Dredged Material Management Plan

EVALUATION OF BASELINE WATER COLUMN CHEMISTRY AND SEDIMENT RESUSPENSION POTENTIAL AT TWO CANDIDATE DREDGED MATERIAL DISPOSAL SITES IN BUZZARDS BAY

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Dredged Material Management Plan Phase 2C
MEPA Scope Item III

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EXECUTIVE SUMMARY

A comprehensive effort was undertaken in November 2000 to characterize baseline physical, chemical, and biological conditions at two candidate dredged material disposal sites in eastern Buzzards Bay and two nearby reference areas. As part of this effort, a bottom current study was conducted to evaluate the potential impact of currents and storm events at the two candidate disposal sites, specifically with respect to the potential for sediment resuspension and transport. In addition, samples were collected in November 2000 to characterize basic water column structure and water chemistry at the two sites.

The potential for sediment resuspension and transport was evaluated in several ways. Detailed bathymetric data collected at candidate Sites 1 and 2 were used to determine whether there were any significant changes in depth over a ten-year period that would indicate significant long-term sediment erosion or deposition in this part of Buzzards Bay. In addition, available data from nearby locations were used to characterize both average and "extreme" winds, waves, and bottom currents likely to be experienced at the two candidate disposal sites. A numerical model then was used to calculate the potential for sediment resuspension at the sites under average and extreme wind, wave and current conditions. Water column structure was characterized through vertical profile measurements of salinity and temperature using a CTD, and water chemistry was evaluated by collecting near-bottom and near-surface seawater samples.

The bathymetric "depth difference" comparisons failed to detect any significant changes in depth (defined as greater than ±0.5 m) in the vicinity candidate disposal Sites 1 and 2 over the ten year period 1990 to 2000. These results indicate an overall lack of long-term, significant sediment erosion potential in the immediate vicinity of candidate disposal Sites 1 and 2.

Based on historical records, a wind speed of 7.76 m/s (17 miles/hour) was considered to be indicative of average conditions at the two candidate disposal sites, while a wind speed of 15 m/s (33.6 miles/hour) was considered representative of extreme conditions likely to be experienced during storm events. Applying these wind speeds to the maximum fetch of 35 km across the central axis of Buzzards Bay to the southwest of the candidate sites resulted in calculated significant wave heights of 0.635 m (average) and 1.6 m (extreme), respectively.

Based on long-term current meter records from a nearby location having a similar water depth, it was found that near-bottom currents at the two candidate sites are likely oriented in a southwest-northeast direction. The average current speed at the candidate sites was taken to be 7 cm/s, while a current speed of 15 cm/s was considered representative of extreme conditions experienced during storm events. The one-dimensional Glenn and Grant model then showed that under the average wind (7.76 m/s), wave (0.635 m) and bottom current (7 cm/s) conditions defined herein, there was no sediment resuspension at the candidate disposal sites. Under the extreme wind (15 m/s), wave (1.6 m) and current (15 cm/s) conditions defined herein, there was limited resuspension of very fine (i.e., silt-sized) sediment particles and negligible resuspension of coarser sediment fractions. Overall, it was concluded that there is very limited potential for significant sediment erosion and transport by average bottom currents and/or during storm events at the candidate disposal sites.

The water column at candidate disposal Sites 1 and 2 was found to be vertically well-mixed at the time of sampling in November 2000. Temperature throughout of the entire water column was consistently between 11° and 12° C, while salinity throughout the entire water column was equally constant at around 32 ppt. Concentrations of a suite of chemical contaminants (metals, pesticides, PAHs and PCBs) in near-surface and near-bottom water samples from Sites 1 and 2 were consistently below EPA Water Quality Criteria. However, copper concentrations in surface water samples obtained at the two sites slightly exceeded the EPA Water Quality Criteria. Copper-containing antifouling paints and copper pipes for water lines both have been identified as possible sources of copper contamination in Buzzards Bay.

1.0 INTRODUCTION

1.1 Background

In 1995, the Massachusetts Department of Environmental Management (DEM) proposed to designate an open-water dredged material disposal site within the area of the former Cleveland Ledge Disposal Site (CLDS) in eastern Buzzards Bay (Figure 1-1). On 8 March 1995, the DEM filed an Environmental Notification Form (ENF) describing the proposed site, a circular area having a diameter of 500 yards centered at 41° 36.00' N, 70° 41.00' W, corresponding to the location of the former Buzzards Bay Disposal Site (BBDS) used by U.S. Army Corps of Engineers (Figure 1-2). In the ENF, the DEM indicated that the proposed new BBDS would be designated for the receipt of coarse-grained dredged material only (i.e., silt-clay fraction of 20% or less). Following regulatory response and public comment, the Secretary of Environmental Affairs issued a Certificate on the ENF on May 10, 1995, requiring the preparation of an Environmental Impact Report (EIR) pursuant to the Massachusetts Environmental Policy Act (MEPA). The required scope for the EIR is described in the Certificate (referred to herein as the MEPA Scope).

As part of a larger project to develop a Dredged Material Management Plan (DMMP) for the state of Massachusetts, the Massachusetts Coastal Zone Management Agency (MCZM) has assumed responsibility for addressing the MEPA Scope and preparing the EIR. In March 1998, MCZM filed a Notice of Project Change, proposing to designate the BBDS for all physical categories of dredged material deemed suitable for open ocean disposal (from fine- to coarse-grained), rather than limiting the designation to coarse-grained material only.

In fulfillment of MEPA Scope Item I, MCZM sponsored a Needs Analysis that documented the regional need for a disposal site, estimated the types and quantities of dredged material to be generated, and identified local, regional and state dredged material use and disposal policies (Maguire Group Inc., 1998a). Under MEPA Scope Item II, an Alternatives Analysis was completed to evaluate: 1) the potential environmental benefits and drawbacks of opening an historic disposal site versus identifying a new site, and 2) the feasibility of using the existing Massachusetts Bay Disposal Site (MBDS) or Cape Cod Disposal Site (CCDS; Maguire Group Inc., 1998b).

The Alternatives Analysis concluded that while the CCDS could be used for disposal of material from dredging projects in the northern end of Buzzards Bay, the significant transit distances generally precluded the use of either the CCDS or MBDS as cost-effective options. The Alternatives Analysis also identified several drawbacks to the BBDS as originally proposed by DEM in 1995 (Figure 1-2), including the potential for erosion of fine-grained sediment, limited access by deeper draft hopper dredges, and inadequate long-term capacity. To overcome these drawbacks, it was recommended that deeper and larger areas within and near the historic Cleveland Ledge Disposal Site be considered as potential disposal site locations.

Under MEPA Scope Item III, MCZM is required to collect data to determine the baseline physical and biological characteristics of any proposed disposal site(s), including bathymetry, sediment grain size and chemistry, benthic community structure, bottom currents, fisheries, and water column chemistry. Under contract to MCZM, SAIC conducted a survey in May 1998 involving high-resolution bathymetry and side-scan sonar across a relatively large area encompassing the southern half of the historic Cleveland Ledge Disposal Site (Maguire Group Inc., 1998c). The objective of this reconnaissance survey was to gather data on the physical characteristics of the seafloor to facilitate optimal siting of the proposed BBDS.

In general, the May 1998 study identified areas having water depths greater than 12 m as being preferred disposal locations, because such areas have the potential to limit sediment resuspension and maximize long-term capacity while accommodating access by deep draft hopper dredges. The May 1998 bathymetric data revealed two locations in the surveyed area having water depths greater than 12 m: a basin located near the eastern boundary of the historic Cleveland Ledge Disposal Site ("eastern basin") and an area near the southern boundary ("southern basin"; Figure 1-3). SAIC conducted a second bathymetric survey in October 2000 to characterize in greater detail the bottom topography in the vicinity of the southern basin. The two candidate disposal sites selected for further study under MEPA Scope Item III are located over the southern and eastern basins and designated as Sites 1 and 2, respectively (Figures 1-3 and 1-4).

Site 2 is a rectangular area with dimensions 1000 m × 1700 m (Figure 1-4). It is under consideration as a potential disposal site because it appears to be a predominantly depositional seafloor environment, having sufficient water depth and capacity, that has already been affected by past dredged material disposal at the historic Cleveland Ledge Disposal Site. However, this site has the drawback of being close to shallow areas (e.g., Gifford Ledge to the east and the historic Cleveland Ledge "dump top" to the west), which could limit access by deeper draft vessels and potentially represent a hazard to navigation.

The deeper parts of the southern basin occur just outside the southern boundary of the Cleveland Ledge Disposal Site (Figures 1-3 and 1-4). Since deeper areas within Buzzards Bay have the greatest potential to act as containment sites for deposited dredged material, a decision was made to establish candidate Site 1 (a square area measuring 1600 m × 1600 m) over this deeper part of the southern basin.

1.2 Study Requirements and Overview of Approach

In evaluating the suitability of any seafloor location for placement of dredged material, it is important to determine whether, over the long-term, it represents an erosional or a depositional environment (i.e., is it primarily a dispersive or a containment site?). Consequently, MEPA Scope Item IIId requires that a bottom current study be conducted to evaluate the potential impact of currents and storm events at candidate Sites 1 and 2 in Buzzards Bay, specifically with respect to the potential for sediment resuspension and transport. This requirement is addressed herein using a multi-step approach:

1) "Depth-difference" comparison of high-resolution bathymetric data collected near the two sites in 1990, 1998 and 2000 are used to provide an indication of any net erosion or deposition in this part of Buzzards Bay over a ten-year period,

2) Existing data from nearby locations are used to characterize both average and "extreme" winds, waves, and bottom currents likely to be experienced at the two candidate disposal sites, and
3) A model is used to calculate the potential for sediment resuspension at the sites under average and extreme conditions.

In addition to the characterization of bottom currents, MEPA Scope Item IIIe requires that the candidate sites be characterized with respect to basic water column structure and water chemistry. This objective is addressed herein as follows:

1) Vertical profiles of temperature, salinity and density obtained at the two sites in November 2000 are used to characterize water column structure, and
2) Concentrations of chemical contaminants measured in near-surface and near-bottom water samples collected at the two sites in November 2000 are used to characterize water column chemistry.

The current study and basic water column characterization reported here are components of a broader effort to evaluate the baseline physical, chemical, and biological features of candidate Sites 1 and 2 and determine the suitability of each for dredged material placement.

2.0 METHODS

2.1 Evaluation of Bottom Currents and Sediment Resuspension Potential

2.1.1 Bathymetric Depth Difference Comparisons

In March 1990 and again in May 1998, SAIC conducted a precision bathymetric survey of a relatively small, 600 m × 600 m area surrounding the former BBDS. In both surveys, the lanes were spaced 25-m apart and oriented north-south. Comparable field procedures and data processing methods were used in both surveys, including editing the raw bathymetric soundings for outliers and applying corrections for sound velocity, transducer draft, and tidal variation, as described in a previous report (Maguire Group Inc., 1998c). To quantify the relative change in depth during the eight years between surveys, a depth difference map was generated. First, bathymetric grids of the same size and resolution (25-m grid cell size) were prepared for each survey. Each depth (grid cell) value from the older (March 1990) survey was then subtracted from the depth value from the more recent (May 1998) survey. The results were then contoured as a bathymetric map, with contours depicting the positive and negative depth differences between the two surveys.

In May 1998 and October 2000, SAIC also acquired precision bathymetric data across relatively large areas near candidate disposal Sites 1 and 2. The May 1998 survey covered a 2,300 m × 3,400 m area encompassing the southern half of the former Cleveland Ledge Disposal Site (Figures 1-3 and 1-4). The October 2000 survey covered a 3,200 m × 3,200 m area surrounding candidate disposal Site 1; this survey overlapped with the May 1998 survey area (Figure 2-1). The lane spacing in both surveys was 50 meters, and comparable field and data processing methods were again employed (SAIC 2001). A depth difference map was generated for the area of overlap shown in Figure 2-1 to quantify the relative depth change in the >2 year period between the two surveys. Creation of this depth difference map followed the procedures described above, with the exception that a 50-m grid cell size was utilized.

2.1.2 Characterization of Winds, Waves and Bottom Currents

Winds

The National Oceanographic and Atmospheric Administration's (NOAA) National Data Buoy Center (NDBC) maintains the BUZM3 C-MAN meteorological station located at the entrance to Buzzards Bay (Figure 2-2). Instruments at this station continuously measure wind speed and direction at an elevation of 24.8 m above mean sea level. It is generally assumed that winds experienced at the BUZM3 station at any given time are comparable to those experienced simultaneously at candidate disposal Sites 1 and 2. Therefore, to provide an accurate representation of conditions actually experienced at the two candidate sites over the long-term, a continuous record of wind speed and direction covering a nine year period (1985 to 1994) was downloaded from the BUZM3 website. This period was chosen because it was the longest one for which a continuous record was readily available from the BUZM3 station (note that this platform and its instruments became unavailable for several years in the mid-1990s). Proprietary SAIC software was used to perform a bivariate analysis (speed versus direction) of this long-term record and produce a summary table and corresponding "wind rose" diagram. Following standard meteorological convention, wind direction in this report is given as the direction *from which* the wind was blowing.

Waves

Given their location in eastern Buzzards Bay, candidate Sites 1 and 2 are relatively well-protected from the effects of large, long-period, open-ocean waves (i.e., swells). Waves produced by winds blowing across the open waters of Buzzards Bay *will* occur at the sites, with the highest waves expected to occur when winds blow from the southwest, across the greatest possible fetch. Therefore, to estimate the maximum waves potentially experienced at the candidate disposal sites under both average and extreme wind conditions, the fetch was taken to be 35 km. This is the distance from the BUZM3 C-MAN station at the bay entrance to the candidate disposal sites; it essentially represents the full length of Buzzards Bay (Figure 2-2). Using this fetch, calculations of maximum wave height were made following standard coastal engineering procedures as described in the Shore Protection Manual (Horikawa, 1978).

Bottom Currents

Over the period January 1982 to November 1985, the Woods Hole Field Center of the United States Geological Survey (USGS) deployed a current meter at Cleveland Ledge, located in eastern Buzzards Bay about 6 km north of candidate disposal Sites 1 and 2 (Figure 2-2). In the absence of any intervening land masses or major bottom features, it is assumed that currents at the USGS meter location are roughly comparable to those experienced at the candidate sites. The water depths of 13 to 14 m at the meter deployment location are similar to the average depths at the candidate sites. The meter made hourly recordings of the speed and direction of currents occurring approximately one meter above the seafloor. The meter was not deployed continuously over the 3+ year period, but rather in several discrete intervals that each lasted for more than one month.

Overall, hourly near-bottom current measurements were obtained from the USGS Cleveland Ledge meter for a total of 291 days over the period January 1982 to November 1985. Similar to the wind data, proprietary SAIC software was used to perform a bivariate analysis of the long-term record of hourly near-bottom current measurements and produce a summary table and corresponding diagrams. Current directions in this report are given in terms of the direction *toward which* the current was flowing.

2.1.3 Modeling of Sediment Resuspension

A key objective of this study concerns the potential ability of waves and currents to mobilize and transport sediments at the candidate disposal sites. Using the data described above, estimates were developed of both average and extreme wave and bottom currents likely to be experienced at the candidate sites. Using these data and information on the grain size of existing surface sediments at the sites, sediment resuspension potential was evaluated using the one-dimensional Glenn and Grant (1987) bottom boundary layer model.

The Glenn and Grant (1987) model requires measurements or estimations of the following parameters: wave amplitude, or significant wave height; peak wave period; current velocity at a given distance from the sea bed (usually 1 m) and the angle between the current vector and the direction of the waves. The model is not particularly sensitive to this angle, and if it is not known, it is assumed to be 90°, because waves generally propagate perpendicular to, and currents generally flow along, the isobaths. The sediment parameters required as input to the model are grain size and density of the bed sands. The model's non-dimensional concentration of sediment at the bed also needs to be estimated and is usually taken at $C_{bed} = 0.6$. The other important input is the total depth of water.

The model outputs a multitude of boundary layer and sediment concentration parameters. Of interest here is the bottom friction velocity caused by the combined action of waves and bottom currents, U_{*cw}, the apparent bottom roughness length, Z_{OC}, the mean sediment concentration in the boundary layer and the instantaneous depth of the seabed that needs to be mobilized to provide the calculated quantity of sediment in suspension. The latter will be referred to herein as the erosion depth. The details of the definitions of these quantities are given by Glenn and Grant (1987).

The performance of Grant and Madsen (1979) and the Glenn and Grant (1987) models has been examined for a number of bottom boundary layer field studies on continental shelves (Wiberg and Smith, 1983; Grant et al., 1984; Cacchione et al., 1987; Drake et al., 1992). The results are encouraging in that the wave-current enhancement of apparent bottom boundary roughness have been confirmed. Uncertainties in the model formulations that have not been well tested against field data include the roughness caused by sand waves, the evolution of ripples under increasing wave generated boundary stress, and the calculation of reference suspended sediment concentration just above the bed (Drake and Cacchione, 1989). However, even the critical Shields parameter for the onset of particle motion on a bed has been shown to differ from established values when the bed is composed of mixed sizes instead of just one (Wiberg and Smith, 1987). Wikramanayak and Madsen (1994) have reviewed the uncertainties in some of the empirical formulae in the Glenn and Grant (1987) model. In some cases they argue for some changes in formulations for roughness caused by ripples, ripple growth and calculation of the reference concentration for the suspended sediment transport.

The Glenn and Grant (1987) model is a one dimensional (depth and time) boundary layer formulation and as such does not take into account larger-scale variations in topography and is unable to calculate redistribution of sediment by the spatially and time-varying bottom currents. Therefore, the model computed instantaneous erosion depth should not be viewed as the amount of sediment that is removed by the bottom stresses, but rather as the depth of the bed that is instantaneously stirred and mixed by the waves and currents. The amount of sediment removed from a site cannot be calculated by a one-dimensional model, and most of the sediment that is in suspension during a major storm will fall back to the bed again after the storm activity dies down.

2.2 Water Column Characterization

2.2.1 Vertical Profiles of Temperature and Salinity

A Seabird Instruments, Inc. SEACAT SBE 19-01 Conductivity, Temperature and Depth (CTD) probe was used to obtain vertical water column profiles of temperature, salinity and density within each of the candidate sites. The measurements were made at the center of each site, where the CTD was deployed at roughly 2 to 3 hour intervals over the course of two different days to detect any temporal or tide-induced variations in water column structure.

2.2.2 Water Chemistry

At each of the two candidate disposal sites, a pre-cleaned Nisken bottle was used to obtain one near-surface and one near-bottom water sample for analysis of chemical contaminants. The near-surface water was collected roughly 1 m below the water's surface, and the near-bottom sample was collected approximately 1 m above the seafloor. These samples were taken from the center of each of the sites. Upon retrieval of the Nisken sampler, the water was transferred to pre-cleaned containers supplied by the laboratory. These samples were then stored on ice in an insulated cooler and held at approximately 4° C during the field sampling operation. The coolers were later packed with additional ice and delivered to Woods Hole Group Environmental Laboratories in Raynham, MA for chemical analysis.

In the chemistry laboratory, the samples were analyzed for "total recoverable" concentrations of selected metals, pesticides, and industrial chemicals, including polychlorinated biphenyls (PCBs) and pentachlorophenol. The specific compounds analyzed are those identified by the U.S. Environmental Protection Agency-Region 1 and the U.S. Army Corps of Engineers-New England District as "required contaminants" for determining compliance with water quality criteria in evaluating the suitability of dredged material for open water disposal. These contaminants are listed in Table 5 of the draft regional implementation manual for dredged material evaluation (U.S. Environmental Protection Agency/U.S Army Corps of Engineers, 1998). The analyses were performed using standard U.S. EPA methods and QA/QC procedures, as follows: metals by chelate extraction (EPA SW-846 Methods 6020/7000 Series), hexavalent chromium (EPA SW-846 Method 7196A), pentachlorophenol (EPA SW-846 Method 8270 modified), total cyanide (EPA SW-846 Methods 9010B/9014), and pesticides/PCB congeners (EPA SW-846 Method 8081A/8082).

3.0 RESULTS

3.1 Bathymetric Depth Difference Comparisons

The results of the depth difference comparison between the May 1998 and March 1990 precision bathymetric surveys around the former BBDS are shown in the bottom contour map of Figure 3-1. In general, positive differences shown in such depth difference maps indicate that material has accumulated, while negative differences indicate that material has either eroded or compacted between 1990 and 1998. However, the error of the depth-differencing procedure, or the depth change considered below the resolution of the method, is estimated to be on the order of about ±0.5 m for the surveys shown in Figure 3-1.

Therefore, the depth difference plot at the bottom of Figure 3-1 indicates little significant change in depth between the two surveys over and above the resolution of the method. Specifically, the topographic change over this period generally was <0.5 m (i.e., less than reliably detected within the resolution of the method) and was dominated by areas with changes of <0.25 m. The random pattern of the positive and negative depth differences depicted in Figure 3-1 provides additional evidence that these apparent topographic changes are artifacts of the depth-differencing procedure rather than areas of true erosion or deposition. The data are consistent with the record of no disposal of dredged material at the BBDS area during the interim period between surveys. The relative absence of any significant *negative* depth changes in Figure 3-1 is particularly relevant to the present study, as it indicates that surface sediments in this area have not experienced appreciable erosion over an eight-year period.

The results of the depth difference comparison between the October 2000 and May 1998 bathymetric surveys in the southern part of the former Cleveland Ledge Disposal Site are shown in Figure 3-2. The contour map indicates that depth differences over the majority of the area were within the range ±0.5 m, again equivalent to the estimated “detection limit” of the method. As previously reported (SAIC, 2001), the contour map does show two small areas of apparent significant depth change calculated over locations representing topographic high points, having vertical relief greater than that found on the surrounding seafloor (Figure 3-2). In such locations, it is known that minor deviations in depth measurements can become exaggerated when successive bathymetric surveys are compared. These apparent depth changes therefore are considered to be exaggerations or artifacts of the depth differencing procedure. Overall, the depth difference comparison depicted in Figure 3-2 was interpreted as showing no significant topographic changes between the two consecutive surveys, indicating an overall absence of significant sediment erosion or deposition in this area.

3.2 Characterization of Winds, Waves and Bottom Currents

Winds and Waves

The BUZM3 C-MAN station shown in Figure 2-2 is located approximately 7 km offshore of the mainland and fully exposed from the west to the southeast. Therefore, winds at this location may be somewhat higher on average than those experienced at the candidate disposal sites, which are exposed to longer fetches only from the southwest, along the center line of

Buzzards Bay. In this sense, using the winds from the BUZM3 station provides a slight "margin of error" in calculating extreme or worst-case conditions likely to be experienced at the candidate sites. Nevertheless, it is assumed that the basic patterns of wind speed and direction are broadly comparable between the two locations.

The bivariate (speed and direction) evaluation of the 9-year record from BUZM3 (Table 3-1) indicates that 49.1% of the winds were in the arc from the south to the west-northwest (180° through 300°). Although these directions accounted for a significant portion of the record, the mean speed in each of the twelve 30° directional increments were comparable, ranging between 6.7 and 8.7 m/s (14.9 to 19.5 miles/hour). The maximum measured speeds in each 30° directional increment were also similar, varying between 21.1 m/s (47.2 miles/hour) from the north-northwest to 34.5 m/s (77.2 miles per hour) from the east-southeast (note: this latter measurement was obtained during Hurricane Bob on August 19, 1991). At the measurement site, the overall mean wind velocity over the indicated measurements was directed *toward* approximately 80° true (i.e., *from* the west-southwest), with a speed of approximately 2.2 m/s (5 miles/hour). These patterns become intuitively clear from the wind rose (Figure 3-3), which graphically summarizes the conditions experienced at the BUZM3 C-MAN station as presented in Table 3-1.

As previously indicated, the estimates of potential wave characteristics at the candidate disposal sites are based on assuming a fetch of 35 km, essentially representing the length of Buzzards Bay. [Note: evaluating the impact of the variable geometry and bottom topography of the Bay on the refraction and diffraction of waves potentially coming from outside the bay is beyond the scope of this undertaking]. Using this fetch distance, waves were calculated for both "average" and "extreme" wind conditions. The overall average wind speed indicated in Table 3-1 of 7.76 m/s (17 miles/hour), blowing from the southwest up the center of the bay, generates a fetch-limited significant wave height of 0.635 m, with a prevailing wave period of 3.77 seconds. For the "extreme" condition, a wind speed of 15 m/s (33.6 miles/hour) was selected. While 15 m/s is not the absolute maximum wind speed observed over the 9-year period, it is considered a realistic "extreme" value because, as shown in Table 3-1, 96% of the wind speeds measured over the 9-year period were equal to or less than this value. In other words, the long-term record indicates that winds as high as 15 m/s are relatively rare in Buzzards Bay, occurring only 4% of the time. Assuming an "extreme" wind of 15 m/s from the west-southwest as the generating process, the computed significant wave height, H_s, at the candidate disposal sites was calculated to be 1.6 m.

Currents

As shown in Table 3-2, the maximum current speed measured during the 291 days of the USGS current meter deployment was 32.74 cm/s (6.36 knots). The bivariate analysis of these data indicates that the overall average current speed (irrespective of direction) was 7.08 cm/s (1.4 knots), and approximately 97.7% of the measured currents were less than 15 cm/s, or 2.9 knots (Table 3-2). The current rose diagram generated from these data indicates that the predominant current orientation was southwest-northeast (Figure 3-4).

While the maximum current speed measured during the meter deployment period (32.74 cm/s) was considerably greater than the overall average (7.08 cm/s), it should be noted that only 0.1% of the measured currents exceeded 25 cm/s (4.86 knots). Thus, if it is assumed that these data statistically represent currents experienced at the candidate disposal sites, then current speeds greater than 25 cm/s would have a cumulative duration for all occurrences of approximately 9 hours out of 291 days. Under this same scenario, currents in excess of 15 cm/s would have a cumulative duration for all occurrences of approximately 200 hours, or 8.4 days out of the total 291 days.

The near bottom current measurements summarized in Table 3-2 were analyzed for tidal velocity constituents. The semi-diurnal (M_2) tidal current was substantially greater than all other diurnal and semi-diurnal constituents (e.g., maximum of 8.1 cm/s for the M_2, 1.9 cm/s for the N_2 and 1.3 cm/s for the S_2). The variation of the M_2 tidal currents is shown graphically in Figure 3-5. The minimum M_2 tidal current is on the order of 2 cm/s (0.4 knots). This tidal current vector rotates counterclockwise, as indicated by the arrow attached to the elliptical path traced by the M_2 tidal current vector end point. Although these measurements were made approximately 6 km north of candidate disposal Sites 1 and 2, they indicate a north-northeast to south-southwest orientation of the M_2 tidal current ellipse, which is generally along-shore relative to the orientation of the main axis of the bay.

Winds exceeding 15 m/s and bottom currents exceeding 15 cm/s are probably not independent events for a semi-enclosed, relatively shallow body of water like Buzzards Bay. However, if, as a broad approximation, these events are assumed to be independent, then the following computations can be made:

- Probability of wind speeds from any direction exceeding 15 m/s = 0.04, and
- Probability of currents from any direction exceeding 15 cm/s (all directions)= 0.023.

The joint probability of these two events is given by the product of the probability of each of the events, thus:

- P[Winds>15 m/s, Currents>15 cm/s]= (0.04)•(0.023)=0.00092 or ≈0.1%

Based on these assumptions, the joint occurrence of extreme winds and currents would exist, on average, approximately 9 hours per year (not necessarily continuously). Clearly, as an approximation, these two conditions combine to represent a relatively rare event. If the winds are restricted to only those from the south-southwest blowing along the longitudinal axis of the bay, then this joint probability reduces to 0.00014 or 0.014% = 1.2 hours per year.

3.3 Sediment Resuspension Modeling

Sediment resuspension at the candidate sites was modeled for both "average" and "extreme" wind/wave and bottom current conditions. As described above, the average wind of 7.76 m/s blowing across the maximum fetch of 35 km was found to generate a significant wave height of 0.635 m, with a period of 3.77 seconds, at the candidate sites. Using these conditions in combination with the observed overall average current speed of 7 cm/s directed toward 15° in a water depth of 12 m, the Glenn and Grant (1987) model indicates that no sediment resuspension would occur, even for fine silt, the smallest diameter grains evaluated.

The extreme wind conditions of 15 m/s described above resulted in a calculated significant wave height of 1.6 m, with a period of 6.6 s, directed toward 30°. As further input to the Glenn and Grant (1987) model, these extreme wind conditions were combined with the extreme bottom current of 15 cm/s, directed toward 15°, in a water depth of 12 m. The speed of 15 cm/s is considered representative of an extreme current condition because approximately 98% of the actual measurements were less than this value (Table 3-2). Using these input parameters, estimates of the depth of the active bottom sediment layer ("erosion depth") were made for five different sediment size classes (Table 3-3).

The erosion depth shown in Table 3-3 reflects the depth, in millimeters, of the layer of bottom sediment with the indicated size that would be put into suspension by the extreme wind/wave and current conditions specified. Thus, for surface sediments at the candidate disposal sites consisting entirely of unconsolidated, fine silt, the model predicts that a layer of 5.688 mm (0.57 cm) will be eroded off the bottom and put in suspension. For coarser sediments (i.e., sediment grains having larger diameters than those of coarse silt), the modeled depth of erosion is considerably less and essentially negligible (<0.016 cm). These model results clearly indicate that even for the relatively infrequent extreme conditions specified for this evaluation, relatively little surface sediment at the candidate disposal sites would be suspended and available for transport as suspended load.

3.4 Water Column Characterization

The CTD profiles obtained at the center of candidate Sites 1 and 2 periodically over the course of several days are presented in Appendix A. Representative profiles from each site are shown in Figures 3-6 and 3-7. Overall, these profiles show almost no vertical structure or stratification of the water column at the time of the sampling. Temperature throughout of the entire water column was consistently between 11° and 12° C, while salinity throughout the entire water column was equally constant at around 32 ppt (Figures 3-6 and 3-7). As indicated by the series of plots in Appendix A, there was little variability in water column structure observed within each site at different stages of the tide over the course of a day, and equally little variability between sites or among different days. These results indicate that the water column was vertically well-mixed at the time of the November 2000 sampling.

Results of the chemical analysis of near-surface and near-bottom water samples obtained at the center of each of the candidate sites in November 2000 are provided in Tables 3-4 through 3-6. All of the analytes were either not detected, or, in the case of several of the metals, detected at very low concentrations (Tables 3-4 through 3-6). Concentrations of several of the metals (cadmium, copper, lead, nickel, and zinc) were higher in the surface water sample than in the bottom water sample at each of the sites. However, with the exception of copper, the concentrations of all of the metal, pesticide and PCB analytes were considerably below the corresponding EPA water quality criteria (where such criteria exist). In the surface water samples from both of the candidate sites, the copper concentrations (3.2 μg/L at Site 1 and 3.0 μg/L at Site 2) were slightly higher than the water quality criterion of 2.9 μgL (Table 3-4).

4.0 DISCUSSON

The main objective of this investigation was to address the MEPA Scope and conduct a study to evaluate the potential impact of currents and storm events at candidate Sites 1 and 2 in Buzzards Bay, specifically with respect to the potential for sediment resuspension and transport. In addressing this objective, a critical first involved characterizing both the normal or "average" wind, wave and current regimes existing at the candidate sites, as well as define "extreme" conditions (i.e., high winds, waves and currents) most likely to occur during storm events. Readily-available, long-term records of wind and bottom currents from nearby locations were used to provide a reasonable approximation of both average and extreme conditions likely to be experienced at the two candidate sites. For this first-order assessment of sediment resuspension potential, this desktop approach is considered sufficient, but it does not necessarily preclude making site-specific wave and/or bottom current measurements if a preferred site is identified in the future.

The bathymetric depth difference comparisons showed that over relatively long time scales (i.e., many years), there was little significant change in seafloor topography detected in specific locations very close to the two candidate disposal sites. Although the overall significance of this observation is muted by the somewhat coarse resolution of the depth differencing method (estimated to be on the order of ±0.5 m, or ±1.64 ft), it at least provides a first-order indication that strong or persistent erosional forces are not characteristic of this area of Buzzards Bay. The depth difference comparison indicating negligible erosion, over an 8-year period, of the dredged material present on the seafloor at the former BBDS is particularly relevant to the present investigation. This former disposal site occurs at shallower depths than candidate Sites 1 and 2 and is therefore more susceptible to erosion, and it should be noted that at least one major storm event (Hurricane Bob in August 1991) directly impacted this site during the period encompassed by the depth difference comparison.

Previous studies have demonstrated that tidal forcing is the dominant factor in the circulation within Buzzards Bay (Howes and Goehringer, 1996), in good agreement with the present results that showed the semi-diurnal (M_2) tidal current to be the dominant constituent of the long-term record. The main orientation of the tidal flow at the USGS current meter deployment location was found to be southwest-northeast, and studies of Bay-wide circulation patterns suggest that this same orientation likely exists at the candidate sites (Figure 4-1). Local wind conditions also can influence the tidal circulation, and both the present and previous studies indicate that winds from westerly quarters (mainly southwest to northwest) are most common over Buzzards Bay (Howes and Goehringer, 1996).

Given their proximity to the shoreline in eastern Buzzards Bay, the candidate disposal sites are relatively well protected from the effects of wind-driven waves in all directions but the southwest. The long-term wind record from the BUZM3 station was used to define average and extreme wind speeds, and these were applied to the longest possible fetch (e.g., southwest across the long axis of the Bay) to calculate corresponding significant wave heights potentially experienced at the candidate sites. These wind/wave conditions were then used in combination with the observed current speeds to model the potential for sediment resuspension under both average and extreme (i.e., "storm event") conditions. The model indicated that no sediment resuspension would occur under the conditions defined as average, and only the finest sediment fraction tested (i.e., fine silt) would be subject to limited resuspension under the conditions defined as extreme, while coarser sediment fractions experienced negligible resuspension (Table 3-3).

Overall, the modeling results indicating negligible long-term erosion potential for all but the finest sediment fractions are supported by the grain size distributions found to exist in surface sediments at the two candidate disposal sites. Specifically, the REMOTS® sediment-profile imaging and grab sampling surveys of November 2000 showed that the shallower areas of both sites were dominated by very fine sands and sand-over-mud stratigraphy, likely the result of longer-term winnowing of fine sediment fractions (i.e., selective resuspension of silts and clays during extreme events, as indicated in Table 3-3). In contrast, the deeper areas of both sites were found to be dominated by silt-clay, indicating net long-term accumulation (i.e., deposition) of fines as a result of bathymetric entrapment and less dynamic current activity. These results are consistent with historical observations indicating that fine-grained sediments tend to accumulate in deeper areas (i.e., depth greater than about 12 m), while sands dominate the shallower nearshore areas of Buzzards Bay (Moore, 1963; Howes and Goehringer, 1996).

A secondary objective of the present study was to characterize water column structure and chemistry at the two candidate sites. Not surprisingly, the water column was found to be vertically well-mixed in November 2000, attributed to the action of winds at this time of year and the breakdown of any seasonal thermal stratification which may existed during the preceding warmer months. Such results are typical for a relatively shallow, temperate estuary like Buzzards Bay. In general, Howes and Goehringer (1996) report that water column stratification can periodically exist during summer months in the central region of Buzzards Bay, mainly as a result of thermal density differences but occasionally due to pulses of freshwater causing salinity effects as well. However, the extent to which such stratification may be experienced at the candidate sites, which are located away from the deeper central region of the Bay, cannot be determined from the limited sampling of the present study.

With the exception of copper, the concentrations of metals, pesticides and PCBs in samples of surface and bottom water from Sites 1 and 2 were all below the EPA Water Quality Criteria. Concentrations of several metals (cadmium, copper, lead, nickel and zinc) were higher in the surface samples than in the bottom, and copper concentrations in the surface water samples from both sites slightly exceeded the Water Quality Criteria value of 2.9 μg/L. The specific cause of this apparent elevation of metal concentrations, particularly copper, in the near-surface water is unknown. In general, Howes and Goehringer (1996) indicate that metals, including cadmium, chromium, lead, mercury, copper, silver, nickel and arsenic, can enter Buzzards Bay waters through industrial waste discharge, boat paint, sewage effluent, and dredged material, as well as through atmospheric deposition and natural rock weathering. In the specific case of copper, Howes and Goehringer (1996) note that it was used historically in the New Bedford metal plating industry, and the use of copper-containing antifouling paints and copper pipes for water lines both provide low-level inputs of copper to the bay in the present day.

5.0 CONCLUSIONS

1) Bathymetric depth difference comparisons suggest there is an overall lack of long-term, significant erosion potential in the immediate vicinity of candidate disposal Sites 1 and 2.

2) Based on historical records, a wind speed of 7.76 m/s (17 mile/hours) was considered to be indicative of average conditions at the two candidate disposal sites, while a wind speed of 15 m/s (33.6 miles/hour) was considered representative of extreme conditions likely to be experienced during storm events. Applying these wind speeds to the maximum fetch of 35 km occurring southwest of the candidate sites resulted in calculated significant wave heights of 0.635 and 1.6 m, respectively.

3) Based on long-term records from a nearby location having a similar water depth, near-bottom currents at the two candidate sites are likely oriented in a southwest-northeast direction. The average current speed at the candidate sites was taken to be 7 cm/s, while a current speed of 15 cm/s was considered representative of extreme conditions experienced during storm events.

4) A one-dimensional model showed that under the average wind, wave and bottom current conditions defined herein, there was no sediment resuspension at the candidate disposal sites. Under the extreme conditions defined herein, there was limited resuspension of very fine (i.e., silt-sized) sediment particles and negligible resuspension of coarser sediment fractions. Overall, these results suggest there is very limited potential for significant sediment erosion and transport by bottom currents and/or during storm events at the candidate disposal sites.

5) The water column at the candidate disposal sites was found to be vertically well-mixed at the time of sampling in November 2000. Concentrations of chemical contaminants were consistently below EPA Water Quality Criteria. Copper concentrations in surface water samples obtained at the two sites slightly exceeded the EPA Water Quality Criteria.

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TABLES

Table 3-1

Summary of bivariate analysis of hourly wind measurements made at the BUZM3 C-MAN station over the 9-year period 1985 to 1994. Values in the main part of the table are the percentage of measurements falling in each direction/speed category or "bin". The platform and instruments became unavailable for several years beginning in 1994.

FREQUENCY DISTRIBUTION

△t= 1 hour Station ID:BUZM3 Time Interval: 8/20/1985 - 1/9/94 70,938 Data Points=96.5% of Total

Direction FROM (Degrees)	Speed (cm/s) 0 to 5	5 to 10	10 to 15	15 to 20	20 to 25	25 to 30	30 to 35	ROW TOTAL (percent)	MEAN SPEED (cm/s)	MIN SPEED (cm/s)	MAX SPEED (cm/s)	STD. DEV.
0-30	1.6	3.5	2.0	0.6	0.1	0.0	0.0	7.8	8.64	0.10	26.80	4.55
30-60	1.7	3.5	1.4	0.2	0.0	0.0	0.0	6.9	7.58	0.10	28.70	4.03
60-90	1.3	1.7	0.6	0.1	0.0	0.0	0.0	3.7	6.70	0.10	25.90	4.07
90-120	1.4	1.7	0.7	0.2	0.0	0.0	0.0	4.0	7.11	0.10	34.50	4.56
120-150	1.6	2.1	0.7	0.2	0.0	0.0	0.0	4.6	6.85	0.10	33.00	4.18
150-180	2.1	2.5	1.0	0.2	0.0	0.0	0.0	5.8	6.80	0.10	29.40	4.12
180-210	3.1	6.6	2.7	0.3	0.0	0.0	0.0	12.8	7.64	0.10	28.30	3.82
210-240	2.4	8.0	4.0	0.4	0.0	0.0	0.0	14.8	8.36	0.10	27.00	3.62
240-270	2.1	4.9	2.4	0.5	0.0	0.0	0.0	9.9	8.21	0.10	26.00	4.16
270-300	2.2	5.4	3.2	0.7	0.0	0.0	0.0	11.6	8.66	0.10	22.70	4.15
300-330	2.0	4.7	2.1	0.2	0.0	0.0	0.0	9.0	7.77	0.10	21.10	3.84
330-360	2.0	4.5	1.3	0.2	0.0	0.0	0.0	8.0	7.28	0.10	24.70	3.73
CALM	1.1							1.1				
COLUMN TOTAL(%)	24.6	49.1	22.2	3.7	0.4	0.0	0.0	100.00				
CUM PRCT	100.0	75.4	26.3	4.1	0.4	0.0	0.0					
MEAN DIR	191	206	204	193	151	151	154					
STD DEV	101	99	99	107	112	72	72					

SUMMARY STATISTICS

MEAN SPEED = 7.76   MAXIMUM = 34.50   MINIMUM = 0.00   RANGE = 34.50
STANDARD DEVIATION = 3.85   SKEWNESS = 0.47

IN A COORDINATE SYSTEM WHOSE Y AXIS IS POSITIONED 0.00 DEGREES CLOCKWISE FROM TRUE NORTH
MEAN X COMPONENT = 2.12   STANDARD DEVIATION = 5.76   SKEWNESS = -0.17
MEAN Y COMPONENT = 0.39   STANDARD DEVIATION = 6.10   SKEWNESS = -0.13

Table 3-2.

Summary of bivariate analysis of near-bottom current measurements obtained by USGS approximately 6 km north of the candidate disposal sites. Values in the main part of the table are the percentage of measurements falling in each direction/speed category or "bin". Note that approximately 291 days of current measurements taken over the indicated time span were used for this analysis.

FREQUENCY DISTRIBUTION

△t= 1 hour Station: BZB-A1 Spanning: 7/05/82 TO 10/22/85 6985 DATA POINTS - 24.2% of Total Interval

Direction TOWARDS (degrees)	Speed (cm/s) 0 to 5	5 to 10	10 to 15	15 to 20	20 to 25	25 to 30	30 to 33	ROW TOTAL (percent)	MEAN SPEED (cm/s)	MIN SPEED (cm/s)	MAX SPEED (cm/s)	STD. DEV.
0-30	3.2	10.0	6.1	1.1	0.1	0.0	0.0	20.6	8.85	0.27	28.94	4.15
30-60	3.3	10.1	3.5	0.2	0.0	0.0	0.0	17.2	7.70	0.34	19.32	3.35
60-90	2.8	3.1	0.1	0.0	0.0	0.0	0.0	6.0	5.10	0.04	12.99	2.90
90-120	2.8	1.2	0.0	0.0	0.0	0.0	0.0	4.0	4.22	0.42	9.36	1.97
120-150	2.8	1.5	0.0	0.0	0.0	0.0	0.0	4.4	4.49	0.28	15.46	2.38
150-180	3.6	4.4	1.2	0.1	0.0	0.0	0.0	9.2	6.26	0.52	19.66	3.45
180-210	3.3	8.8	4.4	0.4	0.1	0.0	0.0	17.0	8.20	0.38	32.74	3.93
210-240	2.1	4.3	1.8	0.1	0.0	0.0	0.0	8.3	7.42	0.11	18.64	3.45
240-270	1.6	1.2	0.0	0.0	0.0	0.0	0.0	2.8	4.52	0.18	10.36	2.79
270-300	1.5	0.8	0.0	0.0	0.0	0.0	0.0	2.2	4.21	0.55	9.06	2.38
300-330	1.6	1.2	0.0	0.0	0.0	0.0	0.0	2.8	4.46	0.31	9.62	2.87
330-360	2.1	2.8	0.4	0.0	0.0	0.0	0.0	5.4	6.05	0.08	18.86	2.88
COLUMN TOTAL(%)	30.8	49.5	17.5	2.0	0.2	0.0	0.0	100.00				
CUM PRCT	100.0	69.2	19.7	2.3	0.3	0.1	0.0					
MEAN DIR	158	131	106	78	89	85	183					
STD DEV	100	101	92	85	91	92	0					

SUMMARY STATISTICS

MEAN SPEED = 7.08 cm/s MAXIMUM = 32.74 cm/s MINIMUM = 0.04 cm/s RANGE = 32.71 cm/s
STANDARD DEVIATION = 3.56 cm/s SKEWNESS = 0.78

IN A COORDINATE SYSTEM WHOSE Y AXIS IS POSITIONED 0.00 DEGREES CLOCKWISE FROM TRUE NORTH
MEAN X COMPONENT = 1.02 cm/s STANDARD DEVIATION = 3.79 cm/s SKEWNESS = -0.16
MEAN Y COMPONENT = 0.64 cm/s STANDARD DEVIATION = 6.86 cm/s SKEWNESS = -0.09

Table 3-3

Sediment resuspension (“erosion depth”) calculated using the Glenn and Grant model (1987) for “extreme” wind, wave, and current conditions at the candidate disposal sites. The following extreme conditions were used as input to the model to produce the results shown in the table: wind speed = 15 m/s, significant wave height = 1.6 m, current speed = 15 cm/s. The resulting erosion depth shown in the table was calculated for five different sediment grain sizes.

Size Description	**Grain Size Diameter (mm)**	**Erosion Depth (mm)**
▪ Fine silt	0.0078	5.688
▪ Coarse silt	0.044	0.158
▪ Very fine sand	0.088	0.129
▪ Fine sand	0.177	0.127
▪ Medium sand	0.35	0.146

Table 3-4

Concentrations of Metals in Near-surface and Near-bottom Water Samples Obtained at the Centers of Candidate Sites 1 and 2. All concentrations are in µg/L, except hexavalent chromium (mg/L).

Metal	Site 1		Site 2		EPA Water Quality Criterion
	Surface	Bottom	Surface	Bottom	
Arsenic, Total	<2.0	<2.0	<2.0	<2.0	69
Cadmium, Total	0.26	0.089	0.096	0.073	43
Copper, Total	3.2	1.7	3.0	0.96	2.9
Hexavalent Chromium	<0.005	<0.005	<0.005	<0.005	1100
Lead, Total	6.7	0.96	3.6	0.82	220
Mercury, Total	<0.2	<0.2	<0.2	<0.2	2.1
Nickel, Total	0.90	0.45	0.86	0.44	75
Selenium, Total	<2.0	<2.0	<2.0	<2.0	300
Silver, Total	<0.02	<0.02	<0.02	<0.02	2.3
Zinc, Total	22	4.7	17	5.4	95

Table 3-5

Concentrations of PCB Congeners in Near-surface and Near-bottom Water Samples Obtained at the Centers of Candidate Sites 1 and 2. All concentrations are in µg/L.

	Site 1		Site 2		EPA Water
Congener No.	Surface	Bottom	Surface	Bottom	Quality Criterion
BZ 8	<0.005	<0.005	<0.005	<0.005	0.03
BZ 18	<0.005	<0.005	<0.005	<0.005	0.03
BZ 28	<0.005	<0.005	<0.005	<0.005	0.03
BZ 44	<0.005	<0.005	<0.005	<0.005	0.03
BZ 52	<0.005	<0.005	<0.005	<0.005	0.03
BZ 66	<0.005	<0.005	<0.005	<0.005	0.03
BZ 101	<0.005	<0.005	<0.005	<0.005	0.03
BZ 105	<0.005	<0.005	<0.005	<0.005	0.03
BZ 118	<0.005	<0.005	<0.005	<0.005	0.03
BZ 128	<0.005	<0.005	<0.005	<0.005	0.03
BZ 138	<0.005	<0.005	<0.005	<0.005	0.03
BZ 153	<0.005	<0.005	<0.005	<0.005	0.03
BZ 170	<0.005	<0.005	<0.005	<0.005	0.03
BZ 180	<0.005	<0.005	<0.005	<0.005	0.03
BZ 187	<0.005	<0.005	<0.005	<0.005	0.03
BZ 195	<0.005	<0.005	<0.005	<0.005	0.03
BZ 206	<0.005	<0.005	<0.005	<0.005	0.03
BZ 209	<0.005	<0.005	<0.005	<0.005	0.03

Table 3-6

Concentrations of Pesticides, Cyanide, and Pentachlorophenol in Near-surface and Near-bottom Water Samples Obtained at the Centers of Candidate Sites 1 and 2. All concentrations are in μg/L, except cyanide (mg/L). NA = EPA Water Quality Criteria do not exist.

Compound	Site 1		Site 2		EPA Water Quality Criterion
	Surface	Bottom	Surface	Bottom	
aldrin	<0.005	<0.005	<0.005	<0.005	1.3
alpha-BHC	<0.005	<0.005	<0.005	<0.005	NA
alpha-chlordane	<0.005	<0.005	<0.005	<0.005	NA
beta-BHC	<0.005	<0.005	<0.005	<0.005	NA
delta-BHC	<0.005	<0.005	<0.005	<0.005	NA
gamma-BHC	<0.005	<0.005	<0.005	<0.005	1.3
gamma-chlordane	<0.005	<0.005	<0.005	<0.005	0.09
4,4'-DDD	<0.005	<0.005	<0.005	<0.005	NA
4,4'-DDE	<0.005	<0.005	<0.005	<0.005	NA
4,4'-DDT	<0.005	<0.005	<0.005	<0.005	0.13
dieldrin	<0.005	<0.005	<0.005	<0.005	0.71
endosulfan I	<0.005	<0.005	<0.005	<0.005	0.034
endosulfan II	<0.005	<0.005	<0.005	<0.005	0.034
endosulfan sulfate	<0.005	<0.005	<0.005	<0.005	NA
endrin	<0.005	<0.005	<0.005	<0.005	0.037
heptachlor	<0.005	<0.005	<0.005	<0.005	0.053
heptachlor epoxide (B)	<0.005	<0.005	<0.005	<0.005	NA
methoxychlor	<0.005	<0.005	<0.005	<0.005	NA
toxaphene	<0.005	<0.005	<0.005	<0.005	0.21
cyanide, total	<0.005	<0.005	<0.005	<0.005	NA
pentachlorophenol	<25	<25	<25	<25	13

FIGURES

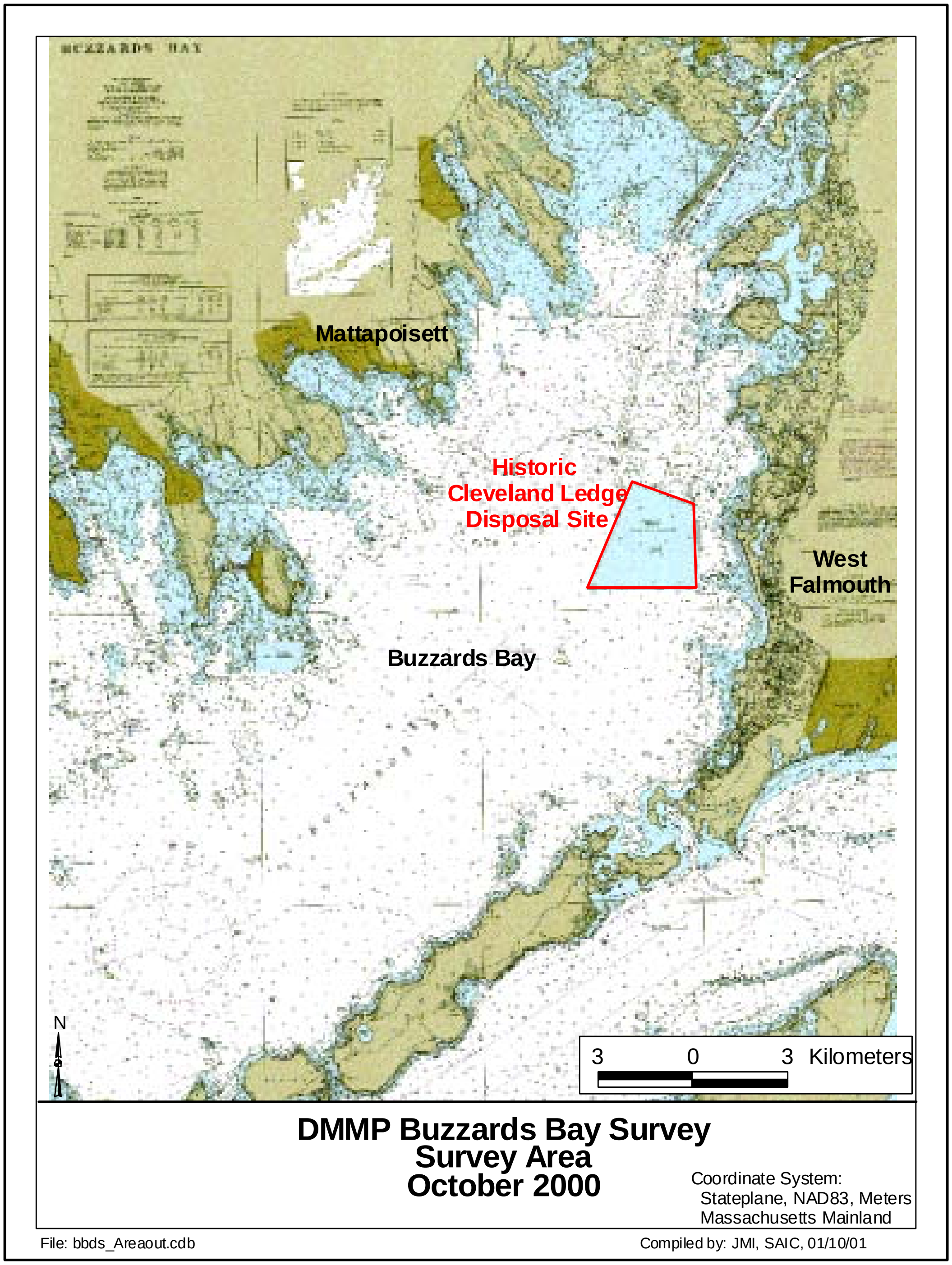


Figure 1-1. General location map showing the boundary of the historic Cleveland Ledge Disposal Site on the eastern side of Buzzards Bay, off of West Falmouth (from NOAA Nautical Chart 13229).

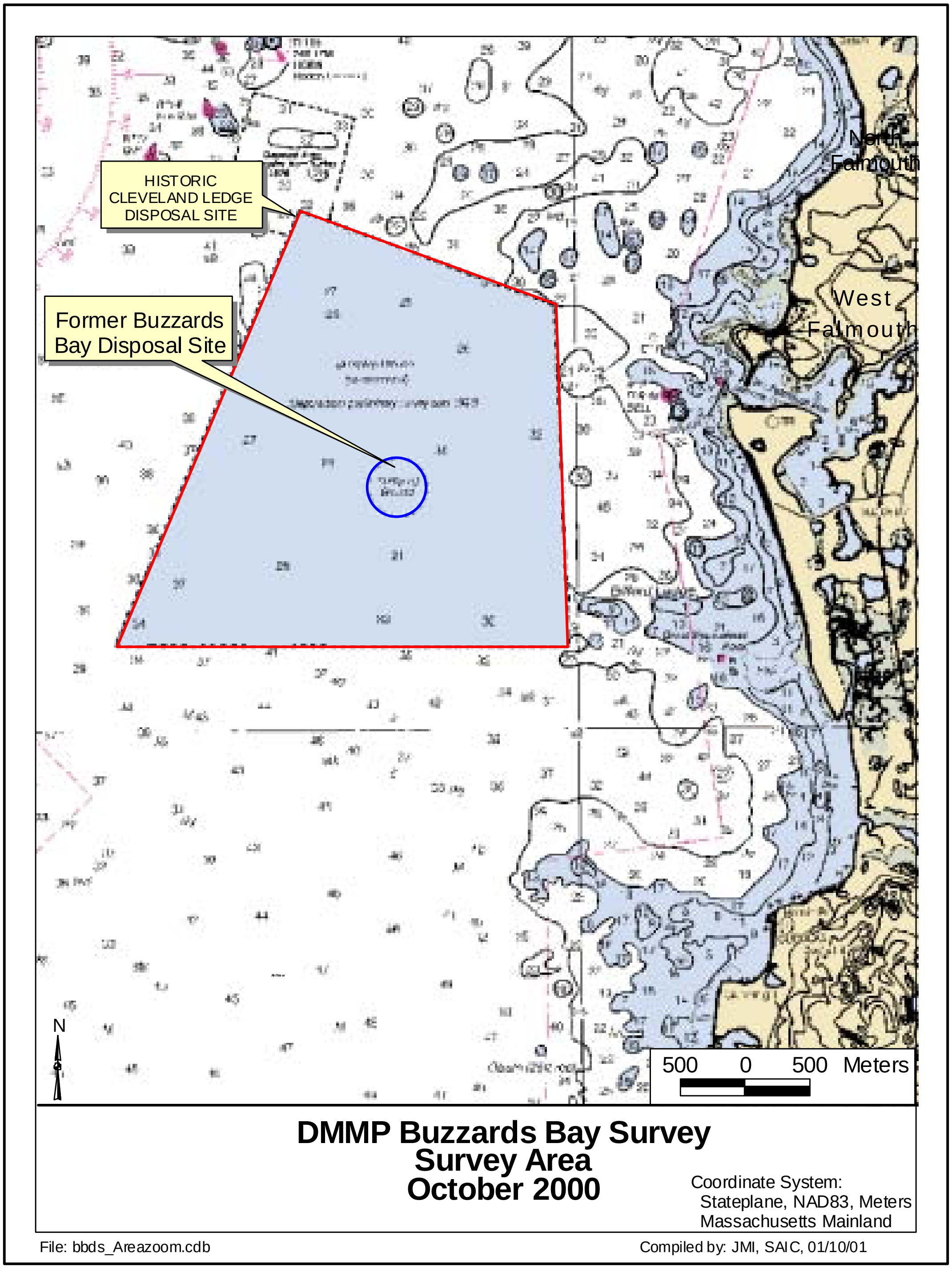


Figure 1-2. Map of the historic Cleveland Ledge Disposal Site showing the location of the former Buzzards Bay Disposal Site (BBDS). In 1995, Massachusetts DEM proposed the designation of a new BBDS in the same location.

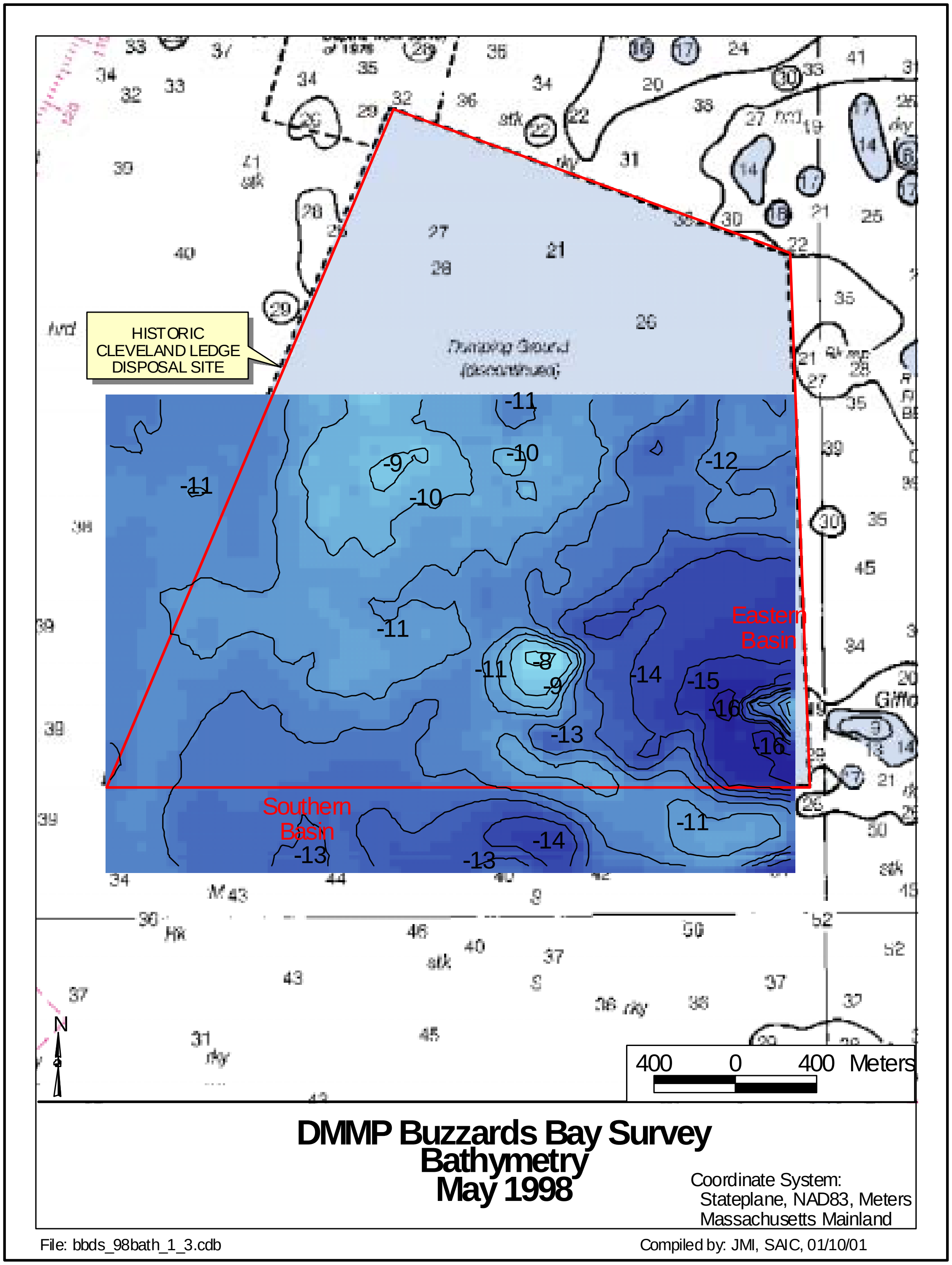


Figure 1-3. Results of the high-resolution bathymetric survey conducted across the southern half of the Cleveland Ledge Disposal Site in May 1998, superimposed on NOAA Nautical Chart 13229. Depths from the bathymetric survey are in meters; nautical chart depth soundings are in feet.

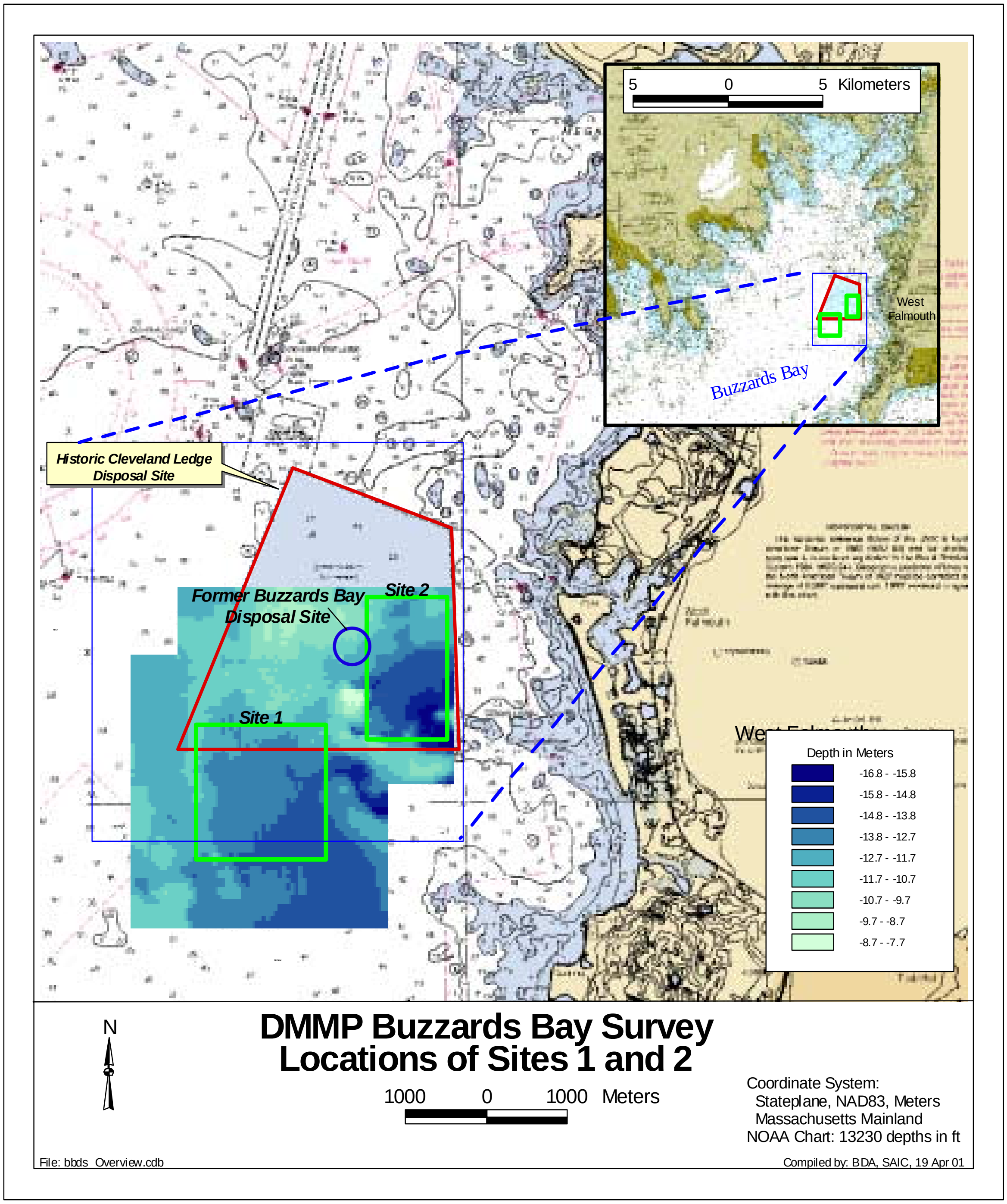


Figure 1-4. Map showing the general location of candidate disposal Sites 1 and 2 within Buzzards Bay and in relation to the historic Cleveland Ledge Disposal Site. Depth contours (in meters) underlying Sites 1 and 2 are from SAIC surveys conducted in May 1998 and October 2000.

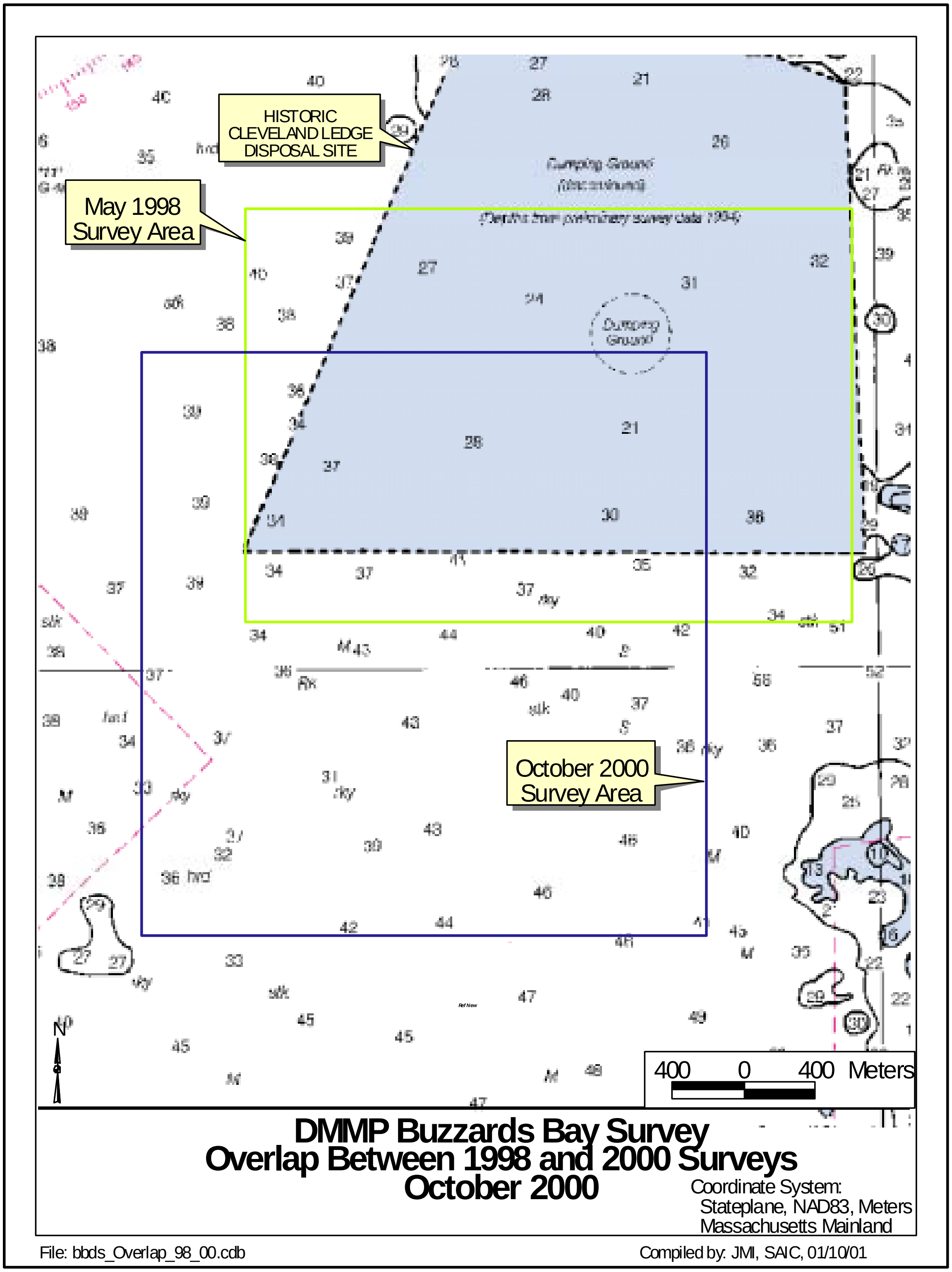


Figure 2-1. Map showing the area of overlap between the May 1998 and October 2000 bathymetric surveys at the historic Cleveland Ledge Disposal Site.

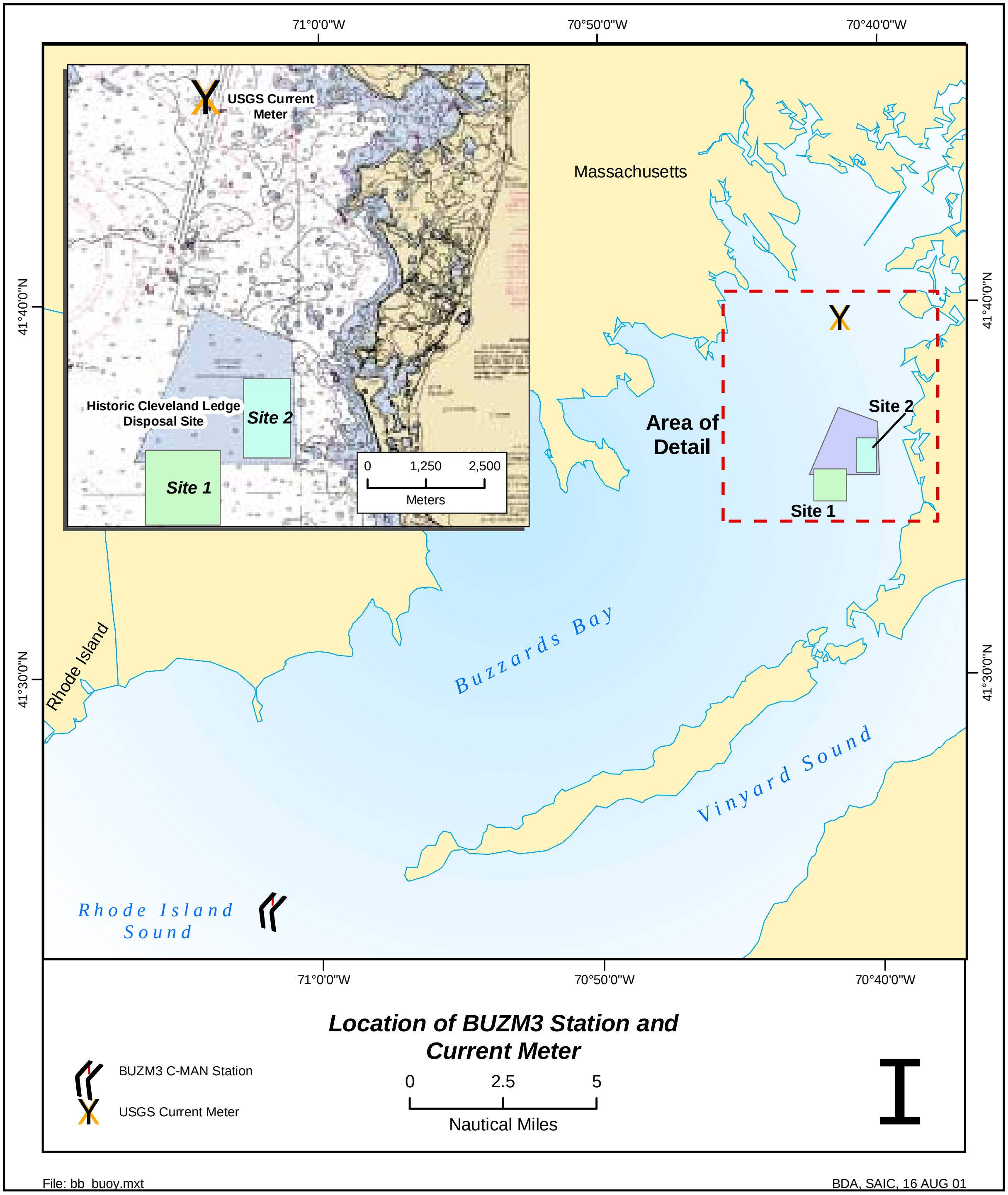


Figure 2-2. Map showing the location of the NOAA BUZM3 C-man station at the entrance to Buzzards Bay and the deployment location of the USGS current meter (inset).

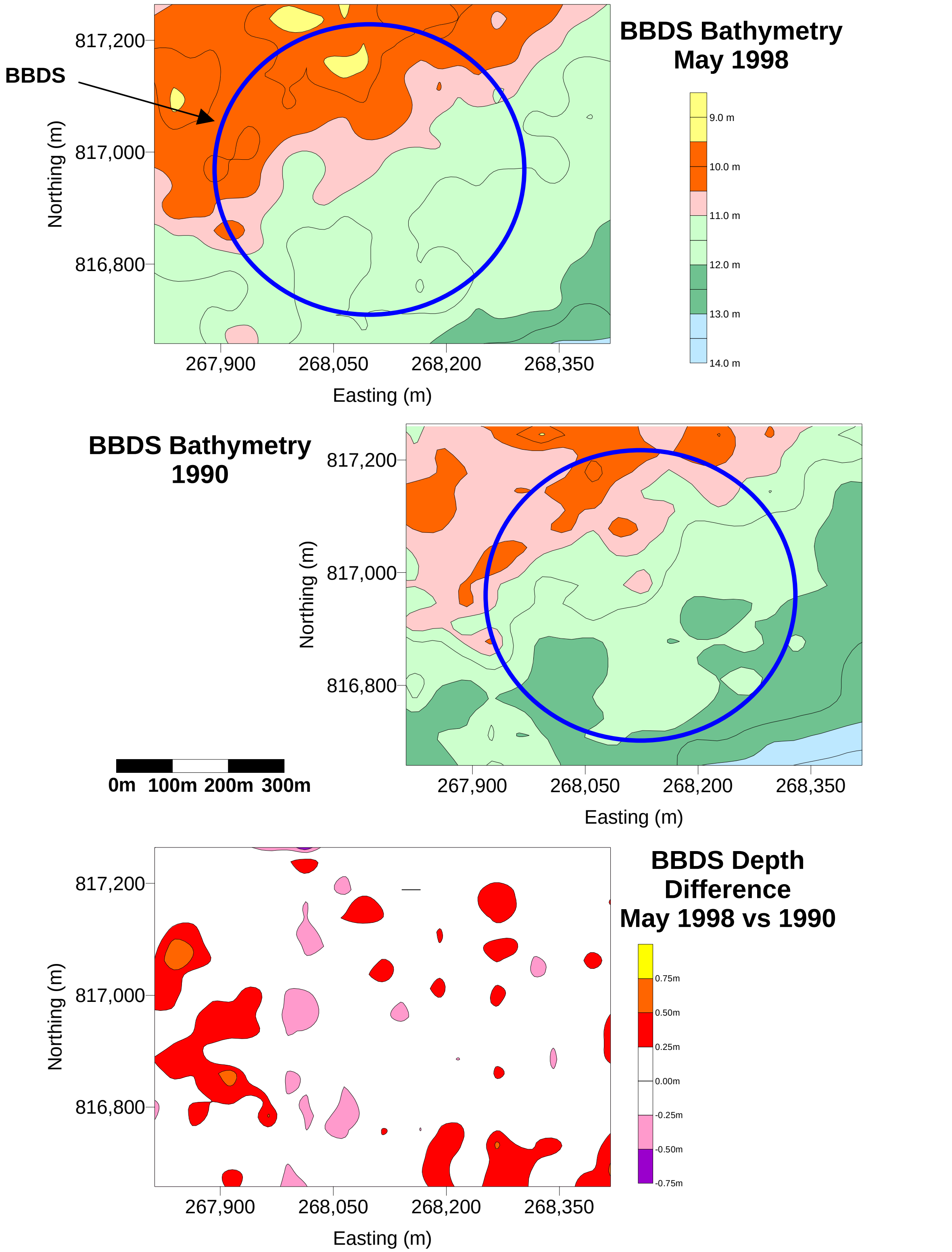


Figure 3-1. Contour map of depth differences (bottom) between the May 1998 (top) and March 1990 (middle) bathymetric surveys at the former BBDS (from Maguire Group Inc., 1998c).

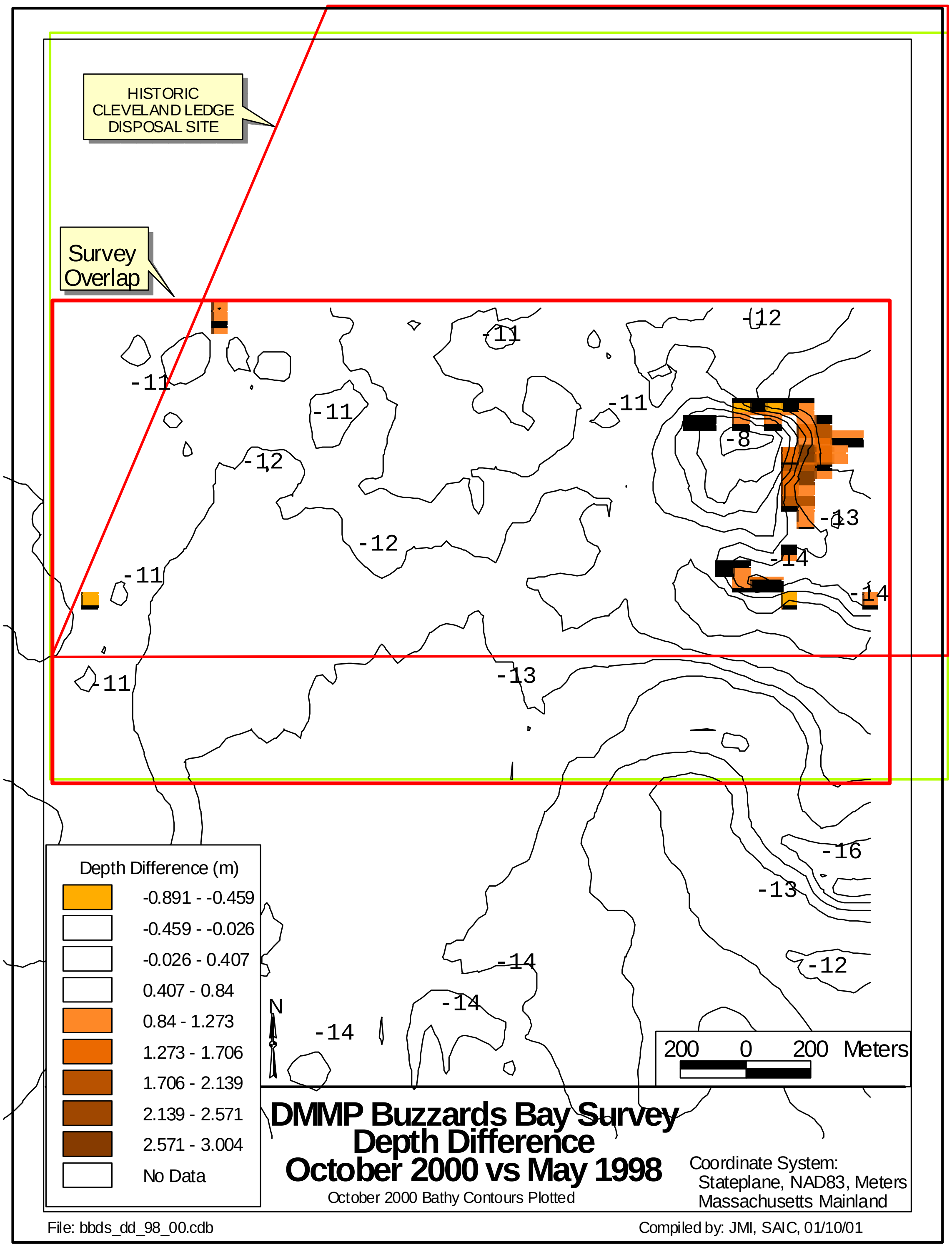


Figure 3-2. Map showing the results of the depth difference comparison between the October 2000 and May 1998 bathymetric surveys. The depth difference results (in meters) are superimposed on the bathymetric contours from the October 2000 survey.

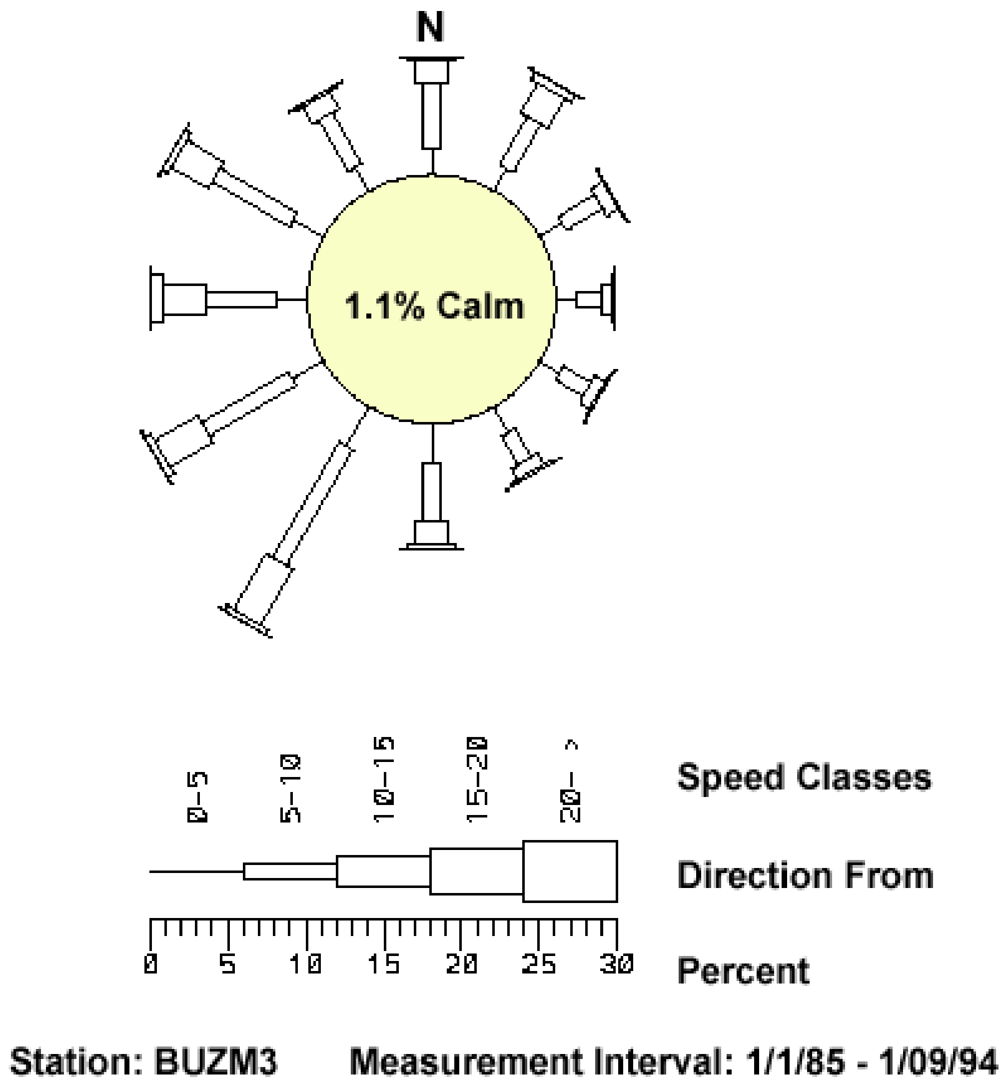


Figure 3-3. A wind rose graphically presenting the bivariate data provided in Table 3-1. The relative occurrence of winds from the west-southwest (essentially blowing up the axis of Buzzards Bay) is evident.

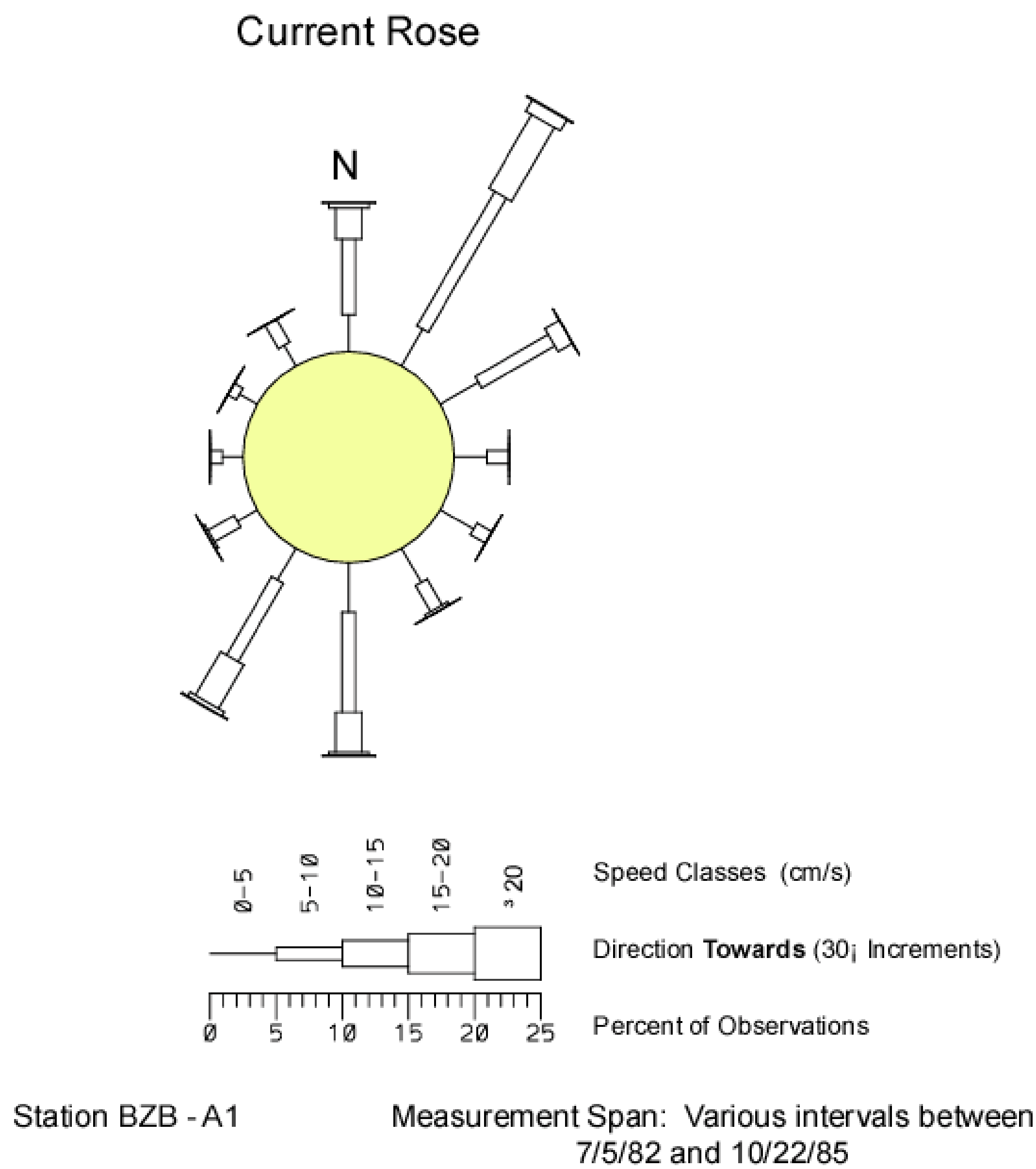


Figure 3-4. A current rose graphically presenting the bivariate data provided in Table 3-2. The relative occurrence of currents oriented east-northeast to west-southwest is evident. As depicted in Figure 3-4, the orientation of the M2 (semi-diurnal lunar) tidal ellipse coincides with this orientation.

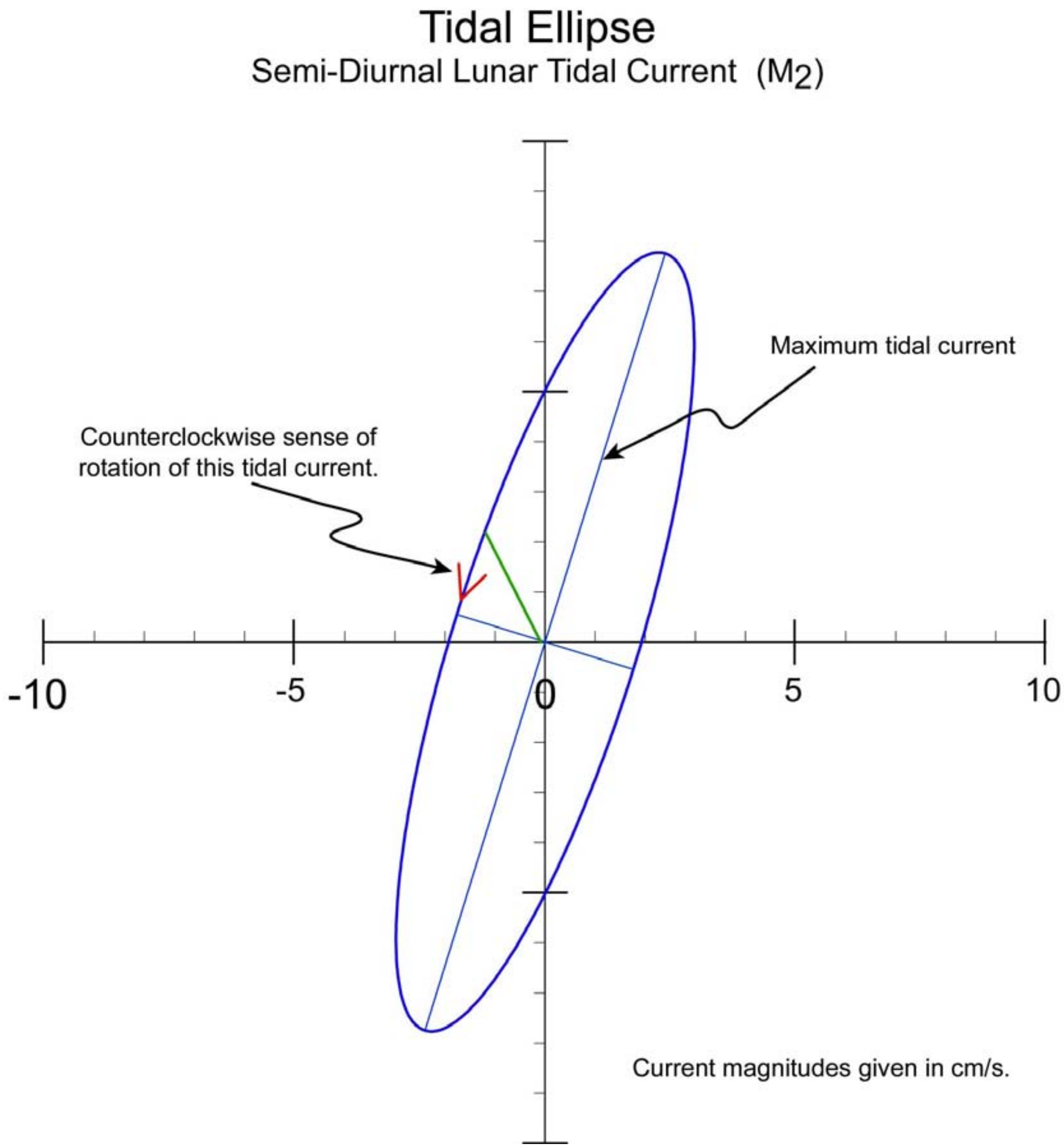


Figure 3-5. Tidal ellipse for the semi-diurnal lunar tidal current based on measurements obtained one meter above the bottom at the USGS current meter location shown in Figure 2-2.

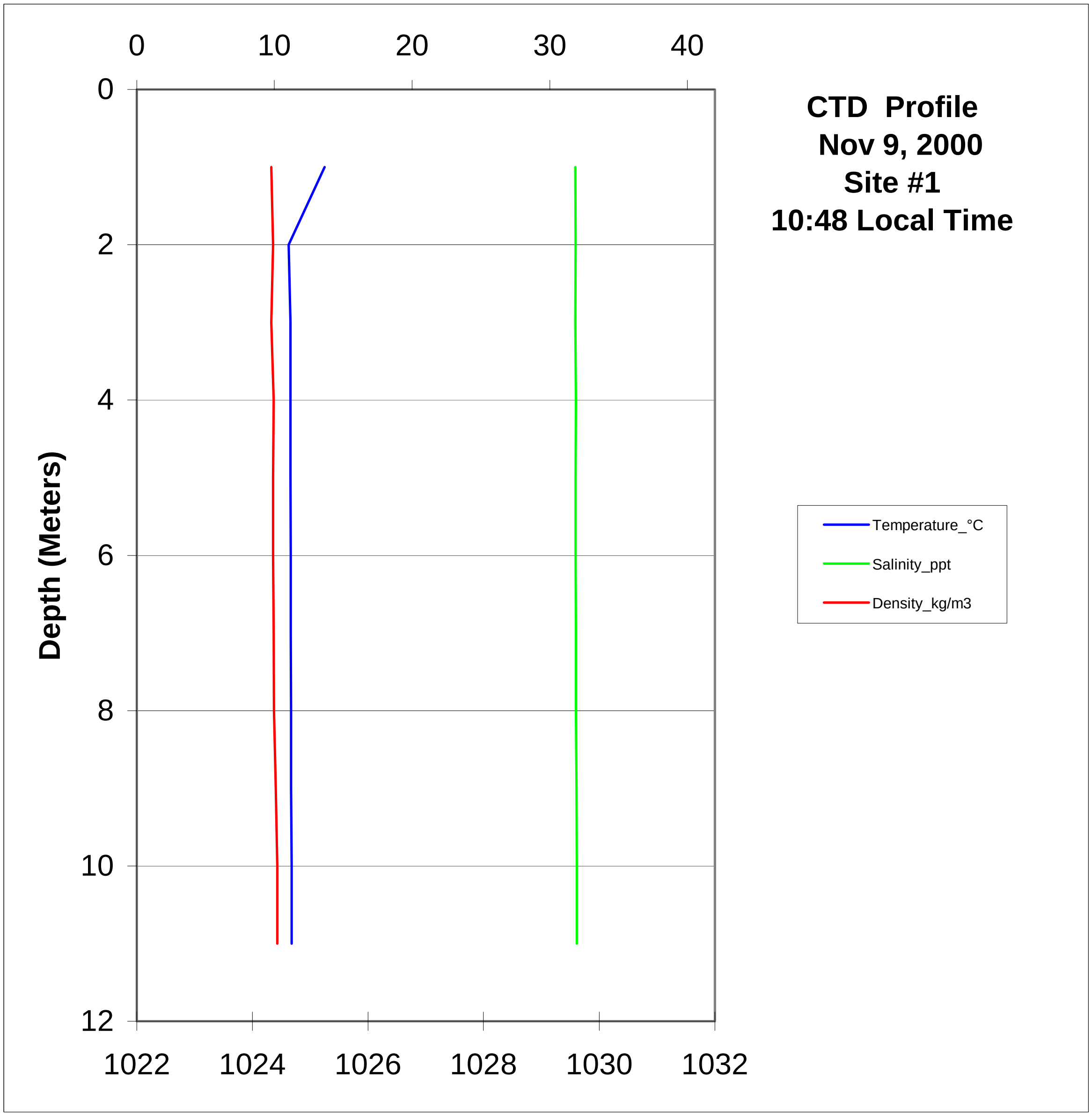


Figure 3-6. Representative CTD profile obtained at the center of candidate disposal Site 1 on November 9, 2000.

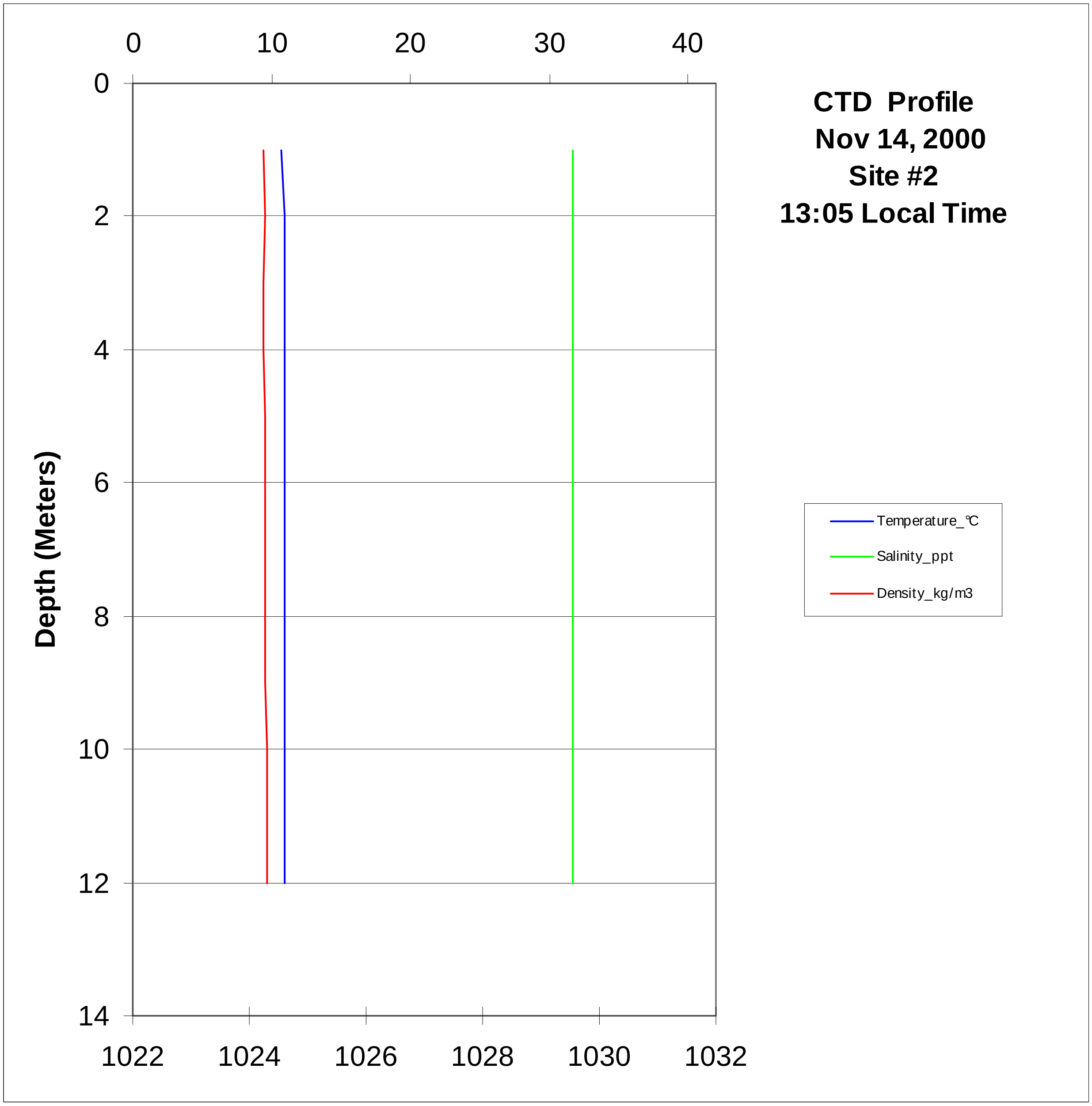


Figure 3-7. Representative CTD profile obtained at the center of candidate disposal Site 2 on November 14, 2000.

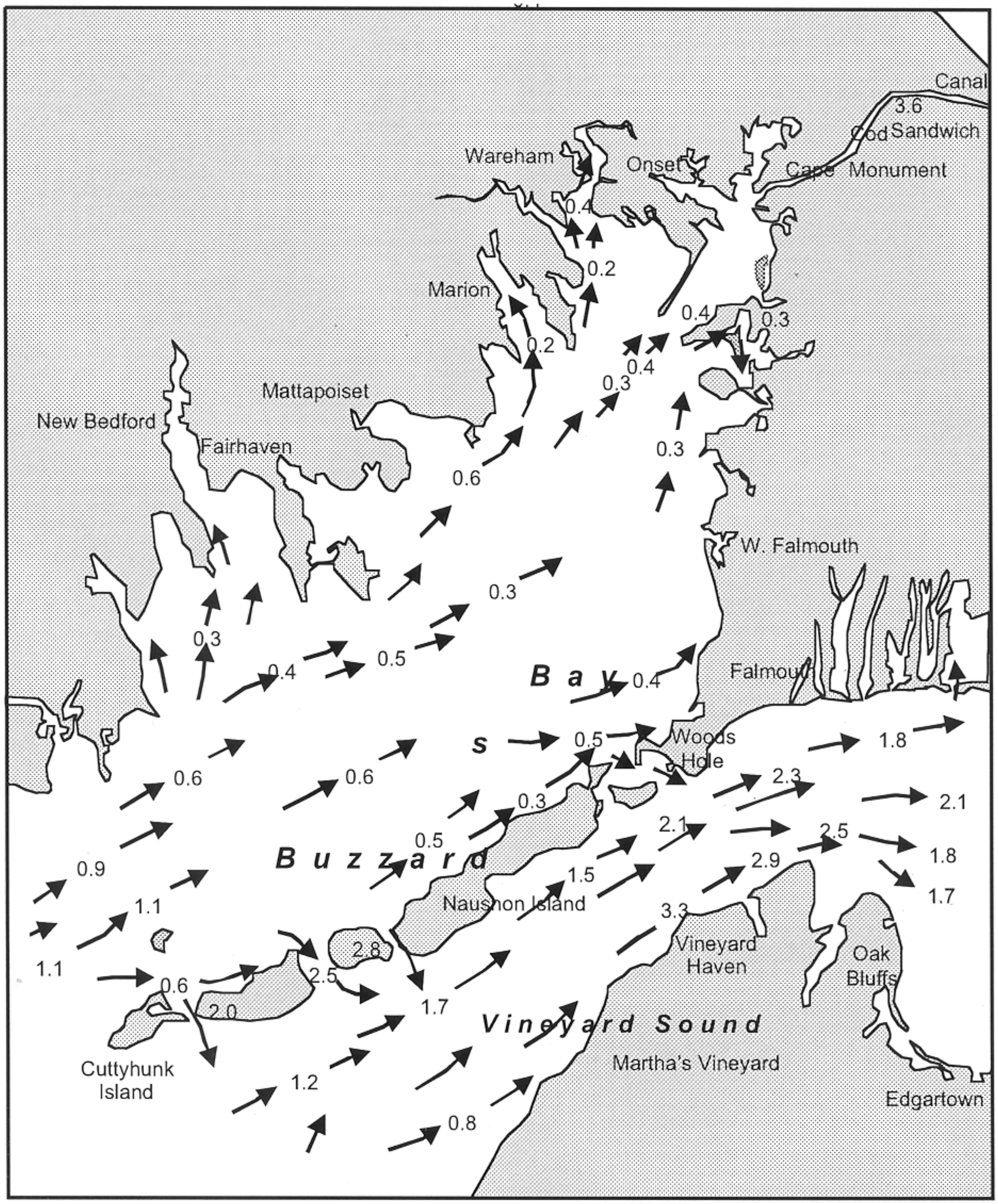
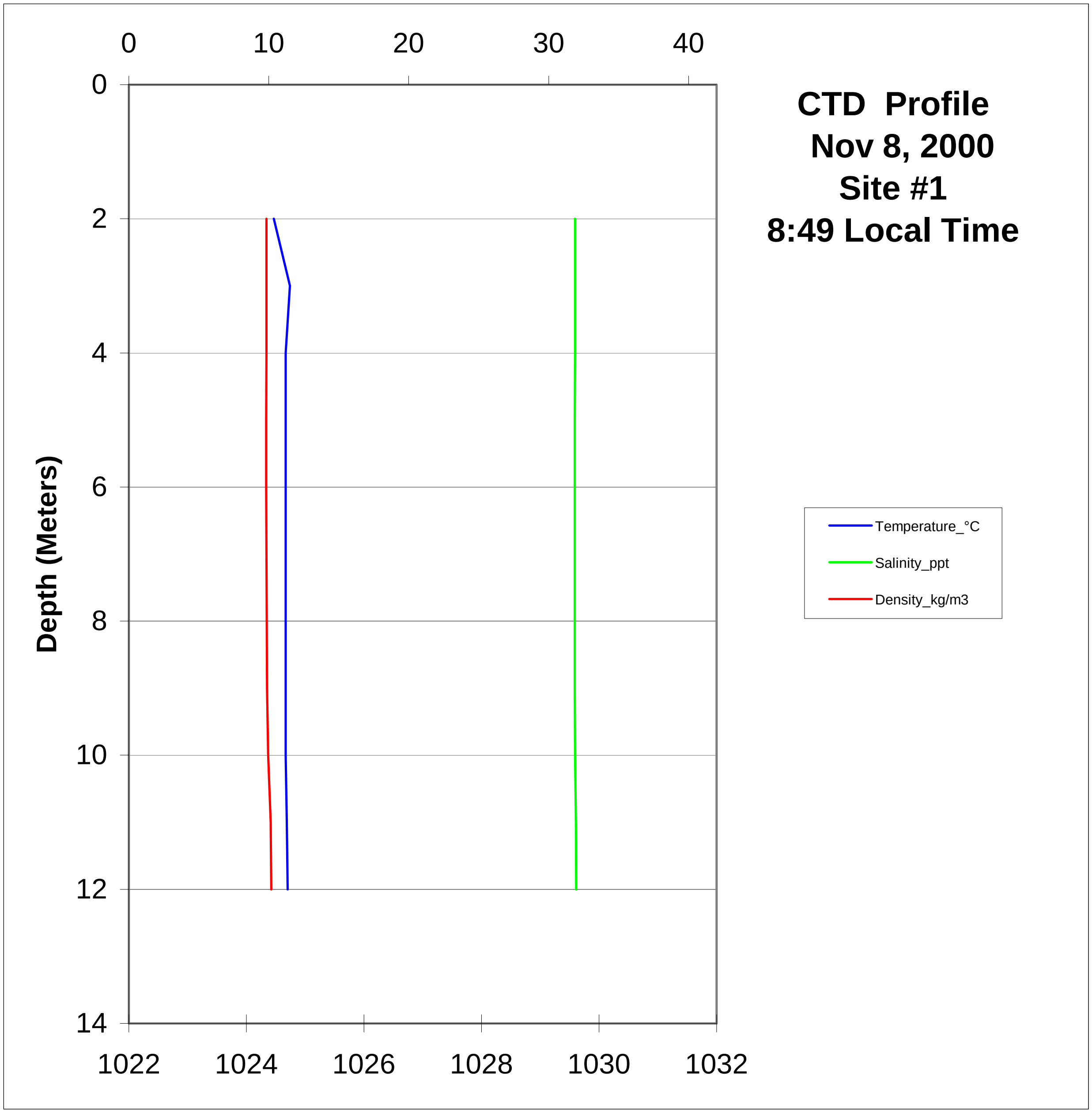
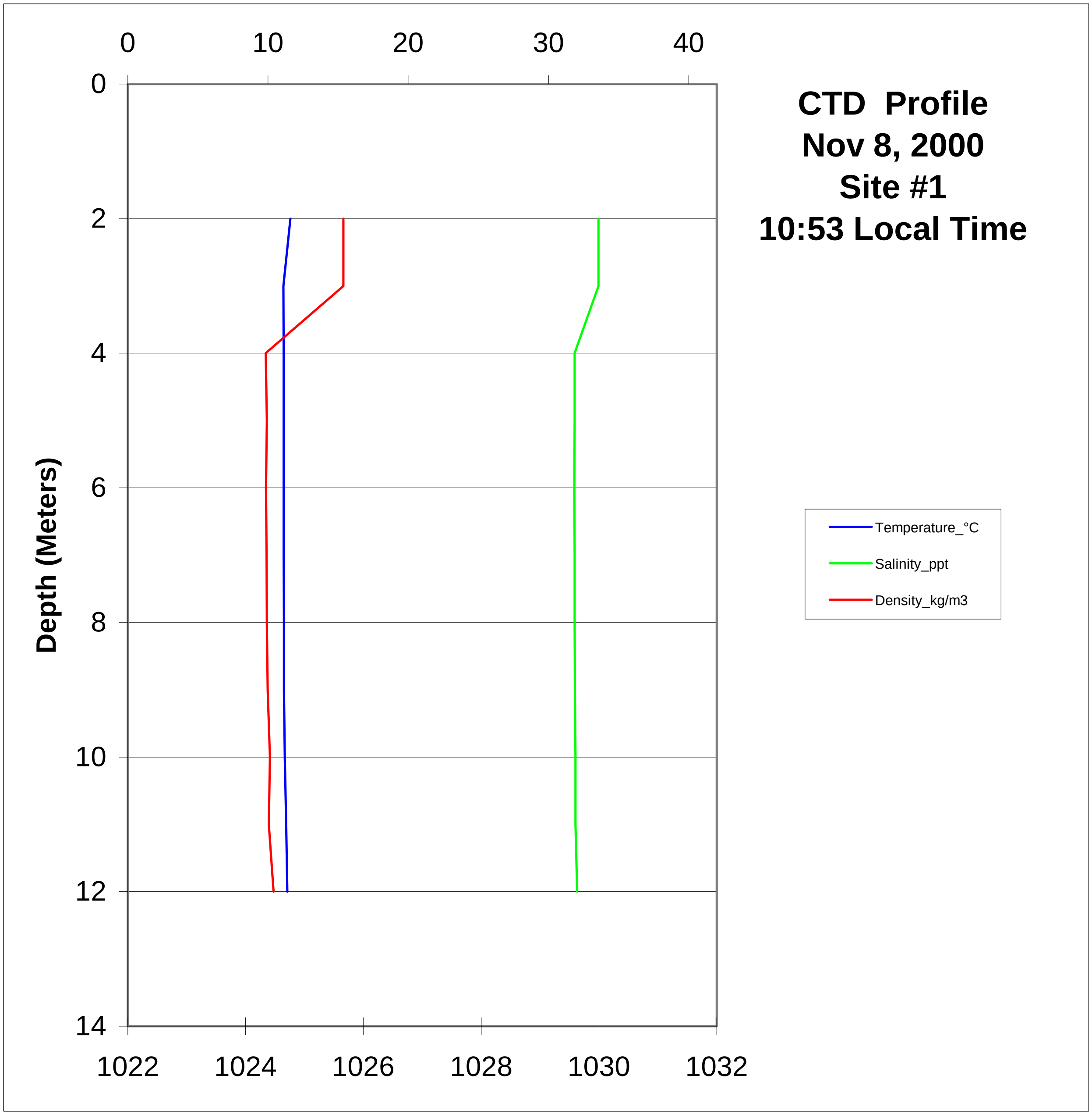
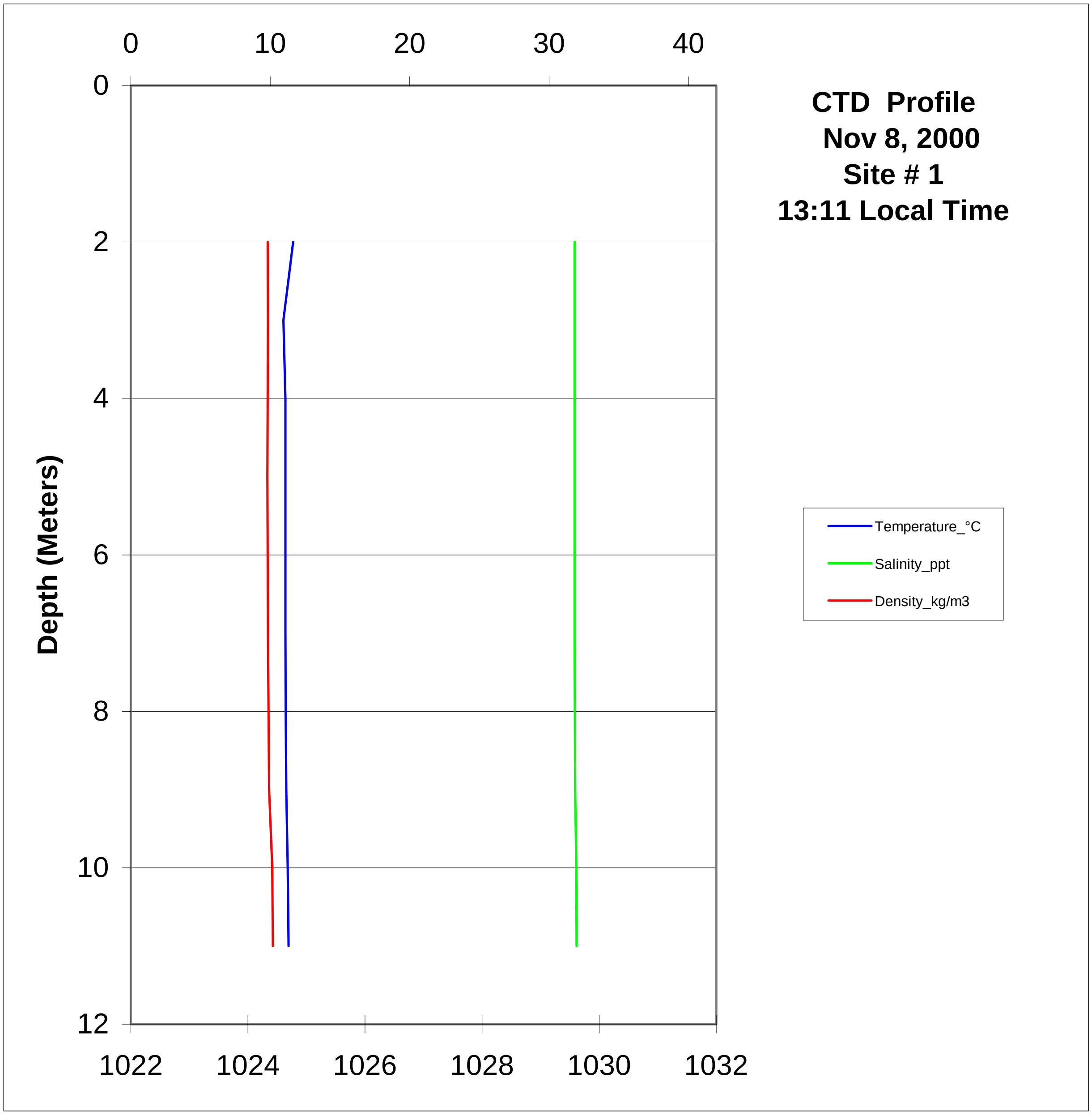


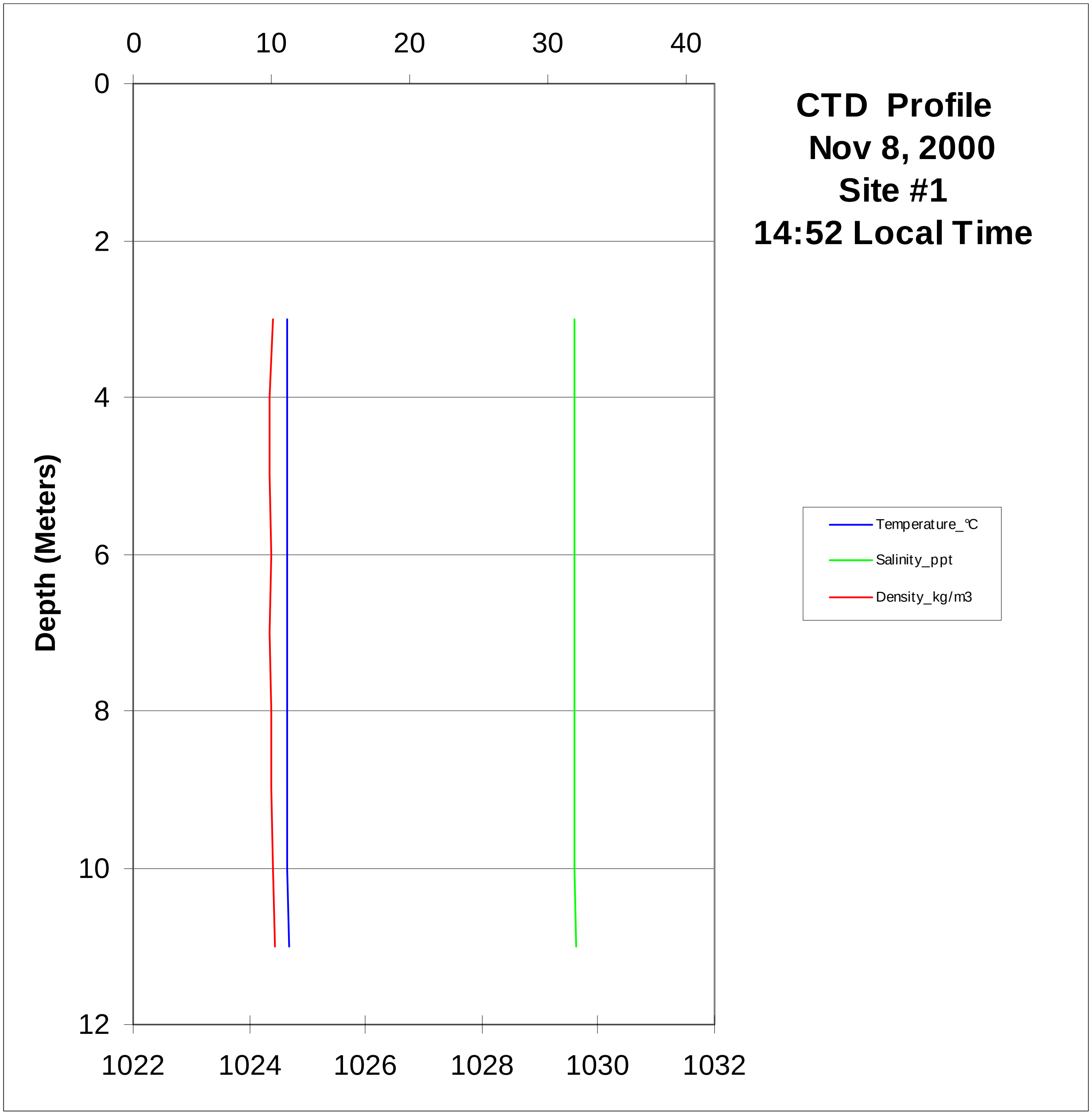
Figure 4-1. Buzzards Bay tidal current chart showing flood currents 4 hr after slack tide. Note the general north-northeast orientation of the current vectors at the head of the Bay and specifically near the candidate disposal sites off of West Falmouth (from Howes and Goehringer, 1996).

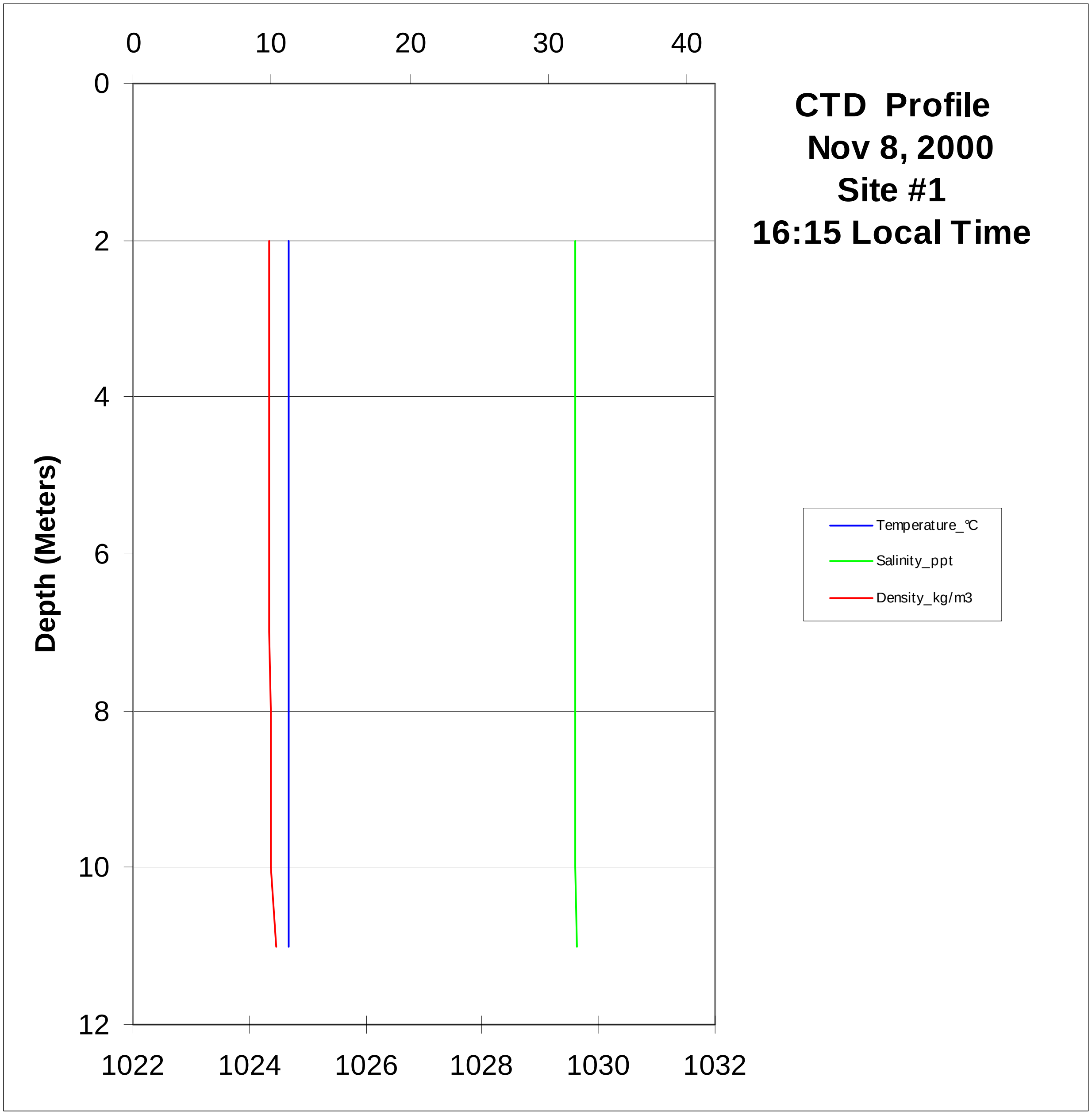
APPENDIX

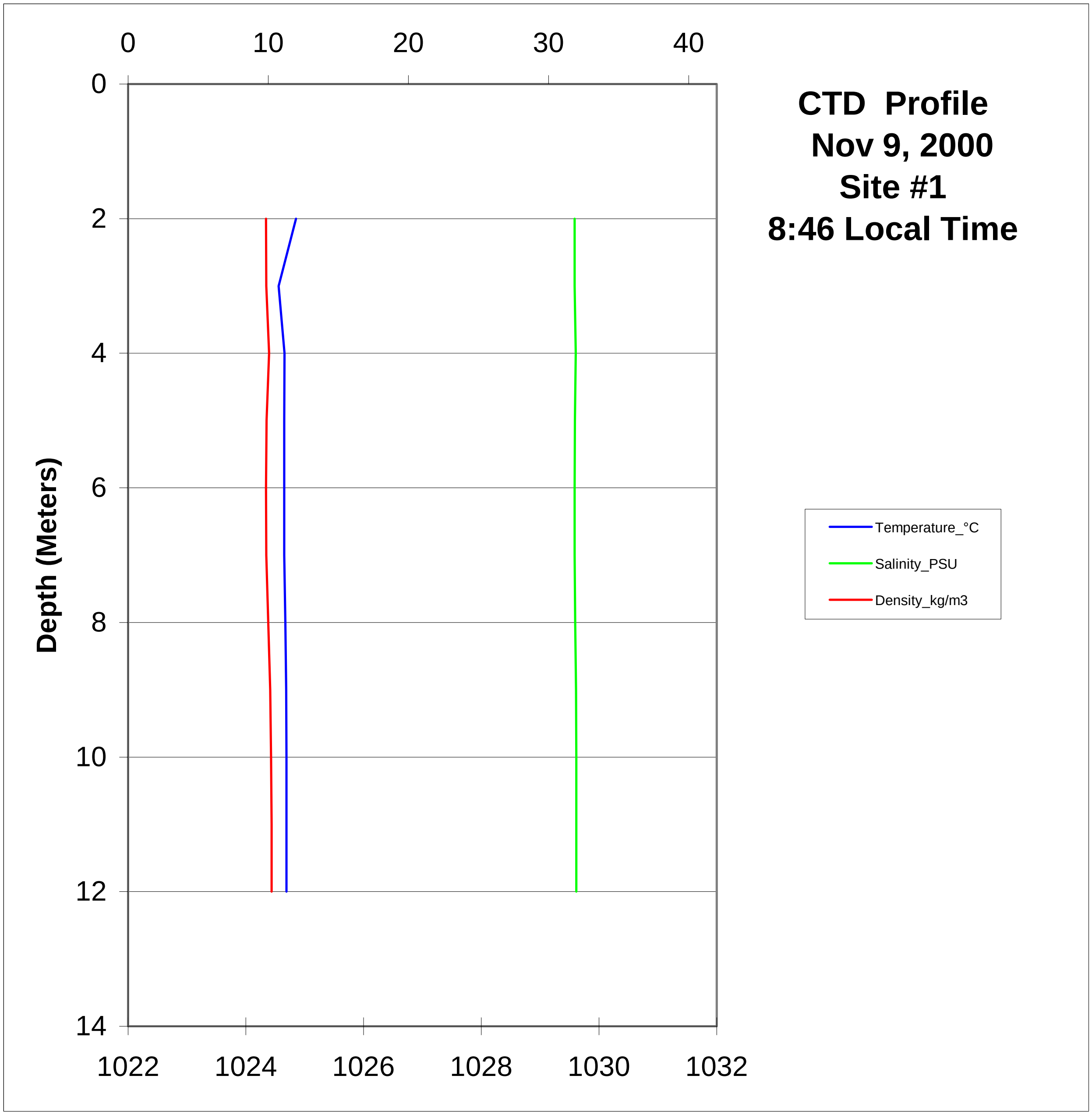

CTD Profile
Nov 8, 2000
Site #1
8:49 Local Time
Depth (Meters)
0
2
4
6
8
10
12
14
0
10
20
30
40
1022
1024
1026
1028
1030
1032
Temperature_°C
Salinity_ppt
Density_kg/m3

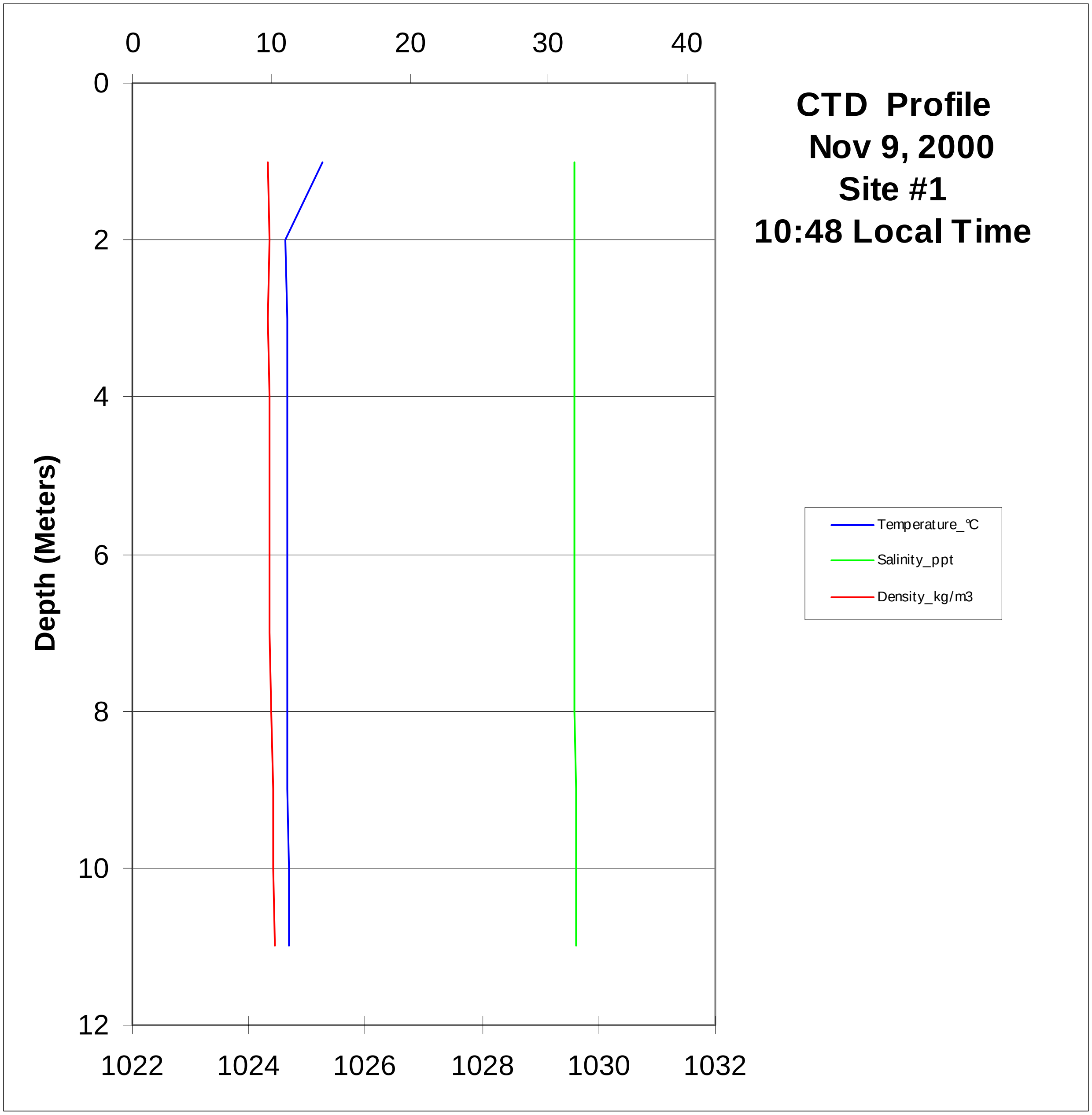

0
10
20
30
40
0
2
4
6
8
10
12
14
Depth (Meters)
1022
1024
1026
1028
1030
1032
CTD Profile
Nov 8, 2000
Site #1
10:53 Local Time
Temperature_°C
Salinity_ppt
Density_kg/m3

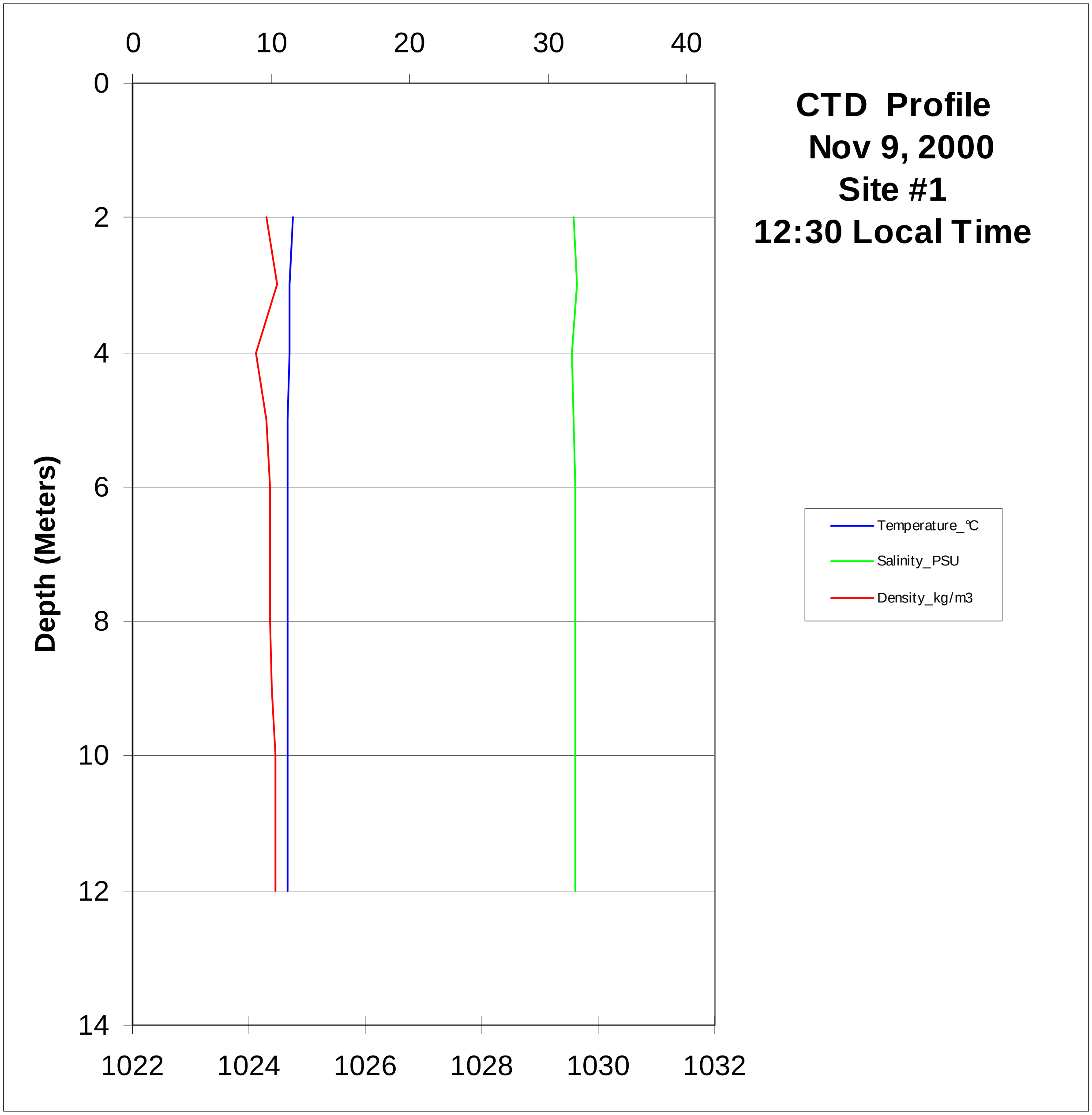

CTD Profile
Nov 8, 2000
Site # 1
13:11 Local Time
Depth (Meters)
0
10
20
30
40
0
2
4
6
8
10
12
1022
1024
1026
1028
1030
1032
Temperature_°C
Salinity_ppt
Density_kg/m3


CTD Profile
Nov 8, 2000
Site #1
14:52 Local Time
Depth (Meters)
0
10
20
30
40
0
2
4
6
8
10
12
1022
1024
1026
1028
1030
1032
Temperature_°C
Salinity_ppt
Density_kg/m3

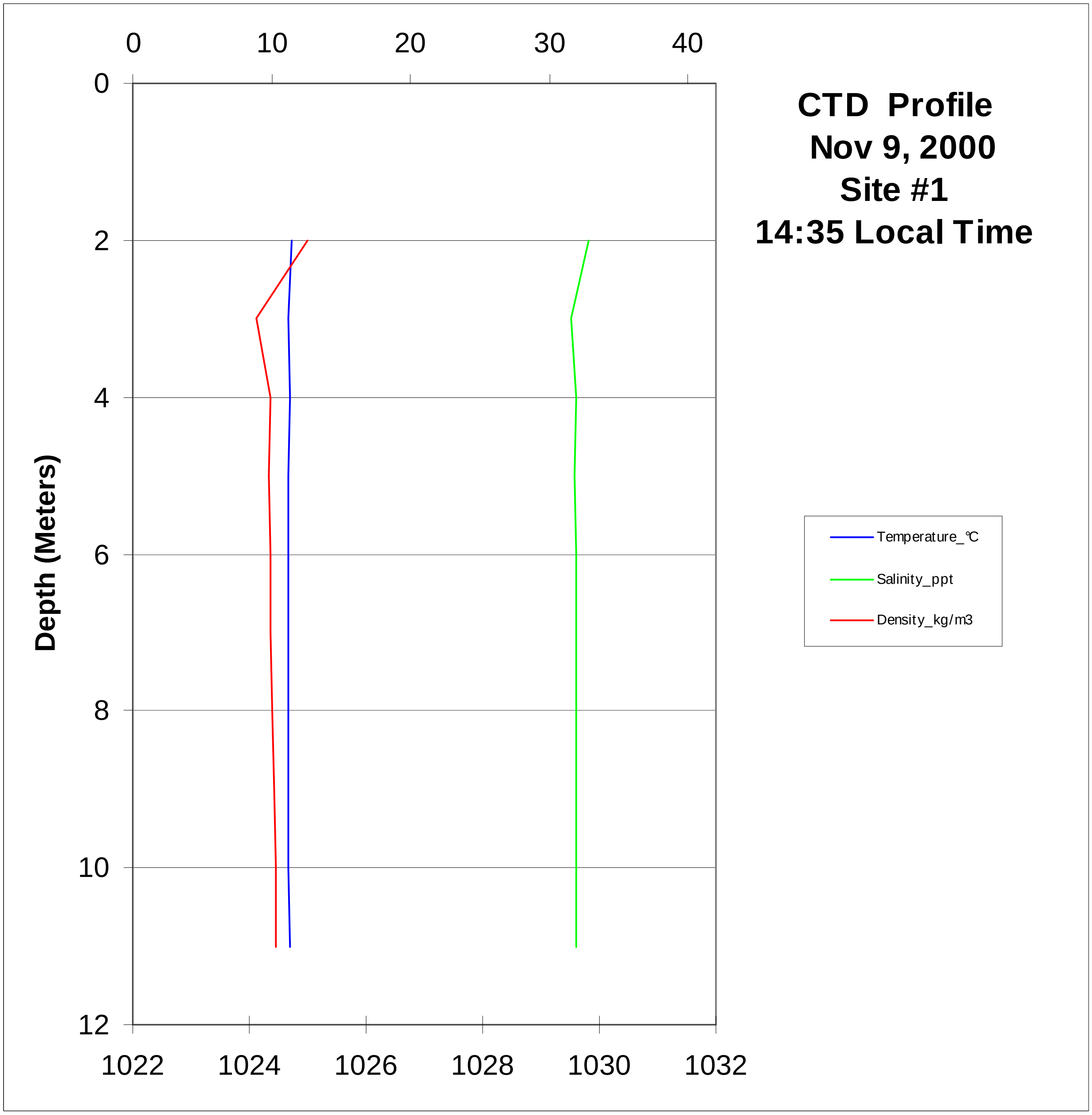

CTD Profile
Nov 8, 2000
Site #1
16:15 Local Time
Depth (Meters)
0
2
4
6
8
10
12
0
10
20
30
40
1022
1024
1026
1028
1030
1032
Temperature_°C
Salinity_ppt
Density_kg/m3

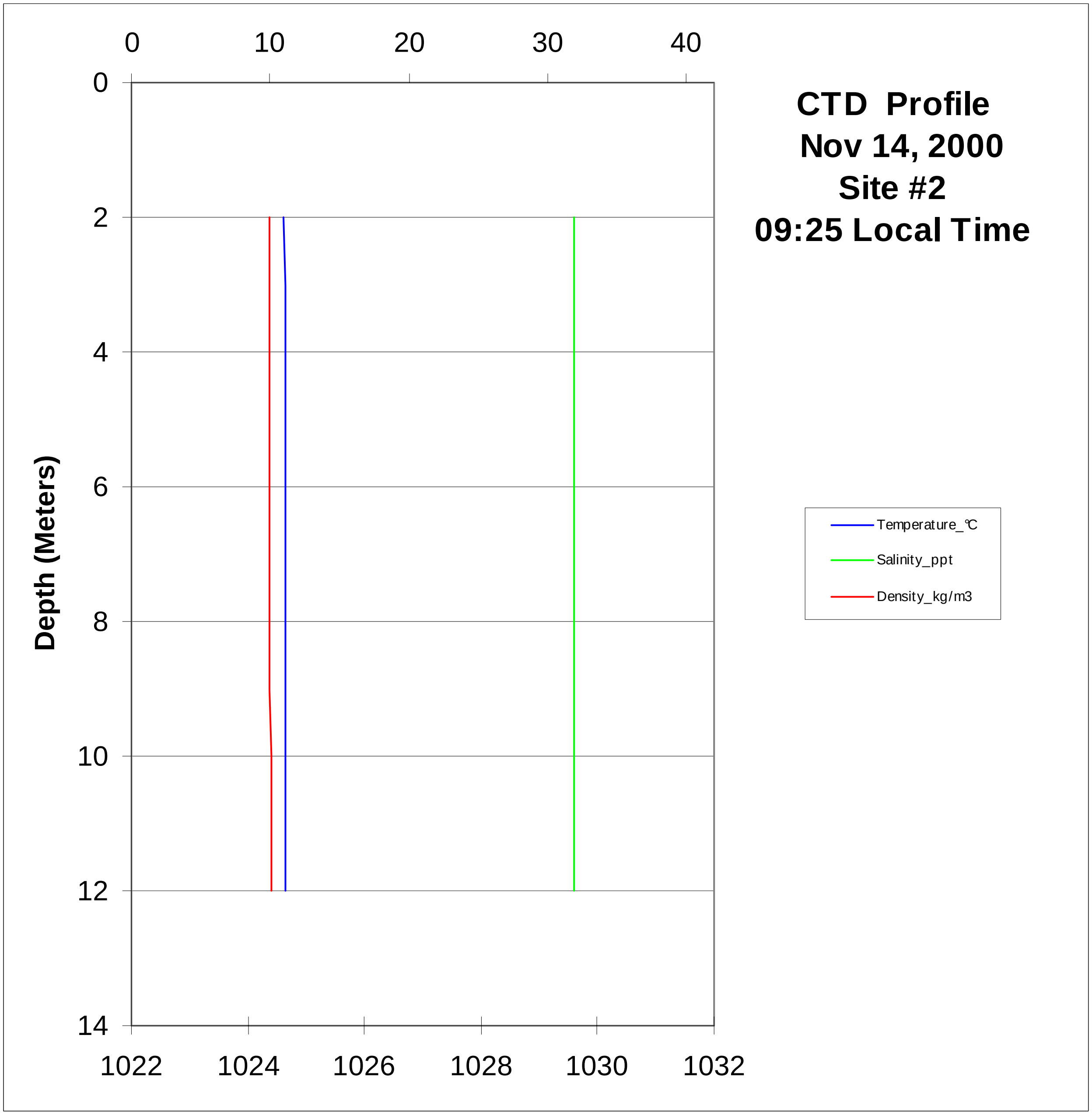

CTD Profile
Nov 9, 2000
Site #1
8:46 Local Time
Depth (Meters)
0
10
20
30
40
0
2
4
6
8
10
12
14
1022
1024
1026
1028
1030
1032
Temperature_°C
Salinity_PSU
Density_kg/m3


CTD Profile
Nov 9, 2000
Site #1
10:48 Local Time
Depth (Meters)
0
10
20
30
40
0
2
4
6
8
10
12
1022
1024
1026
1028
1030
1032
Temperature_°C
Salinity_ppt
Density_kg/m3

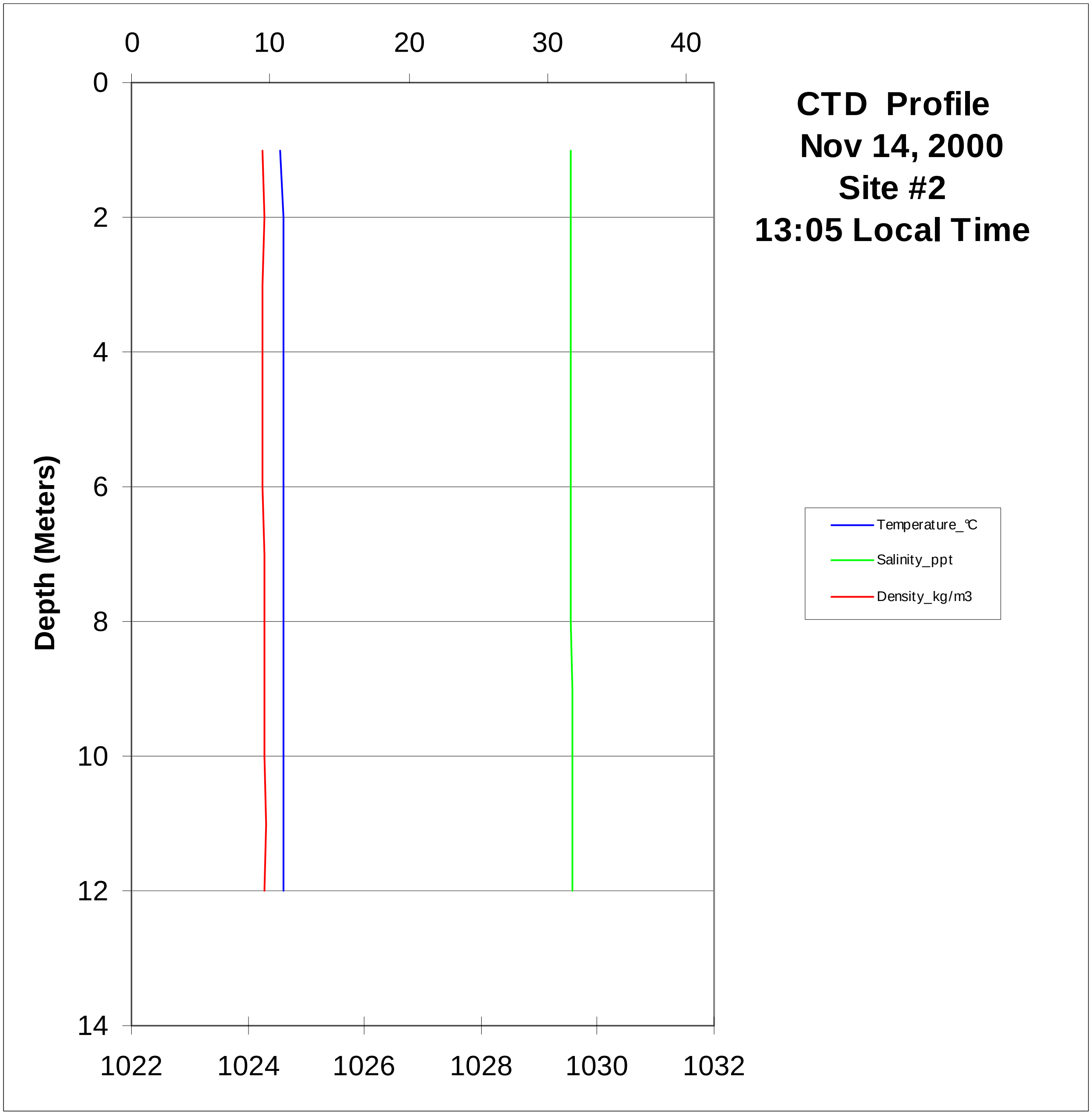


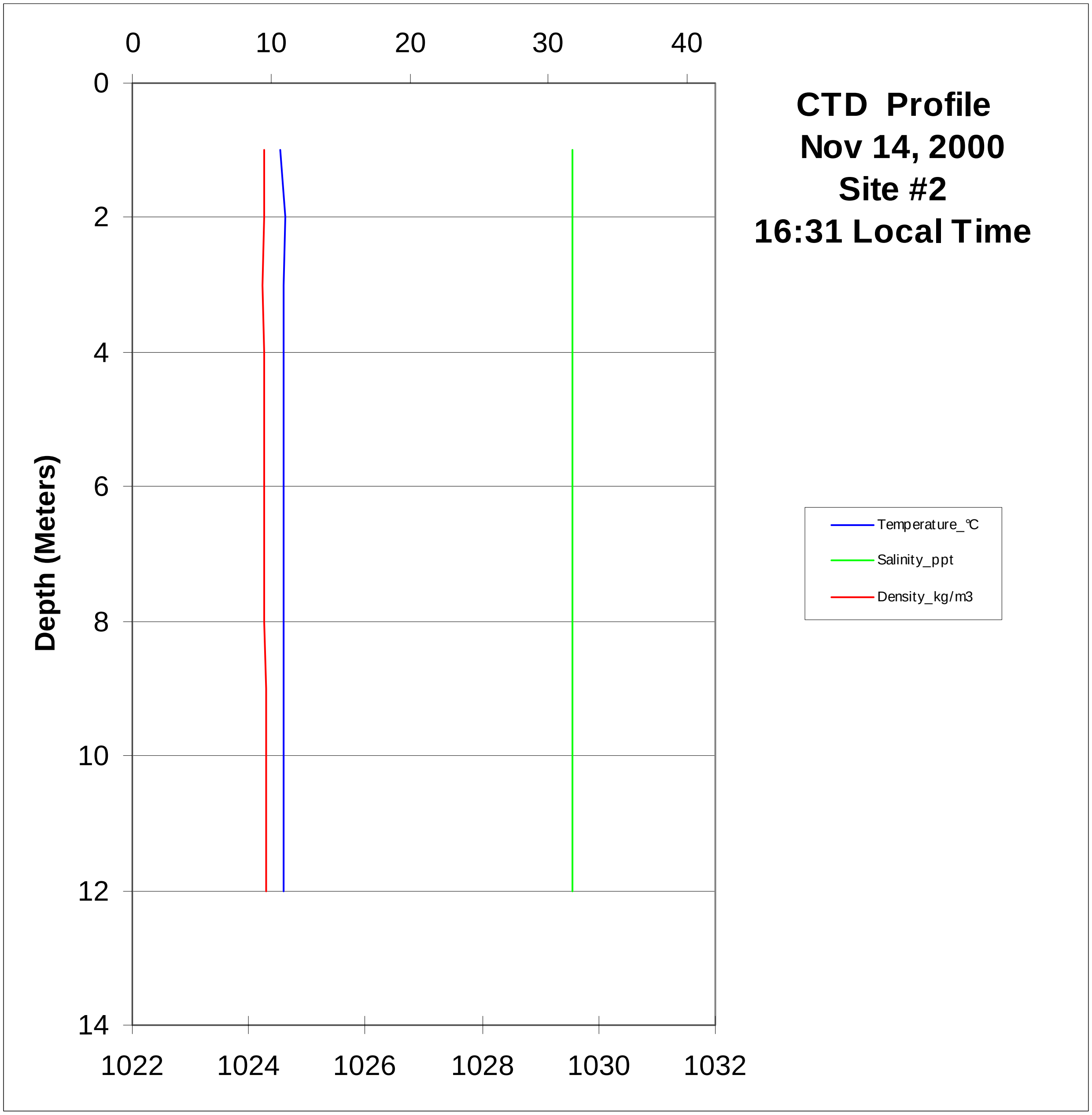
CTD Profile
Nov 9, 2000
Site #1
12:30 Local Time
Depth (Meters)
0
10
20
30
40
0
2
4
6
8
10
12
14
1022
1024
1026
1028
1030
1032
Temperature_°C
Salinity_PSU
Density_kg/m3


CTD Profile
Nov 9, 2000
Site #1
14:35 Local Time
Depth (Meters)
0
2
4
6
8
10
12
0
10
20
30
40
1022
1024
1026
1028
1030
1032
Temperature_°C
Salinity_ppt
Density_kg/m3

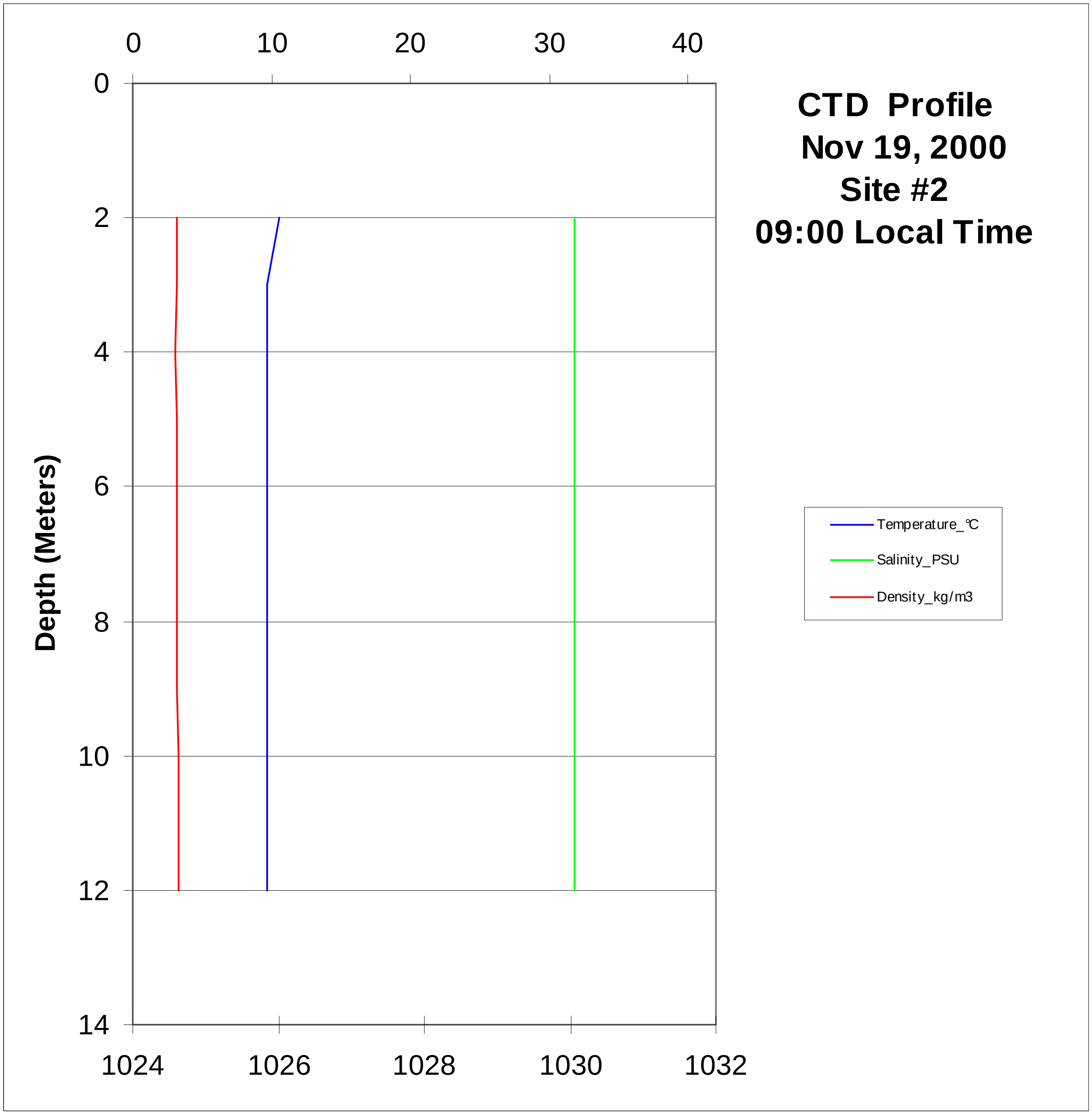


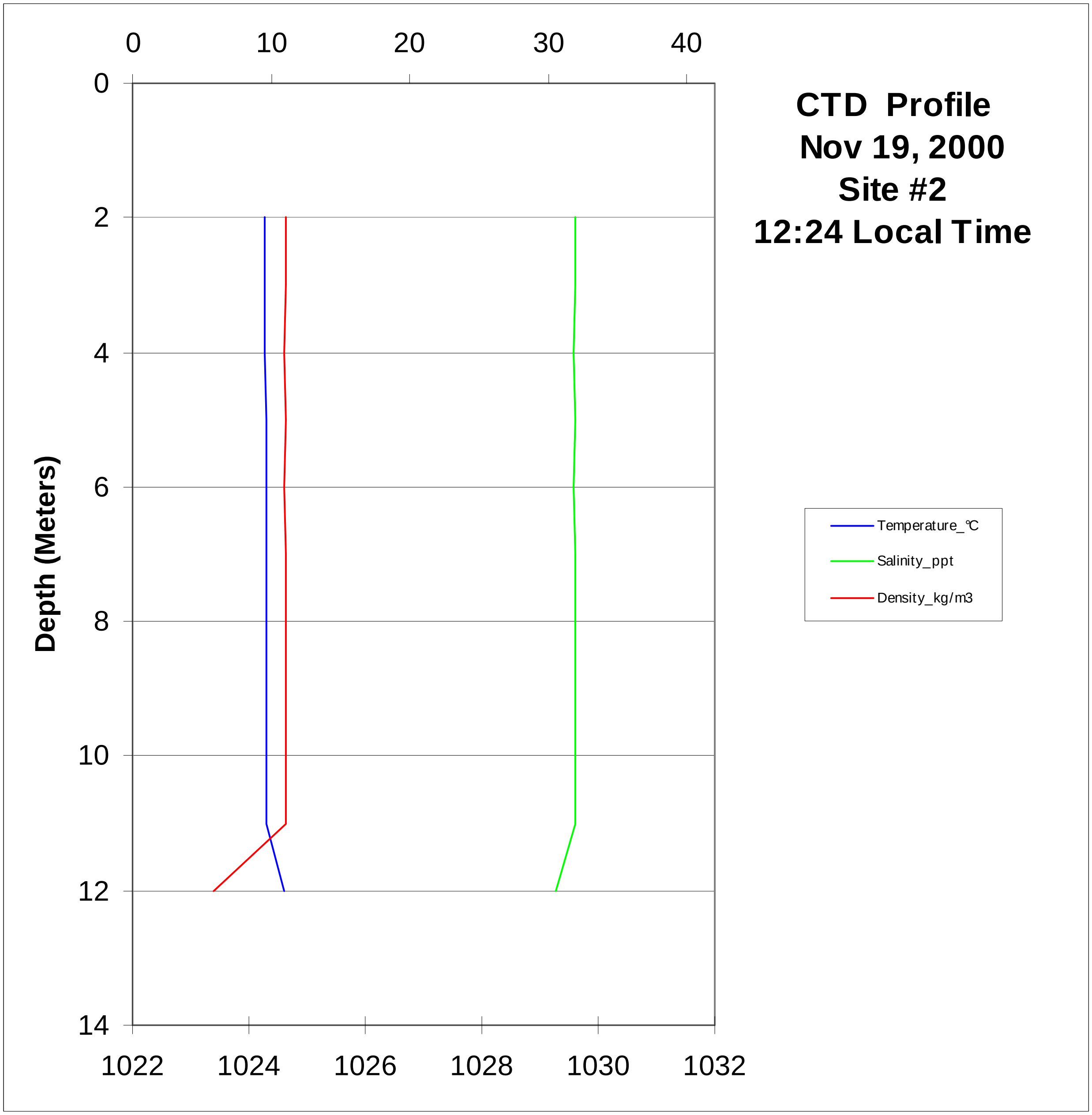
CTD Profile
Nov 14, 2000
Site #2
09:25 Local Time
0
10
20
30
40
0
2
4
6
8
10
12
14
Depth (Meters)
1022
1024
1026
1028
1030
1032
Temperature_°C
Salinity_ppt
Density_kg/m3

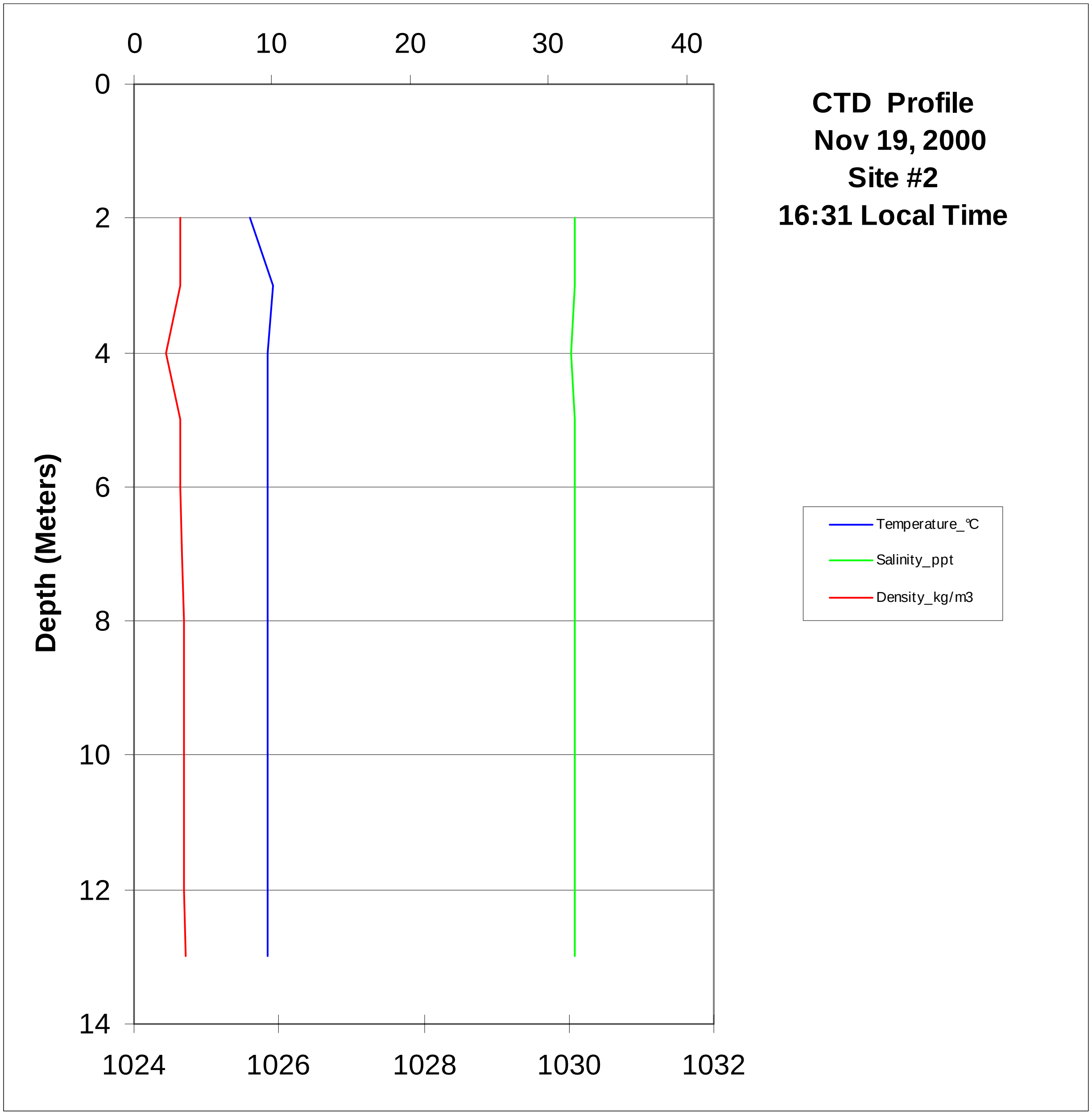

CTD Profile
Nov 14, 2000
Site #2
13:05 Local Time
Depth (Meters)
0
2
4
6
8
10
12
14
0
10
20
30
40
1022
1024
1026
1028
1030
1032
Temperature_°C
Salinity_ppt
Density_kg/m3



CTD Profile
Nov 14, 2000
Site #2
16:31 Local Time
Depth (Meters)
0
2
4
6
8
10
12
14
0
10
20
30
40
1022
1024
1026
1028
1030
1032
Temperature_°C
Salinity_ppt
Density_kg/m3


CTD Profile
Nov 19, 2000
Site #2
09:00 Local Time
Depth (Meters)
0
2
4
6
8
10
12
14
0
10
20
30
40
1024
1026
1028
1030
1032
Temperature_°C
Salinity_PSU
Density_kg/m3


0
10
20
30
40
0
2
4
6
8
10
12
14
Depth (Meters)
1022
1024
1026
1028
1030
1032
CTD Profile
Nov 19, 2000
Site #2
12:24 Local Time
Temperature_°C
Salinity_ppt
Density_kg/m3


0
10
20
30
40
0
2
4
6
8
10
12
14
Depth (Meters)
1024
1026
1028
1030
1032
CTD Profile
Nov 19, 2000
Site #2
16:31 Local Time
Temperature_°C
Salinity_ppt
Density_kg/m3