ANALYSIS OF BOSTON INNER HARBOR DYE STUDY

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MITSG 94-8

Sea Grant College Program
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

Grant: MWRA
Project No: 92-MCI-MF-1 $7

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submitted to

Massachusetts Water Resources authority

by

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March 1993

(revised August 1993)

Summary

During July 1992 a fluorescent dye study was conducted in Boston's Inner Harbor in support of MWRA's System Master Planning Combined Sewer Overflow (CSO) program. Approximately 500 pounds of 20% Rhodamine WT dye were released over a period of 5½ hours into the Charles River just upstream of its entrance to the Inner Harbor at the Charles River Dam. Dye concentrations were recorded throughout the Inner Harbor over the following six days. After the first day, dye was reasonably well mixed laterally, but showed decreasing concentration with depth and distance toward the mouth. The mean residence time of Charles River water in the Inner Harbor, computed from the time variation of total dye recovery, was in the range of 3.5 to 4 days, suggesting that about half of the freshwater leaving the Inner Harbor during ebb tide returns during flood tide. Fecal coliform are often used as indicators of sewage pollution. Reported half lives of fecal coliform, determined by calibrating models to field measurements in Boston Harbor, fall in the range of 0.2 to 0.7 days—significantly shorter than the mean residence time. This suggests that most bacteria entering the Inner Harbor with the Charles River inflow, or from nearby CSOs, die by the time they reach the Outer Harbor.

Background

During July 1992 Aquatec, Inc., and MIT conducted a fluorescent tracer study in Boston's Inner Harbor. The survey was conducted in support of the Massachusetts Water Resources Authority's (MWRA) System Master Planning and Combined Sewer Overflow (CSO) program and was designed to improve understanding of residence times and flushing rates of Charles River water within the Inner Harbor. As such, the study was intended to complement recent field measurements collected on the smaller scale of Fort Point Channel (Adams and Stolzenbach, 1992) and several field studies (Kossik et al., 1986; Adams et al., 1987; Kelly, 1991; Sung, 1991; Shea and Kelly, 1992) and theoretical studies (Ketchum, 1951b; Hydroscience, Inc., 1973; Lee, 1990; Signell and Butman, 1992) conducted on the larger scale of Boston's Outer Harbor. Dye was released at the confluence of the Charles River and the Inner Harbor because the Charles is the major source of freshwater to the harbor (Menzie et al., 1991) and because the river contains high concentrations of pollutants (including CSO sources).

In order to maintain a near constant water level in the Charles River basin, freshwater is usually released by gravity to the Inner Harbor every tidal cycle for a period of time surrounding low tide. Both an upper and lower sluice gate are available at the dam for this purpose. During our survey, we released 501.2 pounds of 20% solution Rhodamine WT (specific gravity 1.03) into the forebay of the upper level sluice as freshwater was being released; see Figure 1. Dye was delivered at a constant rate from 20:35 on the evening of 22 July to 02:00 on the morning of 23 July. Low tide was at 23:37 on 22 July. The $5\frac{1}{2}$-hour release coincided as closely as possible with the release of Charles River water for this tidal cycle; i.e., we tagged all of the river water released during the tidal cycle. (The low level sluice was not used during this cycle.) Based on calibration curves supplied by N. Winter at the dam, we estimate that a near constant freshwater flow rate of 20 m^3/s (700 cfs) was delivered during this interval, corresponding to a total of $3.9 \times 10^5 m^3$ of freshwater over the

5½ hours. This was a dry period of time (Charles River flow was approximately 2 m^3/s at the Waltham gauge immediately prior to and during our survey), and hence freshwater was not released through the sluices during the tidal cycles immediately prior to or following dye release. (Small quantities of Charles River water were discharged to the Inner Harbor, however, to operate the fish ladder.) Prior to the dye survey freshwater was last released through both sluices from 19:00 on 21 July to 02:30 on 22 July. The next release of freshwater following the dye survey was from 14:00 to 16:00 on 24 July. Hence there was an interval of about 18 hours with essentially no freshwater inflow prior to our experiment and an interval of about 36 hours with no freshwater inflow following our experiment.

A boat with a flow-through fluorometer was used to measure fluorescence, temperature, and conductivity (from which salinity and dye concentration were computed) at depth intervals of approximately one foot from surface to bottom at approximately 30 stations throughout the Inner Harbor (Figure 1). Thirteen surveys were conducted of approximately two hours' duration each surrounding daytime low and high tides over the six-day period of 23–28 July. Two earlier surveys were also conducted to assess background fluorescence. Details concerning the measurements and calibration are contained in the appendix (Aquatec, 1993).

Data Presentation

Figure 2 displays longitudinal-vertical sections of dye concentration along a transect extending from Chelsea Creek to the Inner Harbor mouth. In this and subsequent discussion, dye concentration is represented in $\mu g/\ell$ of pure Rhodamine WT. Contouring was accomplished using SURFER software (Golden Software, Inc., Golden, Colorado) by first projecting measured concentration to a regular 600-foot (horizontal) by 1-foot (vertical) grid using inverse-distance-squared weighting and then fitting a 2-D quadratic surface. The vertical sections indicate that the dye is initially concentrated near the surface at the confluence with the Charles River and gradually spreads longitudinally and vertically. After six days the dye is nearly, but not completely, vertically well mixed.

Figure 3 displays horizontal contours of near-surface dye concentrations. Contouring was performed by hand. After a few surveys, the data indicate that dye is reasonably well distributed laterally, across the Inner Harbor and between Mystic River and Chelsea Creek upstream. A gradient of decreasing concentration toward the Inner Harbor mouth is also clearly seen.

For each survey, dye concentrations were integrated spatially to arrive at total dye mass within the Inner Harbor, which is plotted in Figure 4, as a function of time. Except for the first two surveys, where high concentration gradients probably precluded an accurate spatial interpretation, the mass showed the expected monotonic decrease over time. Note that the injected mass was 100.2 pounds.

Interpretation

As demonstrated in Adams and Stolzenbach, 1992, the mean Inner Harbor residence time of dye (and hence of any conservative pollutants dissolved or suspended in the Charles River inflow under the survey conditions) can be found by extrapolating the dye recovery to zero at t = infinity and integrating over time, i.e.,

$$\tau = \frac{\int_0^\infty M(t)dt}{M_0} \qquad (1)$$

where $M(t)$ is the mass of dye in the harbor as a function of time and M_0 is the initial dye mass (100.2 pounds). Using data in Figure 4 the estimated time is between about 3.5 and 4 days. (Using the piece-wise fit to the observed $M(t)$, shown in Figure 5, the calculated value is 3.6 days.)

The observed residence time can be compared with the few other estimates available in the literature. Using the fraction freshwater method, Bumpus et al. (1953) measured Inner Harbor residence times for ten dates during 1951 and 1952. They found the time τ to increase with decreasing freshwater inflow ranging from a low of about 1.6 days to a high of about 10 days. Using their Figure 16 showing residence time versus total runoff to the Inner Harbor and their ratio of 1.33 relating total runoff to Charles River flow measured by the USGS in Waltham, one estimates $\tau \simeq 2.2$ days for an annual average Charles R. flow at Waltham of 8.6 m^3/s (ave. of 1931 to 1992; USGS, 1992) and $\tau \simeq 4$ days corresponding to an average summertime flow of 3.4 m^3/s at Waltham (average of July–September over the same time interval). Although the last value agrees nicely with our experiment, the fraction freshwater method would have to be considered very approximate due to unsteady inflow and the difficulty in accurately defining end member salinity in the Outer Harbor.

A theoretical residence time of 6 days was computed by Ketchum (1951b) for Inner Harbor waters between the Charles River and the mouth using the modified tidal prism technique (Ketchum, 1951a). This is a theoretical method which assumes complete mixing within harbor segments of length equal to the computed local tidal excursion. Another theoretical calculation which is often used as a lower bound estimate on residence time is the tidal prism method

$$\tau = \frac{VT}{P} \tag{2}$$

where V is the high tide volume of the Inner Harbor, P is the intertidal or tidal prism volume of the Inner Harbor, and T is the tidal period (12.4 hr). Using values of $V = 7.8 \times 10^7 m^3$ and $P = 2.2 \times 10^7 m^3$ (Bumpus et al., 1953)) yields a tidal prism residence time of 1.8 days. This value is a lower bound because it assumes concentrations within the whole Inner Harbor are well mixed and that none of the mass that leaves the harbor on ebb tide returns on the following flood tide. The measured time of 3.6 days suggests that about half of the dye exiting on ebb tide is returning on the following flood tide. The value of 50% is typical of return factors often found (or assumed) for tidal embayments (Sanford et al., 1992).

Other quantities of interest can also be calculated from these data. Because freshwater is generally released twice a day, it would appear nearly continuous to an observer at the mouth of the Inner Harbor. As such a flushing rate can be computed as

$$Q_f = \frac{V}{\tau} \tag{3}$$

where again V is the Inner Harbor high tide volume. Using $V = 7.8 \times 10^7 m^3$

$$Q_f \simeq 250 \ m^3/s$$

The flux of a pollutant out of the Inner Harbor is equal to the flushing rate times the average pollutant concentration. In an average summer (July–Sept.) freshwater flow at the Charles River Dam is about 4 m^3/s (61-year average flow at Waltham of 3.4 m^3/s (USGS, 1992) multiplied by estimated factor for low flows of 1.15 (CDM, 1976)). Therefore mixing within the Inner Harbor can be expected to dilute the average concentration of a conservative substance entering with the Charles River inflow by a factor of about $250/4 \simeq 60$.

The dye data can also be applied to the fate of a non-conservative substance by first computing the residence time distribution f(t), defined by

$$f(t) = \frac{-d\,M(t)}{M_0\,dt} \tag{4}$$

Using the piece-wise fit to the M(t) data shown in Figure 5, f(t) is computed as the solid line in Figure 6. Also shown as dashed lines in Figure 6 are first-order decay curves (e^{-kt}) corresponding to values of k = 1, 2, and 3 per day (half lives of 0.69, 0.35, and 0.23 days respectively). The values of k were chosen because calibration of mathematical models against field measurements of fecal coliform (Hydroscience, 1973; CDM, 1989; Adams et al., 1992) has suggested that the disappearance rate of fecal coliform in Boston Harbor is in the range of 1–3 per day.

The fraction of live bacteria that enter the Inner Harbor from the Charles River and exit alive to the Outer Harbor would be given by

$$F = \int_0^\infty e^{-kt} f(t) \qquad (5)$$

Using k = 1, 2, and 3 d^{-1} yields values of F ≃ 0.01, 0.03, and 0.12. These low values are qualitatively consistent with the mathematical simulation of Adams and Zhang (1991) who found that the majority of the CSO impact on the Outer Harbor was due to the (nearby) Outer Harbor CSOs rather than the larger but more distant Inner Harbor CSOs. We are currently in the process of quantitatively comparing model predictions of dye concentration against the July 1992 measurements for purposes of additional model calibration and validation.

Acknowledgments

This work was sponsored by the Massachusetts Water Resources Authority and administered through the Coastal Processes Marine Center of the MIT Sea Grant College Program. We appreciate the assistance of Nick Winter, Superintendent of the Charles River Dam, in arranging for the dye release, and in scheduling sluice operations.

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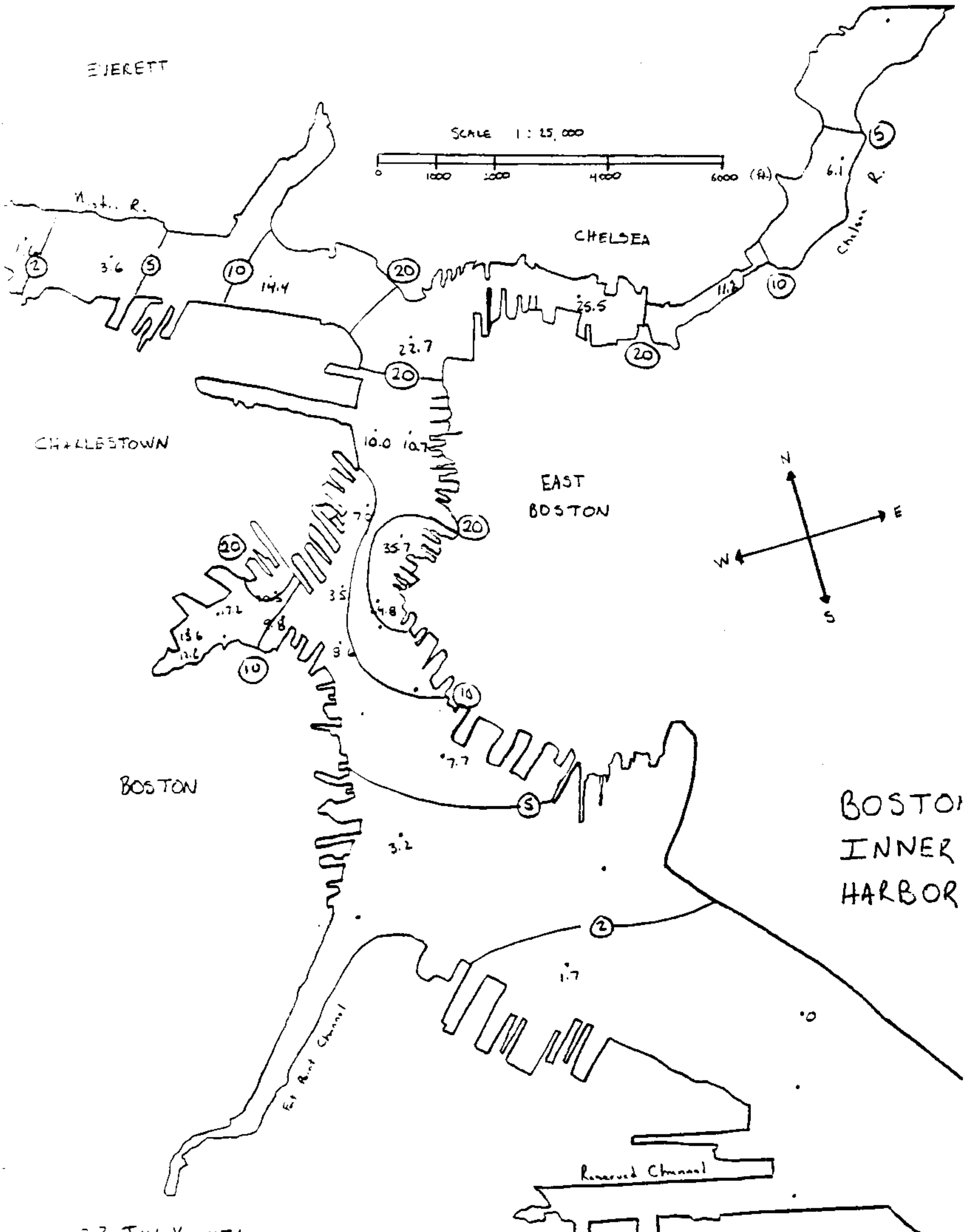
Figure 1 Location of Vertical Profile Stations

Figure 2. Horizontal contours of surface dye concentration ($\mu g/\ell$)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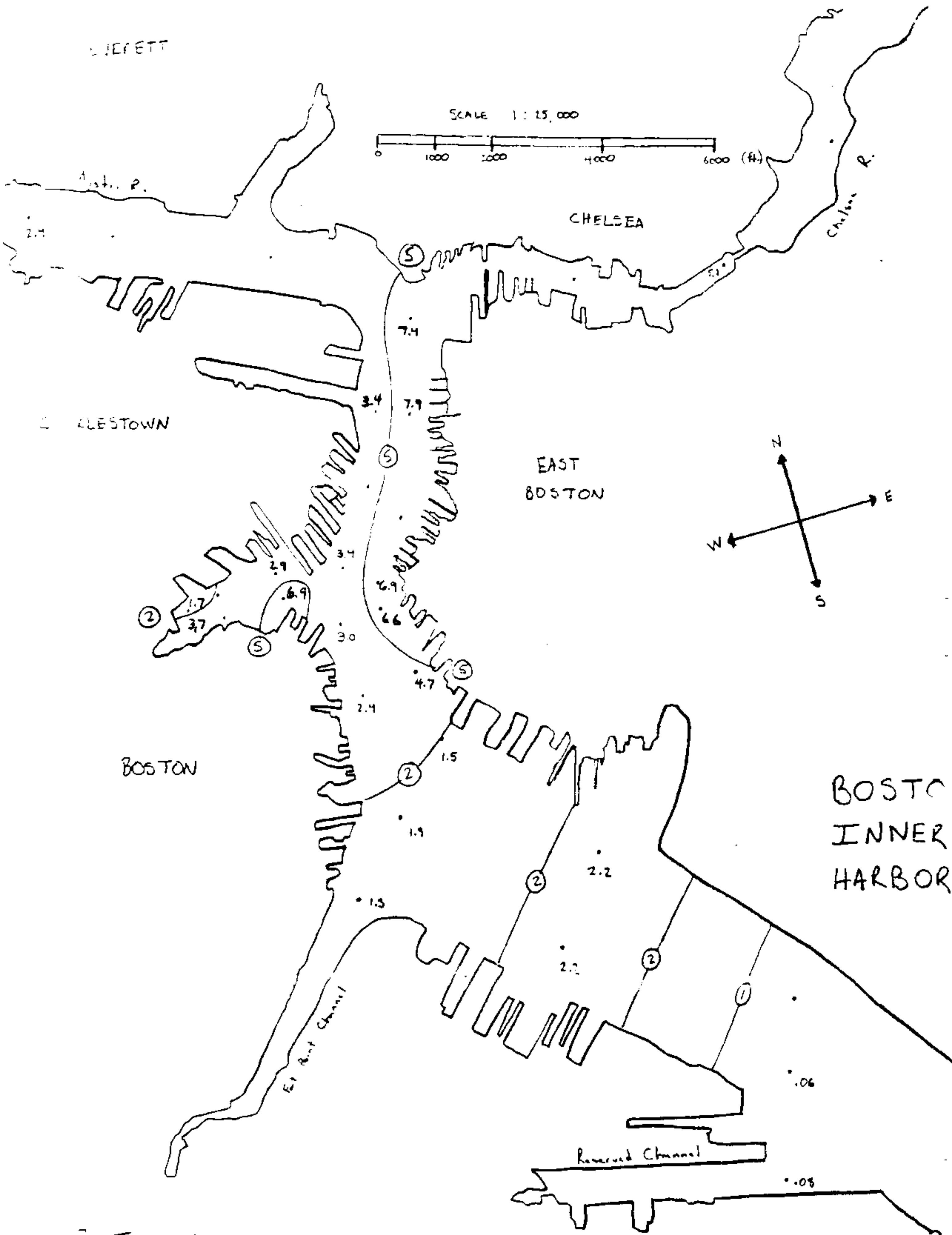

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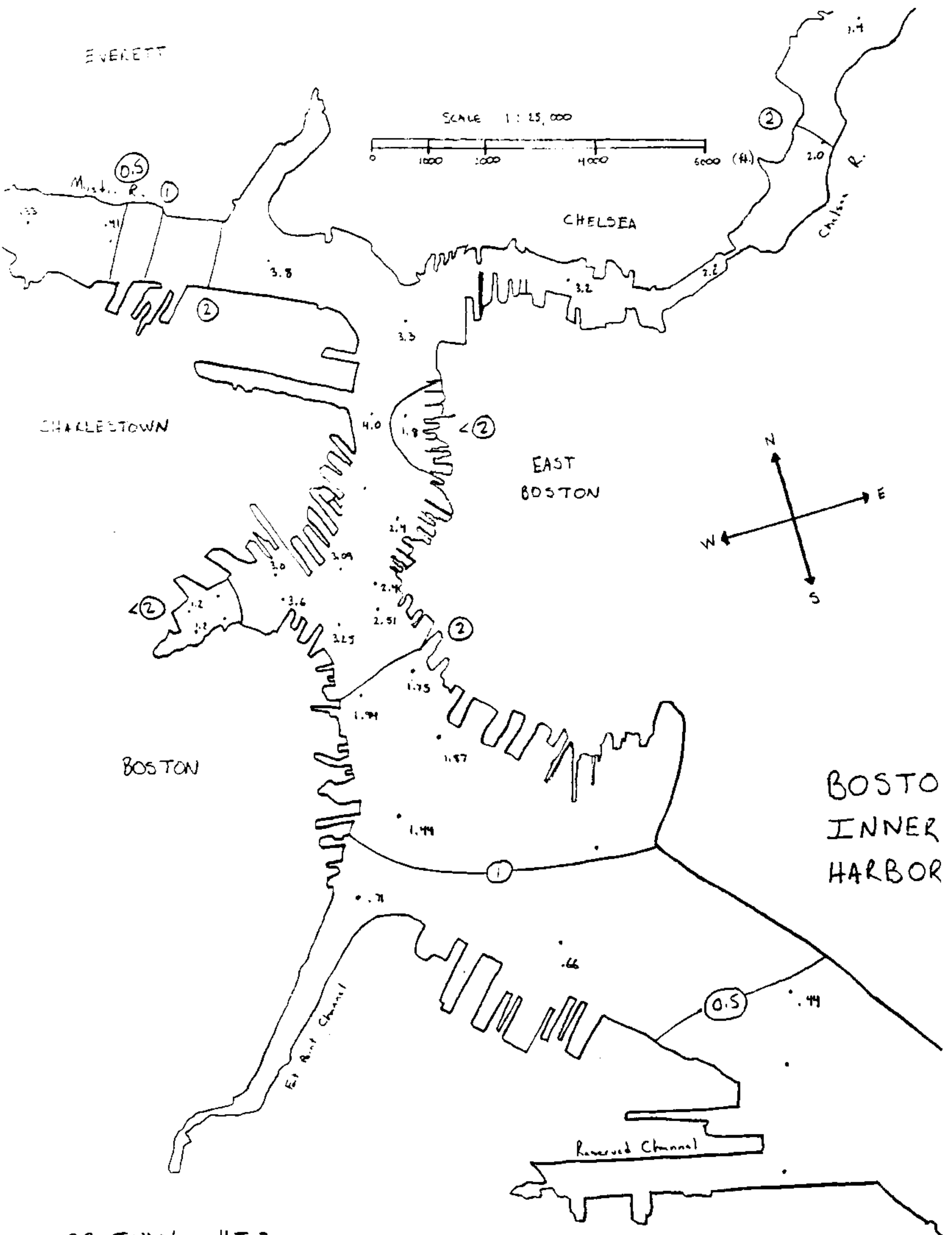
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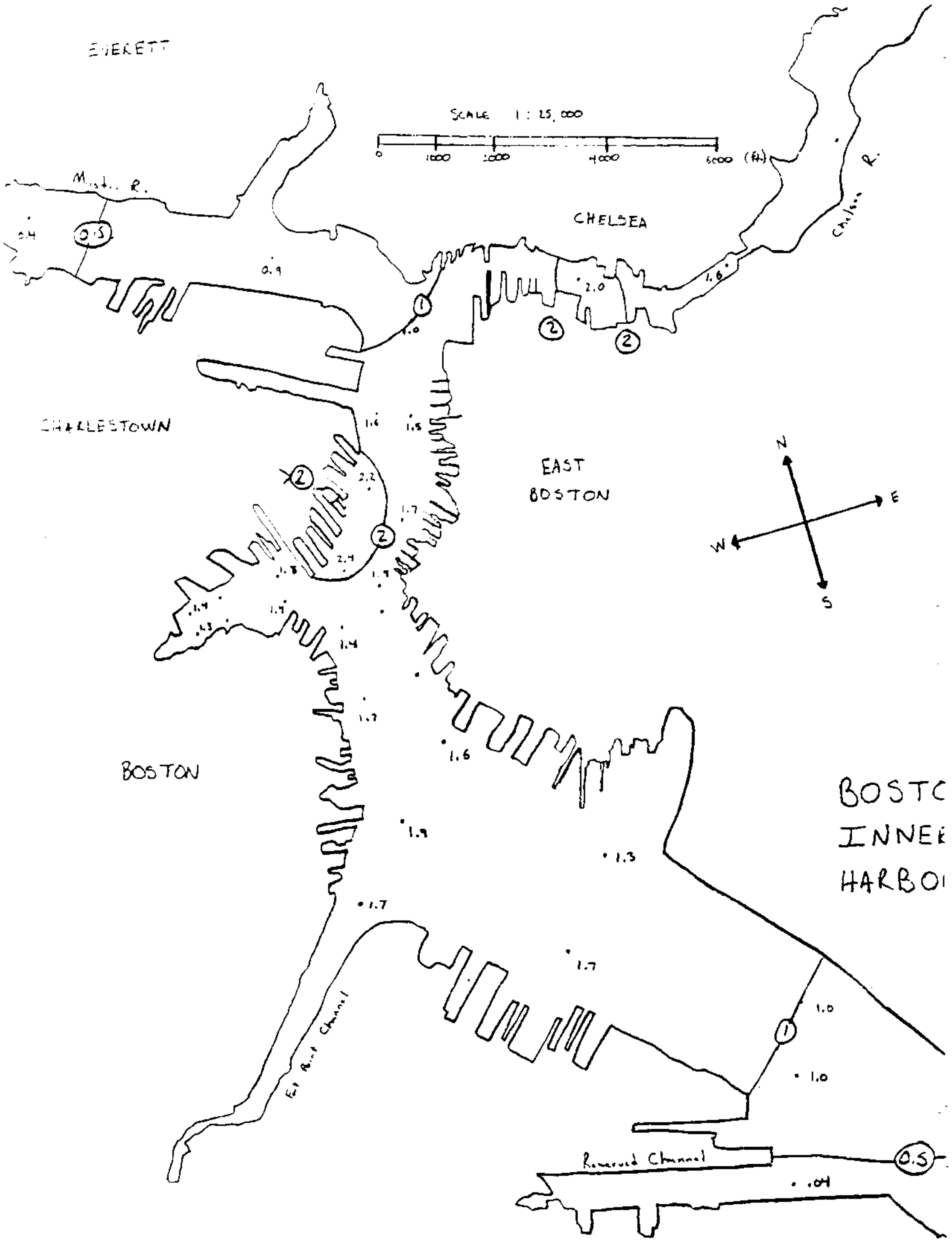
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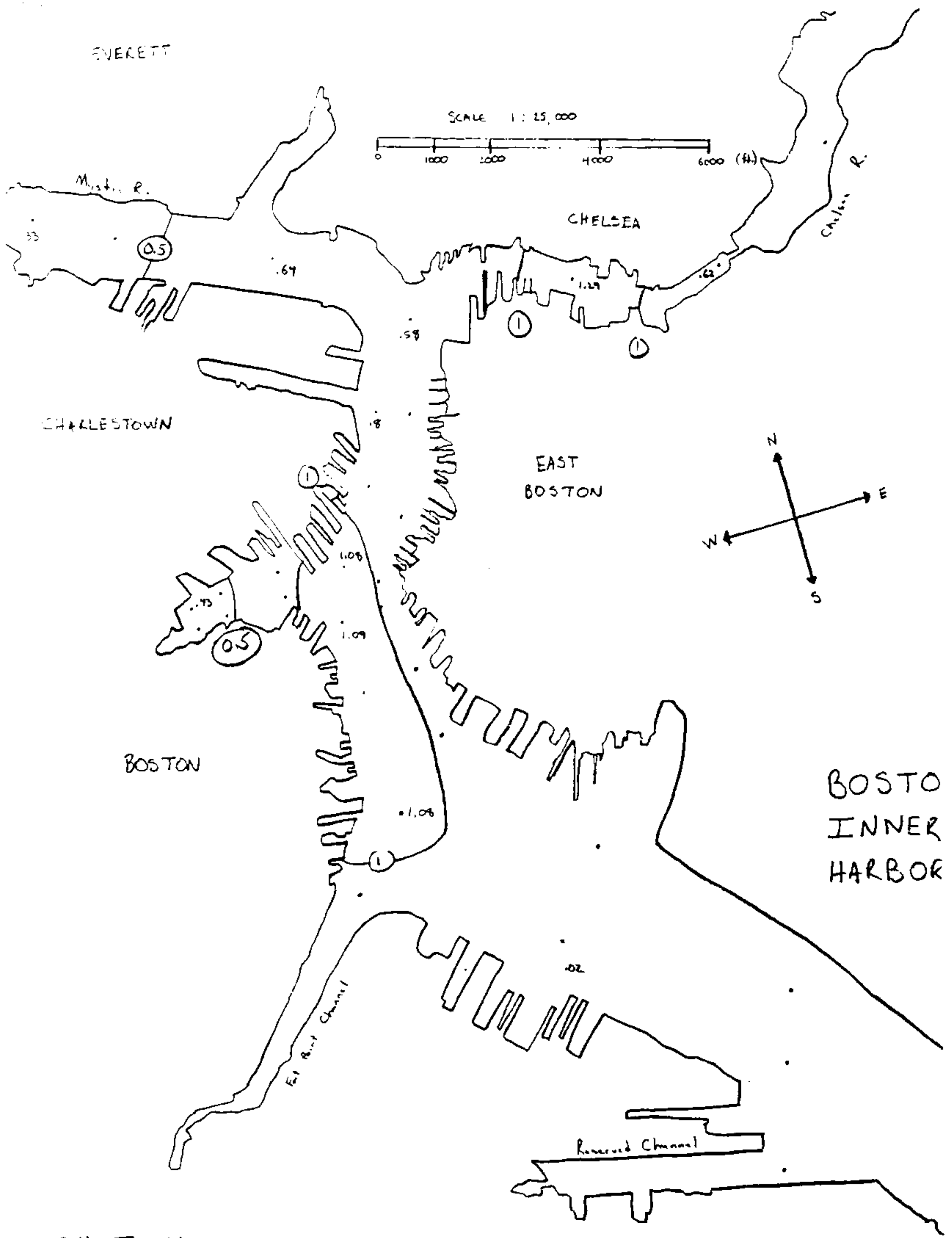
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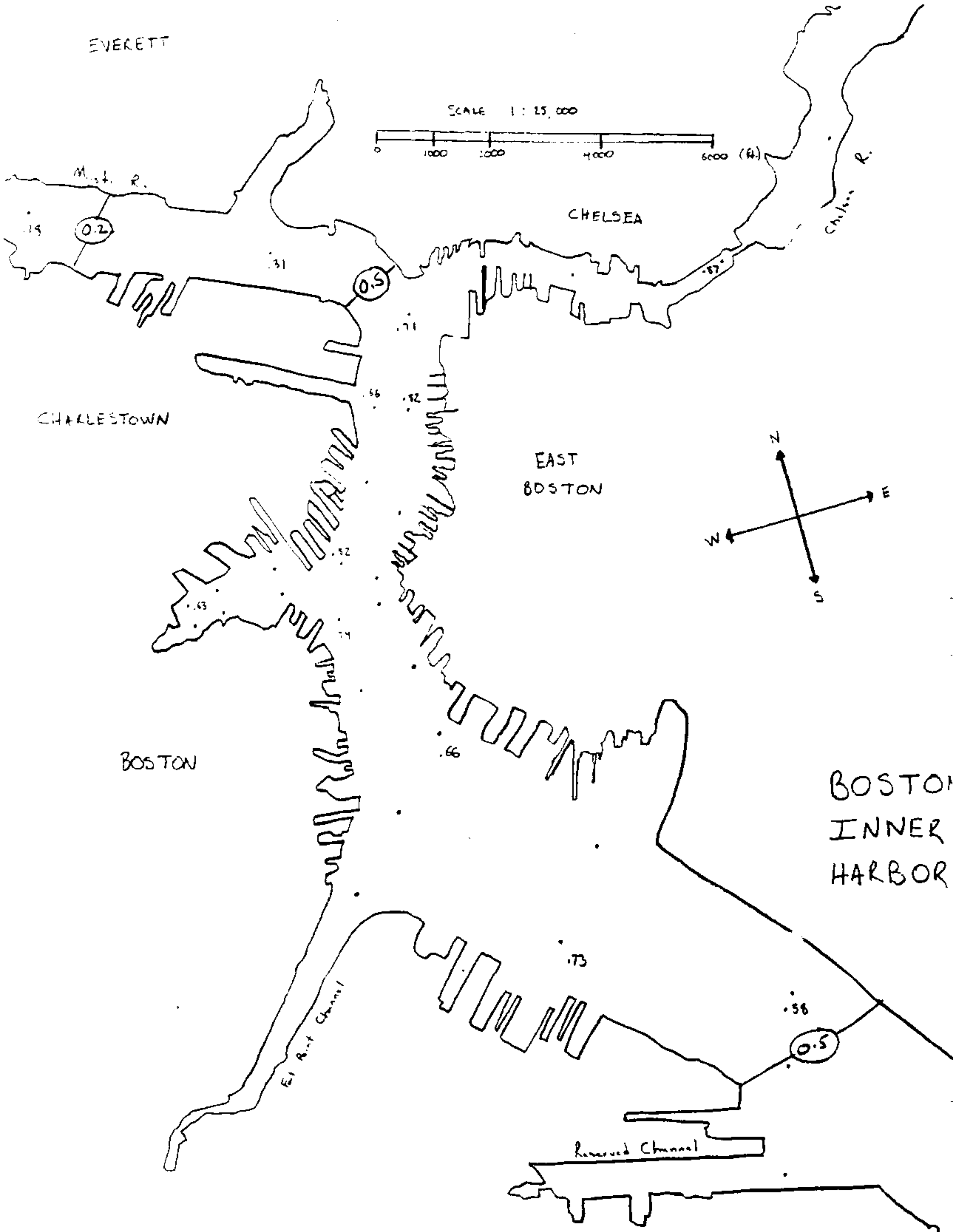

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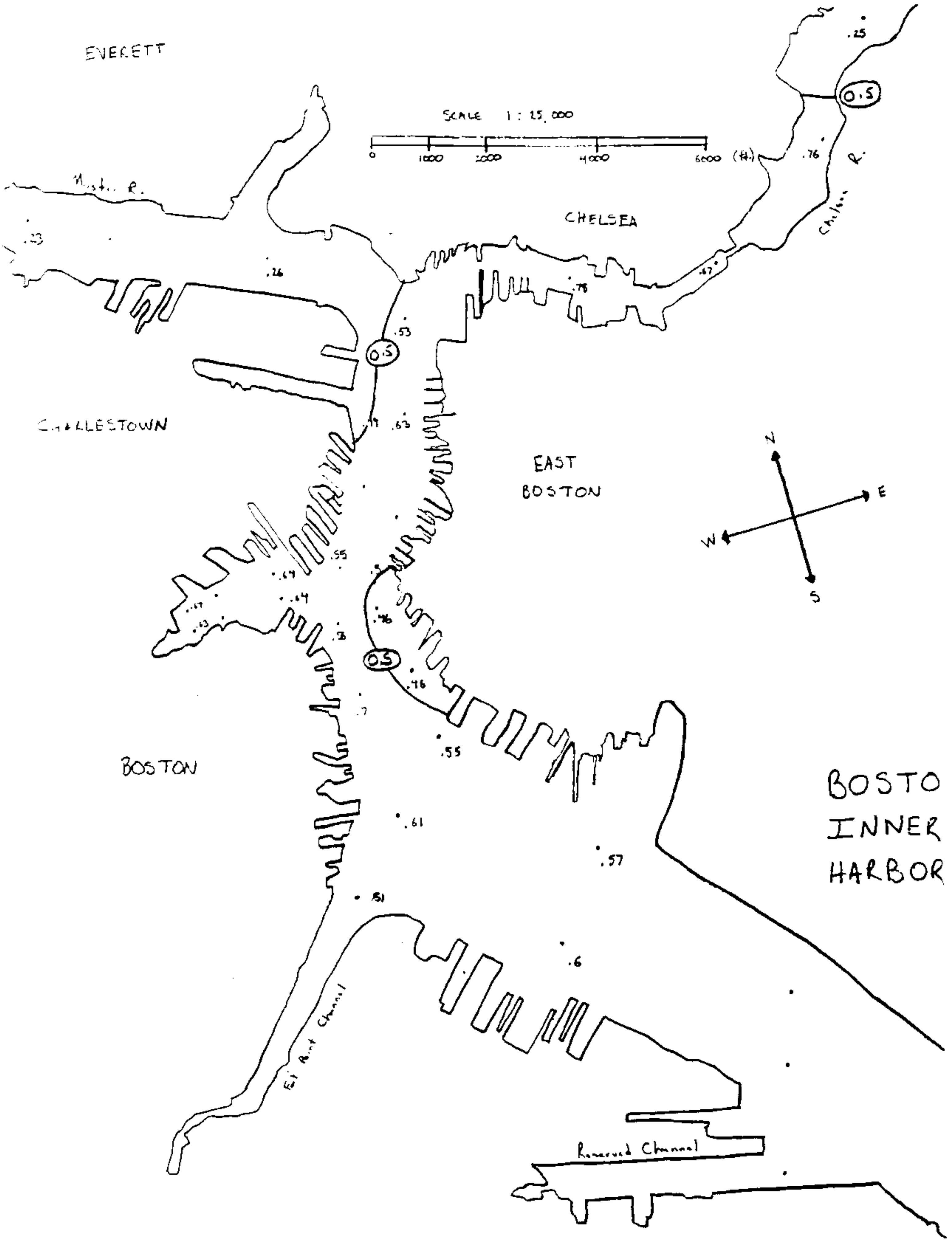

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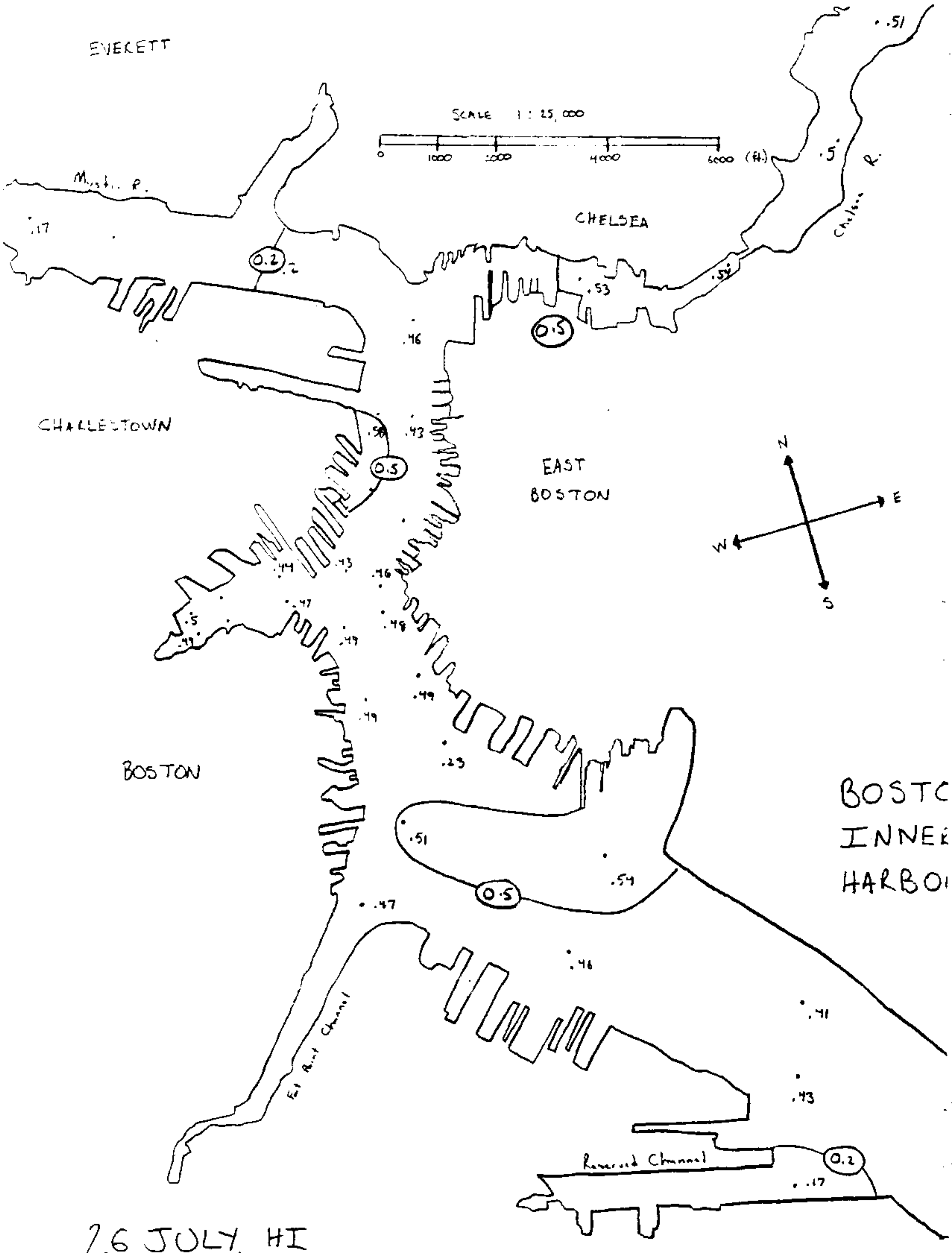
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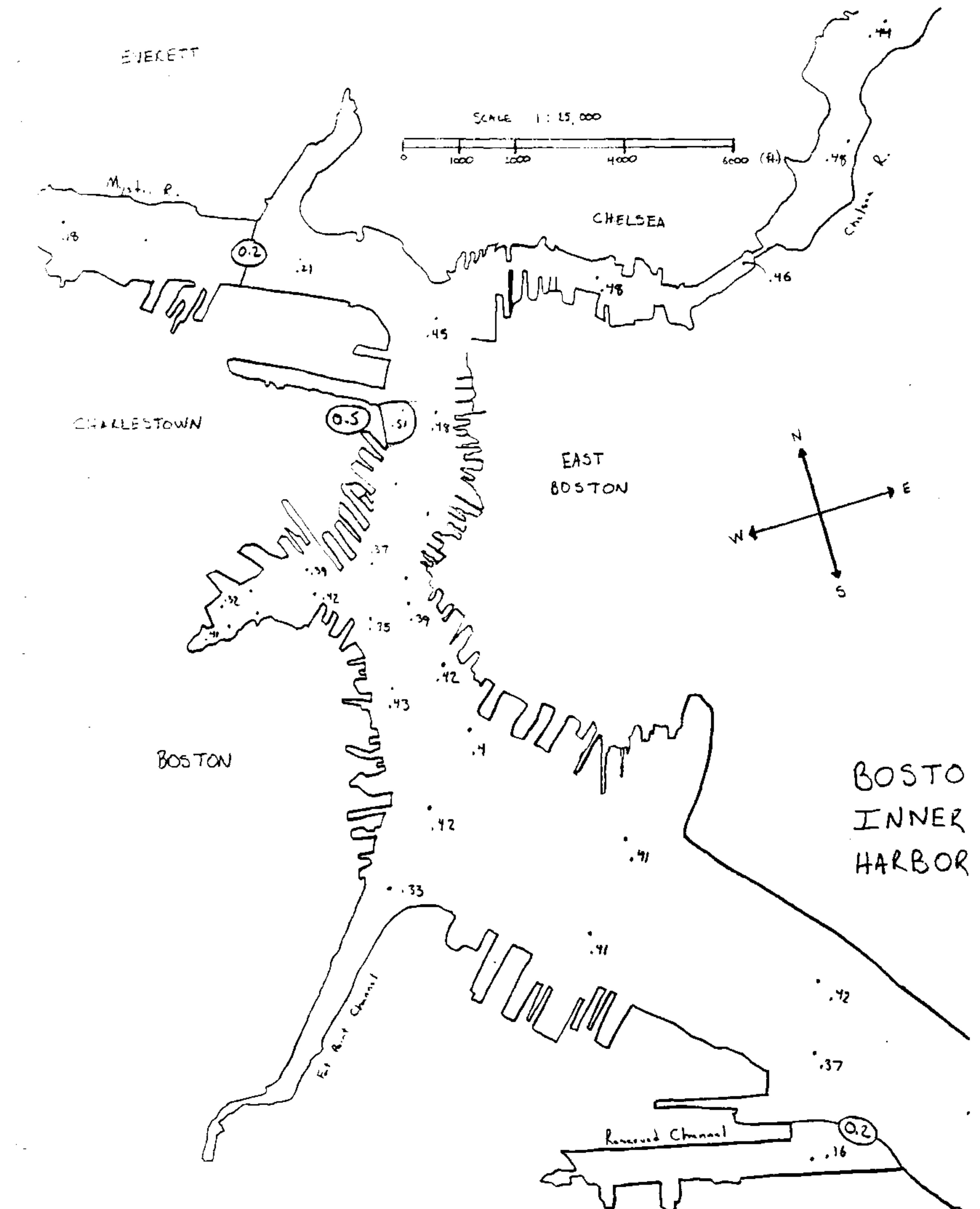
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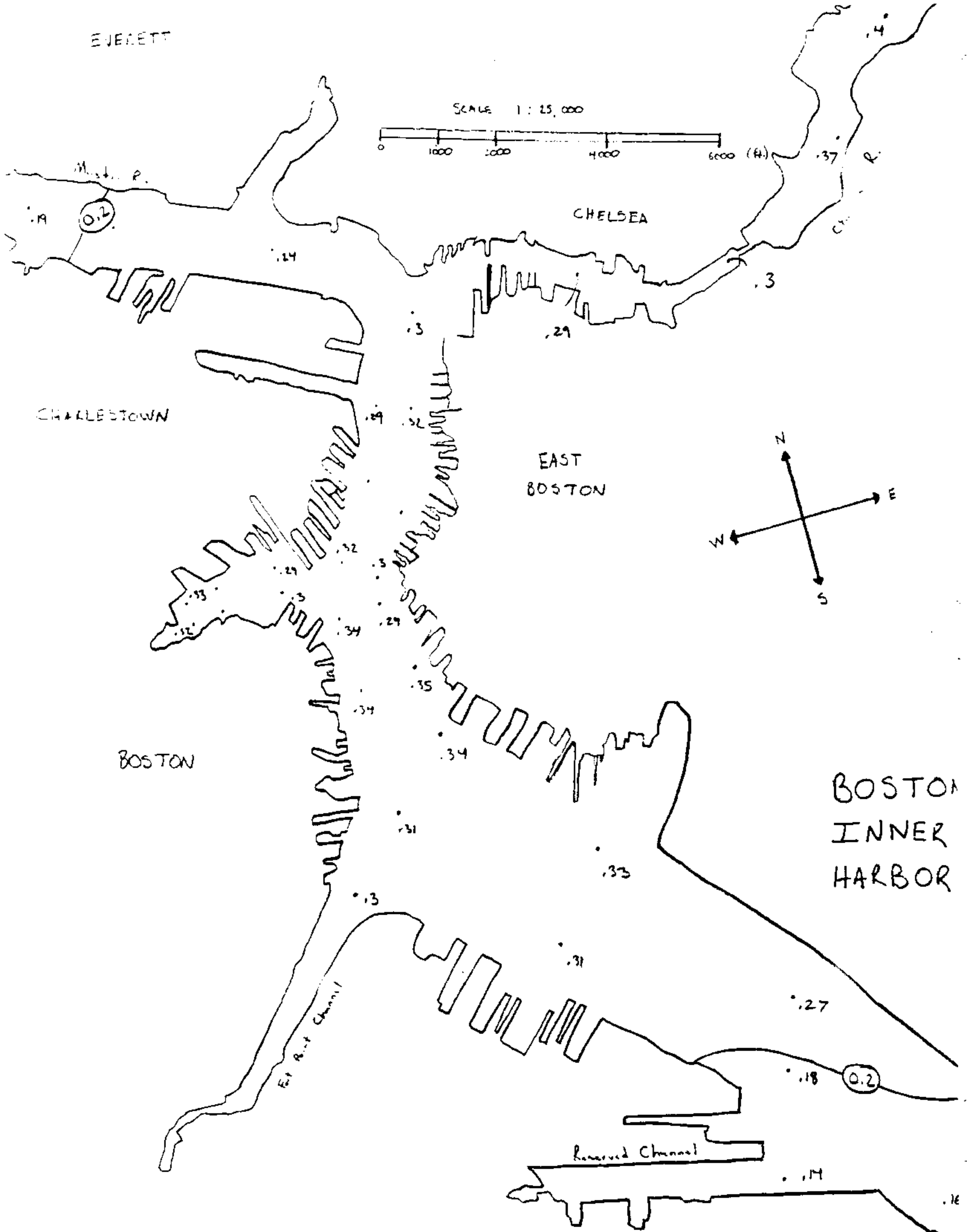

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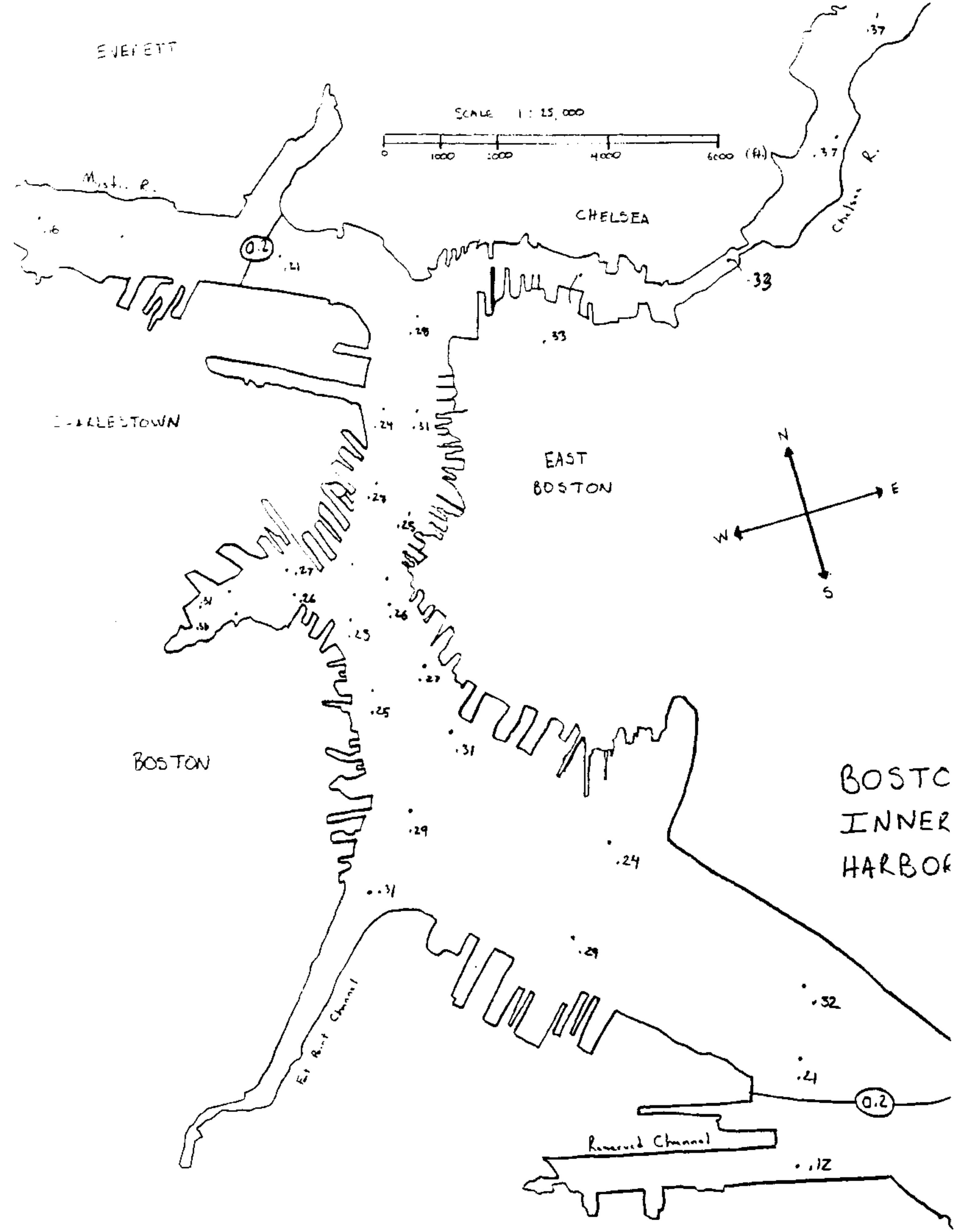

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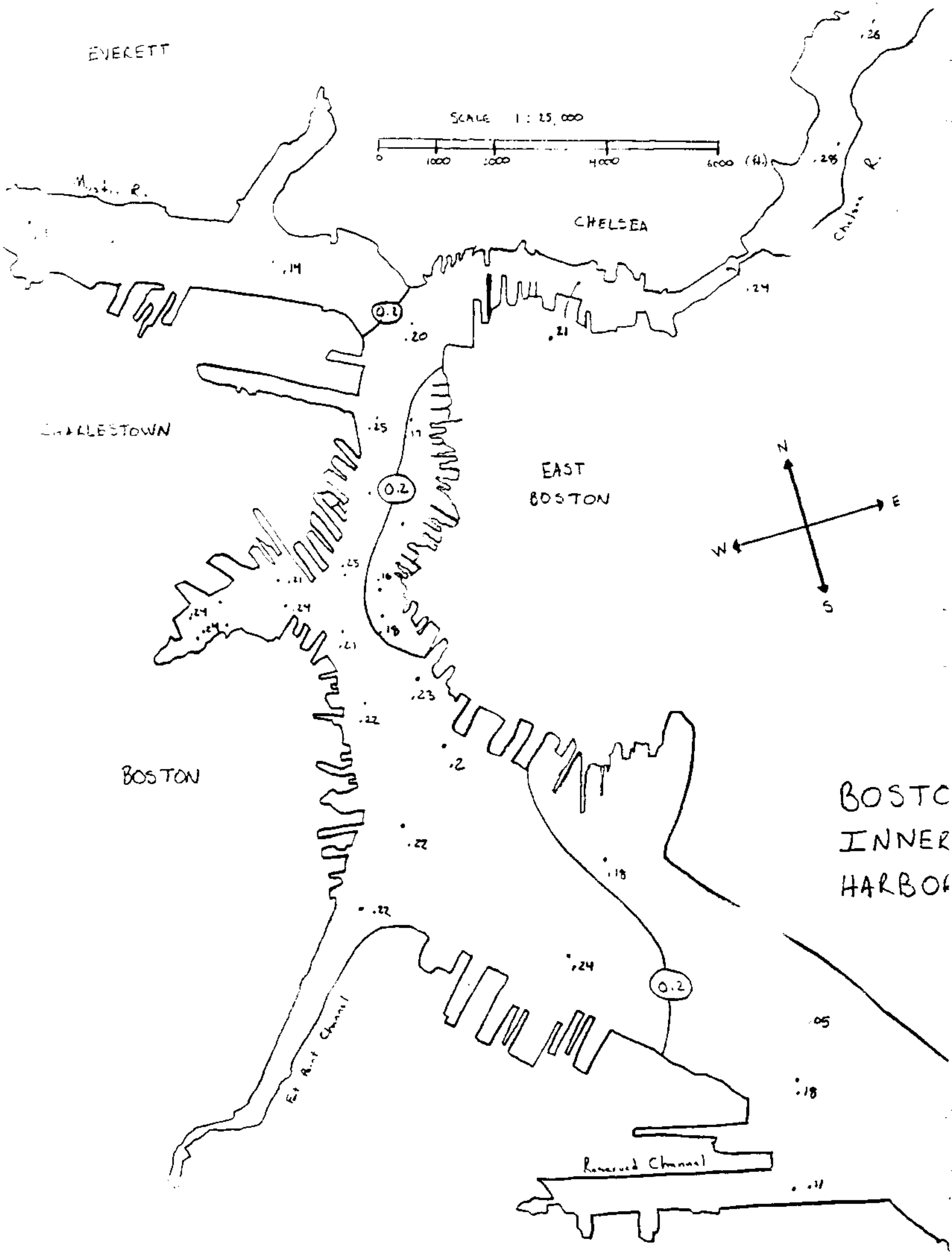

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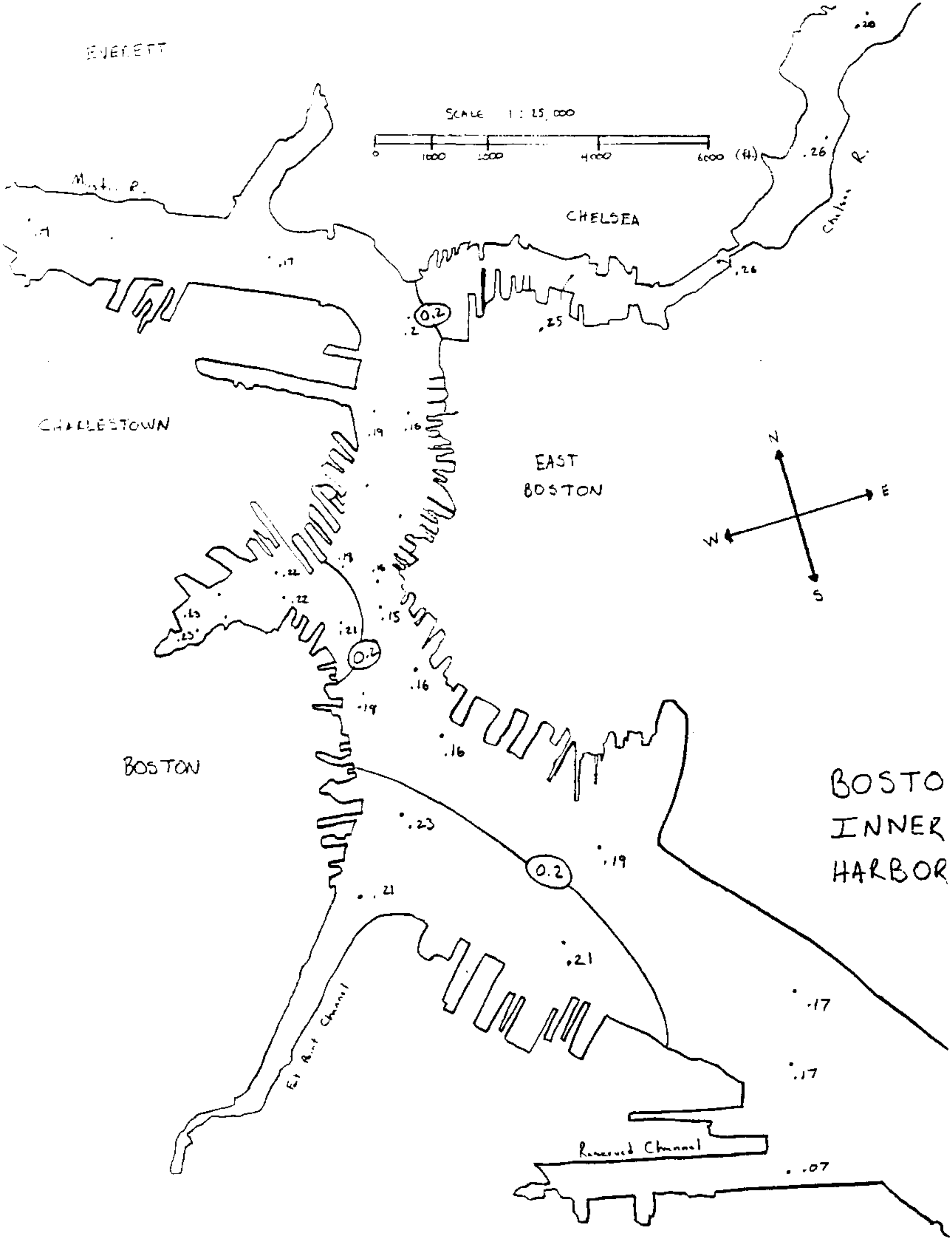
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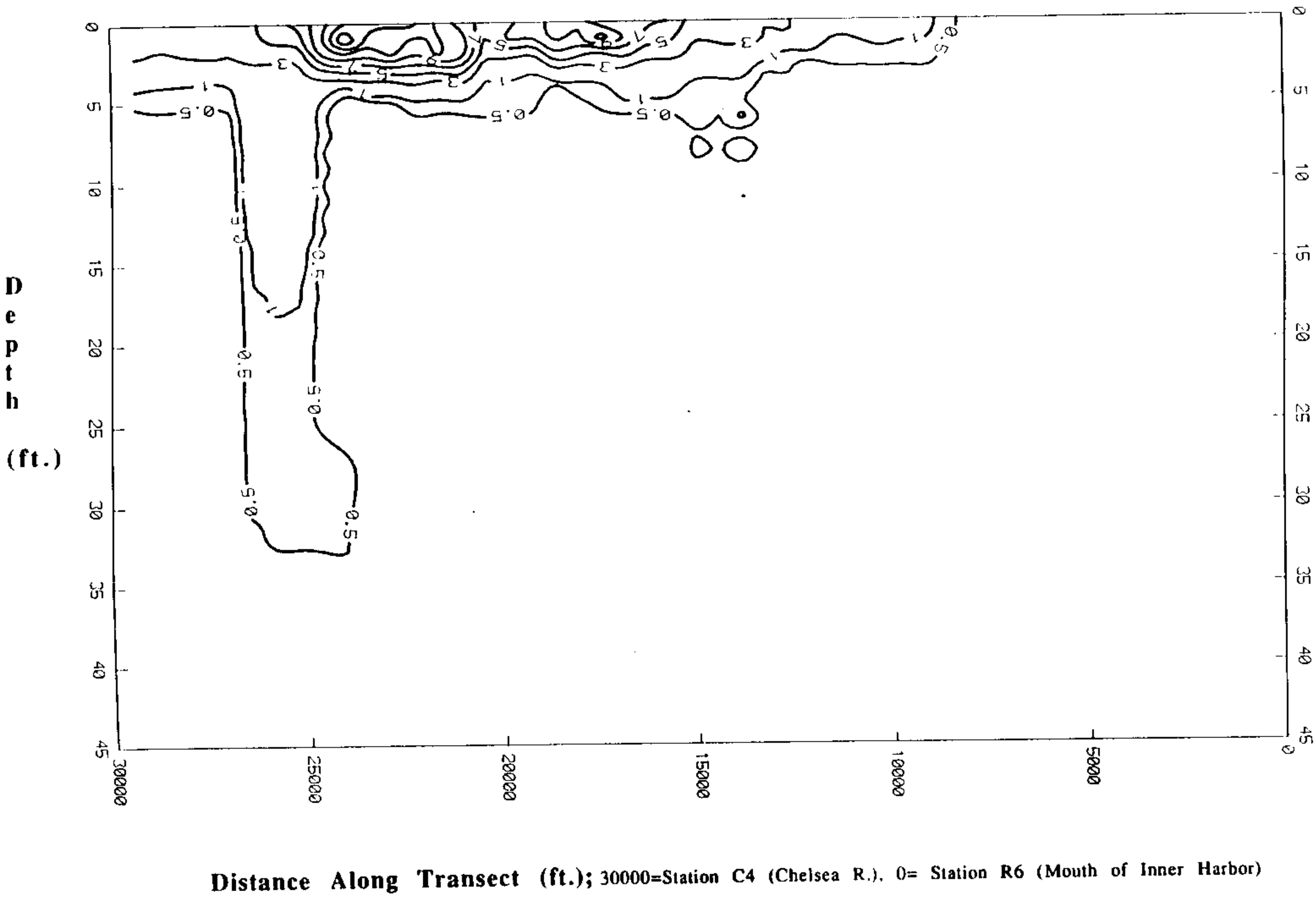
Figure 3. Longitudinal-vertical contours of dye concentration ($\mu g/\ell$) from Chelsea Creek to Inner Harbor mouth

Survey 1: 7/23/92, High Tide 1

Contour Value: ug/L



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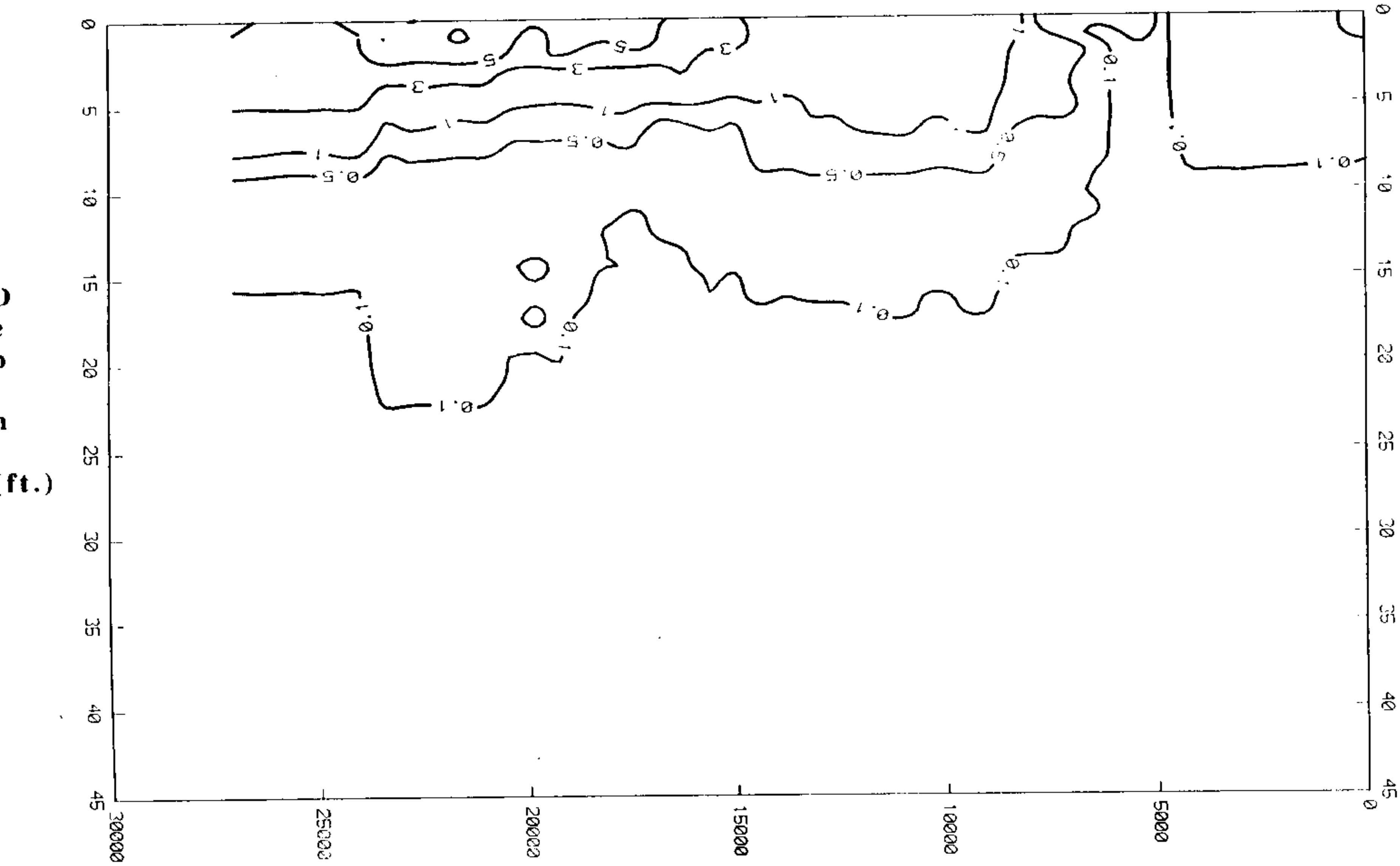
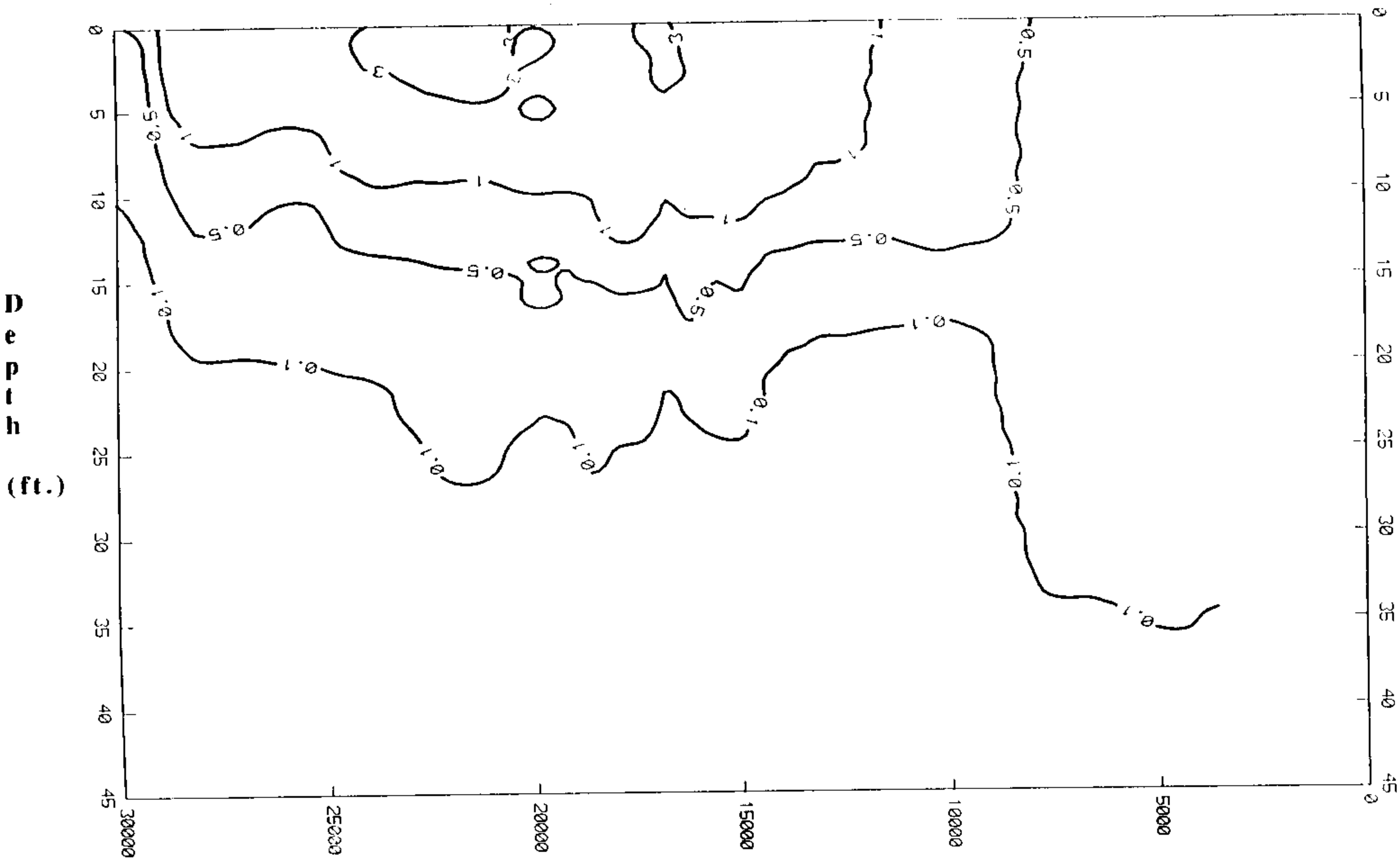


Distance Along Transect (ft.); 30000=Station C4 (Chelsea R.), 0= Station R6 (Mouth of Inner Harbor)

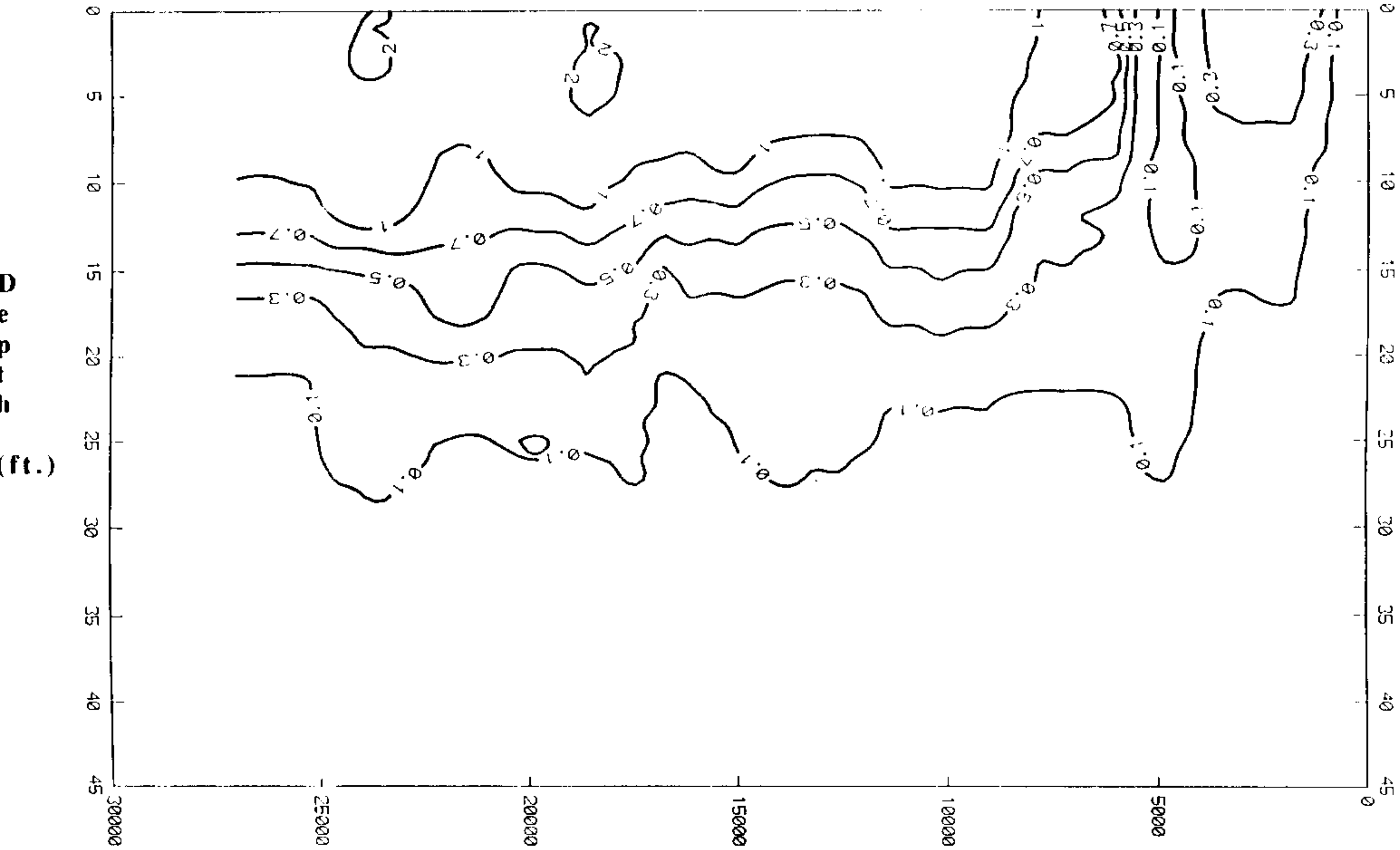
Survey 3: 7/23/92, High Tide 2

Contour Value: ug/L



Distance Along Transect (ft.); 30000=Station C4 (Chelsea R.), 0= Station R6 (Mouth of Inner Harbor)

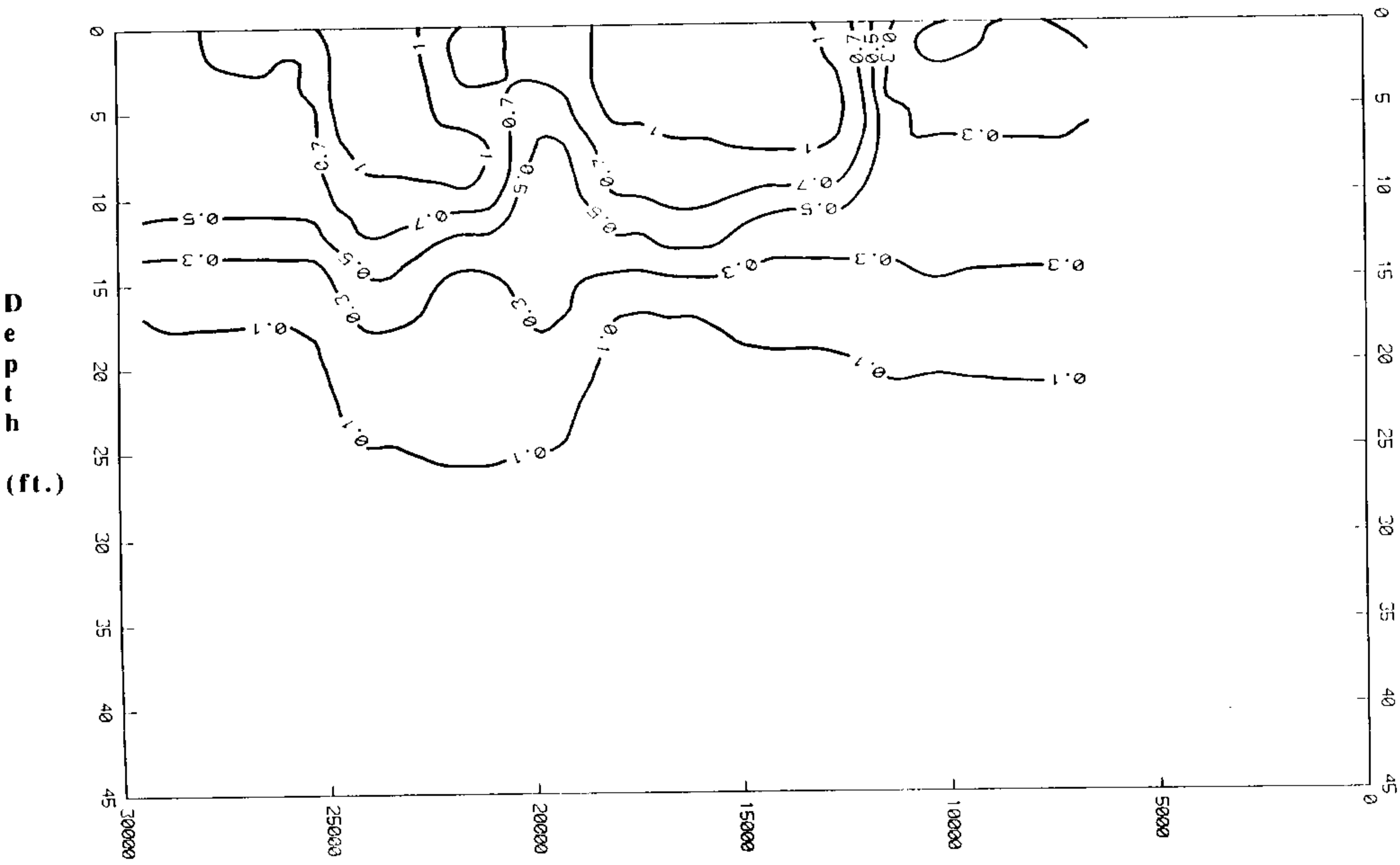
Survey 4: 7/24/92, High Tide
Contour Value: ug/L



Distance Along Transect (ft.); 30000=Station C4 (Chelsea R.), 0= Station R6 (Mouth of Inner Harbor)

Survey 5: 7/24/92, Low Tide

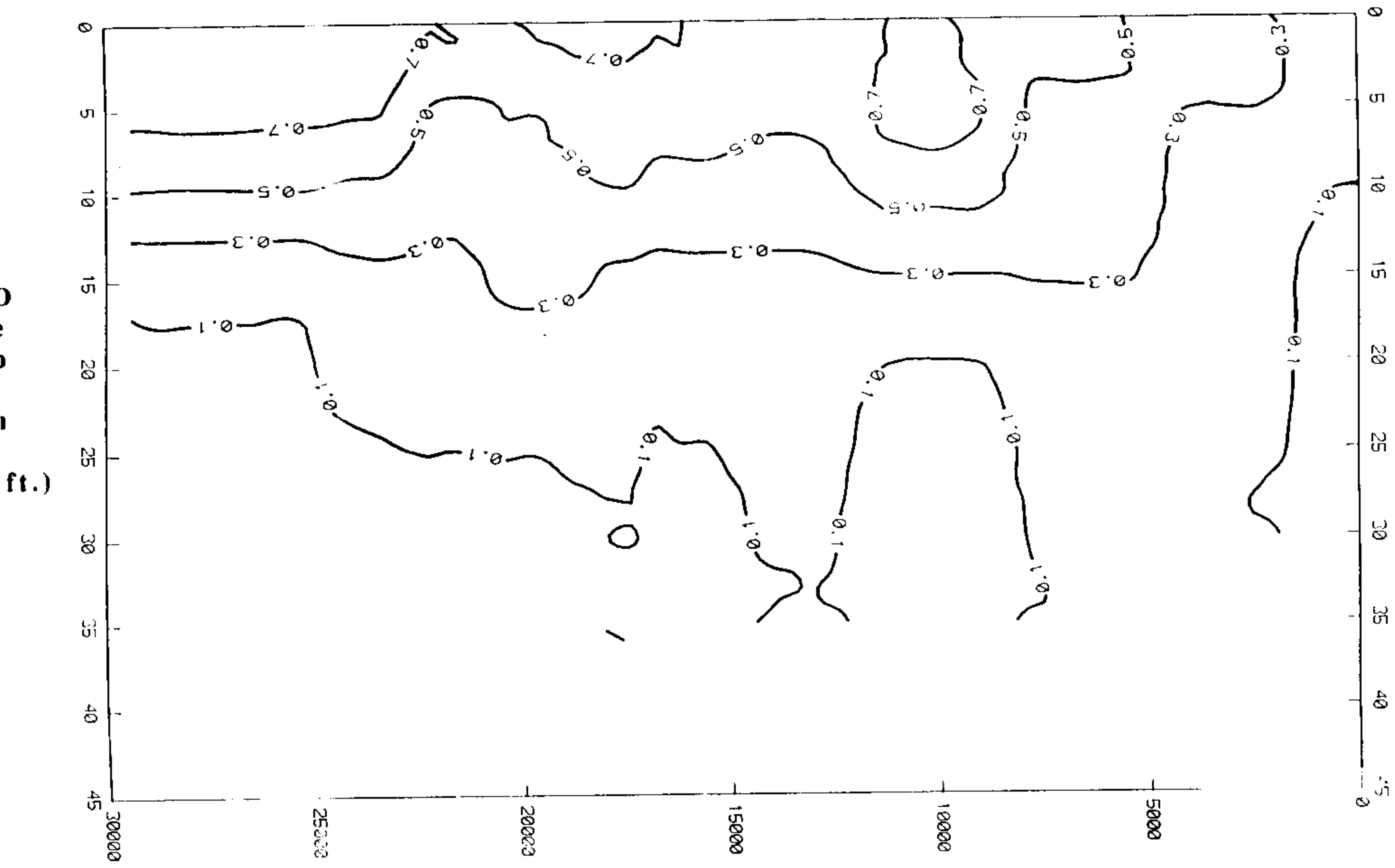
Contour Value: ug/L



Distance Along Transect (ft.); 30000=Station C4 (Chelsea R.), 0= Station R6 (Mouth of Inner Harbor)

Survey 6: 7/25/92, High Tide

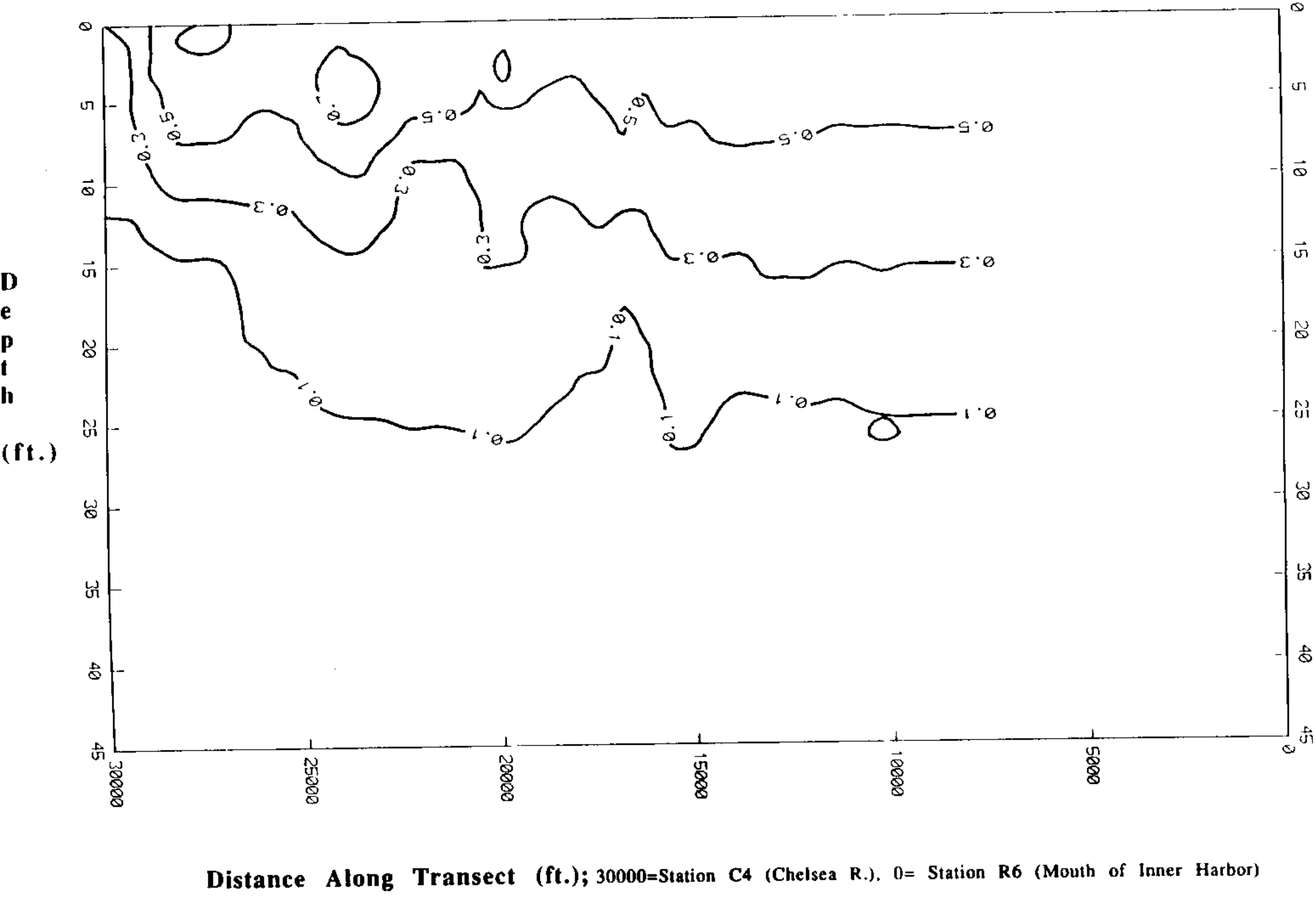
Contour Value: ug/l.



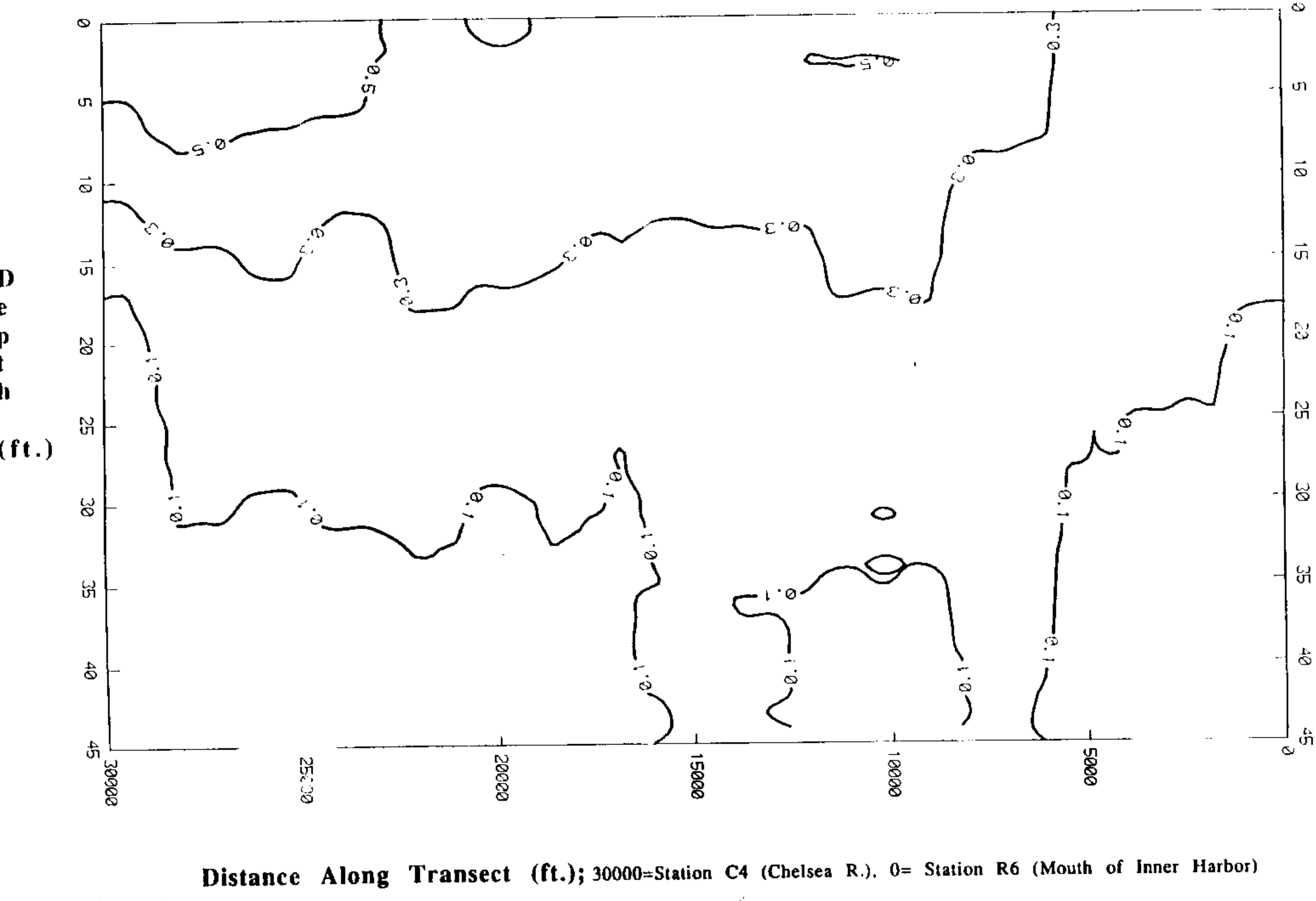
Distance Along Transect (ft.); 30000=Station C4 (Chelsea R.), 0= Station R6 (Mouth of Inner Harbor)

Survey 7: 7/25/92, Low Tide

Contour Value: ug/L

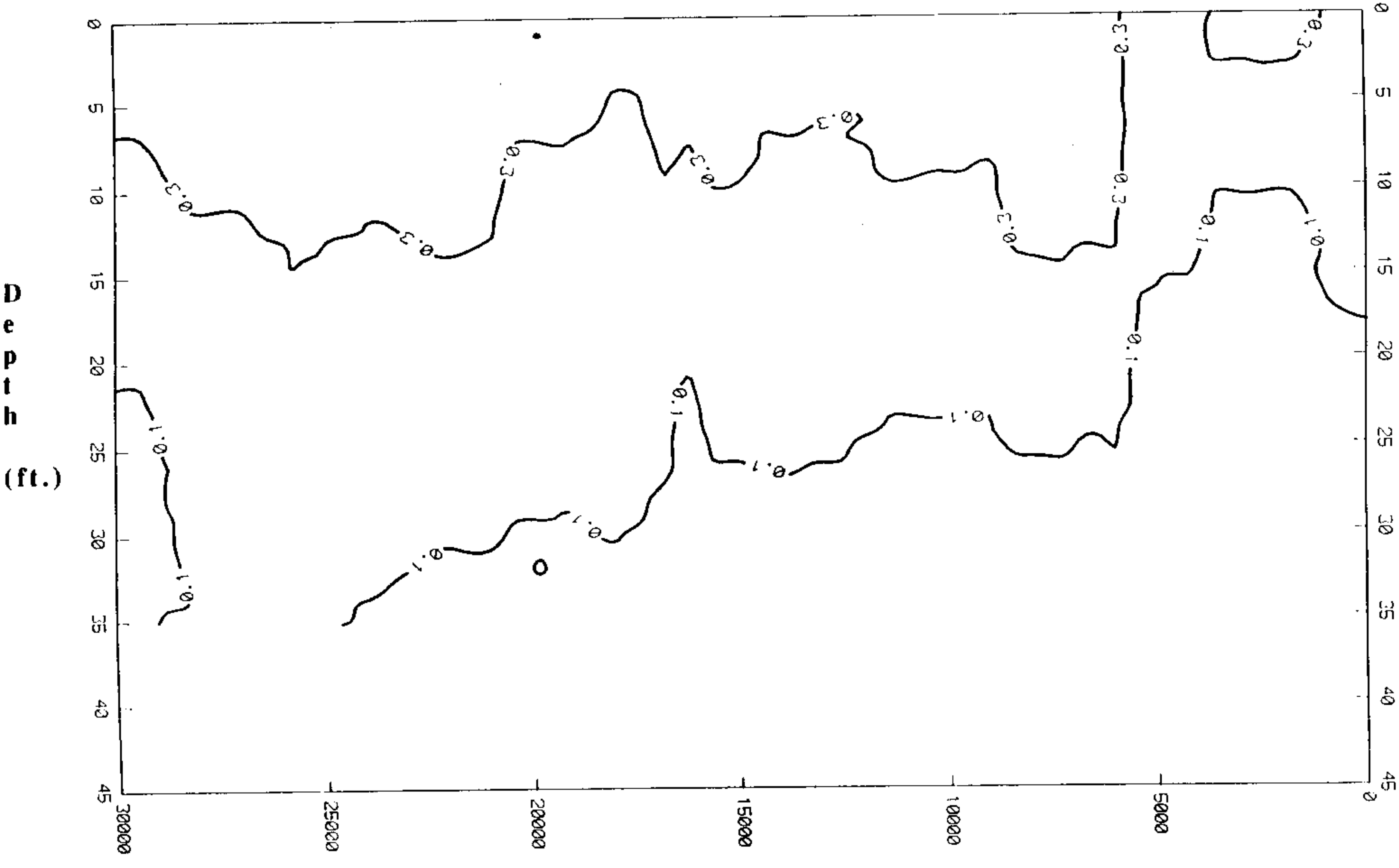


Survey 8: 7/26/92, High Tide
Contour Value: ug/L



Survey 9: 7/26/92, Low Tide

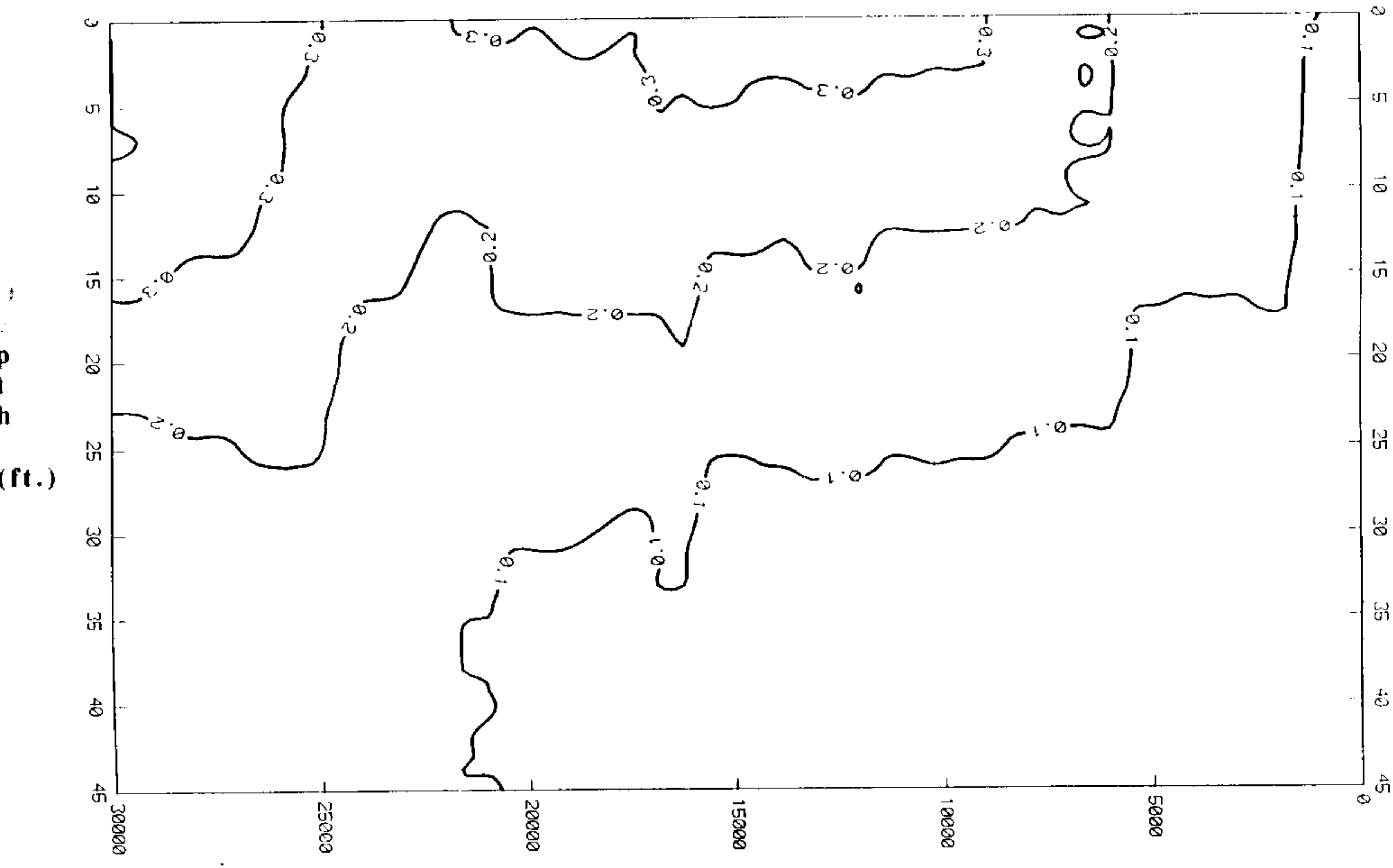
Contour Value: ug/L



Distance Along Transect (ft.); 30000=Station C4 (Chelsea R.), 0= Station R6 (Mouth of Inner Harbor)

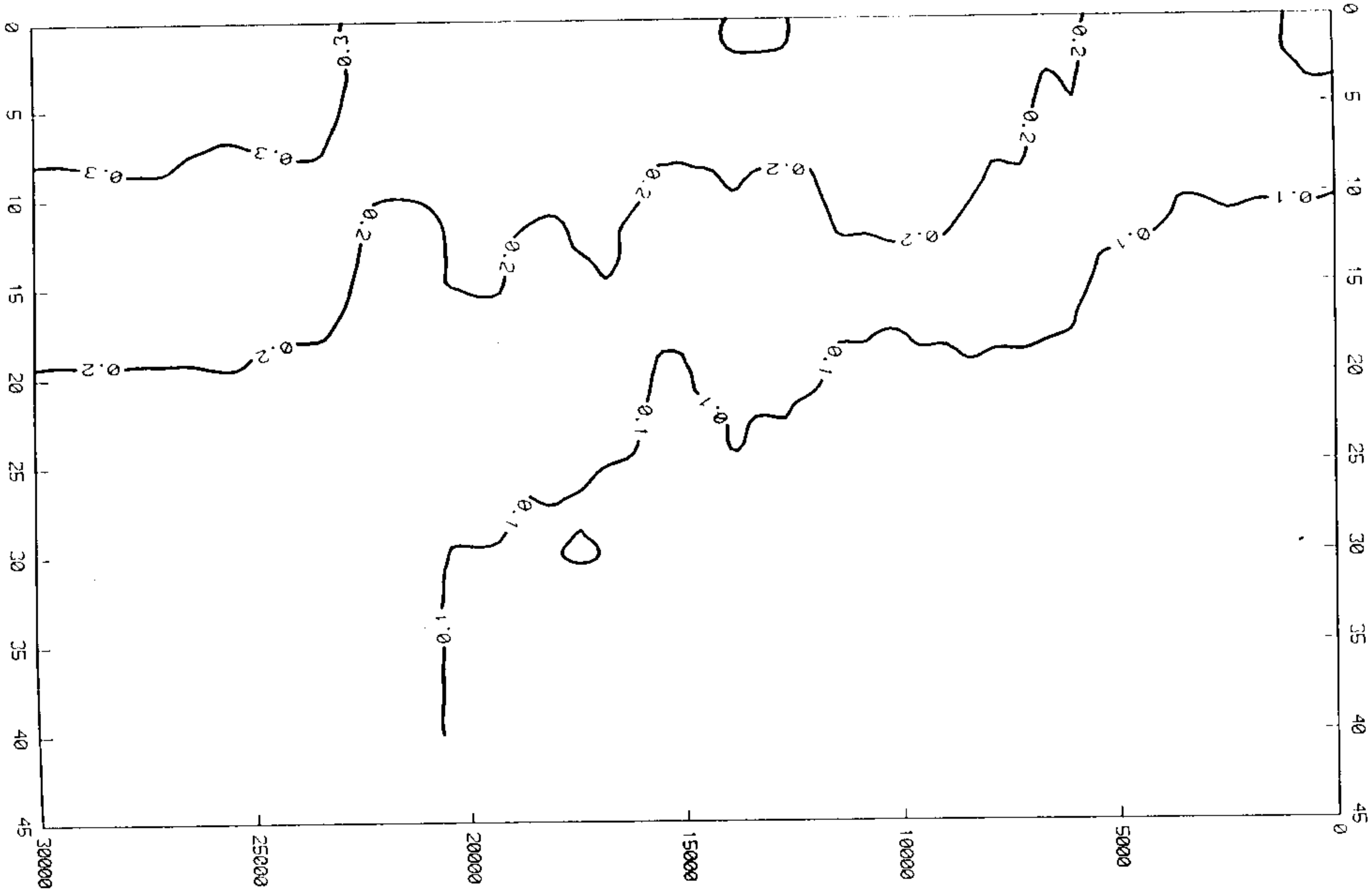
Survey 10: 7/27/92, High Tide

Contour Value: ug/l.



Distance Along Transect (ft.); 30000=Station C4 (Chelsea R.), 0= Station R6 (Mouth of Inner Harbor)

Contour Value: ug/L

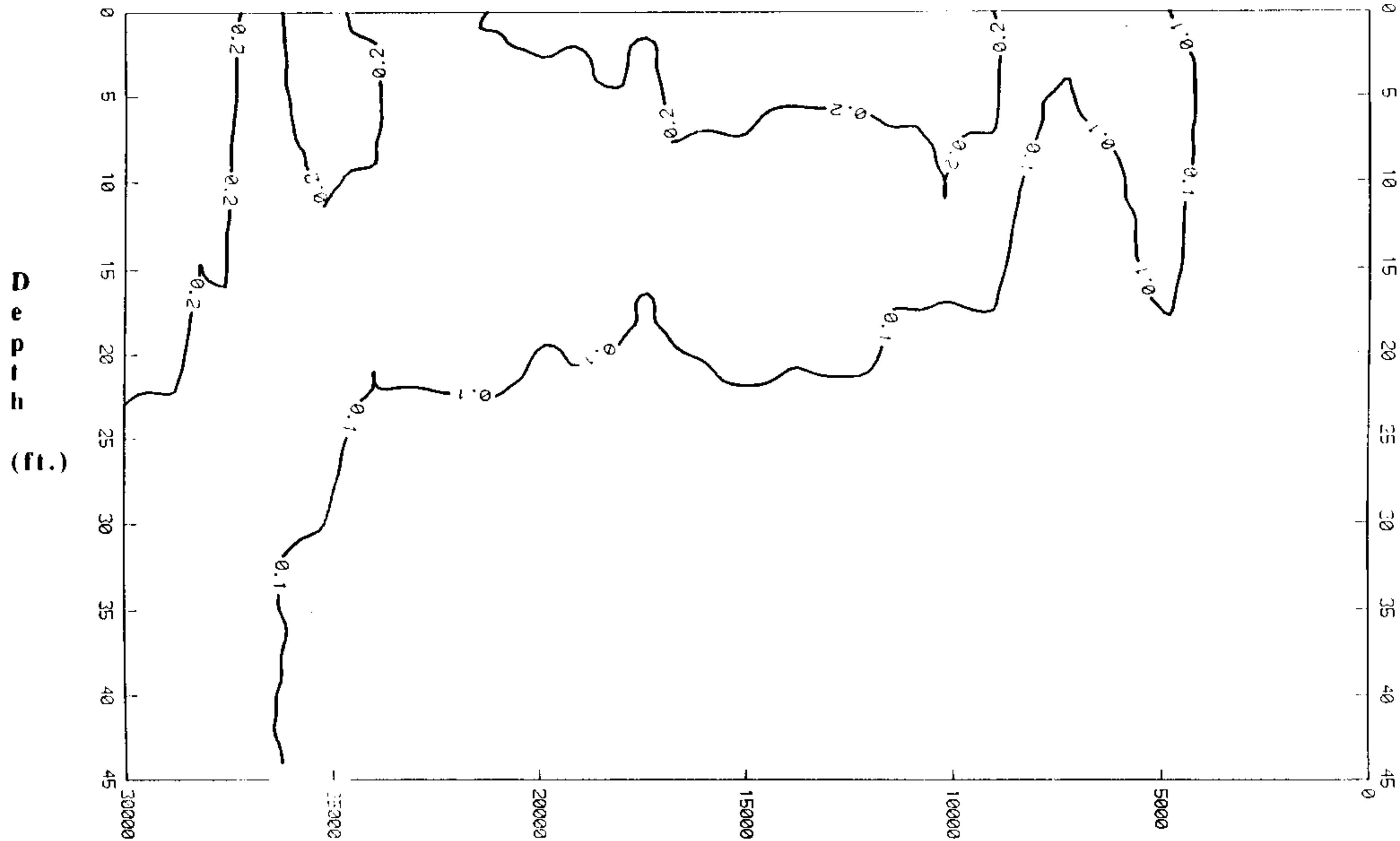


Depth (ft.)

Distance Along Transect (ft.); 30000=Station C4 (Chelsea R.), 0= Station R6 (Mouth of Inner Harbor)

Survey 12: 7/28/92, High Tide

Contour Value: ug/L



Distance Along Transect (ft.); 30000=Station C4 (Chelsea R.), 0= Station R6 (Mouth of Inner Harbor)

Survey 13: 7/28/92, Low Tide

Contour Value: ug/L

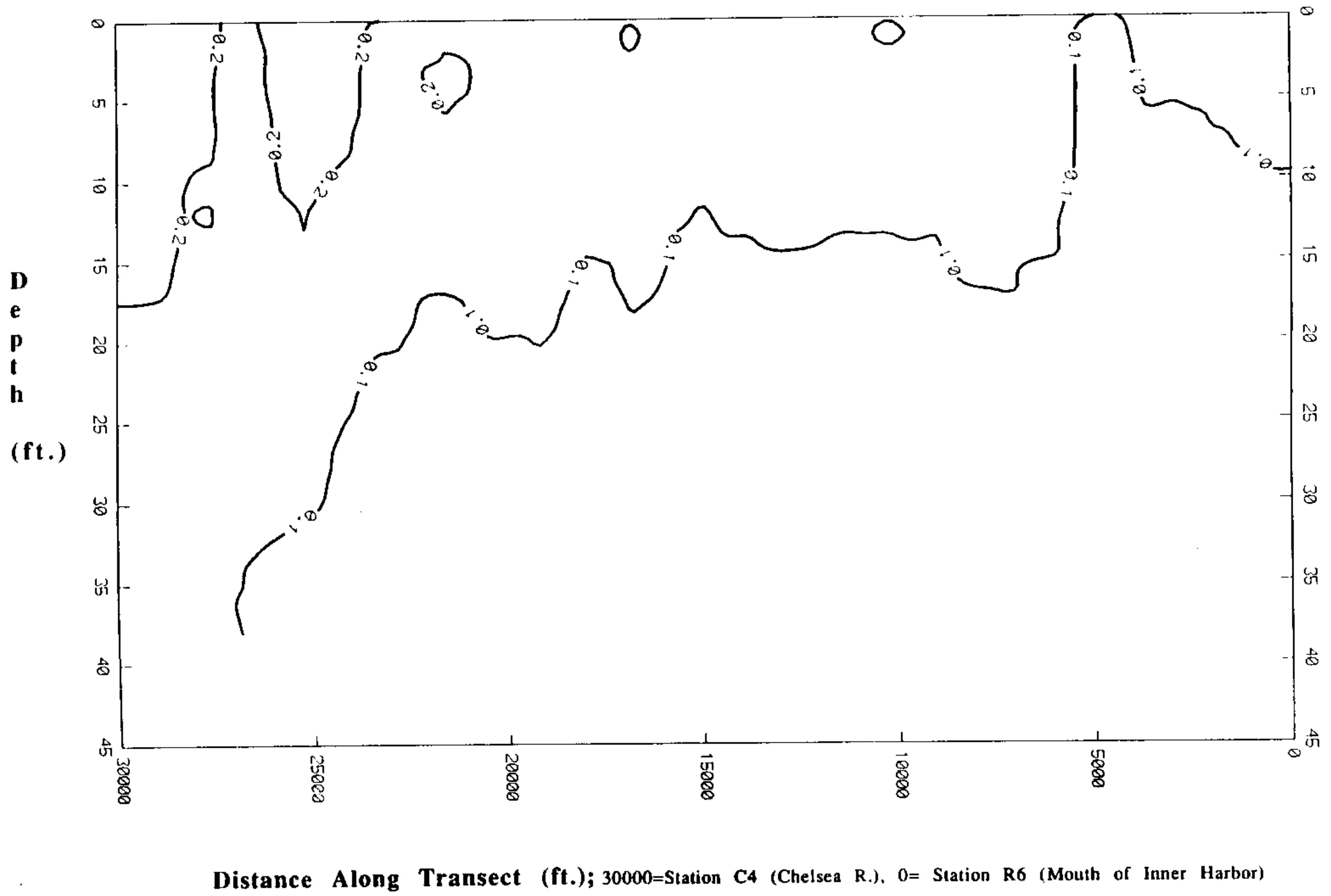


Figure 4. Mass vs. time

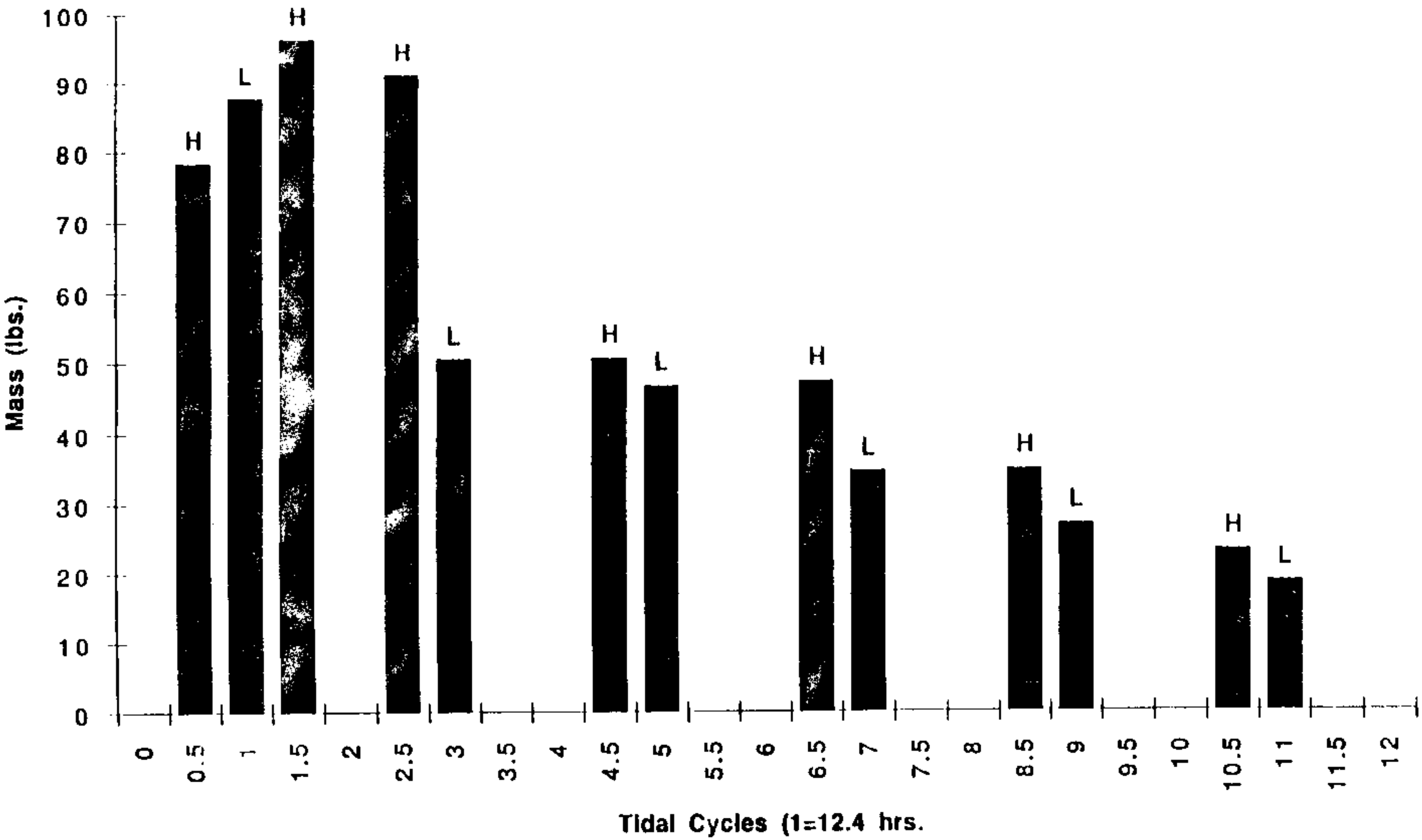


Figure 5. Piece-wise fit to recovered dye mass vs. time

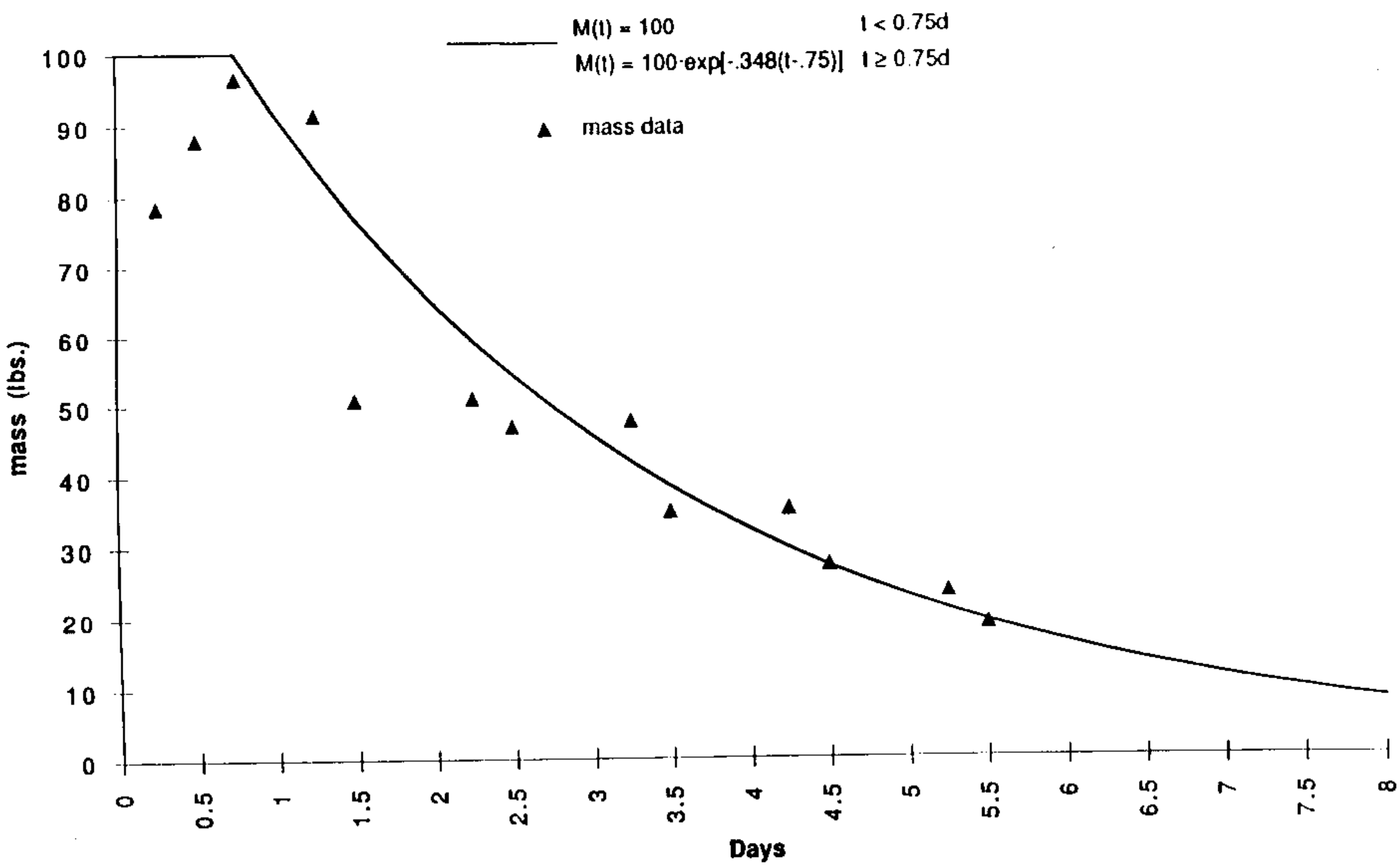
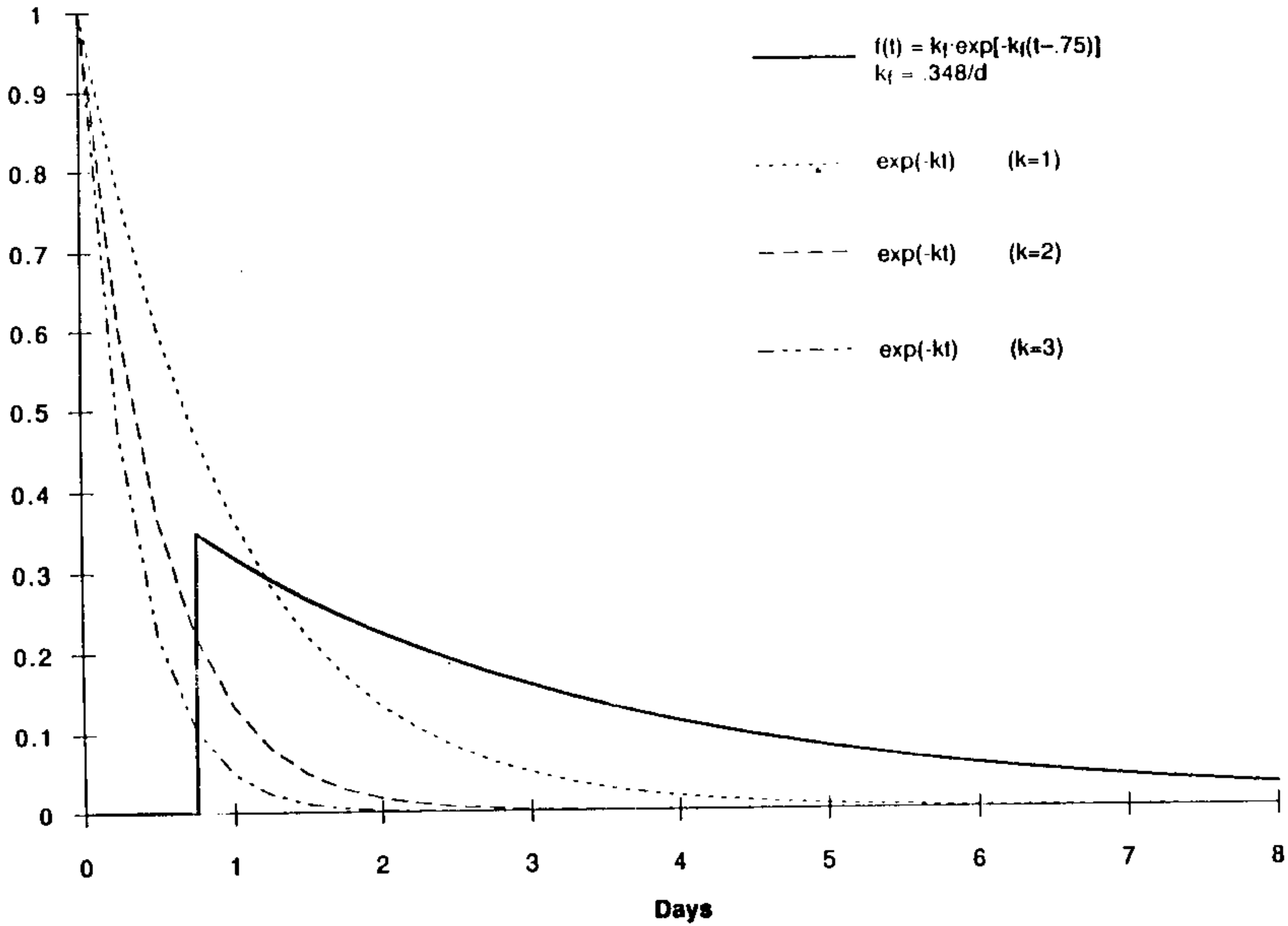


Figure 6. Residence time distribution computed from Figure 5 (solid curve) with superimposed exponential decay curves (dashed lines) using k = 1, 2, and 3 day^{-1}



Appendix

Charles River Dam Dye Release
during
July 1992:

Simulation of CSO Release to Boston's Inner Harbor

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Project No. 91026-001

Version 2

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1.0 INTRODUCTION

A dye study to simulate the impact of a combined sewer overflow (CSO) discharge to Boston's Inner Harbor was conducted by Aquatec, Inc. for the Massachusetts Water Resource Authority in July 1992. The study was designed by Eric Adams of the Massachusetts Institute of Technology with consultation by personnel from Aquatec. The following is a summary of field techniques and the resulting hydrographic data.

2.0 METHODS AND MATERIALS

2.1 Dye Injection

Rhodamine WT dye solution (Lot 81, nominally 20 percent strength, nominal specific gravity of 1.03) was pumped at a constant rate from either of two 30-gallon shipping containers through garden hose using a Wallace & Tiernan diaphragm pump. The dye was released just below the water surface into the high sluice (northern most) channel at the new Charles River Dam. The amount of dye injected was determined from before and after measurements of the dye containers using an electronic balance (300 pound capacity, 0.05 pound resolution).

2.2 Hydrographic Measurements

The measurement of fluorescence, temperature, and conductivity in Boston Harbor was conducted off of a 25 foot survey boat. The majority of hydrographic data was collected while performing vertical profiles of these parameters at selected stations. Some data was also collected from a one foot depth along the main channel centerline (longitudinal profiles).

Vertical profiles consisted of placing a submersible pump at a known depth using a calibrated line while the survey boat remained nominally stationary at a selected station. The pump was then raised using a constant speed winch to a depth of one foot below the water surface. Water was pumped through one half inch inner diameter black nyla-braid tubing and then through on-board fluorometers, a thermistor temperature probe, and a flow-through conductivity cell before being discharged back into the harbor. The response of these sensors was recorded once per second through the use of signal conditioners, analog-to-digital converters, and a laptop computer.

Longitudinal profiles consisted of placing a pipe one foot below the water surface as the boat traveled along the nominal channel centerline. Water was pumped through this pipe and attached nyla-braid tubing into a centrifugal pump. Water exited this pump and flowed through nyla-braid tubing and the on-board sensors as described above. Response from these sensors was similarly recorded as described above.

For both of the above modes of data collection, the lag time from when the water enters the pumping system and reaches the on-board sensors was accounted for in the data reduction algorithms. In addition, sensor response was also accounted for in the data reduction process.

2.2.1 Location Control

Landmarks and a Furuno LP-1000 Loran-C plotter were used to position the boat at selected stations. The readout from this device was checked at fixed objects of known latitude and longitude as taken from the National Ocean Survey Chart 13272 (Boston Inner Harbor, 1:10,000 scale, 41st edition, 1991). The observed difference between the known latitude and longitude and the observed latitude and longitude were entered into the unit so that the readout corresponded to the known locations. The corrected output from this device was recorded at a nominal frequency of once every two seconds on a laptop computer. Via time synchronization, the latitude and longitude data was merged with the water quality data to produce the final data set.

2.2.2 Fluorescence/Dye Concentrations

Fluorescence measurements were obtained using a Turner Designs Model 10 fluorometer with a flow-through cuvette. These instruments have a 0 to 5000 millivolt output corresponding to the instrument response. The output was recorded to the nearest millivolt on the laptop computer via an analog-to-digital converter. The nominal response time of this unit is less than one second.

Calibration of this fluorometer involved placing a known volume of ambient water into a plastic container. This water was continuously circulated through the on-board sensors and back into the container for the duration of the calibration. Ambient fluorescence readings and temperature of the water were recorded for each fluorometer scale. Calibration solution (10 mg/l as prepared gravimetrically/volumetrically) was then incrementally added from a 50 ml burette to raise the circulating water to various dye concentrations. After each addition, the circulating water was given time to mix, and then fluorescence and temperature readings were recorded.

All fluorometer readings were subsequently corrected to a reference temperature (RT in degrees Fahrenheit) using the associated observed temperature (T) and the following formula:

$$\text{Reading (at RT)} = \text{Reading (at T)} * \exp(0.015*(T-RT)) \qquad (1)$$

Corrected readings were then linearly regressed versus dye concentration to determine intercepts (A) and slopes (B). These coefficients were then used in the following equation to calculate dye concentrations (C) from fluorometer readings and water temperature:

$$C = A + B*\text{Reading (at T)} * \exp(0.015*(T-RT)) \qquad (2)$$

Fluorometer calibration also involved performing hydrographic surveys prior to dye injection to determine ambient fluorescence and the resulting apparent dye concentrations as calculated through the use of equation (2).

2.2.3 Temperature

Temperature was determined using a Yellow Springs Instrument Series 700 series banjo style dual thermistor located on-board within the flow-through pumping system. The response of this sensor was signal conditioned and the resulting analog-to-digital converted signal was recorded to a precision of 0.1 degrees Fahrenheit. The nominal response time of this probe is one second.

A hand-held Omega 700F thermistor thermometer equipped with a similar probe was used for grab measurements of temperature.

2.2.4 Conductivity/Salinity

Conductivity was measured using a flow-through Beckman conductivity cell. The cell constant for this unit was determined following procedures found in Standard Methods for the Examination of Water and Wastewater. The nominal cell constant was used to calibrate an AC bridge signal conditioner so that the linear 0 to 1000 millivolt output corresponded to conductivity. An analog-to-digital converter was used to record the output to the nearest millivolt. The nominal response time of this cell and circuit was three seconds.

Recorded conductivity (COND) at the associated temperature (T) was converted to specific conductivity at 77 degrees Fahrenheit (SC) according to Standard Methods as illustrated in the following equation:

$$SC = COND\ (at\ T)/(1+0.0106*(T-77)) \quad (3)$$

The following equation from EPA publication EPA/600/3-85/040 (Rates, Constants, and Kinetics Formulations in Surface Water Quality Modeling, Second Edition) was used to calculate salinity in parts per thousand (ppt) from specific conductivity in millisiemens per centimeter (mS/cm):

$$Salinity\ (ppt) = 0.5572 \times SC + 2.02E\text{-}3 * (SC)^2 \quad (4)$$

A portable Omega Model CDH-70 conductivity meter with automatic temperature compensation was used for grab measurements of specific conductivity.

3.0 RESULTS

3.1 Dye Injection

On 22 and 23 July 1992, 501.2 pounds of dye were injected into the upper sluice at the New Charles River Dam from 2035 until 0200. On 26 July 1992 at 1030, portable conductivity and temperature meters were used to measure a surface water temperature of 74.2°F and a specific conductivity of 0.920 mS/cm in the vicinity of the dye release point. The calculated salinity of this water was 0.51 ppt.

3.2 Location Control

The Northeast U.S. Chain (GRI 9960) was utilized with secondaries W (Caribou, Maine) and X (Nantucket, Massachusetts) and employing Additional Secondary Factors (ASF) for the entire survey. Maually inputted corrections of +0.12 minutes North in latitude and +0.26 minutes West in longitude were used for the study area. With this correction, observed positions generally agreed with calculated positions plotted from the National Ocean Survey chart. Two exceptions were in the vicinity of vertical profile station I8 (near the Massachusetts Transportation Authority building) and by buoy R"6" outside of the inner harbor. It appears that in the outer harbor area, secondaries X and Y (Carolina beach, North Carolina) should be utilized with ASF. Alternatively secondaries W and X should be utilized without ASF in the outer harbor.

3.3 Fluorometer Calibration

On 22 July 1992, 92 liters of surface water in the vicinity of vertical profiling station D1 (see Figure 1) was collected at 1400 and used to calibrate two fluorometers over six scales. The following dye concentrations were used: 0.0, 0.1087, 0.217, 0.435, 0.761, 1.304, 2.28, 5.43, 8.69, 13.03, 18.44, 34.7, and 56.2 micrograms/liter (ug/l or ppb). All correlations were acceptable; it was decided to use the correlations for the fluorometer with Aquatec asset number 00238 for use in the data reduction process. Comparisons between dye concentrations calculated with both fluorometers showed acceptable agreement.

On 25 July and 28 July, stored calibration water (at 56.2 ug/l) was pumped through the on-board instruments to check the stability of the fluorometers. Both fluorometers indicated calculated concentrations within two percent of the actual concentration for both checks.

3.4 Schedule, Area, and Resulting Hydrographic Data

Table 1 lists the date, time (daylight savings time) of low and high water slacks as taken from the 1992 Eldridge Tide and Pilot Book, time interval during which surveys were conducted, the number of vertical and longitudinal profiles conducted during each survey, and the associated data filename for the resulting hydrographic data. Figure 1 illustrates the nominal locations of the vertical profiling stations employed during the study, with the exception of station R6 which was located at Buoy R"6" outside of the Inner Harbor due east of Castle Island.

The vertical and longitudinal data are each contained in separate files for each survey. The vertical profile data file contains all the profiles conducted during a slack water survey. Each profile consists of a header line indicating the station identification (e.g., L1), followed by lines of data with the following information: time (hh:mm:ss), depth below water surface (feet), dye concentration (ug/l), temperature (deg F), salinity (ppt), latitude (deg mm.mm), and longitude (deg mm.mm). Longitudinal data files have the same format.

Figure 1 Location of Vertical Profile Stations

Table 1 Summary of Dye Survey in Boston's Inner Harbor during July 1992 for the MWRA.

Date and Day	Predicted Time and Tidal Height (feet)* High Waters (HW)		Low Waters (LW)		Task	Time Interval	Number of Profiles Vertical	Number of Profiles Longitudinal	Data File Names Vertical	Data File Names Longitudinal
22 Wednesday	0455	1718	1101	2337	LW Ambient survey	0950-1215	29		22JulLO.V	
	8.8	9.5			Calibrate#	1400-1515				
					HW Ambient survey	1625-1730	30		22JulHI.V	
					Inject dye	2030-0200				
23 Thursday	0544	1805	1150		HW Dye survey	0505-0725	25		23JulHI1.V	
	8.6	9.6			LW Dye survey	1025-1305	29	1	23JulLO.V	23JulLO.L
					HW Dye survey	1600-1815	26		23JulHI2.V	
24 Friday	0639	1859	0032	1242	HW Dye survey	0515-0745	30		24JulHI.V	
	8.4	9.8			LW Dye survey	1230-1400	11	1	24JulLO.V	24JulLO.V
25 Saturday	0737	1952	0128	1337	HW Dye survey	0625-0845	15	1	25JulHI.V	25JulLO.L
	8.5	10.1			LW Dye survey	1230-1515	30		25JulHI.V	
26 Sunday	0834	2051	0224	1436	HW Dye survey	0715-1005	30		26JulHI.V	
	8.7	10.5			LW Dye survey	1315-1525	29		26JulLO.V	
27 Monday	0933	2146	0321	1532	HW Dye survey	0830-1100	30		27JulHI.V	
	9.1	11.0			LW Dye survey	1415-1650	30		27JulLO.V	
28 Tuesday	1028	2242	0417	1628	HW Dye survey	0930-1235	30		28JulHI.V	
	9.6	11.5			LW Dye survey	1510-1735	30		28JulLO.V	

*Average rise and fall is 9.5 feet
#Using surface water from vertical profile station D1

91026D30JUL92