncing refusal
FP03-104	756850	498079	-32.4	-33.7	1.3	-40	<-58.8	Refusal not reached
FP03-105	756608	497849	-34.5	-36.5	2.0	-38	<-58.3	Refusal not reached
FP03-106	756500	497989	-39.5	Organic Material	NA	NA	<-58.4	Refusal not reached
FP03-107	755677	498479	-38.4	-38.4	0.0	NA	<-58.2	Refusal not reached
FP03-108	755996	498338	-41.7	-41.7	0.0	NA	<-57.5	Refusal not reached
FP03-109	756098	498777	-40.7	-40.4	-0.3	NA	<-57.7	Refusal not reached
FP03-110	756432	498503	-42.1	-42.0	-0.1	-52.8	<-58.9	Refusal not reached
FP03-201	753321	494081	-38.3	-38.7	0.4	-39.8	-45	Bouncing refusal
FP03-202	753831	494272	-41.5	Organic Material	NA	-48.7	-53	Bouncing refusal
FP03-203	755046	495231	-42.3	Organic Material	NA	NA	<-58.0	Refusal not reached
FP03-204	754049	493729	-40.6	-40.2	-0.4	NA	-43.5	Bouncing refusal
FP03-205	753917	493127	-40.8	-41.0	0.2	NA	-46.3	Bouncing refusal
FP03-206	753128	491971	-40.3	-40.7	0.5	-45	-49.8	Bouncing refusal
FP03-207	752603	492510	-39.5	-38.7	-0.7	-42.2	-43.3	Bouncing refusal
FP03-208	752943	493223	-41.1	-41.7	0.6	-45	-48.2	Bouncing refusal
FP03-301	740563	488260	-38.1	No Data	NA	<-57.6	<-57.6	Soft organics -38.3 to -44
FP03-302	740690	488208	-38.8	Organic Material	NA	-43.2	-43.2	Soft organics -39.5 to -43, bouncing refusal
FP03-303	740590	488052	-38.8	Organic Material	NA	<-57.7	<-57.7	Soft organics -39.7 to -45
FP03-304	741087	487745	-41.5	-40.7	-0.9	<-57.2	<-57.2	Soft organics -42.4 to -47
FP03-305	741519	487814	-42.2	-42.5	0.3	<-58.1	<-58.1	Soft organics -42.7 to -46.5
FP03-306	741643	487970	-40.3	-41.6	1.3	<-57.1	<-57.1	Soft organics -41.3 to -45.7
FP03-307	745543	488924	-40.0	No Data	NA	<-57.8	<-57.8	Soft organics -40.8 to -44
FP03-308	746130	489060	-40.2	-43.7	3.4	<-57.8	<-57.8	Soft organics -40.6 to -47.6
FP03-401	727594	493121	-34.7	-37.7	2.9	NA	-39.4	Bouncing refusal
FP03-402	727403	492019	-28.5	-29.3	0.8	NA	-36.1	Bouncing refusal
FP03-403	728113	492031	-41.4	-41.4	-0.1	NA	-45.6	Bouncing refusal
FP03-404	728833	491830	-41.7	-56.9	15.2	NA	-50	Bouncing refusal
FP03-405	729568	491702	-34.4	-43.0	8.5	NA	-40	Bouncing refusal
FP03-406	730002	491076	-40.4	-42.6	2.1	NA	-45.8	Bouncing refusal
FP03-407	729886	490598	-38.4	-39.2	0.8	NA	<-56.6	Refusal not reached
FP03-408	729293	490877	-35.3	-37.2	1.9	-45.6	-51.6	Bouncing refusal
FP03-409	729548	490709	-35.3	Organic Material	NA	-56.5	-57.6	Bouncing refusal
FP03-410	729725	490497	-35.9	Organic Material	NA	NA	<-56.4	Refusal not reached
FP03-411	729285	490536	No Data	Organic Material	NA	NA	<-57.2	Refusal not reached
FP03-412	729331	490182	No Data	-35.9	NA	-45	-51.4	Bouncing refusal
FP03-413	729624	490196	-28.4	-28.8	0.4	-46.5	-54.9	Bouncing refusal
FP03-414	730183	490052	-41.1	-42.9	1.8	NA	-47.4	Bouncing refusal
FP03-415	730475	490523	-41.6	-41.7	0.1	-45.4	-47.9	Bouncing refusal
FP03-416	730810	490584	-40.7	-42.0	1.3	-47.1	-54.6	Bouncing refusal
FP03-417	731042	490443	-42.2	-42.3	0.2	-45	<-55.8	Refusal not reached
FP03-418	731183	490476	-41.5	-42.5	1.0	NA	-52.5	Bouncing refusal
FP03-419	731558	490550	-41.7	-44.2	2.5	-45.5	-50.6	Bouncing refusal
FP03-420	732444	489314	-37.5	-38.1	0.6	-40	-40.6	Bouncing refusal
FP03-421	732631	489270	-37.1	-37.0	0.0	NA	-39.7	Bouncing refusal
FP03-422	732769	488830	-42.9	-46.7	3.8	NA	-42.2	Bouncing refusal
FP03-423	734087	488157	-36.4	-40.2	3.8	NA	-40.8	Bouncing refusal
FP03-424	734418	487788	-36.8	-36.6	-0.1	NA	-41.2	Bouncing refusal
FP03-425	734798	487450	-36.0	-36.0	0.1	NA	-37.6	Bouncing refusal
FP03-426	732849	488157	-37.1	-38.7	1.6	-45	-46	Bouncing refusal
FP03-427	733655	487677	-40.0	-41.7	1.7	na	-49.6	Bouncing refusal
FP03-428	733986	487552	-40.9	-43.5	2.6	-50	-54.8	Bouncing refusal
FP03-429	733815	487458	-41.7	Organic Material	NA	-54.1	<-54.1	Refusal not reached
FP03-430	734067	487402	-41.0	Organic Material	NA	NA	<-56.0	Refusal not reached
FP03-431	734228	487422	-41.1	Organic Material	NA	NA	-43.5	Bouncing refusal
FP03-432	734427	487399	-40.6	-40.4	-0.3	NA	-43.7	Bouncing refusal
FP03-433	733916	487238	-42.2	-55.0	12.8	NA	<-57.2	Refusal not reached
FP03-434	734613	486944	-38.6	Organic Material	NA	NA	-45.2	Bouncing refusal
FP03-435	735089	486943	-41.0	-42.9	2.0	NA	-49.1	Refusal not reached
FP03-436	734827	486388	-39.8	Organic Material	NA	NA	<-56.3	Refusal not reached
FP03-437	735229	486662	-39.4	Organic Material	NA	NA	-43.9	Bouncing refusal

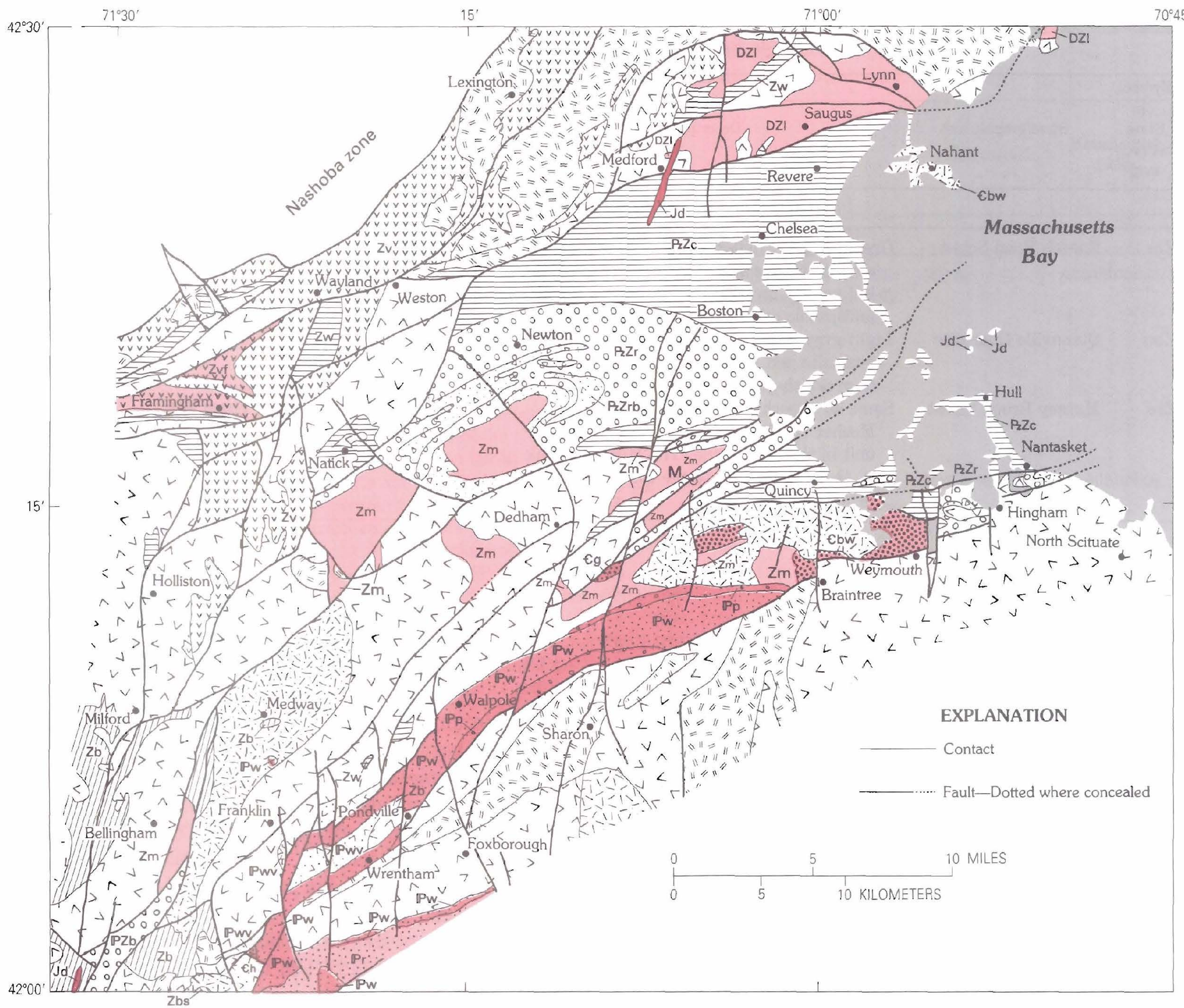
Table I-3
BOSTON HARBOR FEASIBILITY STUDY
Probes vs. Geophysical Acoustic Basement

Sample ID	Easting	Northing	Estimated Harbor Bottom Elevation (FT MLLW)	Acoustic Basement Elevation (FT MLLW)	Estimated Depth to Basement	Probe Data: Hard Zone Elevation	Probe Data: Refusal Elevation	Comments
FP03-438	735472	486759	-39.6	-41.0	1.4	NA	-48.5	Bouncing refusal
FP03-439	736518	486505	-38.8	-40.5	1.7	-46	<-56.8	Refusal not reached
FP03-440	734342	487155	-40.0	Organic Material	NA	NA	< -57.8	Refusal not reached
FP03-501	727158	489739	-40.8	-43.2	2.3	-53.2	<-53.2	Refusal not reached
FP03-502	727317	489650	-41.4	-44.6	3.2	-54	-56	Bouncing refusal
FP03-503	727518	489744	-41.5	-41.7	0.2	-50	-56.4	Bouncing refusal
FP03-504	728004	489682	-42.1	-42.3	0.2	-45.8	-48.1	Bouncing refusal
FP03-505	728233	489831	-36.2	-36.8	0.7	-38	-43.1	Bouncing refusal
FP03-506	728242	489682	-41.5	-42.4	1.0	-44	-48.8	Bouncing refusal
FP03-507	728710	489718	-41.8	-42.2	0.4	-48.9	-57.9	Bouncing refusal
FP03-508	729010	489857	-37.6	-38.6	0.9	NA	-44.2	Bouncing refusal
FP03-601	718224	505457	-34.4	Organic Material	NA	NA	<-48	Refusal not reached
FP03-602	718454	505428	-34.5	Organic Material	NA	NA	<-48	Refusal not reached
FP03-603	718353	505297	No Data	Organic Material	NA	NA	<-48	Refusal not reached
FP03-604	718493	505305	-34.6	Organic Material	NA	NA	<-47	Refusal not reached
FP03-605	718796	505277	-35.1	Organic Material	NA	NA	<-48	Refusal not reached
FP03-606	718566	505153	No Data	Organic Material	NA	NA	<-48	Refusal not reached
FP03-607	718842	505140	-34.1	Organic Material	NA	NA	<-48	Refusal not reached
FP03-608	718212	505163	No Data	Organic Material	NA	NA	<-48.1	Refusal not reached
FD03-701	730597	508563	-41.1	No Data	NA		-51.9	Refusal, 5ft rock core retrieved
FP03-702	730485	507762	-38.5	No Data	NA	NA	<-48.1	Refusal not reached
FP03-703	730303	508283	-37.5	No Data	NA	NA	<-47.7	Refusal not reached
FP03-704	730542	508259	-37.9	No Data	NA	NA	<-47.9	Refusal not reached
FP03-705	730487	508341	-37.8	No Data	NA	NA	<-47.7	Refusal not reached
FP03-706	730508	508448	-38.0	No Data	NA	NA	<-47.7	Refusal not reached
FP03-707	730504	508507	-38.7	No Data	NA	NA	-46.6	Bouncing refusal
FP03-708	730565	508695	-38.6	No Data	NA	NA	-48.3	Bouncing refusal
FP03-709	730618	508749	-38.7	No Data	NA	NA	<-47.7	Refusal not reached
FP03-710	730511	508777	-38.2	No Data	NA	NA	<-47.8	Refusal not reached
FP03-711	730885	508774	-39.2	No Data	NA	NA	<-47.7	Refusal not reached
FP03-712	730922	508908	-38.0	No Data	NA	NA	-46.4	Bouncing refusal
FP03-713	730898	509490	-38.7	No Data	NA	NA	<-48.3	Refusal not reached
FP03-714	731031	509482	-38.6	No Data	NA	NA	<-47.9	Refusal not reached
FP03-715	731239	509072	-38.6	No Data	NA	NA	<-47.9	Refusal not reached
FP03-716	731192	509580	-38.7	No Data	NA	NA	<-47.9	Refusal not reached
VC03-101	754894	497921	-40.0	Organic Material	NA	NA	NA	
VC03-102	754062	496058	-45.6	Organic Material	NA	NA	NA	
VC03-103	751829	491289	-41.5	No Data	NA	NA	NA	
VC03-104	751335	490266	-42.0	No Data	NA	NA	NA	
VC03-105	736917	486390	-39.7	No Data	NA	NA	NA	
VC03-106	733473	488496	-38.5	No Data	NA	NA	NA	
VC03-107	728693	492352	-35.5	No Data	NA	NA	NA	
VC03-108	718915	505081	-34.7	Organic Material	NA	NA	NA	
VC03-109	718102	505362	No Data	No Data	NA	NA	NA	

Note: Northing and Easting are in NAD 27
NA = Not Applicable
All elevations are relative to Mean Lower Low Water (MLLW)
"Hard" implies > 30 blows per foot

*Figure I-1.
STRATIGRAPHIC UNITS
IN AND AROUND THE BOSON BASIN

* Geologic map from Goldsmith (1991)

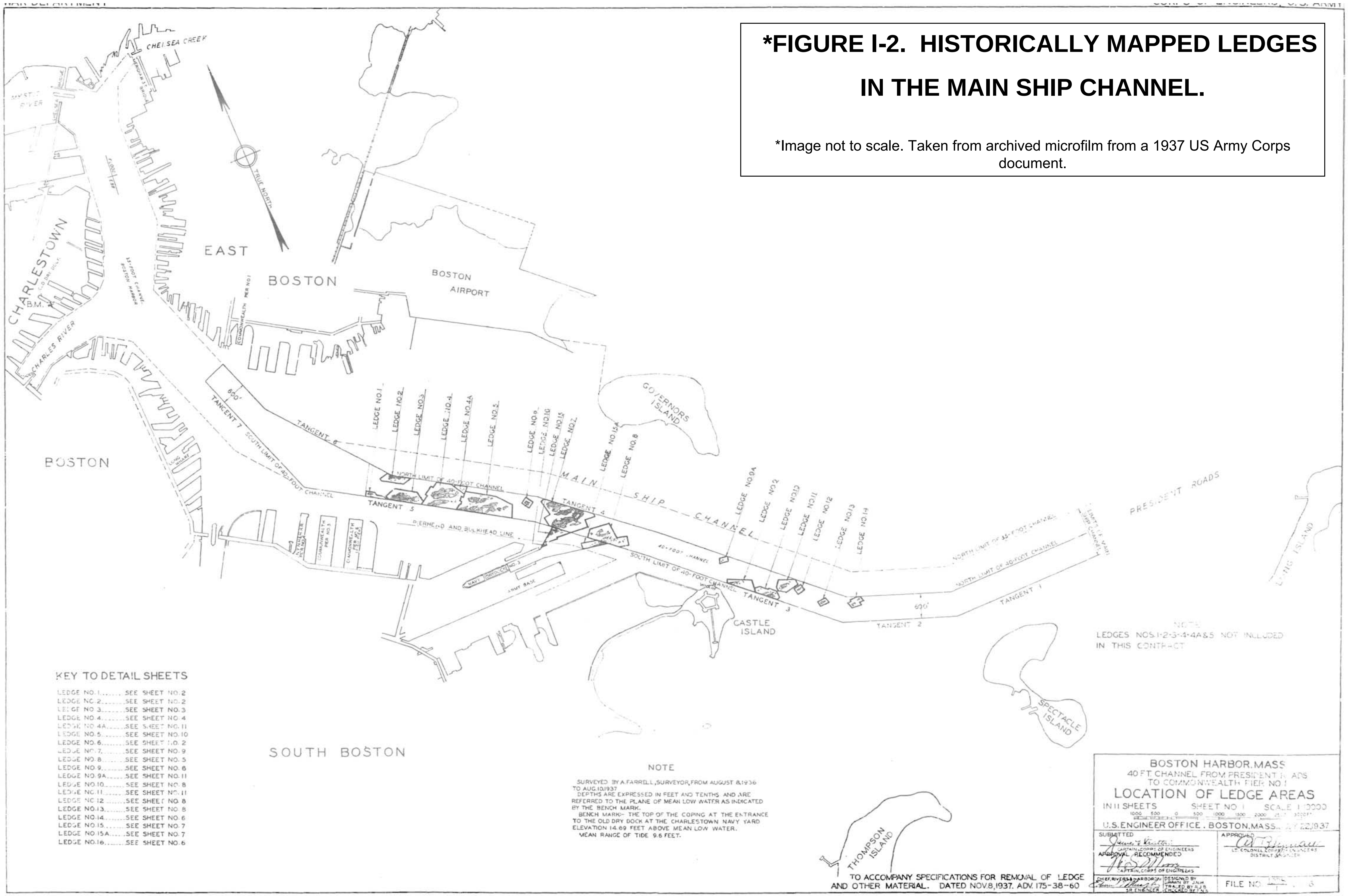


STRATIGRAPHIC UNITS

IPr	Rhode Island Formation
IPw	Wamsutta Formation
IPwv	Rhyolite and mafic volcanic rocks in the Wamsutta Formation
IPp	Pondville Conglomerate
IPZb	Bellingham Conglomerate
	Boston Bay Group
PzZc	Cambridge Argillite
PzZr	Roxbury Conglomerate
PzZrb	Melaphyre in the Roxbury Conglomerate
DZl	Lynn Volcanic Complex
Ꞓg	Green Lodge Formation of Rhodes and Graves (1931)
Ꞓbw	Braintree Argillite and Weymouth Formation
Ꞓh	Hoppin Formation
Zm	Mattapan Volcanic Complex
Zw	Westboro Formation
	Blackstone Group
Zb	Undivided
Zbs	Mica Shist and phyllite - Includes Mussey Brook Shist and Sneech Pond Schist
Zv	Metamorphosed mafic to felsic flow, volcaniclastic, and hypabyssal intrusive rocks
Zvf	Metamorphosed felsic volcanic rocks
Jd	Diabase dikes and sills
	Alkalic granitic and gabbroic rocks
	Batholithic rocks
	Mafic rocks

***FIGURE I-2. HISTORICALLY MAPPED LEDGES IN THE MAIN SHIP CHANNEL.**

*Image not to scale. Taken from archived microfilm from a 1937 US Army Corps document.



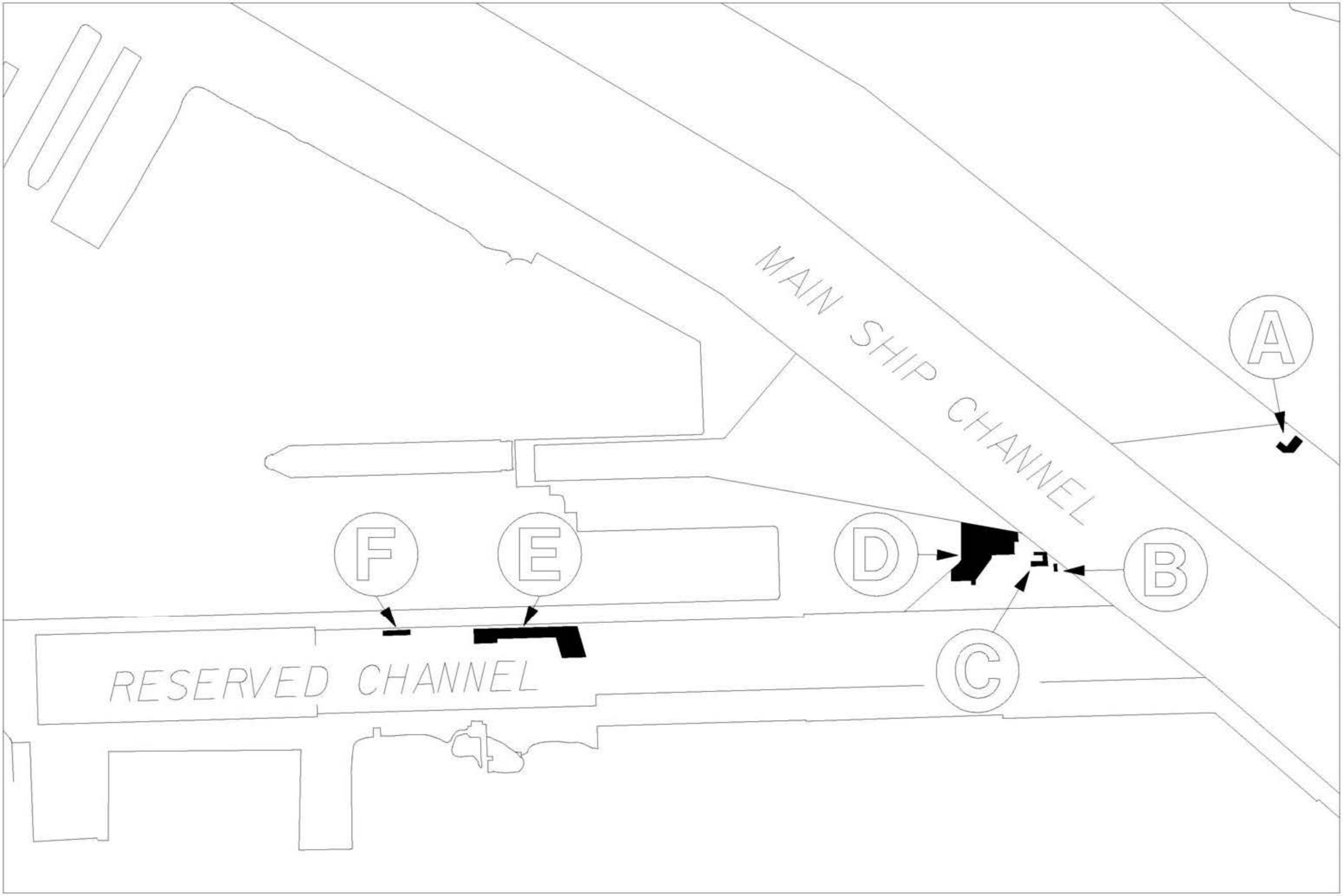


FIGURE I-3. PRIOR ROCK REMOVAL IN THE RESERVED AND MAIN SHIP CHANNEL. Image not to scale.

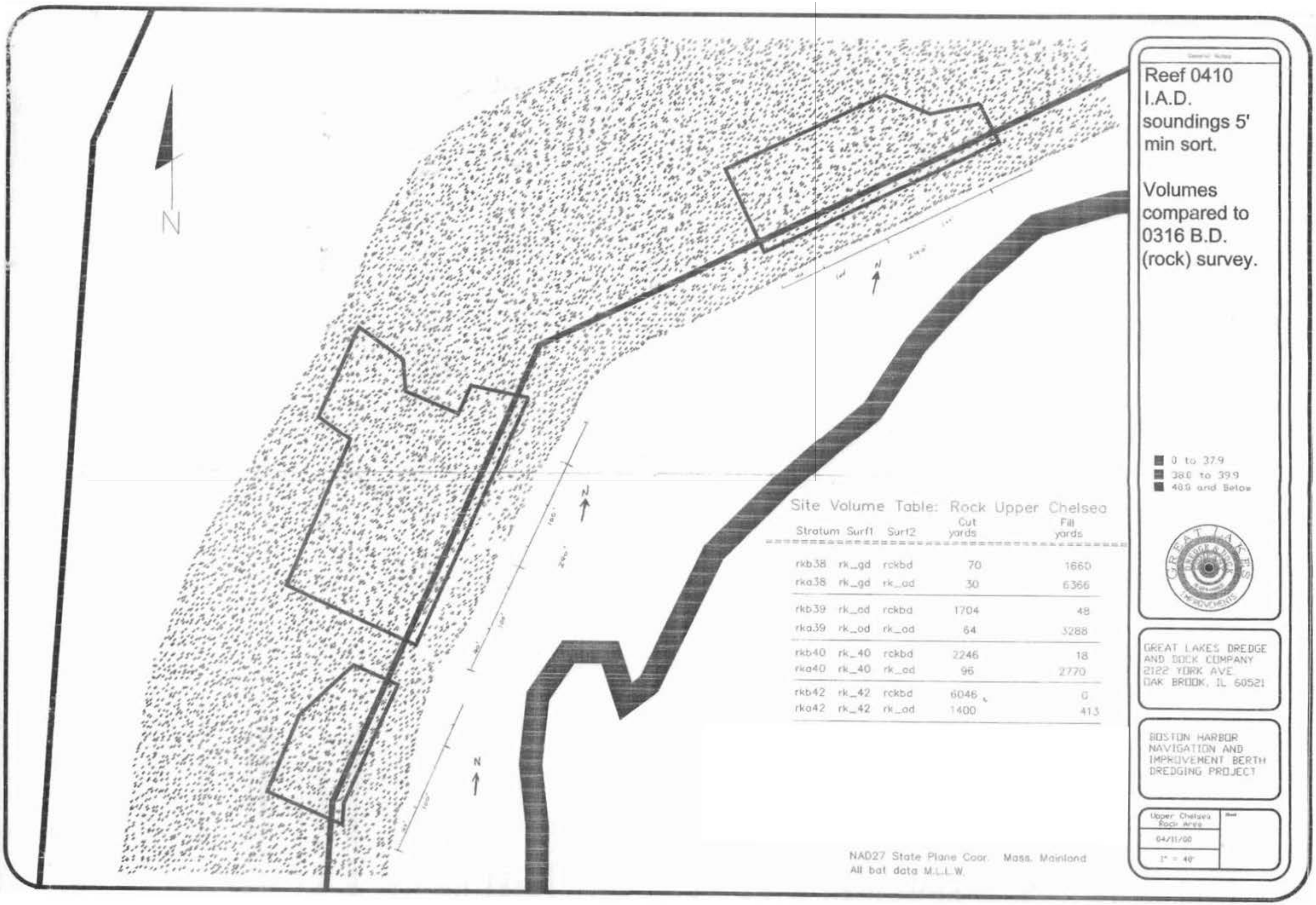


FIGURE I-4. PRIOR ROCK REMOVAL IN THE CHELSEA RIVER. Project dated to the year 2000.

Image not to scale. Taken from Great Lakes Dredge and Dock Company Figure.

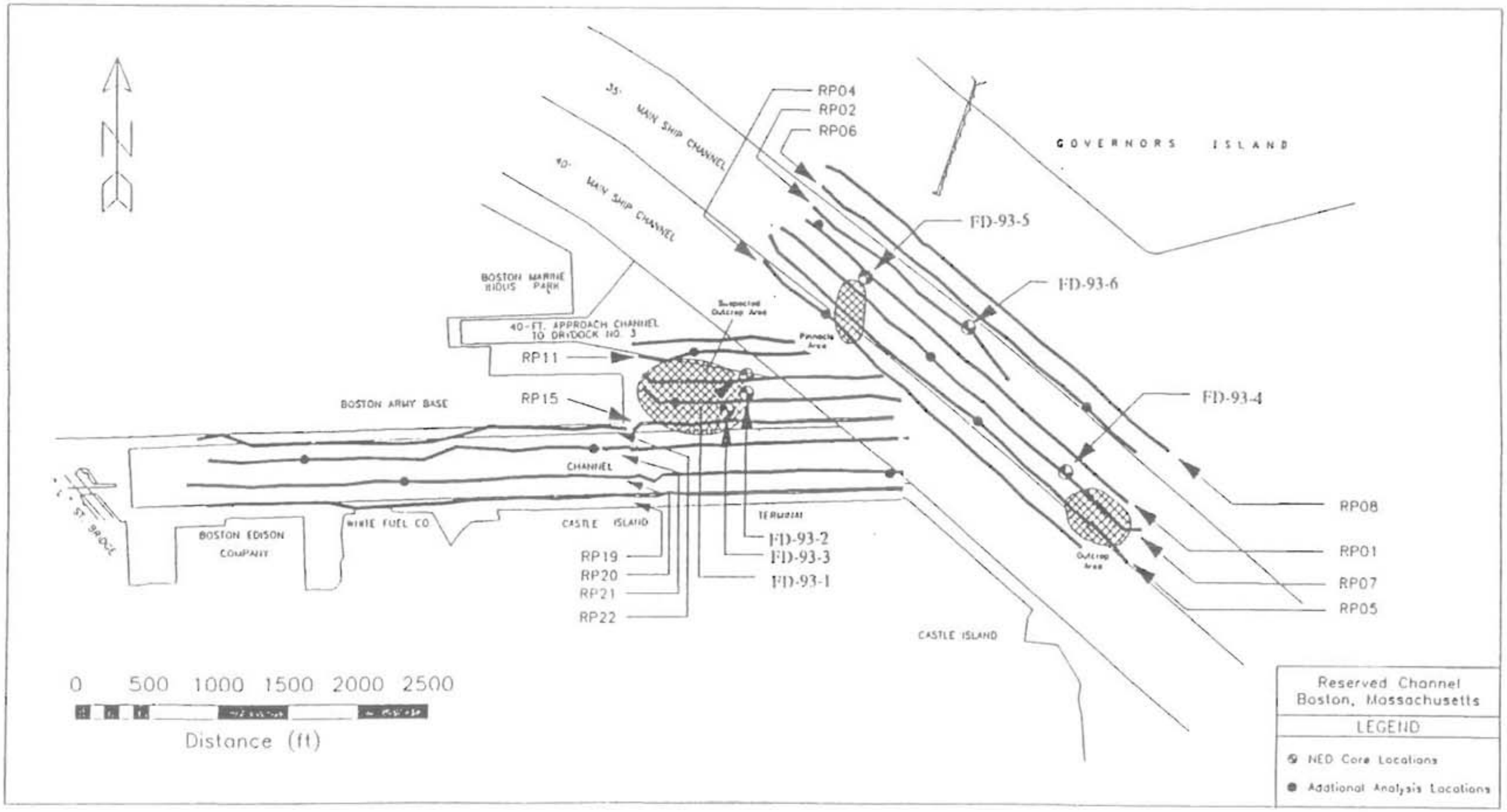


FIGURE I-5. RESERVED CHANNEL AND PORTION OF MAIN SHIP CHANNEL SEISMIC SURVEY AND LOCATIONS OF POSSIBLE ROCK. Crosshatched locations indicate possible outcrop area. (Adapted from WES 1994 Report)

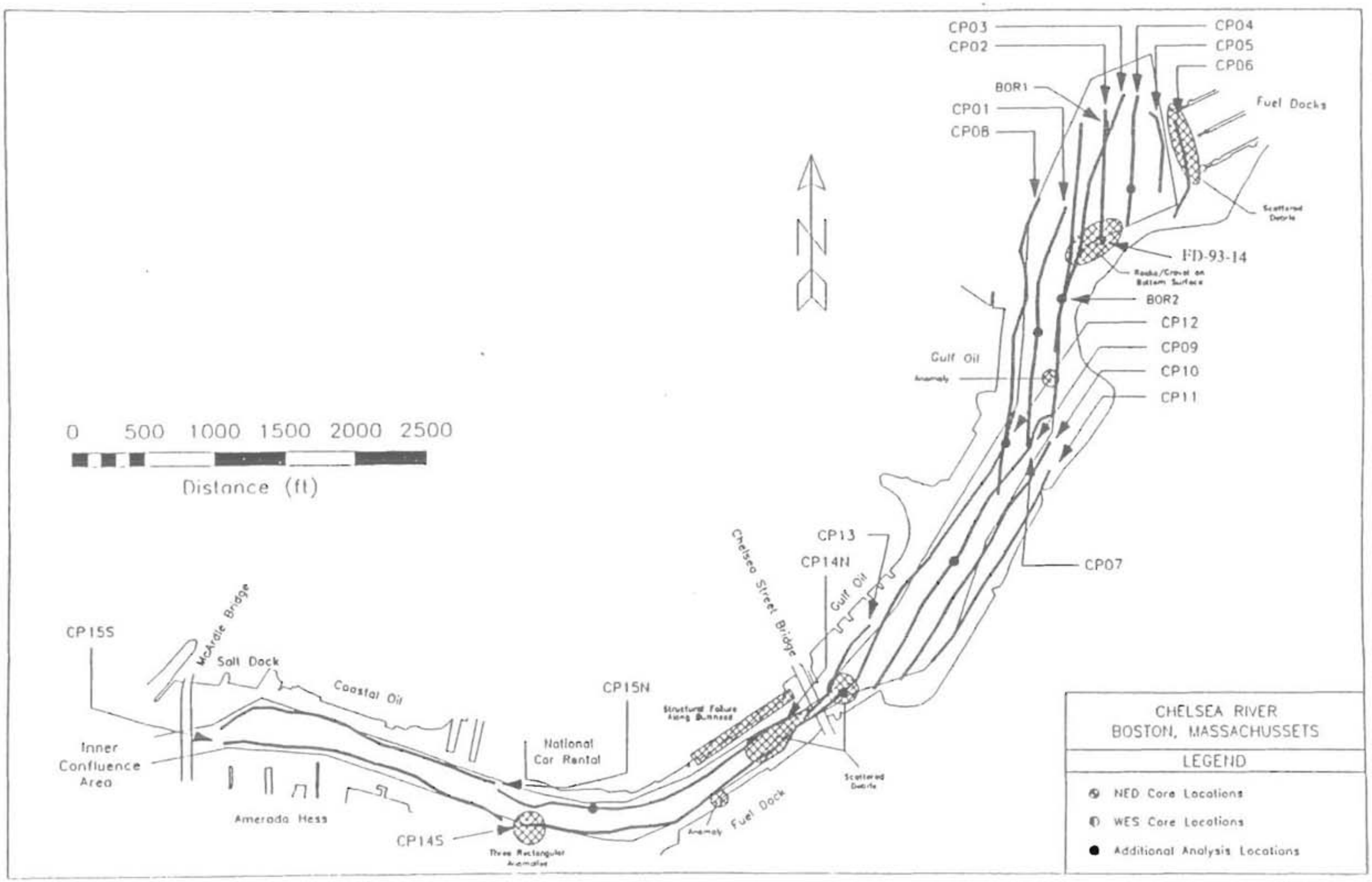


FIGURE I-6. CHELSEA RIVER SEISMIC SURVEY AND LOCATIONS OF POSSIBLE ROCK.
Crosshatched locations indicate possible outcrop area. (Adapted from WES 1994 Report)

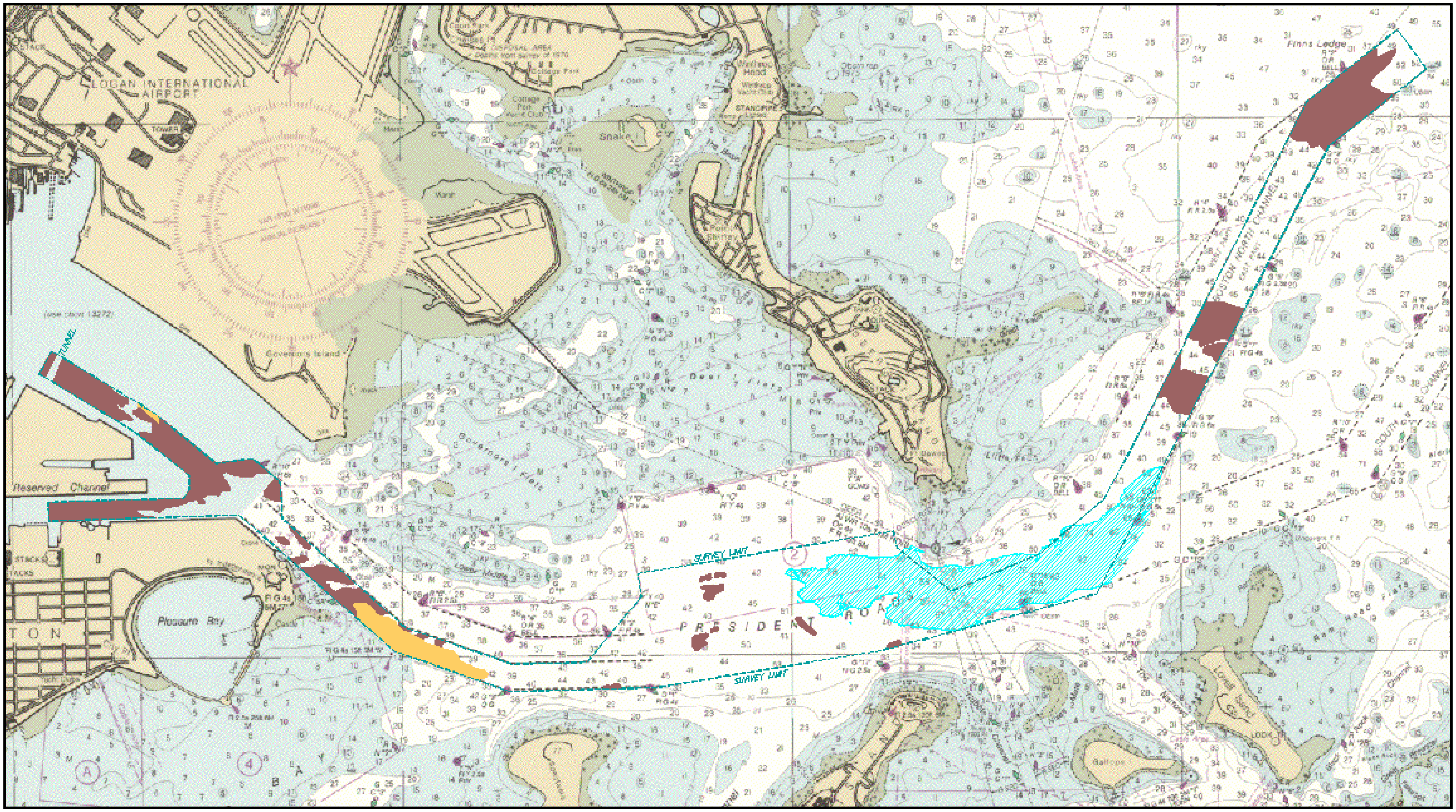


FIGURE I-7. BOSTON HARBOR GEOPHYSICAL INTERPRETATION. Map of the main survey area showing region with water depths greater than 55 ft (cyan hatch), areas where acoustic basement is less than 55 ft (brown), and areas of no signal penetration (yellow). Map from Ocean Surveys, Inc. Geophysics Report (2003).

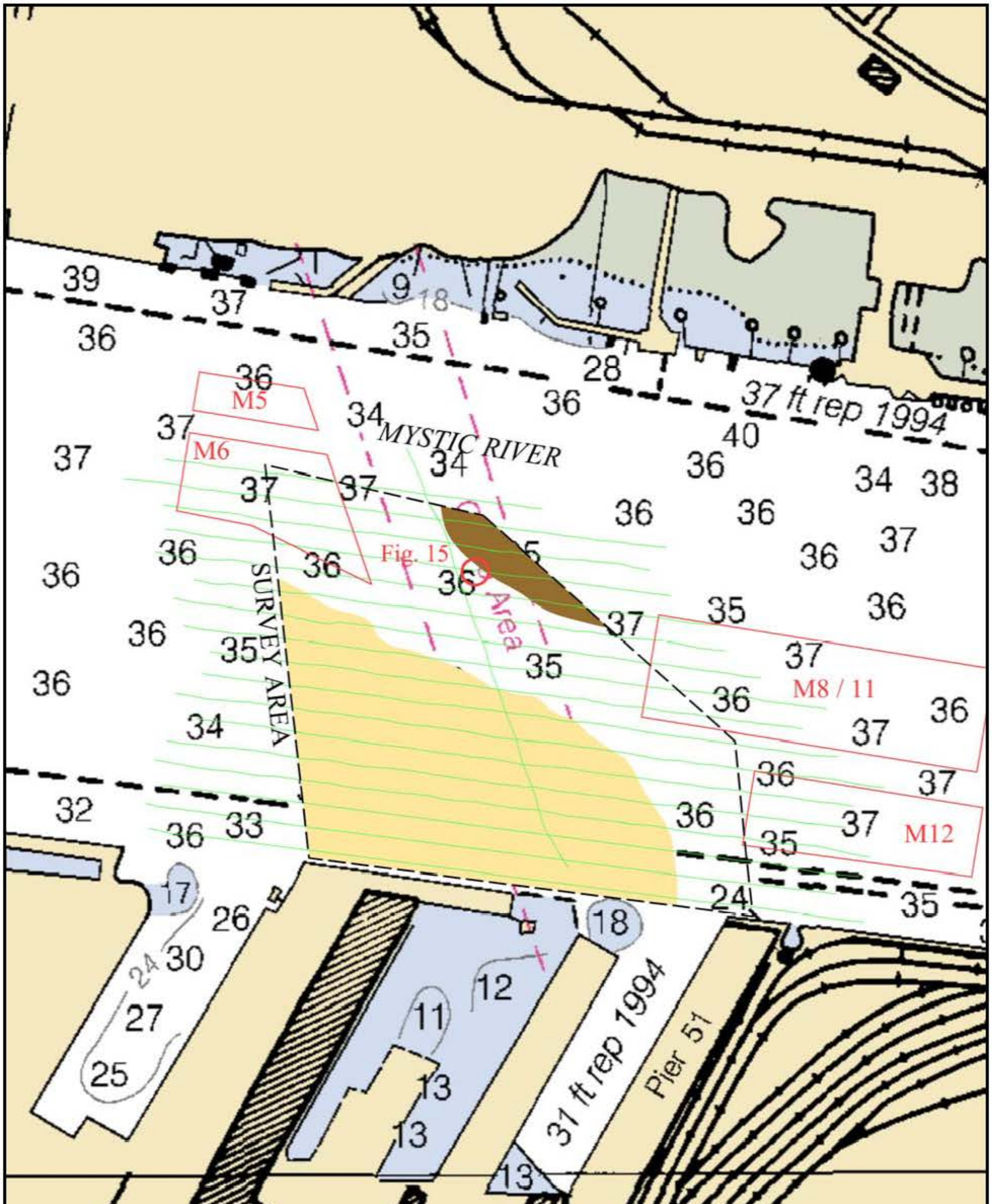
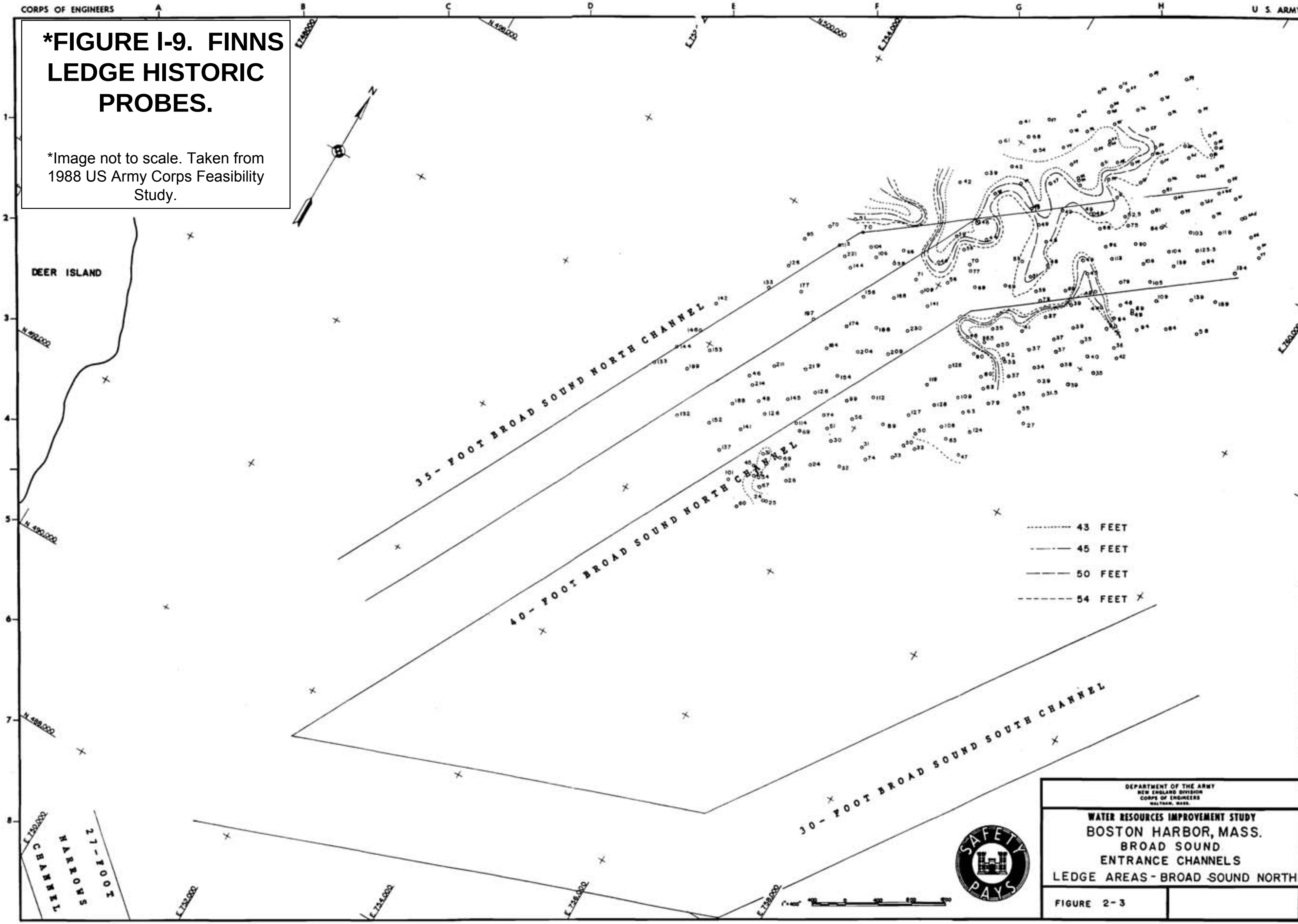


FIGURE I-8. MYSTIC RIVER GEOPHYSICAL INTERPRETATION. Figure shows areas where acoustic basement is less than 55 ft (brown), and areas of no signal penetration (yellow). Map from Ocean Surveys, Inc. Geophysics Report (2003).

***FIGURE I-9. FINNS LEDGE HISTORIC PROBES.**

*Image not to scale. Taken from 1988 US Army Corps Feasibility Study.



US Army Corps
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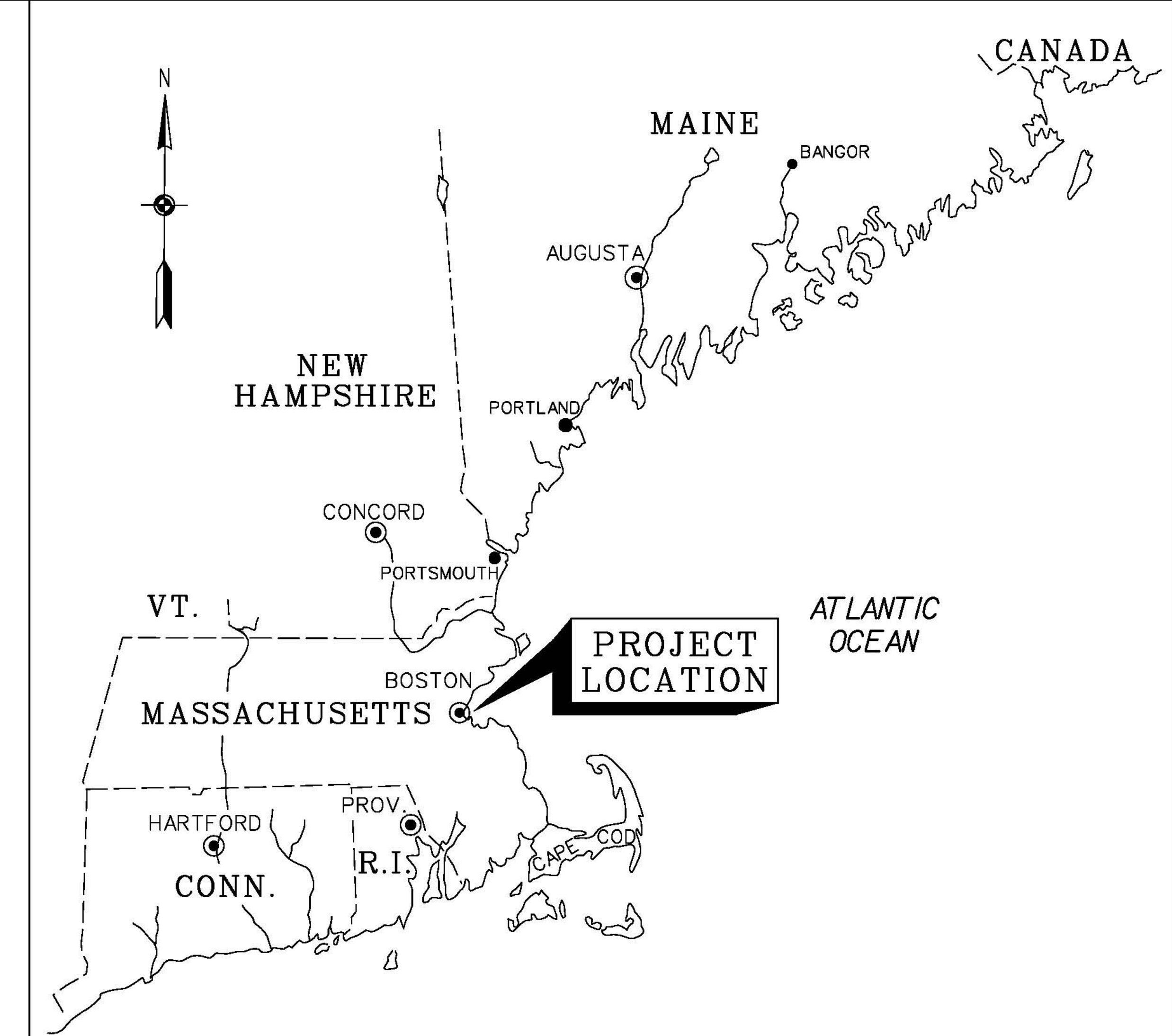
BOSTON HARBOR
BORING AND PROBE LOCATIONS

BOSTON
MASSACHUSETTS



VICINITY MAP
NOT TO SCALE

FIGURE 1-10-A

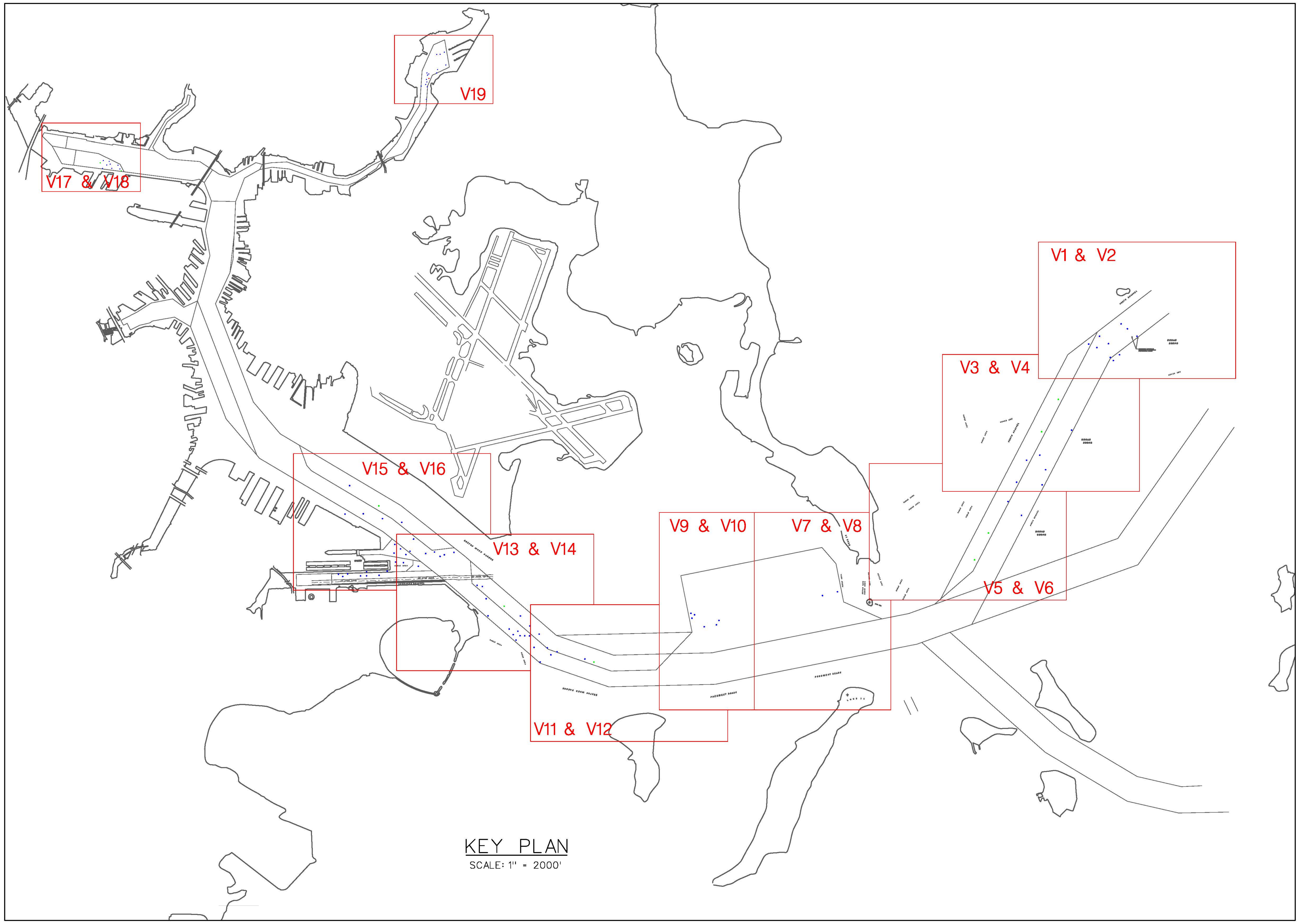
WATER RESOURCES DEVELOPMENT PROJECT
BOSTON HARBOR
BOSTON, MASSACHUSETTS
BORING AND PROBE LOCATIONS

COVER SHEET

Reference number:
G-1
Sheet 1 of 21

BORING
PROBE
VIBRACORE

US Army Corps of Engineers
New England District



NOTES (ACOUSTIC BASEMENT DATA.):

1. COORDINATES ARE THE MASSACHUSETTS STATE PLANE COORDINATE SYSTEM, MAINLAND ZONE, NAD 27 (FEET).
2. DEPTH-TO-ACOUSTIC-BASEMENT CONTOUR IS REFERENCED TO THE MEAN LOWER LOW WATER DATUM (MLLW). CONTOUR INTERVAL IS ONE FOOT. CONTOURS WERE GENERATED USING "QUICKSURF" VERSION 5.1 (SCHREIBER INSTRUMENTS,INC.), OPERATING WITHIN "AUTOCAD" VERSION 14 (AUTODESK) AND WERE HAND EDITED TO MINIMIZE ARTIFACTS FROM THE CONTOURING PROGRAM.
3. THE DEPTH TO ACOUSTIC BASEMENT WAS MAPPED BY ADDING THE WATER DEPTH SURFACE TO THE SEDIMENT THICKNESS SURFACE. THE WATER DEPTH SURFACE WAS GENERATED USING DATA PROVIDED BY THE ARMY CORPS OF ENGINEERS. THE SEDIMENT THICKNESS SURFACE WAS GENERATED USING MEASUREMENTS TAKEN FROM THE SUBBOTTOM PROFILES. A VELOCITY OF 5200 FEET/SECOND WAS USED TO CONVERT SUBBOTTOM INTERVAL TRAVEL TIMES TO DEPTHS.
4. THE CONFIDENCE LEVEL OF ESTIMATED DEPTH TO ACOUSTIC BASEMENT IS DEPENDENT ON THE DENSITY OF DATA IN AN AREA. POINTS REPRESENTING THE LOCATION OF EACH MEASUREMENT TO THE TOP OF THE ACOUSTIC BASEMENT ARE SHOWN TO PROVIDE AN INDICATION OF THE DENSITY OF DATA USED FOR THE INTERPRETATION AND TO DEVELOP THE CONTOURS. CAUTION SHOULD BE TAKEN WHEN USING THE TOP OF ACOUSTIC BASEMENT CONTOURS, ESPECIALLY WHERE DATA DENSITY IS LOW. IN GENERAL, THE CONTOURS SHOULD BE USED FOR PLANNING ADDITIONAL STUDIES SUCH AS FURTHER GEOPHYSICAL DATA ACQUISITION AND GROUND TRUTH MEASUREMENTS. REFER TO PROJECT REPORT FOR FURTHER DISCUSSION OF THE GEOPHYSICAL INTERPRETATION AND EVALUATION OF THE SUBBOTTOM PROFILE DATA.
5. THE MATERIAL REPRESENTING THE ACOUSTIC BASEMENT AND THE OVERLYING MATERIAL HAS NOT BEEN DETERMINED. GROUND TRUTH MEASUREMENTS ARE REQUIRED TO DEFINE SUBBOTTOM STRATIGRAPHY.
6. THE INFORMATION PRESENTED ON THIS DRAWING REPRESENTS THE RESULTS OF A SURVEY PERFORMED BY OCEAN SURVEYS, INC ON 25 SEPTEMBER - 8 OCTOBER 2002 AND 6-9 FEBRUARY 2003 AND CAN ONLY BE CONSIDERED AS INDICATING THE CONDITIONS EXISTING AT THAT TIME. REUSE OF THIS INFORMATION BY CLIENT OR OTHERS BEYOND THE SPECIFIC SCOPE OF WORK FOR WHICH IT WAS ACQUIRED SHALL BE AT THE SOLE RISK OF THE USER AND WITHOUT LIABILITY TO OSI.

NOTES (USACE HYDROGRAPHIC SURVEY DATA):

1. SOUNDINGS ARE IN FEET AND TENTHS AND REFER TO THE PLANE OF MEAN LOWER LOW WATER (MLLW).
2. TOPOGRAPHY SHOWN WAS DIGITIZED FROM NOAA CHART NO. 13270 AND SHOULD BE USED AS A REFERENCE ONLY. ALL UTILITIES ARE SHOWN AT APPROXIMATE LOCATION UNLESS OTHERWISE NOTED.
3. COORDINATES SHOWN ARE BASED ON THE LAMBERT GRID SYSTEM FOR THE COMMONWEALTH OF MASSACHUSETTS (MAINLAND ZONE) AND NAD 1927.
4. THE SOUNDING INFORMATION DEPICTED ON THESE MAPS REPRESENTS THE SHOALEST SOUNDINGS OF THOSE OBTAINED FROM HYDROGRAPHIC SURVEYS CONDUCTED AT VARIOUS TIMES DURING 2000 AND 2001.
5. THE INFORMATION DEPICTED ON THESE MAPS REPRESENTS THE RESULTS OF SURVEYS MADE DURING THE INDICATED TIME, AND CAN ONLY BE CONSIDERED AS INDICATING THE GENERAL CONDITIONS EXISTING AT THE TIME OF SURVEY.

Symbol | Description | Date | Appr.

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CORPS OF ENGINEERS
CONCORD, MASSACHUSETTS

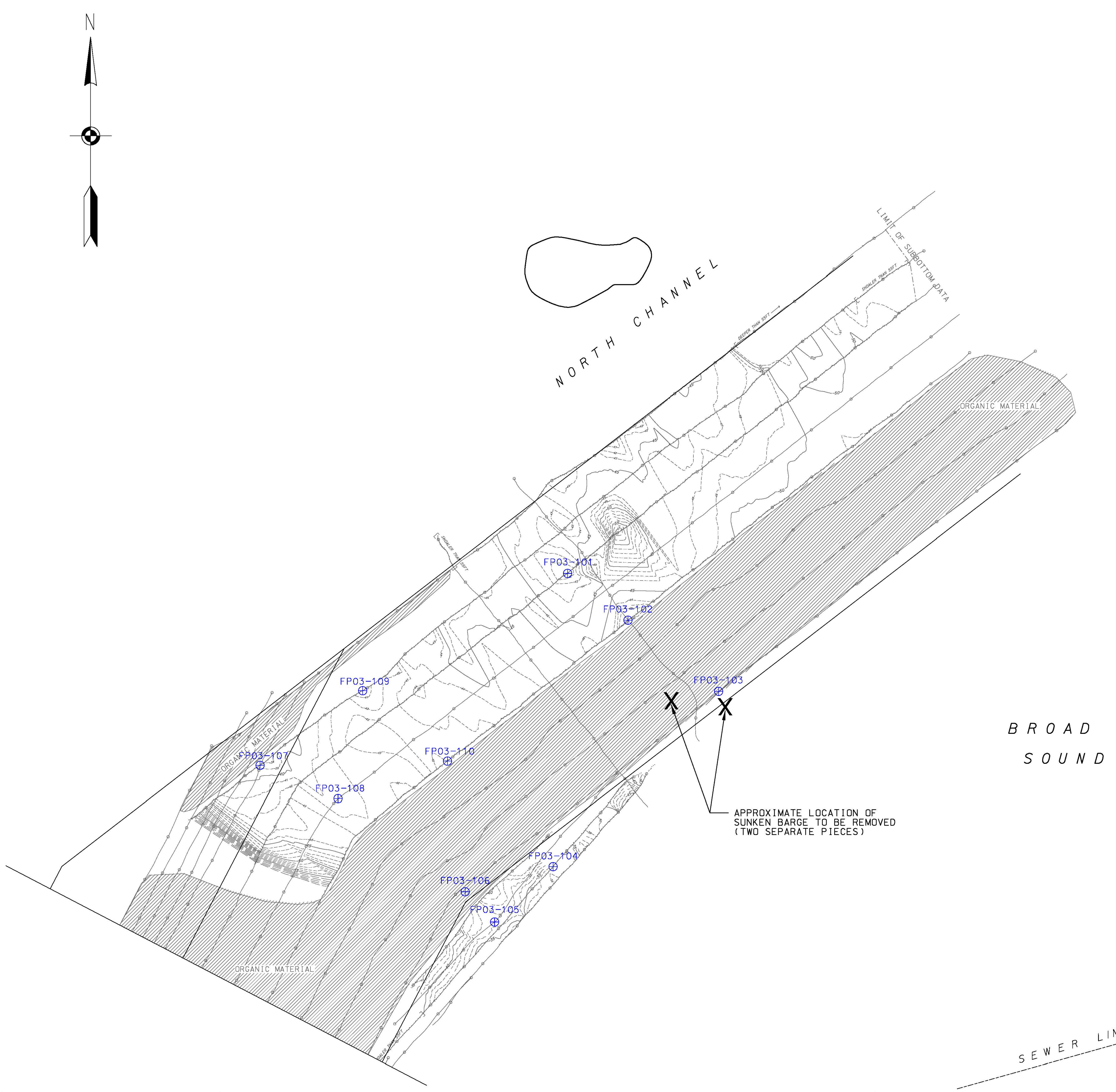
WATER RESOURCES DEVELOPMENT PROJECT
BOSTON HARBOR
BOSTON, MASSACHUSETTS
BORING AND PROBE LOCATIONS

KEY PLAN AND GENERAL NOTES

FIGURE 1-10-B

GRAPHIC SCALE:
2000 0 2000 4000
1" = 2000'

Reference number:
G-2
Sheet 2 of 21



⊕	BORING
⊗	PROBE
⊙	VIBRACORE

GRAPHIC SCALE:
200 0 200 400
1" = 200'

FIGURE 1-10-C

US Army Corps of Engineers
New England District

Symbol	Description	Date	Appr.	Symbol	Description	Date	Appr.

U.S. ARMY ENGINEER DISTRICT
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OCEAN SURVEYS, INC.
OLD SAYBROOK, CONNECTICUT

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Design file: BROADSOUND1.DGN
Drawing code:
File name:
Plot date:
Plot scale:

WATER RESOURCES DEVELOPMENT PROJECT
BOSTON HARBOR
BOSTON, MASSACHUSETTS
BORING AND PROBE LOCATIONS

NORTH CHANNEL - BROAD SOUND

Reference number:
V-1
Sheet 3 of 21

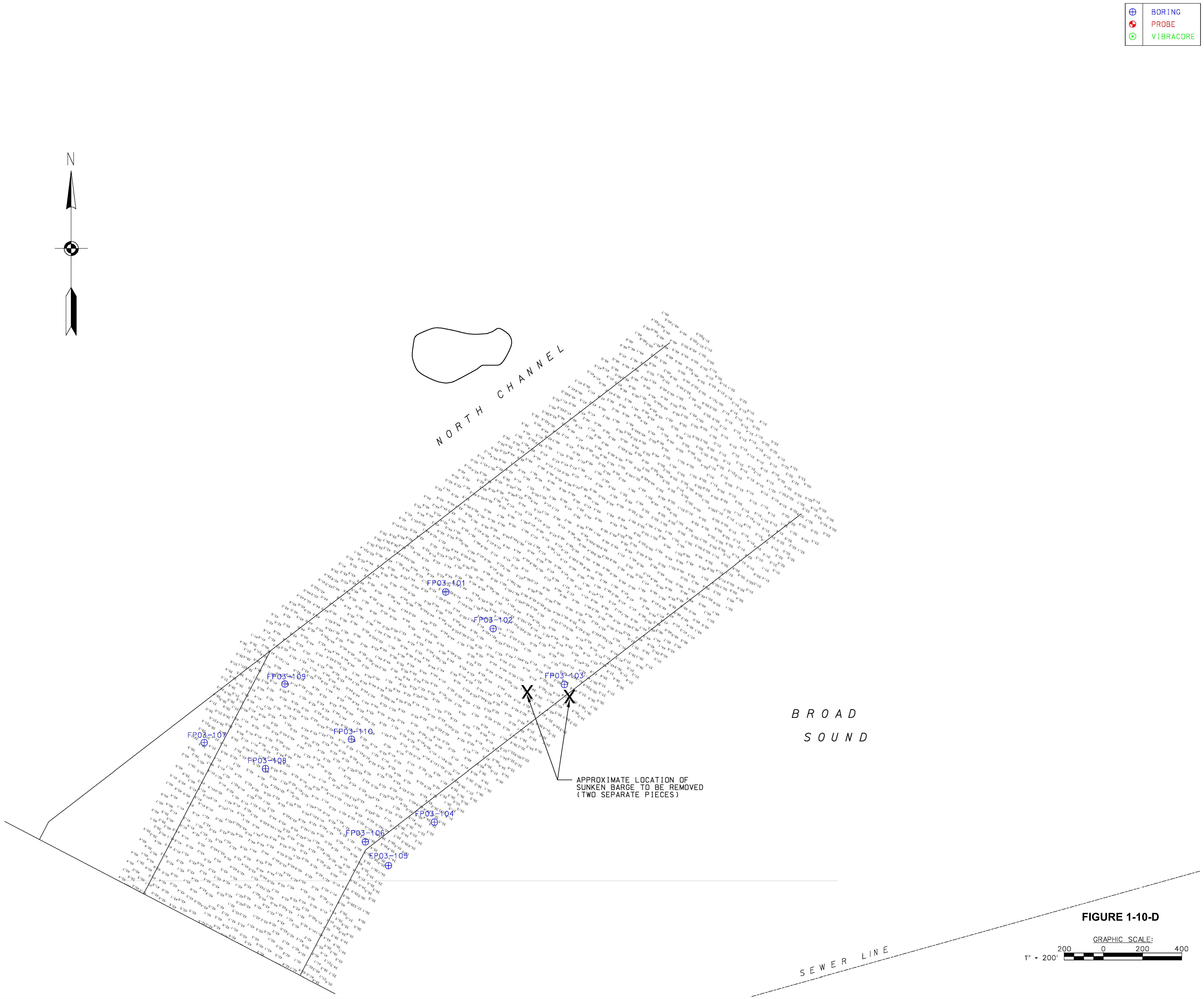

FIGURE 1-10-D

US Army Corps of Engineers
New England District

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CONCORD, MASSACHUSETTS

WATER RESOURCES DEVELOPMENT PROJECT
BOSTON HARBOR
BOSTON, MASSACHUSETTS
BORING AND PROBE LOCATIONS

NORTH CHANNEL - BROAD SOUND

Reference number:
V-2

Sheet 4 of 21

US Army Corps of Engineers
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BOSTON HARBOR
BOSTON, MASSACHUSETTS
BORING AND PROBE LOCATIONS

NORTH CHANNEL - BROAD SOUND

Reference number:
V-3
Sheet 5 of 21

GRAPHIC SCALE:
200 0 200 400
1" = 200'

FIGURE 1-10-E

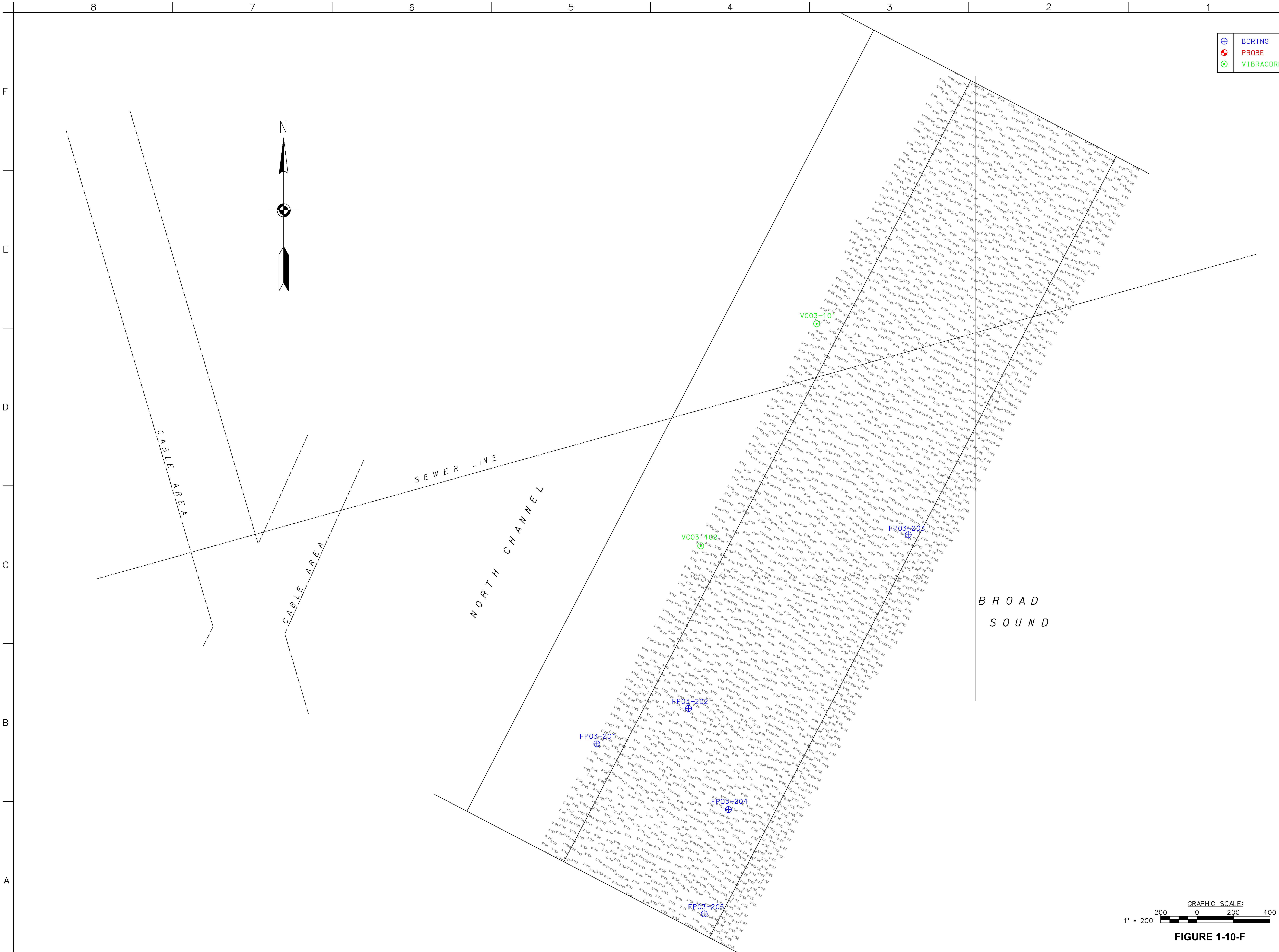

FIGURE 1-10-F

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WATER RESOURCES DEVELOPMENT PROJECT
BOSTON HARBOR
BOSTON, MASSACHUSETTS
BORING AND PROBE LOCATIONS

NORTH CHANNEL - BROAD SOUND

Reference number:
V-4

Sheet 6 of 21

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WATER RESOURCES DEVELOPMENT PROJECT
BOSTON HARBOR
BOSTON, MASSACHUSETTS
BORING AND PROBE LOCATIONS

NORTH CHANNEL - BROAD SOUND

Reference number:
V-5
Sheet 7 of 21

FIGURE 1-10-G

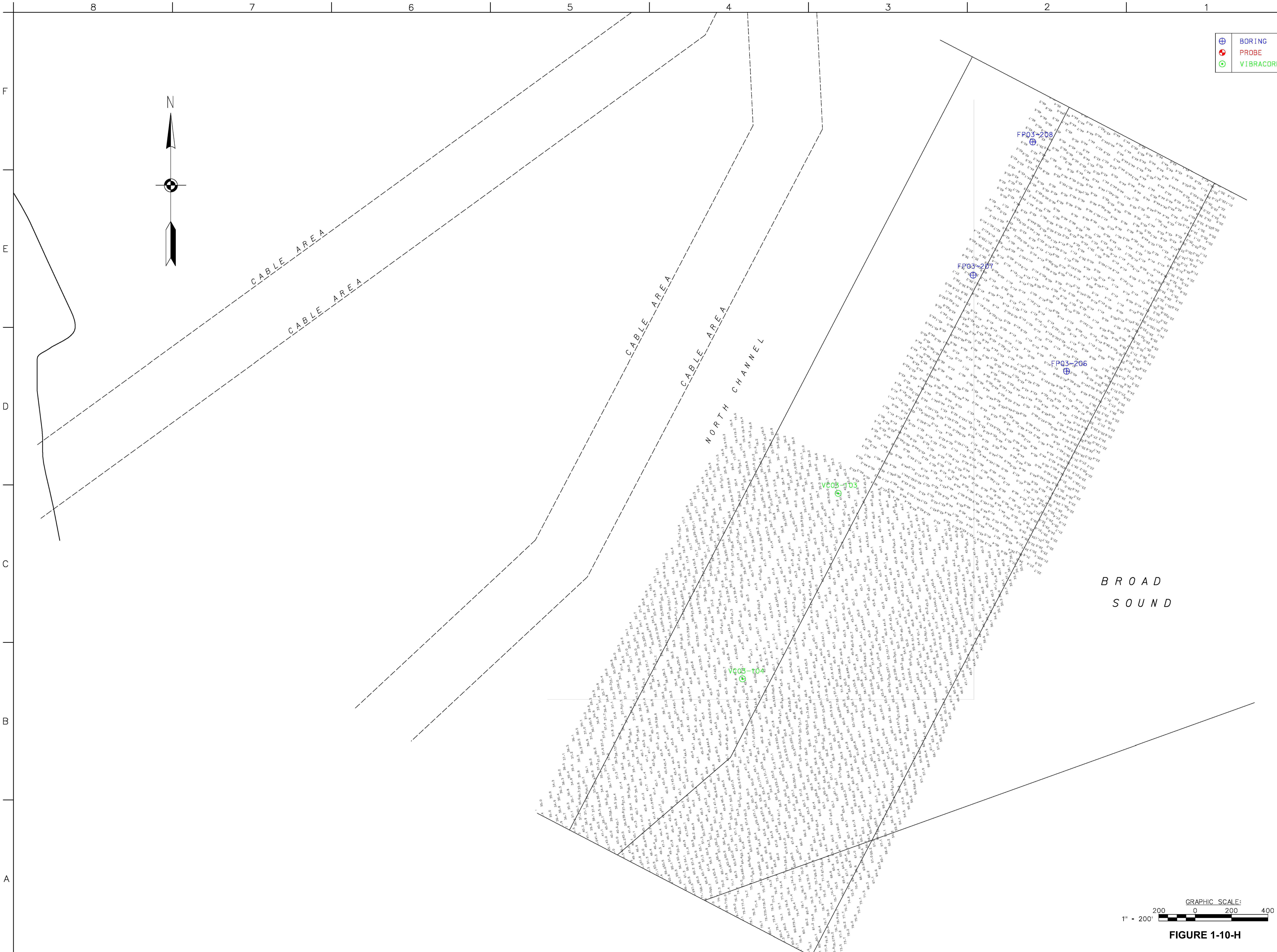

FIGURE 1-10-H

US Army Corps of Engineers
New England District

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WATER RESOURCES DEVELOPMENT PROJECT
BOSTON HARBOR
BOSTON, MASSACHUSETTS
BORING AND PROBE LOCATIONS

NORTH CHANNEL - BROAD SOUND

Reference number:
V-6
Sheet 8 of 21

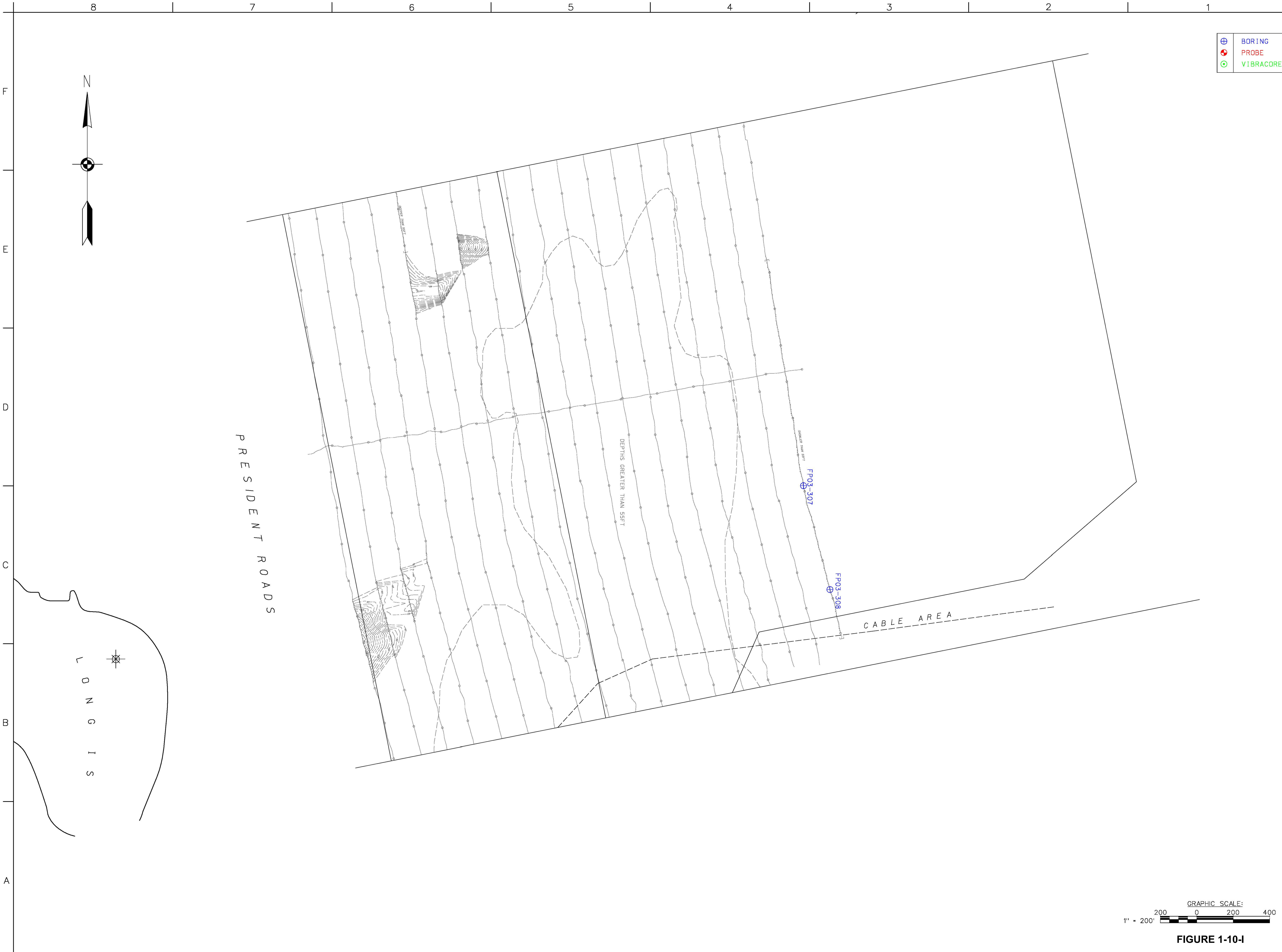

FIGURE 1-10-I

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New England District

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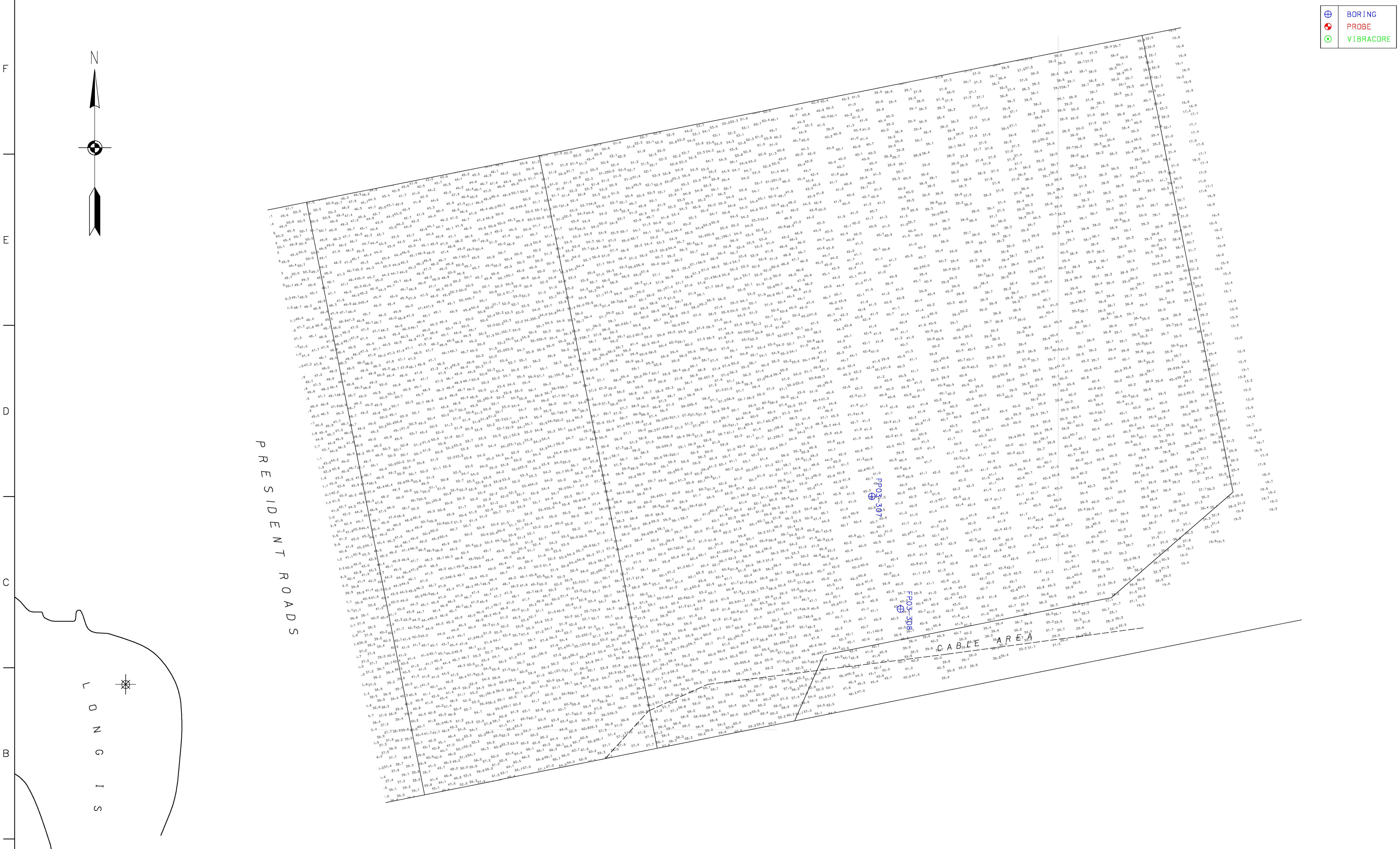
WATER RESOURCES DEVELOPMENT PROJECT
BOSTON HARBOR
BOSTON, MASSACHUSETTS
BORING AND PROBE LOCATIONS

PRESIDENT ROADS

Reference number:
V-7
Sheet 9 of 21



GRAPHIC SCALE:
200 0 200 400
1" = 200'

FIGURE 1-10-J

US Army Corps of Engineers
New England District

Symbol	Description	Date	Appr.

Symbol	Description	Date	Appr.

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Design file: PRESROADS2.DGN
Drawing code:
File name:
Plot date:
Plot scale:
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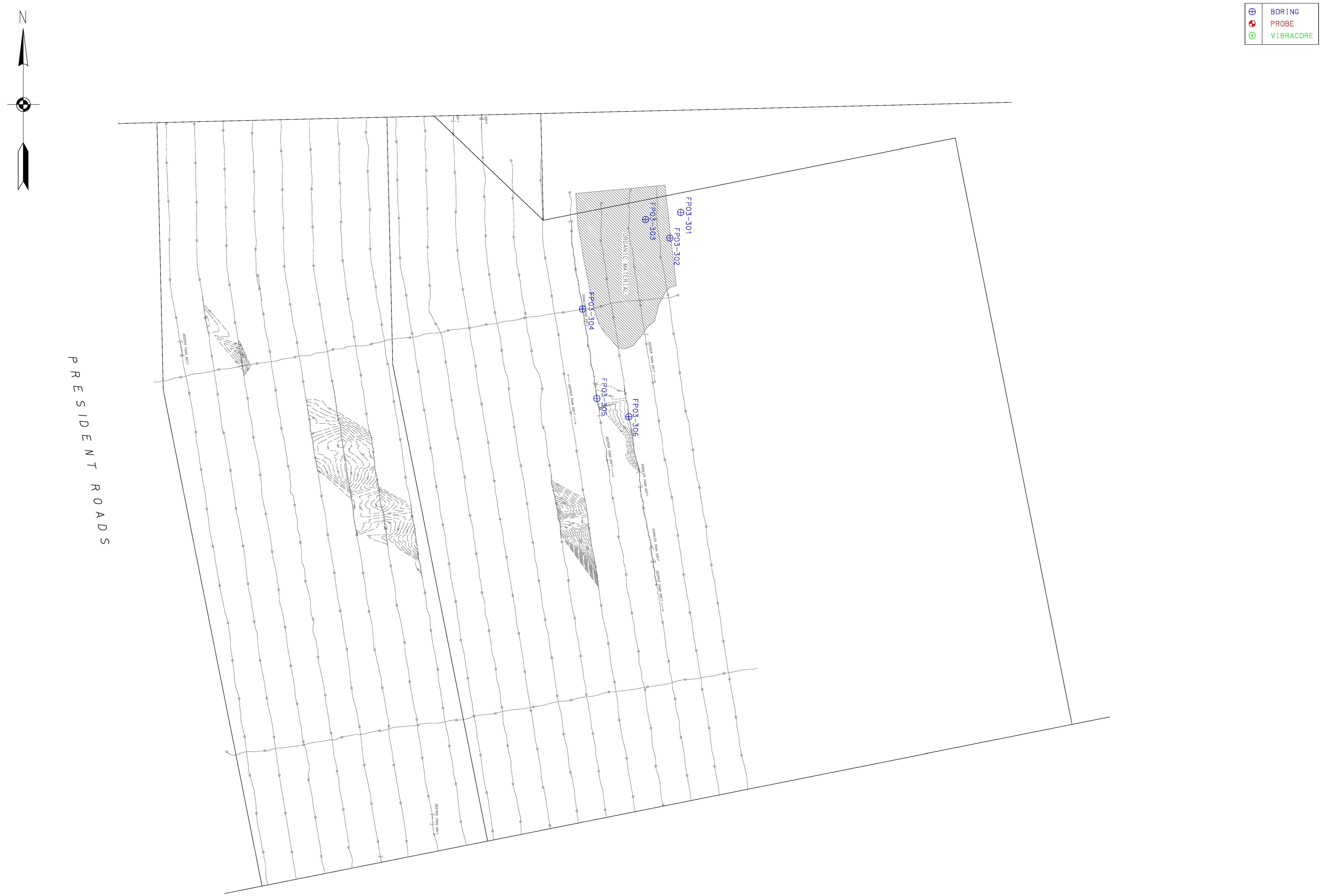
CONCORD, MASSACHUSETTS

WATER RESOURCES DEVELOPMENT PROJECT
BOSTON HARBOR
BOSTON, MASSACHUSETTS
BORING AND PROBE LOCATIONS

PRESIDENT ROADS

Reference number:
V-8
Sheet 10 of 21



US Army Corps of Engineers
New England District

U.S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS
CONCORD, MASSACHUSETTS

OCEAN SURVEYS, INC.
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Design file: PRESROADS3.DGN

WATER RESOURCES DEVELOPMENT PROJECT
BOSTON HARBOR
BOSTON, MASSACHUSETTS
BORING AND PROBE LOCATIONS

PRESIDENT ROADS

GRAPHIC SCALE:
200 0 200 400
1" = 200'

FIGURE 1-10-K

Reference number:
V-9
Sheet 11 of 21

BORING
PROBE
VIBRACORE

US Army Corps of Engineers
New England District

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Date:
Design file: PRESROADS3.DGN
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Plot scale:
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CONCORD, MASSACHUSETTS

WATER RESOURCES DEVELOPMENT PROJECT
BOSTON HARBOR
BOSTON, MASSACHUSETTS
BORING AND PROBE LOCATIONS

PRESIDENT ROADS

GRAPHIC SCALE:
200 0 200 400
1" = 200'

FIGURE 1-10-L

Reference number:
V-10
Sheet 12 of 21

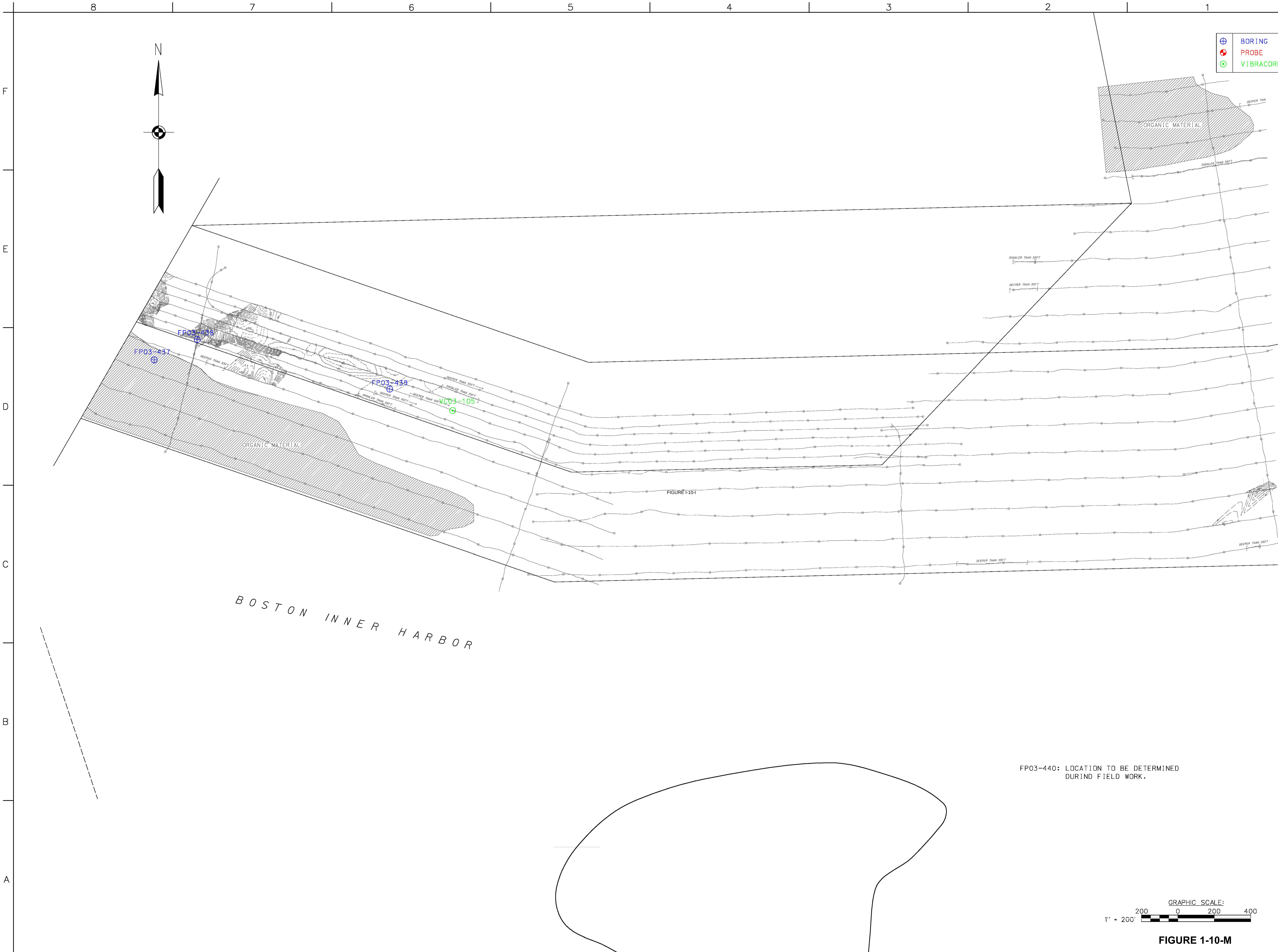

FIGURE 1-10-M

US Army Corps of Engineers
New England District

Symbol	Description	Date	Appr.	Symbol	Description	Date	Appr.

U.S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS
CONCORD, MASSACHUSETTS

OCEAN SURVEYS, INC.
OLD SAYBROOK, CONNECTICUT

Designed By: R.A.S.
Drawn By: A.W.C / S.A.F.
Date:
Rev.
Design file: MAINSHIP1.DGN
Drawing code:
File name:
Plot date:
Plot scale:

WATER RESOURCES DEVELOPMENT PROJECT
BOSTON HARBOR
BOSTON, MASSACHUSETTS
BORING AND PROBE LOCATIONS

MAIN SHIP CHANNEL

Reference number:
V-11
Sheet 13 of 21

FIGURE 1-10-N

US Army Corps
of Engineers
New England District

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Date:
Design file: MAINSHIP1.DGN
Drawing code:
File name:
Plot date:
Plot scale:
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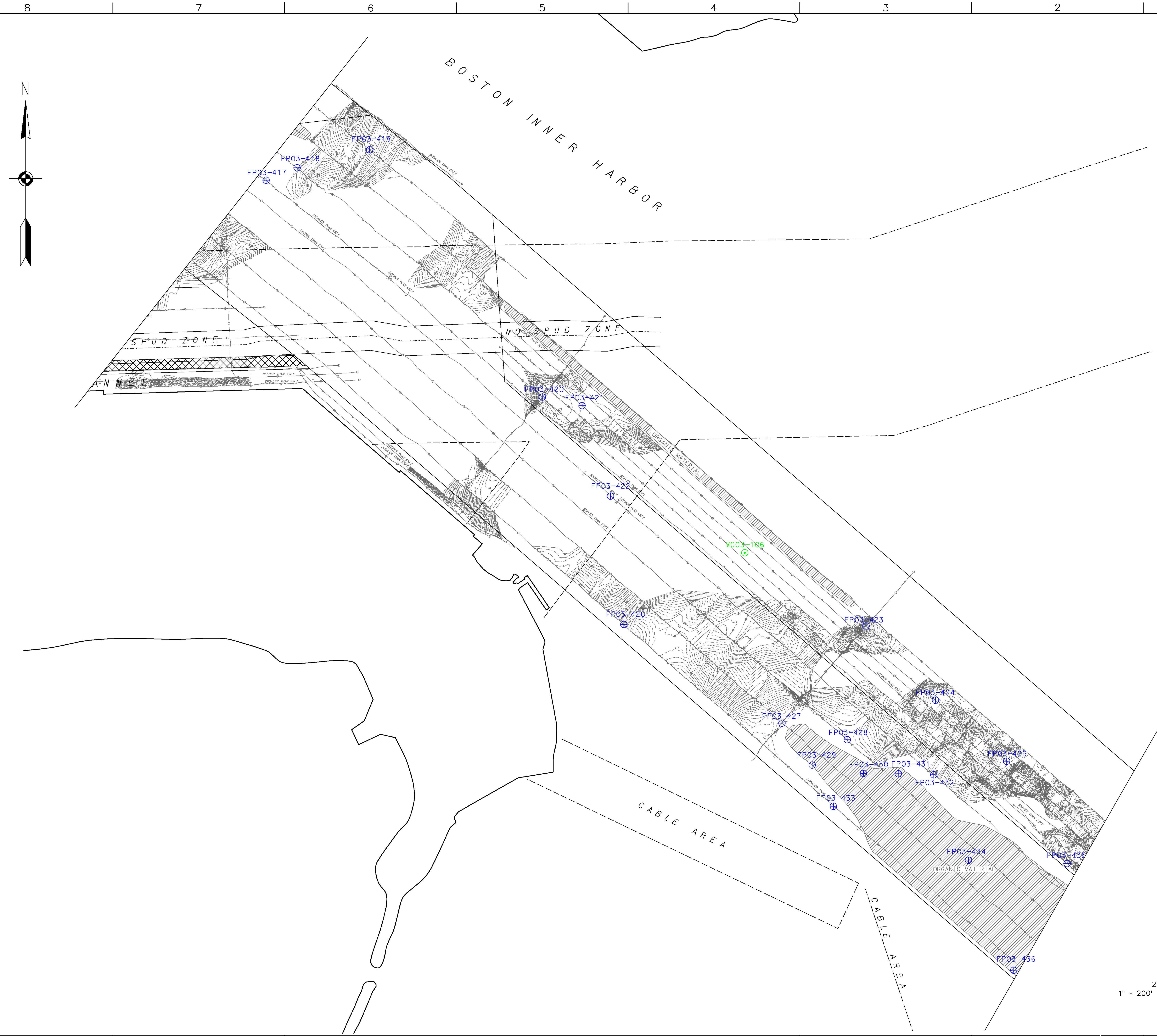
WATER RESOURCES DEVELOPMENT PROJECT
BOSTON HARBOR
BOSTON, MASSACHUSETTS
BORING AND PROBE LOCATIONS

MAIN SHIP CHANNEL

Reference number:
V-12
Sheet 14 of 21



BORING
PROBE
VIBRACORE

GRAPHIC SCALE:
200 0 200 400
1" = 200'

FIGURE 1-10-O

US Army Corps of Engineers
New England District

Symbol	Description	Date	Appr.	Symbol	Description	Date	Appr.

U.S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS
CONCORD, MASSACHUSETTS

OCEAN SURVEYS, INC.
OLD SAYBROOK, CONNECTICUT

Designed By: R.A.S.
Drawn By: A.W.C / S.A.F.
Date:
Rev.
Design file: MAINSHIP2.DGN
Drawing code:
File name:
Plot date:
Plot scale:

WATER RESOURCES DEVELOPMENT PROJECT
BOSTON HARBOR
BOSTON, MASSACHUSETTS
BORING AND PROBE LOCATIONS

MAIN SHIP CHANNEL

Reference number:
V-13
Sheet 15 of 21

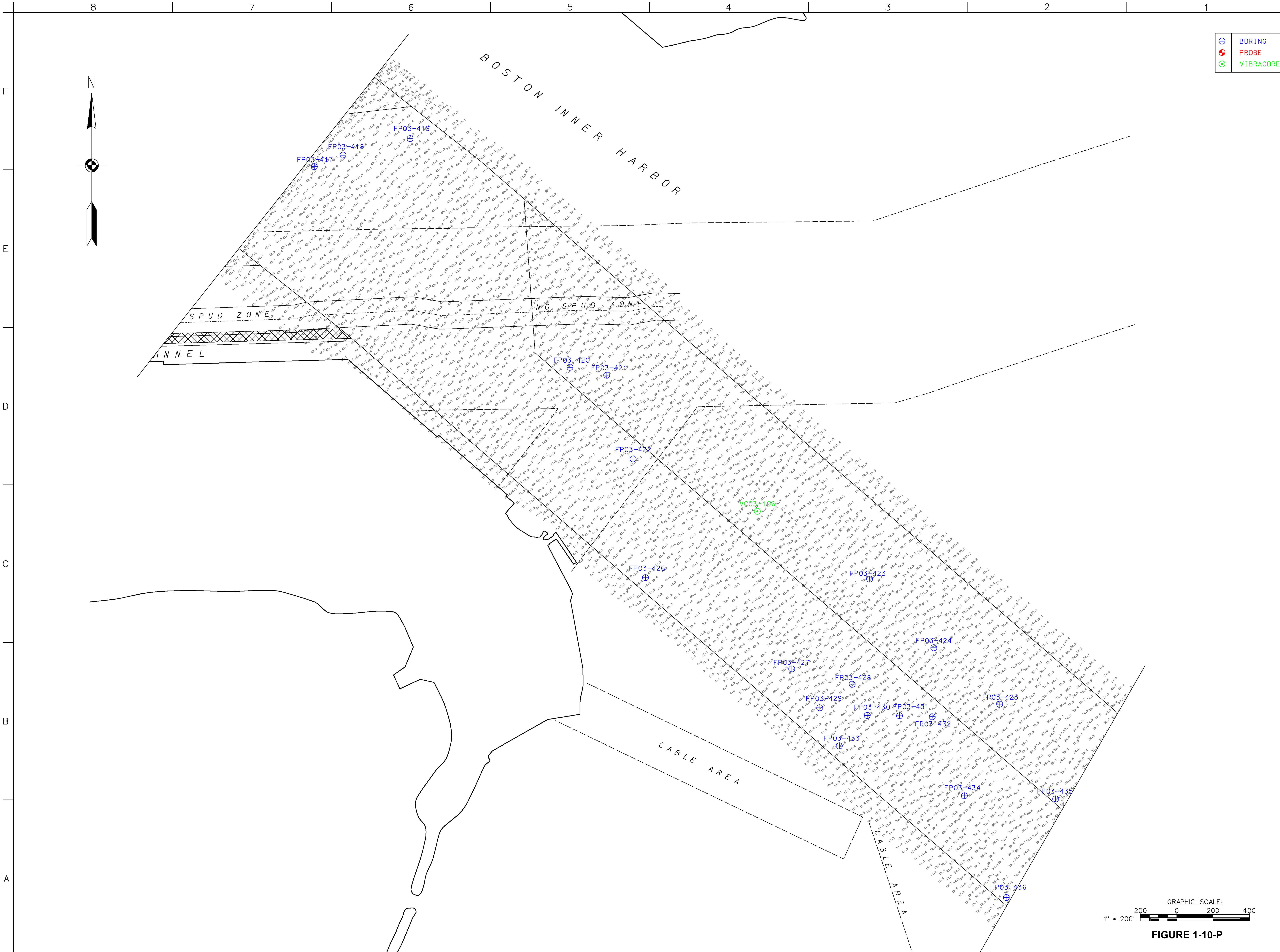


FIGURE 1-10-P

US Army Corps of Engineers
New England District

Symbol | Description | Date | Appr.

Designed By: R.A.S.
Drawn By: A.W.C / S.A.F.
Date:
Design file: MAINSHIP2.DGN
Drawing code:
File name:
Plot date:
Plot scale:
Rev.

U.S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS
CONCORD, MASSACHUSETTS

WATER RESOURCES DEVELOPMENT PROJECT
BOSTON HARBOR
BOSTON, MASSACHUSETTS
BORING AND PROBE LOCATIONS

MAIN SHIP CHANNEL

Reference number:
V-14

Sheet 16 of 21

BORING
PROBE
VIBRACORE
US Army Corps of Engineers
New England District
N
FP03-401
FP03-402
FP03-403
FP03-404
FP03-405
FP03-406
FP03-407
FP03-408
FP03-409
FP03-410
FP03-411
FP03-412
FP03-413
FP03-414
FP03-415
FP03-416
FP03-501
FP03-502
FP03-503
FP03-504
FP03-505
FP03-506
FP03-507
FP03-508
VC03-107
ORGANIC MATERIAL
CABLE AREA
NO SPUD ZONE
RESERVED CH
GRAPHIC SCALE:
200 0 200 400
1" = 200'
Designed By: K.A.S.
Drawn By: A.W.C. / S.A.F.
Design file: MAINSHIP3.DGN
U.S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS
CONCORD, MASSACHUSETTS
OCEAN SURVEYS, INC.
OLD SAYBROOK, CONNECTICUT
WATER RESOURCES DEVELOPMENT PROJECT
BOSTON HARBOR
BOSTON, MASSACHUSETTS
BORING AND PROBE LOCATIONS
MAIN SHIP CHANNEL AND RESERVED CHANNEL
Reference number:
V-15
Sheet 17 of 21

FIGURE 1-10-Q


N
BORING
PROBE
VIBRACORE
US Army Corps of Engineers
New England District
CABLE AREA
CABLE AREA
FP03-401
FP03-402
FP03-403
FP03-404
FP03-405
FP03-406
FP03-407
FP03-408
FP03-409
FP03-410
FP03-411
FP03-412
FP03-413
FP03-414
FP03-415
FP03-416
VC03-107
CABLE AREA
FP03-501
FP03-502
FP03-503
FP03-504
FP03-505
FP03-506
FP03-507
FP03-508
NO SPUD ZONE
NO
RESERVED CH
GRAPHIC SCALE:
200 0 200 400
1" = 200'
Designed By: K.A.S.
Drawn By: A.W.C. / S.A.F.
Design file: MAINSHIP3.DGN
U.S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS
CONCORD, MASSACHUSETTS
WATER RESOURCES DEVELOPMENT PROJECT
BOSTON HARBOR
BOSTON, MASSACHUSETTS
BORING AND PROBE LOCATIONS
MAIN SHIP CHANNEL AND RESERVED CHANNEL
Reference number:
V-16
Sheet 18 of 21

FIGURE 1-10-R

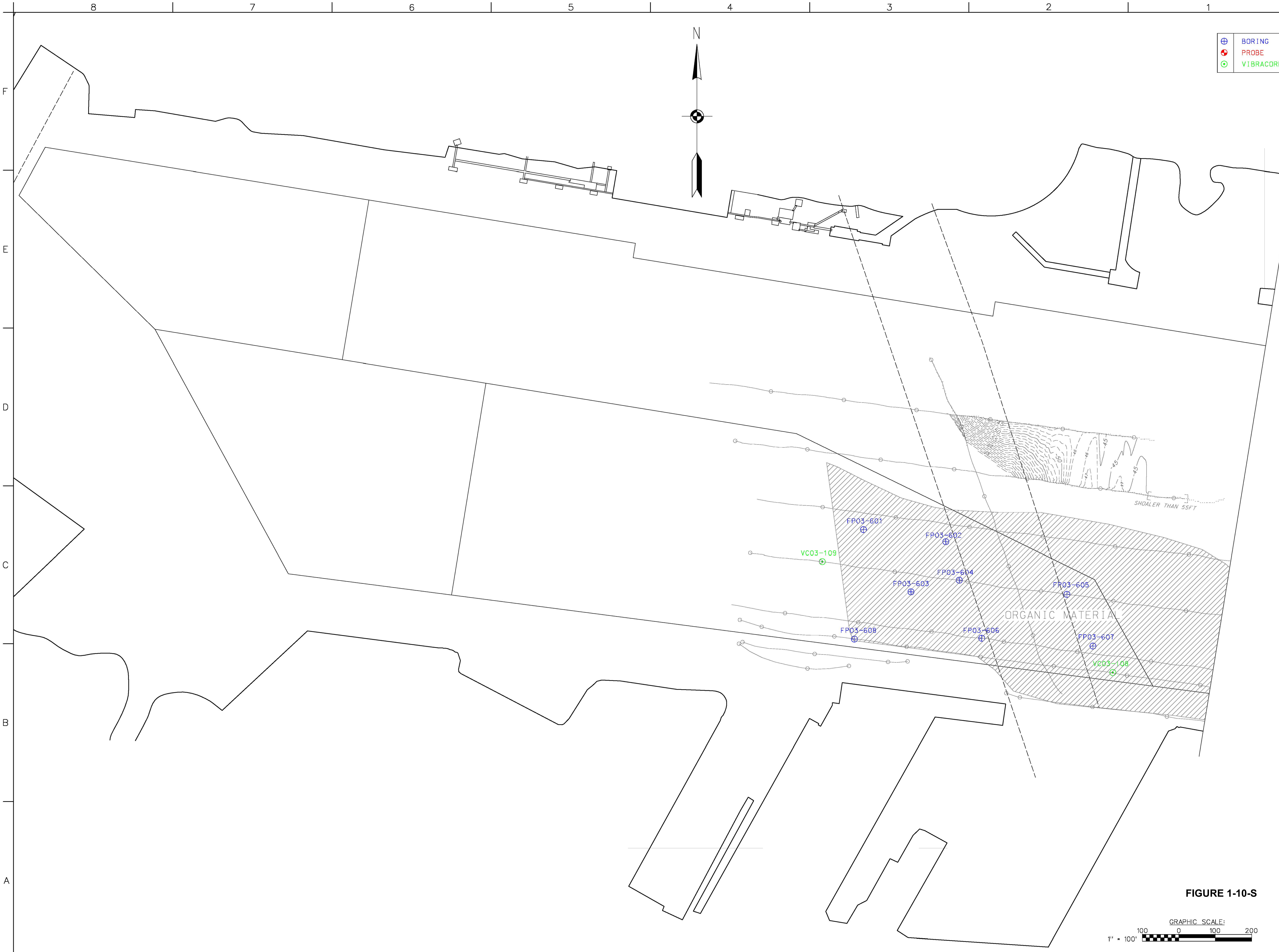


FIGURE 1-10-S

US Army Corps of Engineers
New England District

Symbol	Description	Date	Appr.	Symbol	Description	Date	Appr.

U.S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS
CONCORD, MASSACHUSETTS

OCEAN SURVEYS, INC.
OLD SAYBROOK, CONNECTICUT

Designed By: R.A.S. JDG, JMB
Drawn By: A.W.C / S.A.F. AMR
Date: 05/06/03
Rev.
Design file: MYSTICRIVER2.DGN
Drawing code:
File name:
Plot date:
Plot scale:

WATER RESOURCES DEVELOPMENT PROJECT
BOSTON HARBOR
BOSTON, MASSACHUSETTS
BORING AND PROBE LOCATIONS

MYSTIC RIVER

Reference number:
V-17
Sheet 19 of 21

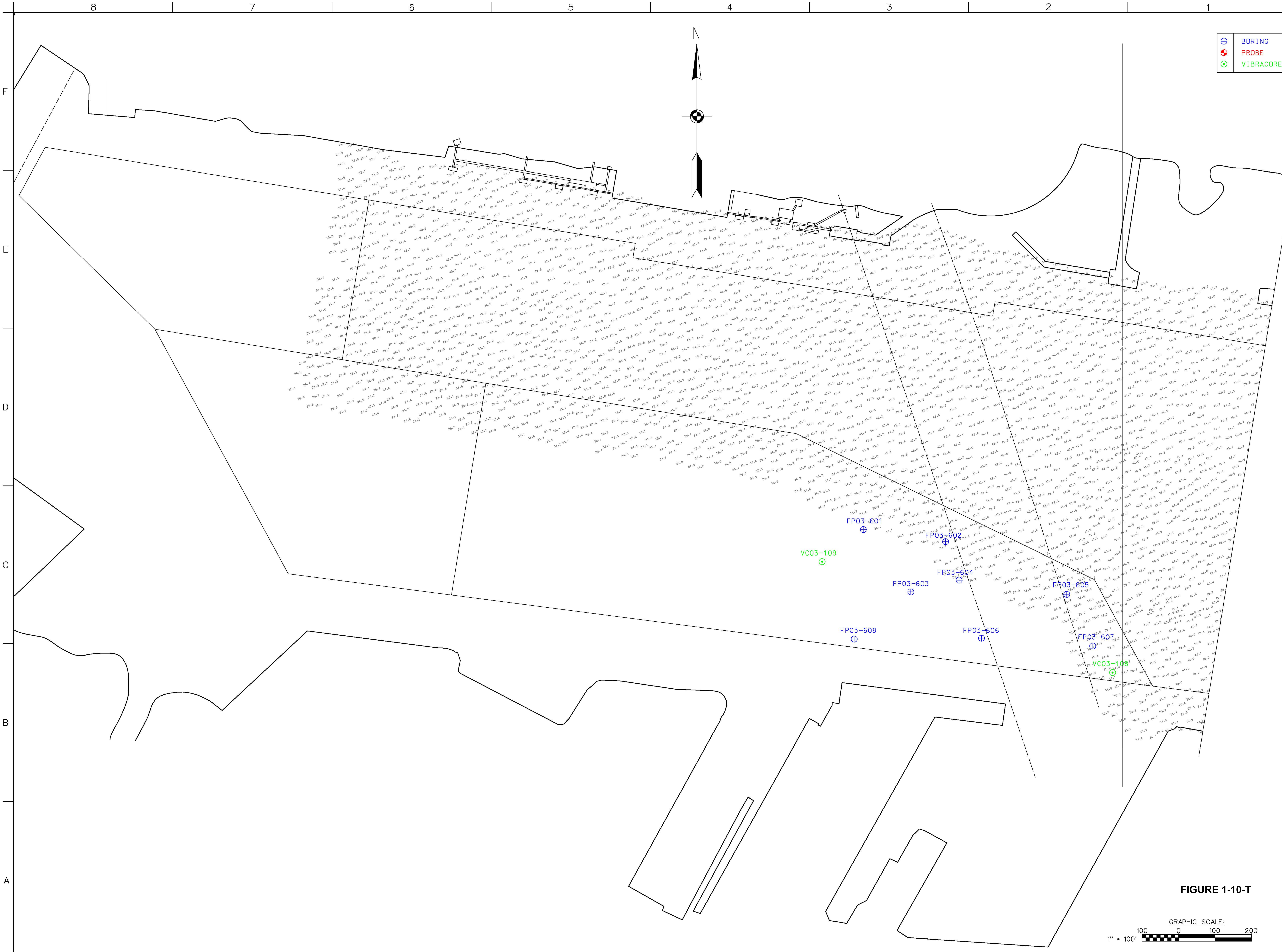


FIGURE 1-10-T

US Army Corps of Engineers
New England District

Symbol	Description	Date	Appr.

U.S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS
CONCORD, MASSACHUSETTS

Designed By: R.A.S. JDG, JMB
Drawn By: A.W.C / S.A.F. AMR
Date: 05/06/03
Rev.
Design file: MYSTICRIVER2.DGN
Drawing code:
File name:
Plot date:
Plot scale:

WATER RESOURCES DEVELOPMENT PROJECT
BOSTON HARBOR
BOSTON, MASSACHUSETTS
BORING AND PROBE LOCATIONS

MYSTIC RIVER

Reference number:
V-18
Sheet 20 of 21

N
BORING
PROBE
VIBRACORE
US Army Corps of Engineers
New England District
FP03-716
FP03-713
FP03-714
FP03-715
FP03-712
FP03-710
FP03-711
FP03-709
FP03-708
FP03-701
FP03-707
FP03-706
FP03-705
FP03-703
FP03-704
FP03-702
Designed By: K.A.S.
Drawn By: A.W.C. / S.A.F.
Design file: MYSTICRVER2.DGN
U.S. ARMY ENGINEER DISTRICT
CORPS OF ENGINEERS
CONCORD, MASSACHUSETTS
WATER RESOURCES DEVELOPMENT PROJECT
BOSTON HARBOR
BOSTON, MASSACHUSETTS
BORING AND PROBE LOCATIONS
CHELSEA RIVER
GRAPHIC SCALE:
1" = 100'
Reference number:
V-19
Sheet 21 of 21

FIGURE 1-10-U

GEI Consultants, Inc. 1021 Main Street Winchester, MA 01890	Project: Boston Harbor Feasibility Study Location: Boston, MA	Boring No.: FD03-701

Client:	U.S. Army Corp of Engineers	**Boring Location:**	N 508,555.77 ft E 730,602.45 ft	**Drilling Method:**	CWB
Driller:	Geologic	**Mud Line Elevation (ft.):**	-43.5	**Casing ID/OD:**	HW 4"/4.5"
Operator:	T. Tucker	**Datum:**	MLLW	**Sampler:**	2-1/2" I.D. Split Spoon
Logged By:	S. DiBartolo	**Total Depth (ft.):**	5.2	**Hammer Wt./Fall:**	300#/ 30"
Date Start/Finish:	9/24/03-9/24/03	**Water Level:**	Standing Water		

ABBREVIATIONS:
S = Split Spoon Sample
A = Auger Sample
U = Thin Wall Tube Sample
C = Rock Core Sample
NX,BX = Rock Coring
n/a,n/m = not Applicable, not Measured

HSA = Hollow Stem Auger Boring
SSA = Solid Stem Auger Boring
CWB = Cased Wash Boring
Open = Open Hole Boring
Pen. = Penetration length
Rec. = Recovery Length

WOC = weight of casing
WOR = weight of rods
WOH = weight of 300lb. hammer
RQD = Rock Quality Designation

S_u = Insitu Field Vane Shear Strength (psf)
$S_{u(lab)}$ = Lab Vane Shear Strength (psf)
S_v = Pocket Torvane Shear Strength (tsf)
Q_p = Pocket Penetrometer Unconfined Compressive Strength (tsf)

Elevation (ft.)	Casing Blows (/1 ft.)	Depth (ft.)	Sample No.	Pen./Rec. (in.)	Sample Depth (ft.)	Blows (/6 in.) Shear Strength (psf) or RQD (%)	N-value	Top Elevation (ft.)	Water Level*	Graphic Log	USCS Visual Descriptions and Remarks	Stratum
		0										
	24		S1	24/14	0.0 - 2.0	8-12-16-20	30				S1 (0-2") - ORGANIC SEDIMENT (OL); mostly homogeneous, nonplastic, organic fines; <5% fine sand; slight organic odor; black to dark gray.	ORGANIC SEDIMENT
-45	26										0.3 FEET/ El. -43.8 FEET	
											S1 (2-14") - GRAVELLY CLAY (CL); mostly medium plastic clay; ≅30-35% fine to coarse, subangular to angular gravel, max size ≅2"; ≅5-10% fine to coarse sand; gray.	GLACIAL TILL
			S2	24/21	2.0 - 4.0	15-15-21-25	36	-45.5			S2 - GRAVELLY CLAY (CL); Similar to S1 (2-14"); except finer gravel @ 12-21".	
			S3	14/12	4.0 - 5.2	11-35-100/2"	135/8"	-47.5			S3 - GRAVELLY CLAY (CL); Similar to S1 (2-14"); except max size ≅1-1/4".	
		5						-48.7			BOTTOM OF BOREHOLE, 5.2 FEET/ EL. -48.7 FEET.	
-50												
		10										
-55												
		15										
-60												
		20										
-65												
		25										
-70												

Remarks:

US State Plane, NAD27, Massachusetts Mainland Zone.
11.5' Tide Gage Reading @ 1150 hrs(-2.7' Tidal Bench-Mark difference).
7.5' Freeboard with 59.8' to Mud Line.

Stratification lines represent approximate boundaries between soil types; transitions may be gradual.

Project No.: 03176-0

GEI Consultants, Inc. 1021 Main Street Winchester, MA 01890	**Project:** Boston Harbor Feasibility Study **Location:** Boston, MA	**Boring No.:** FD03-701A

Client:	U.S. Army Corp of Engineers	**Boring Location:**	N 508,562.69 ft E 730,597.26 ft	**Drilling Method:**	CWB
Driller:	Geologic	**Mud Line Elevation (ft.):**	-43.8	**Casing ID/OD:**	HW 4"/4.5"
Operator:	T. Tucker	**Datum:**	MLLW	**Sampler:**	N/A
Logged By:	S. DiBartolo	**Total Depth (ft.):**	13.1	**Hammer Wt./Fall:**	300#/ 30"
Date Start/Finish:	9/25/03-9/24/03	**Water Level:**	Standing Water		

ABBREVIATIONS:
S = Split Spoon Sample
A = Auger Sample
U = Thin Wall Tube Sample
C = Rock Core Sample
NX,BX = Rock Coring
n/a,n/m = not Applicable, not Measured

HSA = Hollow Stem Auger Boring
SSA = Solid Stem Auger Boring
CWB = Cased Wash Boring
Open = Open Hole Boring
Pen. = Penetration length
Rec. = Recovery Length

WOC = weight of casing
WOR = weight of rods
WOH = weight of 300lb. hammer
RQD = Rock Quality Designation

S_u = Insitu Field Vane Shear Strength (psf)
$S_{u(lab)}$ = Lab Vane Shear Strength (psf)
S_v = Pocket Torvane Shear Strength (tsf)
Q_p = Pocket Penetrometer Unconfined Compressive Strength (tsf)

Elevation (ft.)	Casing Blows (/1 ft.)	Depth (ft.)	Sample No.	Pen./Rec. (in.)	Sample Depth (ft.)	Blows (/6 in.) Shear Strength (psf) or RQD (%)	N-value	Top Elevation (ft.)	Water Level*	Graphic Log	USCS Visual Descriptions and Remarks	Stratum
-45	WOC/ PUSH, PUSH, PUSH, PUSH, PUSH, 27	0									Note: No Sampling 0-8.1 ft. Casing to 8.1 ft. Roller-bit to Refusal @ 8.1 ft.	
-50	30, 40, 80/0.1'	5										
			C1	60/60	8.1 - 13.1	RQD = 25%	25%	-51.9			**8.1 FEET/ El. -51.9 FEET** C1 - PINK GRANITE; very hard; igneous; slightly weathered to unweathered; fractured throughout @ close spacing, with rust-coloring in most joints; pink with rust-coloring, some spots with green coloring; RQD = 25%.	BEDROCK
-55		10										
								-56.9			BOTTOM OF BOREHOLE, 13.1 FEET/ EL. -56.9 FEET.	
-60		15										
-65		20										
-70		25										

Remarks:

US State Plane, NAD27, Massachusetts Mainland Zone.
13.0' Tide Gage Reading @ 1206 hrs(-2.7' Tidal Bench-Mark difference).
7.5' Freeboard with 61.6' to Mud Line.

Stratification lines represent approximate boundaries between soil types; transitions may be gradual.

Project No.: 03176-0