DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

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STUDIES OF CIRCULATION AND POLLUTANT TRANSPORT IN MASSACHUSETTS COASTAL WATERS

A joint funding agreement between
The Massachusetts Water Resources Authority
and
The U. S. Geological Survey

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ABSTRACT

This document describes the work elements and progress during the first six months of a Joint Funding Agreement (cost share) between the Massachusetts Water Resources Authority (MWRA) and the U. S. Geological Survey for oceanographic work in western Massachusetts Bay. The objective of this study is to develop a predictive capability for the fate and transport of contaminants which are strongly sorbed by suspended and bottom sediments. The present Agreement covers the first two years of a planned five-year monitoring program. This program will be coordinated with the comprehensive research program that is directed by the Massachusetts Bays Management Committee. The major components of this Joint Funding Agreement and the progress to date include:

* Continuous measurements of currents and sediment transport in the vicinity of the proposed ocean outfall using instrumented moorings and bottom tripods. The first deployment of moorings took place on December 5, 1989. The moorings will be replaced three times per year during the two-year period of this contract. The long-term continuous measurements are necessary to characterize the transport processes over time as well as during catastrophic events, such as storms. Material in suspension is being collected with new instrumentation, permitting chemical and physical analysis of the sediment transported during storms.

* Creation of a digital map of the sea-floor morphology and texture, as interpreted from continuous-coverage sidescan-sonar data calibrated with photographs and sediment analyses at representative locations. The hand drawn interpretive map has been completed in the 20 square nautical mile survey area around the proposed outfall. The digital map has been completed over 5 sq miles. Our preliminary maps have been of value in deciding the precise location of the outfall.

* Determination of the rates of sediment accumulation and mixing and the inventories of contaminants in sediments of Massachusetts Bay. Sediment cores have been collected in depositional areas of Mass Bay and the depth profiles of radioisotopes, heavy metals and sediment texture are being determined. This information will be used to characterize the long-term fate of contaminants added to Massachusetts coastal waters from a variety of sources.

* Analysis of the exchange of water and particulates between Boston Harbor and Massachusetts Bay using numerical models and field measurements. The development of a high resolution numerical model of the tidal exchange between Boston Harbor and Massachusetts Bay is nearly completed. The new model was successful in predicting a weakly recirculating gyre observed over the Deer Island flats during flood tide. After the current field has been further verified by comparison with moored current observations, particle tracking experiments will be conducted to quantify the exchange between Boston Harbor and Massachusetts Bay induced by these currents. This effort will provide critical basic information on the physical processes influencing the fate of contaminants at the harbor entrance.

INTRODUCTION

In 1987, the U.S. Geological Survey (USGS) began a pilot study in Boston Harbor and Massachusetts Bay. The long-term objective of this study is to understand the processes controlling the transport and deposition of sediments and their associated contaminants. Components of the pilot study included geologic mapping in Boston Harbor, circulation and sediment transport studies in western Massachusetts Bay, and studies of the geochemistry of the bottom sediments and the rate of sediment accumulation and mixing as indicated by the depth profiles of ^{14}C and ^{210}Pb in sediment cores (Bothner and others, 1988; Butman and Fry, 1990; Knebel and others,1989; Rendigs and Oldale, 1990).

A cooperative agreement between USGS and MWRA extends and expands the previous work conducted by the USGS. The new study has an initial geographic focus in the area proposed for the outfall and an additional effort at the entrance to Boston Harbor. The study gains regional, bay-wide perspective through coordination with research sponsored by the Massachusetts Bays Management Committee and other state and federal agencies working in the Boston Harbor/Massachusetts/Cape Cod Bays area.

STUDY COMPONENTS

A. <u>Long-term monitoring and sediment characterization</u>

The USGS has established and will maintain a long-term monitoring station in western Massachusetts Bay (Figure 1) near the location of the new ocean outfall for at least two years to measure currents, suspended sediment concentration, temperature, and salinity. Long-term measurements are essential to assess the seasonal and annual variability of sediment movement and to quantify the transport processes during and between infrequent catastrophic events, such as storms. The observations characterize the physical processes that transport particles at the outfall site in western Massachusetts Bay and provide important supporting information for the design and interpretation of other physical, chemical, and biological studies. Instruments on subsurface moorings and on a tripod at the sea floor make continuous current and sediment-transport measurements as well as collect suspended sediments for chemical analysis. Samples collected with this instrumentation before discharge from the new ocean outfall begins will provide a basis for assessing changes in the chemical and physical character of the mobile sediments once the outfall is operational.

Current speed and direction, conductivity, temperature, and light transmission are measured at two depths in the water column (about 6 m from the surface and 10 m above the bottom, in water depth of about 30 m). The mooring design is shown in Figure 2. The bottom tripod system measures these same parameters plus bottom pressure (waves), and obtains time-series photographs of the sea floor about once every 6 hours during a 6-month deployment to document changes in the bottom microtopography in response to physical forcing (Butman and Folger, 1979; Butman, 1987). The current measurements are made with EG&G

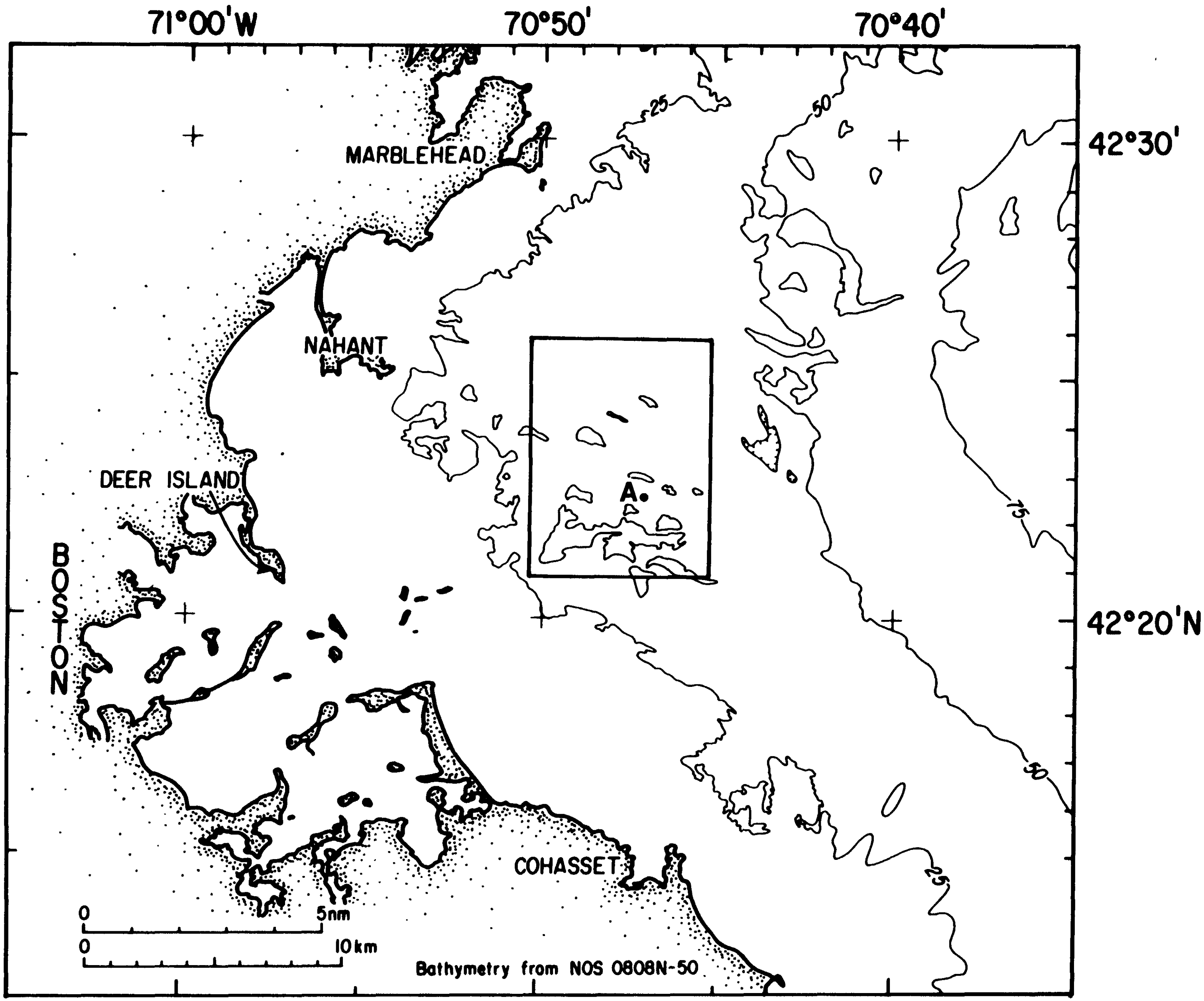

Figure 1. Box outlines area of sidescan sonar survey conducted in April 1989. Proposed sites for Boston's outfall diffusers are near center of boxed area. Long-term moorings are positioned at location marked A.

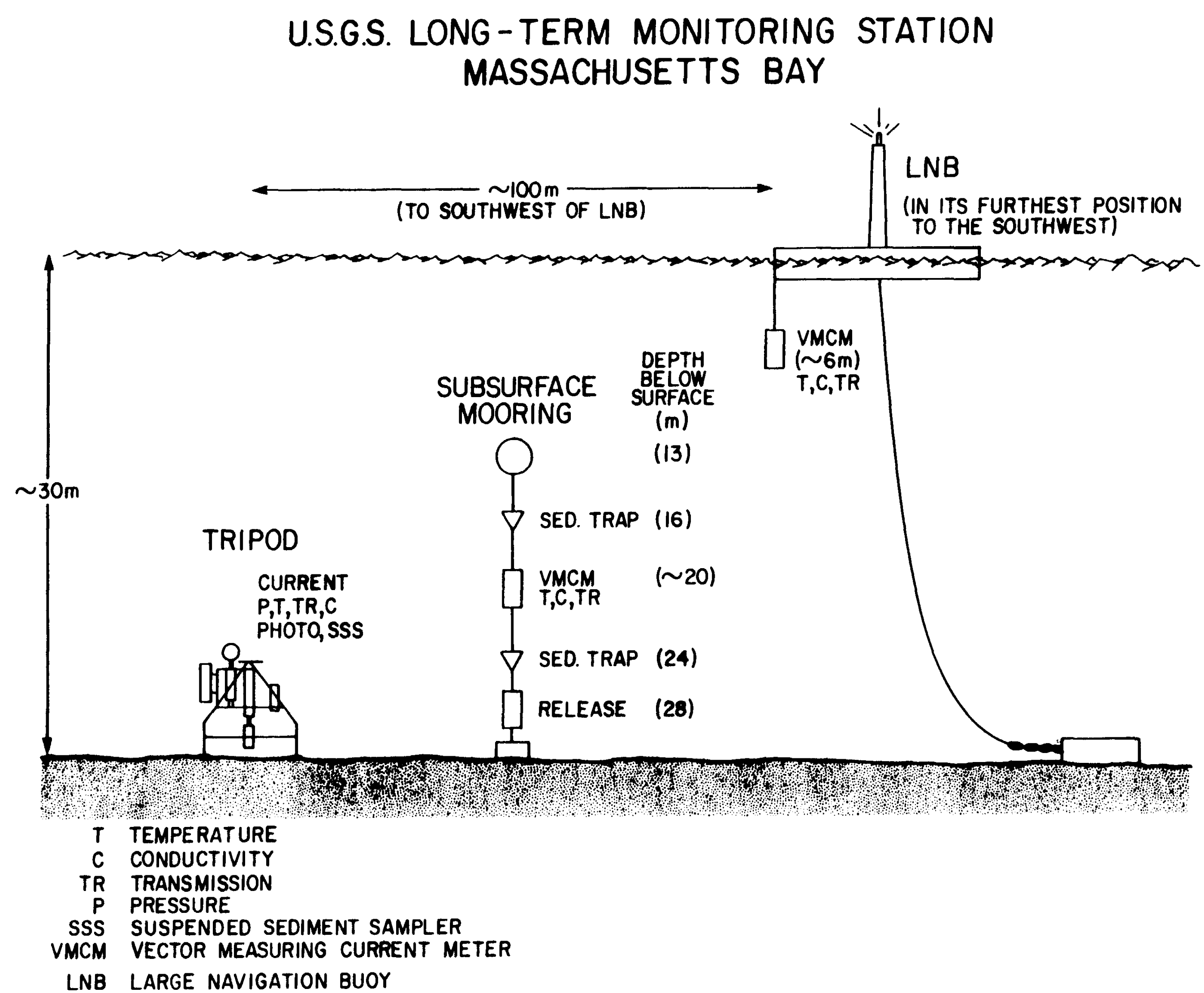

Figure 2. Schematic of USGS current meter installation near Boston Large Navigation Buoy (LNB) showing the three components: bottom tripod, subsurface mooring, and current meter hung below the LNB.

Vector Measuring Current Meters (VMCM) to avoid aliasing of the measurements by waves. Transmission and salinity measurements in the water column will be made with Sea Bird SEACAT data loggers, employing a Sea Bird Inc. conductivity cell and a Sea Tech. Inc. LED transmissometer. The Savonius rotor-and-vane current sensors on one USGS bottom-tripod system will be changed to either electromagnetic or acoustic sensors during the first year of the program in order to eliminate the potential effect of surface waves on bottom-current measurements. This modified system will be used for the winter deployment during the second year. At least one additional system will require modification in subsequent years of the program so that upgraded systems can be deployed year-round. Near-bottom measurements made with the unmodified system will be corrected using data from the VMCM on the adjacent mooring 10 m above the bottom. This correction will only be necessary during periods of large surface waves, which will be easily identified by the bottom pressure measurements.

Samples of suspended sediments will be collected periodically during the deployment period by means of a 18-port filtration instrument. This instrument is linked to a transmissometer that commands the collection of some samples during periods of anomalously high suspended-sediment concentration (i.e., during storms). The 18 suspended-sediment samples will be used to calibrate the continuous record of light transmission, which is known to be sensitive to both the concentration, composition, and grain size of particulates (Moody and others, 1987). Analyses will provide data on the concentration, size, and chemical composition of material in suspension during major storm events, when most of the sediment transport presumably occurs.

Sediment traps are used to collect larger amounts of suspended sediments for analyses of organic and heavy metal contaminants, spores of *Clostridium perfringens*, radioisotopes (^{210}Pb, and $^{239,240}Pu$), and grain size. These traps will be placed at mid-depth and near the bottom. The deeper trap mechanically separates samples into different time intervals throughout the deployment in order to define the variability in the relative flux and composition of material entering the trap. This information will complement that obtained with the filtration/ transmissometer system by providing large samples of suspended matter delivered during storm and non-storm periods.

Samples of bottom sediment will be collected from areas of fine grained sediment at the time of each instrument deployment/recovery in order to monitor the composition and physical characteristics of material at the water/sediment interface over time and to compare these temporal changes with those measured in suspended matter. A modified Van Veen grab sampler or a hydraulically damped gravity corer, designed specifically to collect material at the water/sediment interface without disturbance, will be used for sample collection. Careful collection and analysis of the surface (to a depth of up to 1 cm) will test the hypothesis that fine-grained sediments, rich in organic matter, accumulate on the bottom during quiet periods of the year and are resuspended and transported to other areas during major storms.

B. Sea-floor mapping and bottom characterization

From April 2-11, 1989, the USGS conducted a detailed survey of the seafloor in a 5 by 4 nautical mile area in western Massachusetts Bay that includes the proposed site for the ocean outfall. Ship time was provided by the Environmental Protection Agency on the Ocean Survey Vessel Anderson. The primary objective of the cruise was to acquire complete sidescan-sonar coverage (150-m line spacing) as well as to collect bathymetric and high-resolution, seismic-reflection data. The sidescan-sonar data were used to infer the location, type, and extent of the different sediments within the survey area since these are known to have a patchy distribution in the region. The interpretations of the sidescan-sonar images were confirmed during the second phase of the cruise by photography and sampling of the bottom sediments at specific targets. Precise navigation for this survey was provided by means of a shore-based microwave system. The digital sidescan data will be processed to produce a digital mosaic of the seafloor.

C. Long-term rates of sedimentary processes and contaminant inventories

USGS will analyze sediment cores (undisturbed hydraulically damped gravity cores and conventional gravity cores) from the mooring location and from other areas of fine-grained sediment mapped in the detailed survey area around the proposed outfall location and from Stellwagen Basin. In each of four locations we will determine the depth profiles of texture, geotechnical properties, organic carbon, ^{210}Pb, (^{234}Th in suitably fresh samples), $^{239,240}Pu$, ^{14}C, and trace metals. Analytical methods and scope of work are described in Appendix B to the Joint Funding Agreement between USGS and MWRA. Splits of samples collected for organic contaminants will be made available to other contractors or Federal/State Laboratories as required. Suitable cores for some of these measurements were collected on the April '89 cruise aboard the O.S.V. Anderson. Additional cores will be taken at the time of mooring deployments.

The objectives of this work are to estimate:

* The depth to which sediments are mixed by biological and/or physical processes
* The rates of sediment mixing and/or accumulation
* The relative potential of sediments at these sampling locations to accumulate contaminants
* The concentrations of metal contaminants in subsurface sediments and to characterize the physical and geotechnical properties of sediments with depth in sites of active contaminant deposition

This work extends part of a previous study (MWRA Contract 5526A) by USGS and Battelle Labs (Wade et al., 1989). Only four sediment cores were analyzed for contaminant and isotope profiles under this earlier study, and they were not collected in areas of fine sediment near the proposed outfall. The new information provided by our recent sidescan-sonar survey now makes it possible to map and sample these fine-grained areas, which are most likely to have the highest predischarge contaminant concentrations and the highest potential for accumulating contaminants introduced by the outfall.

D. Harbor-Bay Exchange

A critical problem in determining the flushing of Boston Harbor is the lack of an accurate evaluation of the net exchange of material through the harbor entrance. This exchange is intimately related to the flow characteristics of the area, influenced by the nonlinear tidal effects in a mixing region on both sides of the harbor entrance. Because of the complex geometry of the entrance and the nearby islands, much of the exchange will result chiefly from ebb/flood asymmetry combined with rapid spatial variation in the tidal flow imposed by the constriction. Conceptually, on the ebb tide, the high velocity of water leaving the harbor causes a jet of harbor water to penetrate the bay water. On the subsequent flood tide, however, the flow is more uniformly drawn from all directions toward the harbor entrance, with the result that some of the harbor water contained in the ebb jet remains in the bay after a complete tidal cycle.

A numerical study will be conducted to examine the exchange of water between Boston Harbor and western Massachusetts Bay. The work utilizes mathematical models and software already developed (Signell, 1989). Components of this work element include:

* Acquisition and development of accurate, high resolution bathymetric maps (100 m line spacing) of Boston Harbor and Massachusetts Bay in the vicinity of the harbor entrances

* Calculation of tidal currents using an existing depth-averaged nonlinear numerical circulation model (Signell, 1989)

* Particle tracking through integration of the simulated velocity field to investigate the regionally important processes which influence exchange and to determine the long-term behavior of the mixing process over many tidal cycles

* Comparison of model results to existing field data and to future measurements obtained as part of exchange studies potentially supported by the Mass Bays Management Committee or other state/federal agencies

* Recommendations for any additional field measurements necessary to verify model results.

PRODUCTS

The USGS will provide annual Open-file Reports that will contain tabulations of the data, maps, and preliminary interpretations. Results will be subsequently published in summary form in the reviewed literature. All data will be transferred in a digital format compatible with the data management protocol used by the MWRA. The schedule of work described in this report is summarized in Table 1.

The specific topics to be addressed in the reports for this project are as follows:

1. Mean current and seasonal variability.

2. Current fluctuations associated with tides, storms, river runoff, and internal waves and integration of these observations with the basin-wide measurements to be made by other investigators.

3. Frequency and magnitude of sediment resuspension and transport and the processes causing sediment transport.

4. Physical and chemical characterization of the particles in suspension, and the variability in these characteristics in response to seasonal biological cycles and the forces causing sediment transport. Information on the seasonal biological activity will be obtained from the literature or from studies conducted by MWRA or the Massachusetts Bays Management Committee.

5. Physical and chemical characterization of the bottom sediment and the variability in response to seasonal biological cycles and the forces causing sediment transport.

6. Items 4 and 5 above provide a time series of analyses that will address the question of changes in contaminant levels in sediments as the outfall becomes operational. An aliquot of representative samples will be archived frozen.

7. Sidescan mosaic of the bottom in the vicinity of the ocean outfall and characterization of the bottom morphology and texture based on a combination of sidescan images, sampling, and bottom photography.

8. Estimates of the rates of sediment mixing and(or) sediment accumulation in fine-grained deposits and estimates of the potential for pollutant accumulation based on inventories of contaminants and sediment reactive radioisotopes. This will build on the previous work at four locations in western Mass Bay (Wade and others, 1989).

9. Estimates of the tidally-induced Lagrangian transport in the vicinity of the mouth of Boston Harbor and estimates of the exchange of water and suspended particles caused by this transport. Comparisons of model predictions to previous field data in the harbor and to future measurements of the type proposed by W. Geyer (WHOI).

Table 1. Schedule of program elements; start date changed from July to August 2, 1989.
D1 = deployment one, R = recovery, S = start, F = finish

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                                                  1989                                          1990                                          1991
                                              A    S    O    N    D    J    F    M    A    M    J    J    A    S    O    N    D    J    F    M    A    M    J    J
DEPLOY/RECOVER                                                    D1             R1                                  R3                                      R5
 (Mooring No.)                                                                   D2                  R2              D4                       R4             D6
                                                                                                     D3                                       D5

CURRENTS AND SEDIMENT TRANSPORT
  Equipment Prep/Test/Install                 S---------1---------F 12/5    S----2----F    S----3----F    S----4----F              S-----5-----F     S---5----F
  Data Analysis & Interpretation                                                      S---1-----F    S----2----F    S----3----F                S-----4-----F

SUSPENDED/BOTTOM SEDIMENT
  CHARACTERIZATION
  Equipment Prep/test/install                 S---------1---------F 12/5    S----2----F    S----3----F    S----4---F                 S-----5----F   S-----6----F
  Sample analysis & Interpretation                                                    S------1-----F S-----2------F                            S--------4------F
                                                                                                              S--------------3-----------F

SEAFLOOR MAPPING
  Process Bathymetry                          -------F 9/15
  Process Sidescan                            ---------------F 11/1
  Textural Analysis of Sediment               -----F 9/1
  Describe video & photos                     -------F 9/15
  Construct mosaic using analog
      sidescan records                        S------------------F 12/1
  Construct digital sidescan mosaic
      1.  of diffuser area                    S--------------------F 12/15
      2.  of total survey area                S-----------------------------------------------------------------------------------------F
  Final maps & Interpretation                 S-----------------------------------------------------------------------------------------F

RATES OF SEDIMENTARY PROCESSES
ANALYSIS OF SEDIMENT CORES
  Collect/x-ray/subsample                       ---F                                                 S---------F
  Texture                                                  S------F 12/1                                    S----------F
  Organic carbon                                           S-----------------F                              S---------------F
  Heavy metals                                             S-----------------F                              S---------------F
  Radioisotopes                                            S------------------------------F                 S-----------------------------------F
  Geotechnical properties                                  S------------------------------F                 S-----------------------------------F

HARBOR BAY EXCHANGE
  Compile NOAA bathymetry                                  S---------F 12/15
  Model tidal currents and
    particle tracking                                                S-----------------------------------------------F
  Compare model results to
    other studies                                                                                       S-------------------------------------F
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PROGRESS ON WORK ELEMENTS

This section summarizes the progress on each of the four program elements described above.

Element A1. Currents and sediment transport

Instrumented moorings were deployed in western Massachusetts Bay (Figure 1) next to the large navigation buoy "B" on December 5, 1989. This location (42° 22.61'N, 70° 47.05'W, 30 m water depth) is approximately 1 km south-east of the MWRA's diffuser option 1. The Coast Guard strongly recommended this location because of the protection from shipping and fishing traffic provided by buoy "B". The design of the moorings is shown in Figure 2.

The bottom tripod measures the following variables: current speed and direction, pressure (a function of surface waves), temperature, conductivity, and light transmission. These measurements are taken every 7.5 minutes. Still photographs are taken of the seafloor once every 6 hours throughout the deployment. The bottom tripod also carried four sediment traps (tube type) and a suspended sediment sampler described below under Element A2.

Vector measuring current meters (VMCM) were deployed at about 20 m depth and within 6 m of the surface. A SEACAT instrument package was attached to the VMCM to measure temperature, conductivity and light transmission.

Recovery and redeployment of this array of instruments is scheduled for approximately March 27, 1990.

Element A2. Suspended sediment characterization

Suspended sediment will be collected from the tripod by means of an 18 sample filtration system that responds on the basis of both time and light transmission. In the absence of resuspension events, caused by major storms, samples will be taken at regular time intervals. Storm events are recognized when the transmissometer signal, averaged over 4 hours, exceeds a threshold voltage that we determined from data collected in the winter of 1987. When the software controlling the sampler measures the threshold voltage, a sample is taken. A delay of 18 hrs is imposed before another sample is taken. A more involved control program, one that collects samples during different stages of a storm, is being written and tested for the next deployment.

Three types of sediment traps were deployed on the moorings in order to collect larger samples of suspended material than are collected with the filtration system. The most sophisticated trap, placed at the bottom of the subsurface mooring, separates the material into 13 individual sample bottles at evenly spaced time intervals (8.5 days) throughout the deployment. The differences in chemical and physical characteristics of suspended matter collected in sequential sample bottles will be related to the frequency and intensity of storms and to changes in primary production (as determined by others).

A second trap type, placed at a depth of 16 m on the subsurface mooring, is designed to funnel all material into a single long tube. Differences in texture of material entering the trap during the deployment can be identified as discrete bands on bulk x-rays of the sample tube. The spacing and relative intensity of x-ray banding will give an indication of composition of suspended matter and the frequency of resuspension.

Seven tube-type sediment traps were attached to the tripod and the subsurface mooring. Samples from these traps will give us an indication of the effectiveness of the sodium azide preservative used in the primary traps.

Element B. Seafloor mapping and bottom characterization

The bathymetric and sidescan interpretive maps of the 5 X 4 nautical mile area surrounding the proposed outfall sites in Massachusetts Bay have been completed at a scale of 1"=1000'. Page sized reductions of these maps are presented as Figures 3, 4, and 5. Positions of camera transects and sediment samples are presented in Figures 6 and 7. Tables of textural data (Table 2 and 3) and descriptions of video coverage (Appendix Table 1) are also included. The texture and video coverage are in excellent agreement with respect to sediment characterization and support the interpretation of sidescan sonar images.

Draft copies of a larger scale bathymetric map and a digital sidescan mosaic of the area containing both options for the diffuser were delivered to MWRA in draft form on December 15, 1989. The scale of these maps are 1"= 486'.

The map produced from the acoustic images of the seafloor and from textural/photographic data defines areas of boulders, rippled sand, and fine-grained sediments where contaminants added to coastal waters are most likely to accumulate. Knowledge of the distribution of sediment types is critical to the design of future environmental studies in this region. The map has also been of use in evaluating potential sites for the outfall of Boston's treated sewage effluent.

The maps show the spatial variability in the seafloor in more detail than previously available in this region. Bathymetric highs are probably drumlins and are typically armored by glacially-derived gravel and boulders. This presumed glacial drift can often be traced as a strong reflector under the adjacent depressions using seismic reflection profiling. Some of the depressions (5 within the study area, the largest about 1 km in diameter) have sediments that contain as much as 60 % silt and 15 % clay. Well-developed mega-ripples in well-sorted sand exist in small localized patches representing less than 5 % of the survey area. The crests of these ripples are oriented north-south and spaced 2-3 meters apart. Ripple amplitudes (crest to trough) were not measured but are estimated to be a maximum of 60 cm on the basis of reports in the literature. The mega-ripples are probably generated and maintained by oscillatory currents from large swells from the east or northeast. The most common sediment type, typically found between topographic highs and lows, is a poorly sorted sand which contains variable amounts of gravel and fines, and is characterized by high reflectivity in the sidescan sonar images.

Table 2. Location and Summary Textural Data for Surficial Sediments Collected in Massachusetts Bay from OSV ANDERSON, April 1989.

Station	Lat°	Lon°	x[1]	y[1]	Water Depth(')	%Gravel	%Sand	%Silt	%Clay	Mean φ	Median φ	St.Dev φ
1-vv1	42 24' 10.6"	70 50' 1.5"	779953	511931	100	0.00	29.26	49.51	21.22	5.72	5.32	2.33
2-vv1	42 23' 41.9"	70 47' 59.7"	789111	509106	106	51.31	48.23	0.26	0.19	-0.91	-1.03	1.20
3-vv1*	42 23' 24.0"	70 48' 31.1"	786768	507268	112	86.72	10.47	1.90	0.91			
4-sm1	42 23' 23.4"	70 49' 16.0"	783400	507183	110	7.17	86.06	4.85	1.92	1.97	1.94	1.63
5-vv3	42 24' 52.6"	70 46' 10.4"	797251	516323	132	57.29	36.19	4.16	2.36	-0.94	-1.71	3.43
6-vv1	42 23' 23.2"	70 49' 52.0"	780704	507137	98	0.00	24.86	60.43	14.71	5.52	5.24	2.12
7-sm1	42 22' 0.1"	70 50' 18.5"	778776	498712	100	0.00	37.61	53.73	8.66	4.68	4.45	2.05
9-vv1	42 20' 50.4"	70 48' 58.2"	784866	491710	101	0.26	44.88	47.64	7.22	4.49	4.19	1.93
9-sm1	42 20' 50.0"	70 48' 58.7"	784825	491669	101	0.16	46.18	44.29	9.38	4.53	4.17	2.13
11-vv1	42 22' 28.3"	70 48' 6.9"	788637	501644	112	0.08	96.23	2.56	1.13	2.45	2.41	1.08
12-sm3	42 22' 50.9"	70 49' 4.1"	784321	503897	95	0.00	98.32	1.14	0.54	2.35	2.37	0.77
13-vv1*	42 23' 21.9"	70 48' 19.8"	787619	507068	112	55.37	39.96	3.23	1.44			
14-vv1	42 24' 50.7"	70 48' 4.4"	788703	516065	108	4.03	93.32	1.80	0.85	1.61	1.60	1.41
14-vv3	42 24' 50.0"	70 48' 4.6"	788692	515994	108	3.47	95.18	0.87	0.48	1.56	1.58	1.17
15-vv1	42 24' 59.4"	70 47' 18.0"	792176	516977	125	55.74	42.20	1.41	0.66	-1.41	-1.20	2.02
16-vv1	42 23' 42.9"	70 47' 32.6"	791147	509224	105	7.35	87.58	3.34	1.73	1.87	2.24	1.54
16-vv2	42 23' 40.7"	70 47' 34.8"	790982	508994	105	93.38	5.99	0.39	0.24	-3.26	-3.70	1.62
18-vv1*	42 23' 36.2"	70 47' 27.4"	791543	508545	289	96.90	3.04	0.02	0.04			
18-vv2*	42 23' 40.1"	70 47' 26.0"	791646	508937	289	94.15	5.64	0.09	0.12			
25-vv1*	42 23' 45.5"	70 46' 38.2"	795227	509515	115	97.09	2.68	0.11	0.12			
25-vv3	42 23' 45.9"	70 46' 37.6"	795273	509560	115	0.10	98.03	1.27	0.60	2.27	2.33	0.91
B2-vv1*	42 25' 13.0"	70 47' 44.6"	790169	518334	124	85.25	11.50	1.99	1.26			
B2-vv2*	42 25' 15.6"	70 47' 46.8"	790002	518596	124	99.33	0.51	0.11	0.05			

[1] State Plane Coordinates (NAD 27)

* Insufficient fine material for full analysis

vv= van Veen grab sample
sm= Smith-MacIntyre grab sample

Table 3. Textural Data for Surficial Sediments having Sufficient Fine Fraction for Complete Analysis Samples Collected from OSV ANDERSON, April 1989.

Station	Coarse Pebbles	Medium Pebbles	Fine Pebbles	Granules	Very Coarse Sand	Coarse Sand	Medium Sand	Fine Sand	Very Fine Sand	Silt 5ϕ	Silt 6ϕ	Silt 7ϕ	Silt 8ϕ	Clay 9ϕ	Clay 10ϕ	Clay >10ϕ
1-vv1	0.00	0.00	0.00	0.00	0.07	0.32	1.48	7.13	20.26	15.56	15.96	9.54	8.46	8.49	8.53	4.20
2-vv1	0.00	2.37	8.84	40.10	36.61	5.50	4.15	1.69	0.29	0.03	0.07	0.08	0.08	0.07	0.08	0.05
4-sm1	0.00	0.00	5.93	1.24	0.09	6.02	38.81	34.94	6.20	0.81	1.51	1.40	1.13	0.86	0.73	0.33
5-vv3	28.44	9.26	9.30	10.28	2.53	9.01	9.99	11.62	3.04	0.66	1.09	1.10	1.31	1.14	0.84	0.38
6-vv1	0.00	0.00	0.00	0.00	0.03	0.28	2.20	7.02	15.32	20.26	20.08	12.06	8.09	5.77	5.76	3.18
7-sm1	0.00	0.00	0.00	0.00	0.00	0.46	8.22	10.81	18.11	27.62	13.81	7.18	5.13	3.82	3.29	1.55
9-vv1	0.00	0.00	0.00	0.26	0.00	0.18	5.66	14.45	24.60	25.03	11.96	5.90	4.76	3.65	2.58	0.99
9-sm1	0.00	0.00	0.00	0.16	0.00	0.40	6.29	19.03	20.46	21.57	12.06	6.14	4.52	3.96	3.71	1.70
11-vv1	0.00	0.00	0.00	0.08	0.48	3.12	17.79	70.15	4.70	0.73	0.77	0.56	0.49	0.46	0.45	0.23
12-sm3	0.00	0.00	0.00	0.00	0.26	1.19	21.66	72.37	2.84	0.38	0.33	0.22	0.22	0.22	0.22	0.11
14-vv1	0.00	0.00	2.59	1.43	2.52	16.05	45.35	26.50	2.89	0.41	0.61	0.40	0.39	0.35	0.33	0.16
14-vv3	0.00	0.00	1.10	2.37	1.14	19.42	44.92	28.16	1.52	0.17	0.27	0.21	0.21	0.20	0.19	0.10
15-vv1	16.90	2.05	7.49	29.29	36.63	2.62	1.18	0.84	0.93	0.36	0.46	0.30	0.29	0.29	0.25	0.12
16-vv1	0.00	2.79	3.02	1.54	5.34	6.92	19.97	48.70	6.66	0.83	1.02	0.69	0.80	0.77	0.67	0.29
16-vv2	42.54	24.77	16.64	9.43	2.74	1.27	1.10	0.81	0.07	0.07	0.13	0.10	0.09	0.09	0.10	0.05
25-vv3	0.00	0.00	0.00	0.10	0.47	5.80	21.05	67.94	2.77	0.31	0.35	0.32	0.29	0.26	0.22	0.11

vv= van Veen grab sample
sm= Smith-MacIntyre grab sample

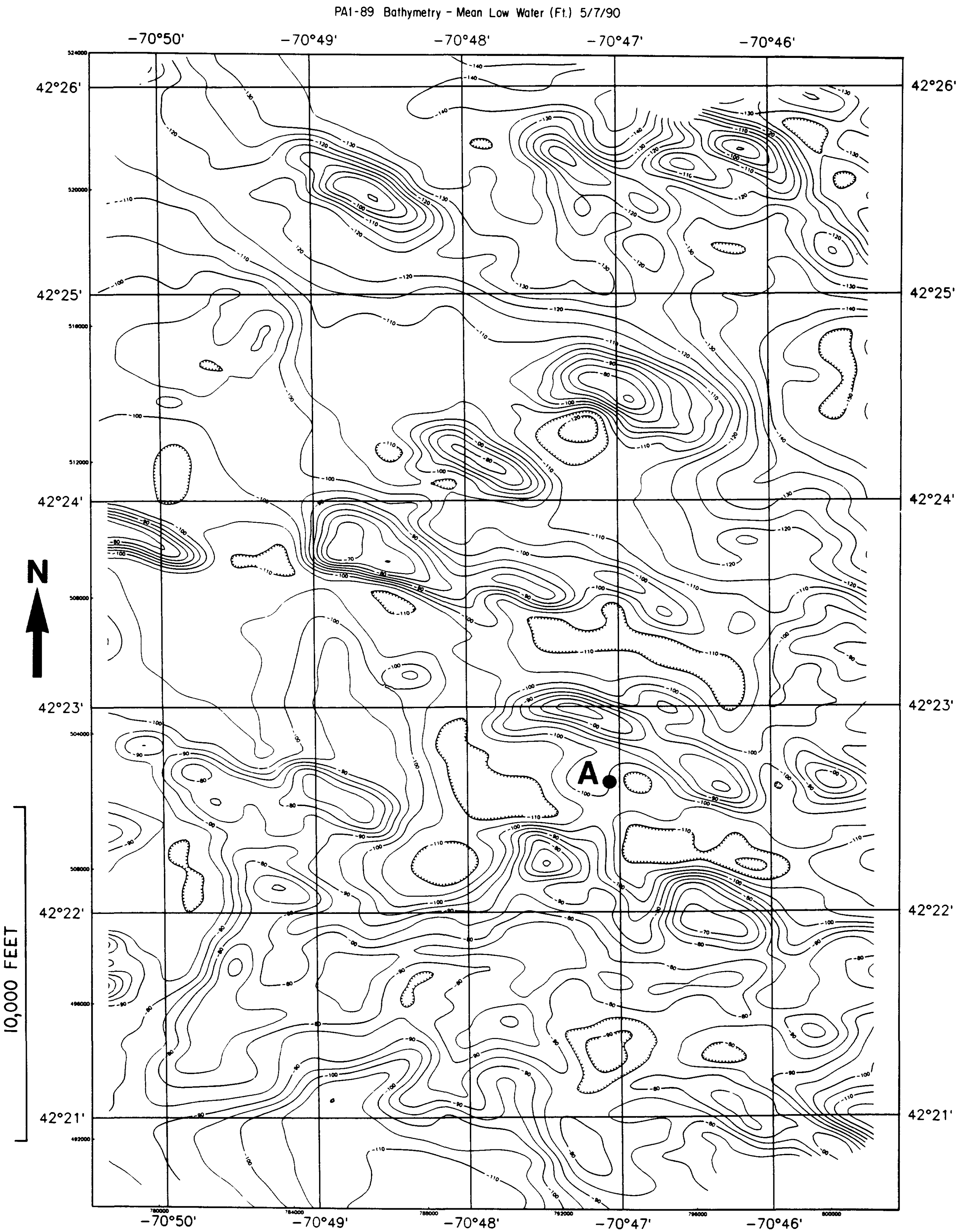

Figure 3. Bathymetric map (feet below mean low water). "A" markes location of long-term mooring.

Figure 4. Geologic map based on sidescan sonar images, video camera and textural analysis of surficial sediments. "A" marks location of long-term mooring.

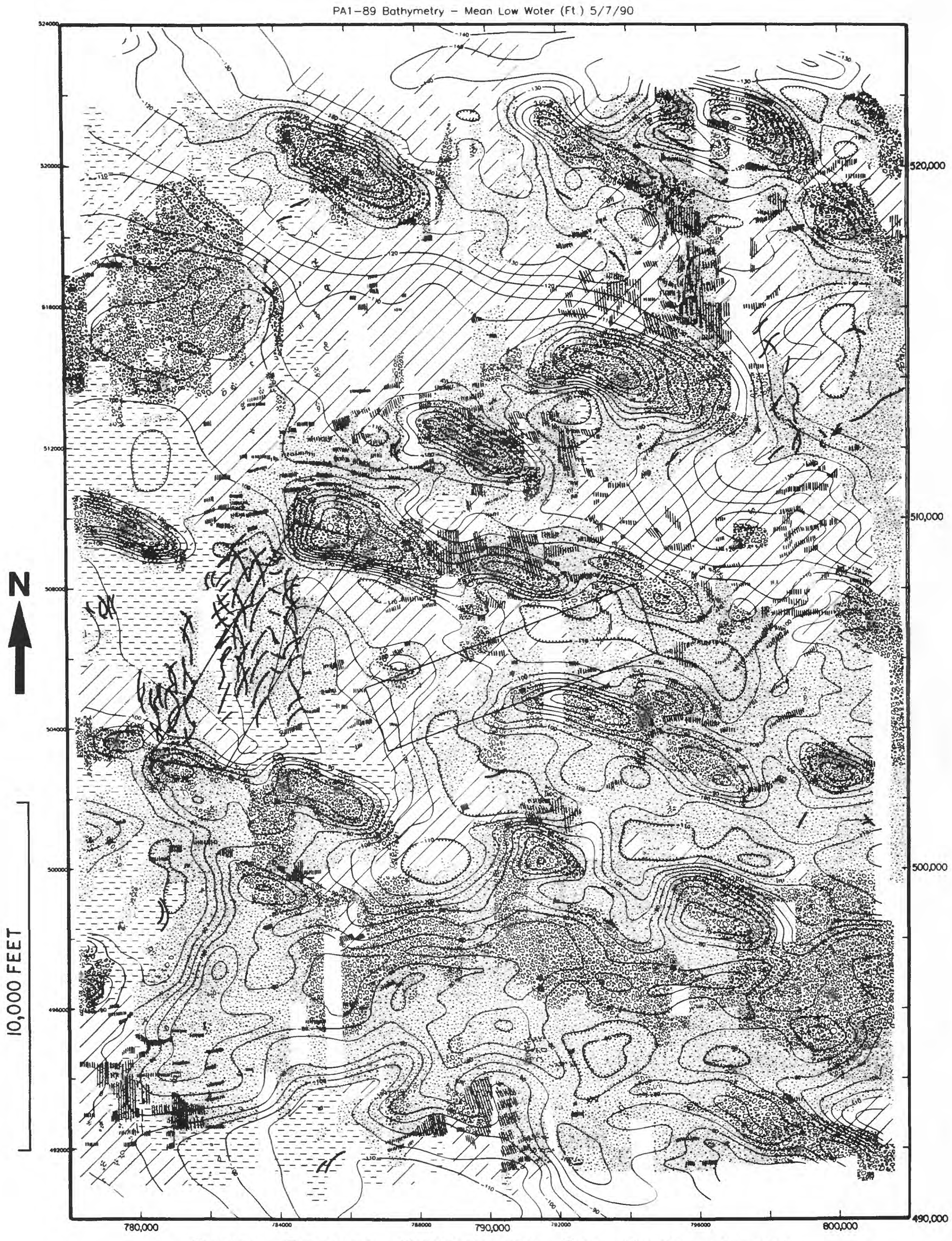

Figure 5. Geologic map with bathymetry superimposed. Rectangles outline two options considered for the outfall diffuser.

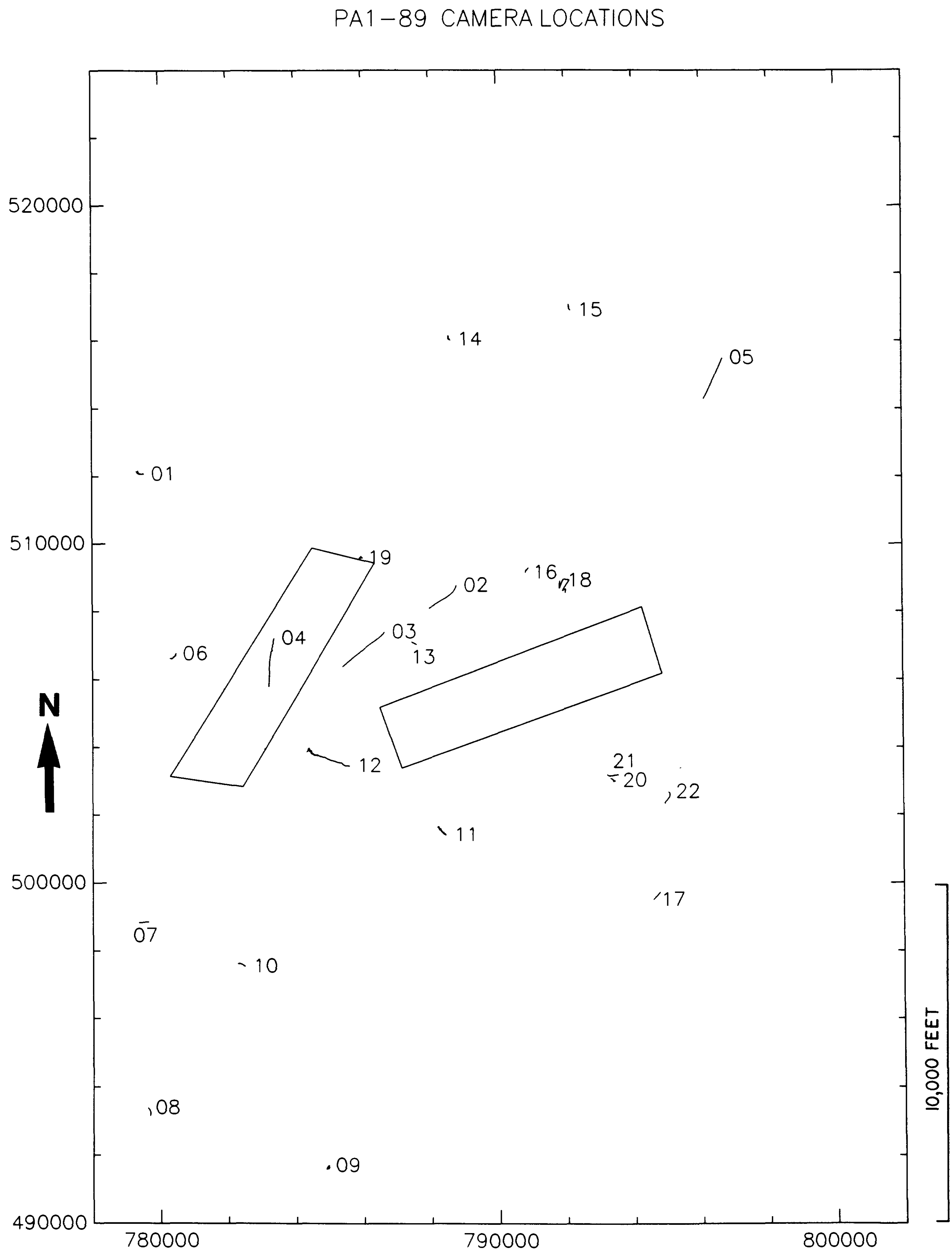

Figure 6. Locations of video camera and still photographic transects.

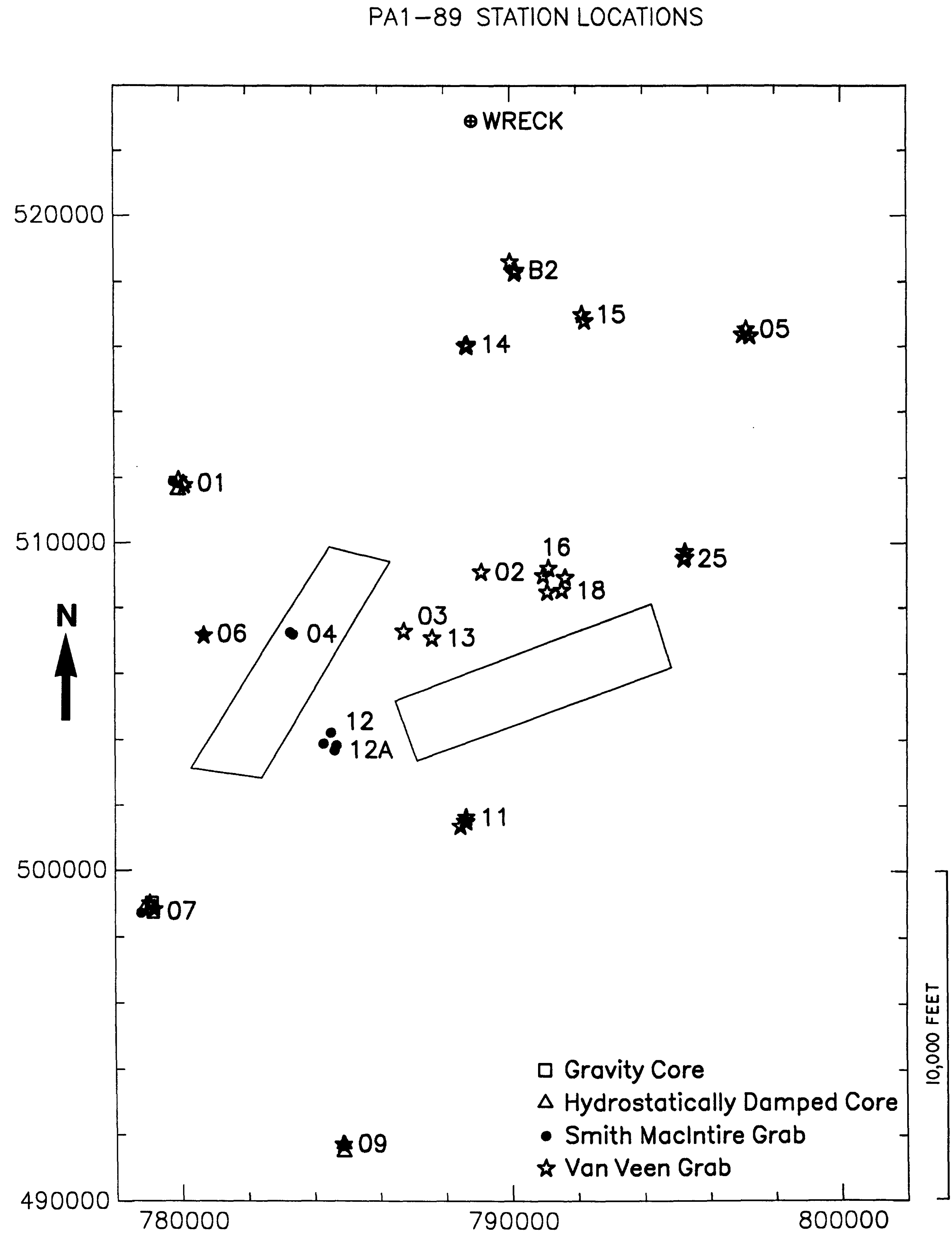

Figure 7. Locations of sediment samples collected in April, 1989. Location of a shipwreck discovered with the sidescan sonar (see text for coordinates).

Trawl marks are obvious in the area of diffuser option 2. It is not clear whether this area of the seafloor is more extensively fished than other areas or whether the sediment type in this area is better suited to record the marks generated by the fishing gear.

One interesting discovery made while analyzing the sidescan sonar data was the presence of a shipwreck in the north central section of the survey area. The position of the shipwreck is 42° 25.97' N, 70° 48.00' W in 135 feet of water. The Loran C positions are approximately 13933.14 (W), 44296.43 (Y). We have not found earlier reference to shipwrecks at this position so the identity is unknown. The shape of the wreck on the sonograph suggests that it might be a barge approximately 100 feet in length.

Element C. Long-term rate of sedimentary processes and contaminant inventories

Sediment cores collected during the cruise aboard the ANDERSON in April, 1989 are being analyzed for rates of sediment mixing and accumulation as well as for texture and heavy metal concentrations. X-ray, textural analyses, and most of the ^{210}Pb counting have been completed. Analysis of heavy metals and geotechnical properties have just begun. Second counts, required for ^{234}Th, and submission of samples for $^{239,240}Pu$ and ^{14}C, will occur in February.

During the deployment cruise on December 5, 1989, sediment samples were collected at two locations of fine-grained sediment within the area surveyed using the ANDERSON. A sub-core from a grab sample collected from each of the two locations has been sectioned at one-half cm intervals. The first counting for ^{234}Th and ^{210}Pb has been completed to a depth of 4 cm. The remaining core and the second counts for ^{234}Th will be completed in March. Sample preparation is underway for textural, organic carbon and metal analyses.

Element D. Harbor-Bay exchange

Development of a high resolution numerical model of the tidal exchange between Boston Harbor and Massachusetts Bay is nearly completed. This model utilizes high resolution digital bathymetric data in a grid with 250 m horizontal resolution. The data were obtained from the National Geophysical Data Center and from USGS. The model predicts tidal currents throughout Boston Harbor at any given time using 16 tidal elevation constituents obtained from NOAA. The predictions of current magnitude at President Roads using the high-resolution model compare well with the more general predictions from NOAA. The new model results show that during flood tide, a weakly recirculating gyre forms over the Deer Island flats (Figure 8). The existence of this flow feature has been noted by previous field investigators (EG&G, 1984), and has been suspected of enhancing the accumulation of sludge material released from Deer Island. Previous numerical circulation studies in Boston Harbor have not reproduced this gyre.

Work continues on testing sensitivity of model current predictions in response to varying bottom friction representation, island configuration, and the location of the open boundaries. After the current field has been further verified by comparison with moored current observations, particle tracking experiments will be conducted to quantify the exchange between Boston Harbor and Massachusetts Bay induced by these currents.

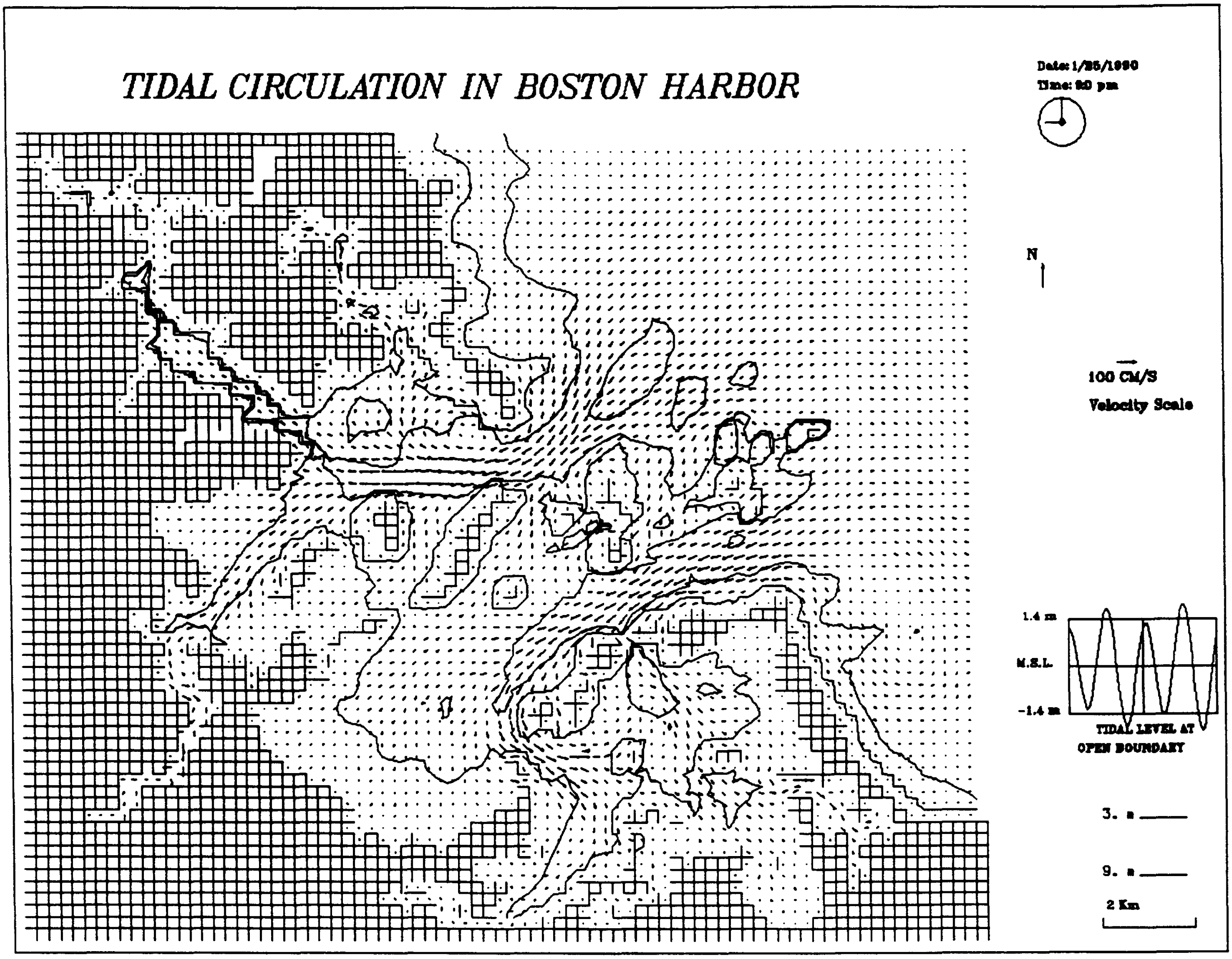

Figure 8. Current vectors predicted 2 hours after maximum flood.

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Appendix 1. LOG OF VIDEO CAMERA TRANSECTS

EXPLANATION OF COLUMN HEADINGS AND SYMBOLS USED IN VIDEO LOG

STA	Station number assigned to video camera track line.
TAPE	VHS tape number.
EL.TIME	Elapsed time from beginning of each video transect (see SOL below).
TD X, Y, and W	Navigation of ship during camera tow using the Northeast U.S. Loran-C chain (GRI 9960). TD X, Y, and W represent time difference in microseconds between signal reception from the master station (Seneca, N.Y.) and slave stations at Nantucket, Mass.(X), Carolina Beach, N.C. (Y), and Caribou, Me.(W).
LAT	Latitude in decimal degrees North computed from state plane coordinates generated from miniranger navigation system.
LON	Longitude in decimal degrees West (longitude value preceded by a minus sign) computed from state plane coordinates generated from miniranger navigation system.
SP X and Y	State plane coordinates X and Y generated from miniranger stations located on benchmarks at Nahant, Marblehead, and Boston Light. Units are in feet - North American Datum, 1927.
TAPE DIST	VCR tape counter distance.
24hrTIME	Time of day, 24 hour, UCT (GMT) - hours, minutes, seconds.
% GRVL	Percent estimate of gravel coverage on bottom from video.
MAX	Maximum diameter in inches of individual rocks in the gravel fraction.
MEAN	Average diameter in inches, gravel fraction.
CS	Course sand present.
MS	Medium sand present.
FS	Fine sand present.
SLT	Silt present.
CLAY	Clay present.
COMMENTS	Video observations; start and end of line; problems with navigation.

EXPLANATION OF COLUMN HEADINGS AND SYMBOLS (CONTINUED)

SOL and EOL	Denotes start and end, respectively, of video tape coverage for each track line. Keyed to elapsed time (EL.TIME).
sol, Mol, eol	Denotes start, middle and end of track line according to miniranger navigation. Keyed to time of day (24hrTIME).
X	Indicates presence of sediment type listed at head of column.

STA	TAPE	EL.TIME	TD X	TD Y	TD W	LAT	LON	SP X	SP Y	TAPE DIST	24hrTIME	% GRVL	MAX	MEAN	CS	MS	FS	SLT	CLAY	COMMENTS
1	1	0:00	SOL 25808.2	44290.4						0041							X	X	X	Cast # 1. The bottom sediment is a fine sand with silt and finer material. The sediment is easily resuspended. There are abundant burrow holes.
1	1	2:00	25808.5	44290.5						0105							X	X	X	Same as above.
			sol 25808.6	44290.5	13955.8	42.40332	-70.83525	779545	512069		02:14:36									
1	1	4:00	25808.8	44290.5						0167							X	X	X	Same as above.
			Mol 25808.8	44290.6	13955.9	42.40337	-70.83570	779423	512085		02:16:06									
			eol 25809.0	44290.7	13956.0	42.40355	-70.83609	779317	512149		02:17:26									
1	1	6:00	EOL 25809.1	44290.7						0228							X	X	X	Same as above. End of line. At tape dist. 0222, There is a good view of a fish.
1	1	0:00	SOL 25807.7	44290.1						0425							X	X	X	Cast # 2. The bottom sediment is a fine sand with silt and finer material. There are many burrow holes. At tape mileage 0451-0480, there is a hint of sand waves. The sediment is easily resuspended.
1	1	2:00	25807.7	44289.9						0480							X	X	X	The sediment is the same as above. There are no more sand waves.
1	1	4:00	25807.9	44289.9						0534							X	X	X	Same as above.
1	1	6:00	25808.1	44290.0						0588							X	X	X	Same as above.
1	1	7:00	EOL 25808.2	44290.1						0610							X	X	X	Same as above. End of line. At tape dist. 0497 there is a lobster. At tape dist. 0600 there is a flounder.
2	1	0:00	SOL 25791.4	44283.8						0974		5%	3	1	X	X	X	X		Sand waves are present. There is a scattering of pebbles. The sand is medium grained and finer. The sediment is easily resuspended.
			sol 25791.4	44283.6	13945.4	42.39405	-70.80115	788781	508762		5:09:06									
2	1	2:00	25791.3	44283.5						1021		5%	3	1	X	X	X	X		Same as above.
2	1	3:10	25791.3	44283.3						1048		40%	3	1	X	X	X	X		The sand waves end. The area becomes patchy with gravel and medium to fine grained sands.
2	1	4:00	25791.5	44283.4						1068		95%	6				X	X	X	The bottom is no longer patchy, but is all gravel with some growth and a dusting of fines.
			Mol 25791.6	44283.3	13946.2	42.39300	-70.80248	788426	508376		5:12:36									
2	1	6:00	25791.7	44283.2						1115		95%	12				X	X	X	Same as above.
			eol 25792.0	44283.3	13947.1	42.39223	-70.80418	787968	508092		5:16:06									
2	1	8:00	EOL 25791.9	44283.3						1161		95%	12				X	X	X	Same as above. End of line.

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STA	TAPE	EL.TIME	TD X	TD Y	TD W	LAT	LON	SP X	SP Y	TAPE DIST	24hrTIME	% GRVL	MAX	MEAN	CS	MS	FS	SLT	CLAY	COMMENTS
3	1	0:00	SOL 25793.2	44283.2						1259	5:32:29	X	10	6				X	X	The bottom is patchy, gravel areas mixed with areas of fines. The fines are easily resuspended. There are worm tubes and some good size boulders.
			sol 25793.3	44283.2	13949.6	42.39035	-70.80909	786647	507397		5:32:26									
3	1	2:00	25793.4	44283.0						1304		X	10	6				X	X	Same as above.
3	1		25793.6	44283.0						1346	5:36:00	X	10	6				X	X	Same as above.
3	1	4:00	25793.7	44282.9						1350		X	10	6				X	X	Same as above.
			Mol 25793.7	44283.0	13950.8	42.38699	-70.81137	786036	506897		5:37:16									
3	1	6:00	25793.8	44282.9						1393		X	10	6				X	X	Same as above.
3	1		25794.0	44282.9						1429	5:40:00	X	10	6				X	X	Same as above.
3	1	8:00	25794.0	44282.7						1436		X	10	6				X	X	Same as above.
3	1	10:00	25794.2	44282.7						1478		X	10	6				X	X	Same as above.
			eol 25794.2	44282.8	13952.2	42.38759	-70.81373	785403	506380		5:42:26									
3	1	12:00	25794.3	44282.5						1521		X	10	6				X	X	Same as above.
3	1	13:10	EOL 25794.4	44282.6						1542	5:45:00	X	10	6				X	X	Same as above. End of line.
4	1	0:00	SOL 25798.2	44284.3						1619		15%	6	3			X	X	X	The bottom sediment is fine sand, silt and finer. There are shell fragments and burrow holes. There is a scattering of pebbles and cobbles. The fine sediment is easily resuspended.
			sol 25798.0	44284.4	13954.3	42.38993	-70.82120	783379	507218		6:07:45									
4	1		25798.1	44284.2						1652	6:09:00	15%	6	3			X	X	X	Same as above.
4	1	2:00	25797.9	44284.1						1659		15%	6	3			X	X	X	Same as above.
4	1	4:00	25797.8	44283.9						1700		15%	6	3			X	X	X	Same as above.
			Mol 25797.6	44283.8	13955.1	42.38805	-70.82169	783251	506530		6:12:16									
4	1	6:00	25797.4	44283.6						1740		15%	6	3			X	X	X	Same as above.
4	1		25797.3	44283.5						1766	6:15:00	15%	6	3			X	X	X	Same as above.
4	1	8:00	25797.1	44283.3						1779		15%	6	3			X	X	X	Same as above.
			eol 25796.9	44283.2	13955.7	42.38602	-70.82183	783220	505793		6:16:46									
4	1	9:15	EOL 25797.0	44283.2						1803		15%	6	3			X	X	X	Same as above. End of line.

STA	TAPE	EL.TIME		TD X	TD Y	TD W	LAT	LON	SP X	SP Y	TAPE DIST	24hrTIME	% GRVL	MAX	MEAN	CS	MS	FS	SLT	CLAY	COMMENTS
5	1			25796.4	47024.1						1920	7:10:00									The camera sled is on its way down to the bottom. TD's do not seem to be reliable.
5	1	0:00	SOL								2130		X	5	2		X	X	X		TD's are not reliable. Bottom sediment is medium to fine sand with a dusting of finer material. There is a scattering of pebbles and cobbles.
			sol	25785.6	44190.6	13926.3	42.41231	-70.77166	796690	515483		7:14:16									
5	1	2:00									2238		X	5	2		X	X	X		Same as above.
5	1	4:00									2343		X	5	2		X	X	X		Same as above.
5	1	4:27									2360		X	6	4		X	X	X		Sand waves are present here. The sediment is medium to fine grained and is easily resuspended. There is also a scattering of rocks.
			Mol	25789.7		13931.6	42.41074	-70.77265	796430	514910		7:18:46									
5	1	6:00									2446		X	6	4		X	X	X		Same as above.
5	1	8:00									2548		X	24							The bottom sediment is now boulders and gravel.
5	1	8:45	EOL									7:22:00									
			eol	25786.3	44285.6	13930.3	42.40905	-70.77377	796131	514289	2585	7:23:36	X	24							Same as above. End of line.
6	2	0:00	SOL	25802.2	44285.1						0513						X	X	X	X	The bottom sediment is fine grained and easily resuspended. There are many burrow holes.
			sol				42.38872	-70.83198	780470	506755		22:40:06									
6	2	2:00		25802.1	44285.1						0597						X	X	X	X	Same as above.
			Mol				42.38855	-70.83201	780461	506693		22:42:16									
6	2	4:00		25802.2	44285.1						0682						X	X	X	X	Same as above.
			eol				42.38836	-70.83247	780339	506621		22:44:36									
6	2	5:20	EOL	25802.2	44285.1						0734						X	X	X	X	Same as above. End of line.
7	2	0:00	SOL	25795.8	44278.3						0751	23:43:02	X	36	12			X	X		The bottom sediment is a boulder field with some fines inbetween the boulders.
			sol				42.36702	-70.83633	779356	498836		23:40:06									
7	2	2:00		25795.7	44278.3						0827		X	36	12			X	X		Same as above.
			Mol				42.36704	-70.83582	779493	498846		23:42:16									
7	2	4:00		25795.4	44278.1						0884		X	36	12			X	X		Same as above.
			eol				42.36707	-70.83523	779652	498856		23:44:36									
7	2	5:45	EOL	25795.3	44278.2						0951		X	36	12			X	X		Same as above. End of line.

STA	TAPE	EL.TIME		TD X	TD Y	TD W	LAT	LON	SP X	SP Y	TAPE DIST	24hrTIME	% GRVL	MAX	MEAN	CS	MS	FS	SLT	CLAY	COMMENTS
8	2	0:00	SOL	25790.3	44273.1						1108	00:39:09	X	3	1	X	X				The sediment is medium to coarse sand with gravel and some shell fragments.
			sol				42.35204	-70.83555	779608	493379		00:36:36									
8	2	2:00		25790.2	44272.9						1176		X	3	1	X	X				Same as above.
			Mol				42.35176	-70.83530	779678	493280		00:40:16									
8	2	4:00		25790.2	44273.0						1244		X	3	1	X	X				Same as above.
8	2										1258		X	3	1	X	X				The sediment is the same as above with a two foot long piece of wood.
			eol				42.35141	-70.83531	779677	493151		00:44:06									
8	2	4:45	EOL	25790.1	44272.9						1268		X	3	1	X	X				Same as above. End of line.
9	2	0:00	SOL	25780.6	44269.2													X	X	X	The sediment is fine sand, silt and finer. The sediment is very easily resuspended. There are lots of burrow holes.
			sol				42.34731	-70.81593	784925	491698		01:10:36									
9	2	2:00		25780.6	44269.3													X	X	X	Same as above.
			Mol				42.34716	-70.81598	784912	491642		01:13:26									
9	2	4:00		25780.5	44269.2													X	X	X	Same as above.
			eol				42.34709	-70.81580	784963	491620		01:16:36									
9	2	5:45	EOL	25780.5	44269.2													X	X	X	Same as above. End of line.
10	2	0:00	SOL	25790.1	44275.9						1570	1:44:14	X	8	3			X	X	X	The sediment is gravel, 1/4" to 8" in diameter. There are some fines inbetween the gravel. There is also some suspended sediment and some growth on the rocks.
			sol				42.36340	-70.82474	782499	497544		01:42:36									
10	2	2:00		25790.2	44275.8						1633		X	8	3			X	X	X	Same as above.
10	2			25790.3	44276.0						1659	1:47:10	X	8	3			X	X	X	Same as above with a possible view of a scallop.
			Mol				42.36356	-70.82509	782402	497599		01:46:16									
10	2	4:00		25790.3	44275.9						1694		X	8	3			X	X	X	Same as above.
10	2	6:00		25790.4	44276.0						1753		X	8	3			X	X	X	Same as above.
			eol				42.36363	-70.82557	782274	497623		01:53:06									
10	2	8:00	EOL	25790.4	44275.9						1812		X	8	3			X	X	X	Same as above. End of line.

STA	TAPE	EL.TIME	TD X	TD Y	TD W	LAT	LON	SP X	SP Y	TAPE DIST	24hrTIME	% GRVL	MAX	MEAN	CS	MS	FS	SLT	CLAY	COMMENTS
11	2	0:00	SOL 25784.5	44276.8						2524							X	X	X	The bottom sediment is fine grained sand, silt and finer. The sediment is easily resuspended. There is a heavy concentration of shell debris. There are some burrow holes.
			sol			42.37385	-70.80260	788451	501398		02:21:06									
11	2	2:00	25784.7	44276.9						2574							X	X	X	Same as above.
11	2									2612							X	X	X	Same as above with a good view of a fish.
11	2	4:00	25784.9	44276.9						2624							X	X	X	Same as above.
			Mol			42.37416	-70.80305	788329	501509		02:24:46									
11	2	4:45	25784.9	44277.0						2643							X	X	X	The amount of shell debris has decreased. Now there is just a light scattering of shells. The sediment texture is the same but there are now sand waves or ripples present.
11	2									2656							X	X	X	Same as above with a good view of a crab.
11	2	6:00	25785.0	44277.1						2674							X	X	X	Same as above.
11	2	8:00	25785.2	44277.1						2723							X	X	X	Same as above.
			eol			42.37448	-70.80356	788188	501627		02:28:36									
11	2	9:00	EOL 25785.2	44277.1						2746							X	X	X	Same as above. End of line.
12	2	0:00	SOL 25793.2	44280.8						2819	2:47:53					X	X	X		Small sand waves are present. The sediment texture ismedium to fine sand and silt. The sediment resuspends easily. There are some worm tubes and shell debris.
			sol			42.37953	-70.81310	785598	503447		02:40:06									
12	2	2:00	25793.3	44280.8						2867						X	X	X		Same as above.
			Mol			42.38067	-70.81719	784488	503851		02:47:26									
12	2	4:00	25793.3	44280.9						2914						X	X	X		Same as above.
12	2	6:00	25793.4	44281.0						2960						X	X	X		Same as above.
			eol			42.38103	-70.81750	784403	503984		02:55:06									
12	2	6:30	EOL 25793.5	44281.0						2972						X	X	X		Same as above. End of line.

STA	TAPE	EL.TIME		TD X	TD Y	TD W	LAT	LON	SP X	SP Y	TAPE DIST	24hrTIME	% GRVL	MAX	MEAN	CS	MS	FS	SLT	CLAY	COMMENTS
13	2	0:00	SOL	25791.5	44282.4						3077		X	2	1			X	X	X	The bottom sediment is a fine sand, silt and finer. There is an abundance of burrow holes, a very light scattering of pebbles and a few shell fragments.
			sol				42.38935	-70.80560	787595	507040		03:34:06									
13	2										3120	3:36:00	X	2	1			X	X	X	Same as above.
13	2	2:00		25791.8	44282.6						3123		X	2	1			X	X	X	Same as above.
			Mol				42.38944	-70.80586	787524	507073		03:37:36									
13	2	4:00		25791.8	44282.4						3168		X	2	1			X	X	X	Same as above.
			eol				42.38954	-70.80615	787444	507108		03:41:06									
13	2	5:30	EOL	25791.8	44282.6						3203		X	2	1			X	X	X	Same as above. End of line.
14	2	0:00	SOL	25799.0	44290.4						3227	4:16:35	15%	4	1			X	X	X	The bottom texture is fine sand, silt and finer with a scattering of pebbles. 10-15% coverage in dense areas. There are some burrow holes and shell fragments. The sediment is easily resuspended.
			sol				42.41401	-70.80150	788629	516035		04:16:06									
14	2	2:00		25799.0	44290.4						3271		15%	4	1			X	X	X	Same as above. there is a good view of a fish.
			Mol				42.41416	-70.80163	788592	516089		04:20:06									
14	2	4:00		25799.1	44290.4						3316		15%	4	1			X	X	X	Same as above.
14	2	6:00		25799.1	44290.5								15%	4	1			X	X	X	Same as above.
			eol				42.41430	-70.80173	788565	516142		04:24:36									
14	2	7:00	EOL	25799.2	44290.5								15%	4	1			X	X	X	Same as above. End of line.
15	3	0:00	SOL	25794.6	44289.7						0050		15%	4	1			X	X	X	The bottom texture is fine sand, silt and finer. The area is patchy with fines and pebbles. The sediment is easily resuspended.
			sol				42.41632	-70.78828	792190	516907		04:51:06									
15	3	1:35		25794.6	44289.7						0075	4:51:00	15%	4	1			X	X	X	Same as above.
15	3	2:00		25794.6	44289.7						0144		15%	4	1			X	X	X	Same as above.
15	3	4:00		25794.7	44289.7						0236		15%	4	1			X	X	X	Same as above.
			Mol				42.41657	-70.78844	792146	516996		04:55:56									
15	3	6:00		25794.7	44289.7						0325		15%	4	1			X	X	X	Same as above.
15	3	8:00		25794.7	44289.7						0411		15%	4	1			X	X	X	Same as above.
			eol				42.41681	-70.78849	792134	517086		05:01:06									
15	3	9:00	EOL	25794.7	44289.8						0451		15%	4	1			X	X	X	Same as above. End of line.

STA	TAPE	EL.TIME		TD X	TD Y	TD W	LAT	LON	SP X	SP Y	TAPE DIST	24hrTIME	% GRVL	MAX	MEAN	CS	MS	FS	SLT	CLAY	COMMENTS
16	3	0:00	SOL	25788.8	44283.0						0487	5:57:00	X	1	1/2		X	X	X	X	The bottom texture is medium sand to finer than silt. There are patchy areas of gravel. There is a dusting of fines on the gravel which is easily resuspened.
			sol				42.39502	-70.79357	790827	509135		05:57:06									
16	3	2:00		25788.9	44283.1						0568		X	1	1/2		X	X	X	X	Same as above.
16	3	4:00		25788.9	44283.1						0648		X	1	1/2		X	X	X	X	Same as above.
			Mol				42.39525	-70.79345	790859	509218		06:02:26									
16	3	6:00		25788.9	44283.1						0727		X	1	1/2		X	X	X	X	Same as above.
16	3	8:00		25788.9	44283.2						0803		X	1	1/2		X	X	X	X	Same as above.
16	3	10:00		25788.8	44283.2						0877		X	1	1/2		X	X	X	X	Same as above.
			eol				42.39542	-70.79326	790909	509281		06:08:06									
16	3	10:35	EOL	25788.8	44283.1						0904	6:08:00	X	1	1/2		X	X	X	X	Same as above. End of line.
17	3	0:00	SOL	25773.7	44272.7						1118	7:07:41	X	30	8				X	X	The bottom texture is very rocky. Boulders and cobbles are covered with growth and a dusting of fine sediment. The fine sediment is easily resuspended.
			sol				42.36847	-70.78003	794565	499487		07:07:06									
17	3	2:00		25773.6	44272.7						1187		X	30	8				X	X	Same as above.
17	3	4:00		25773.6	44272.7						1255		X	30	8				X	X	Same as above.
			Mol				42.36877	-70.77964	794669	499599		07:11:26									
17	3	6:00		25773.6	44272.7						1321		X	30	8				X	X	Same as above.
17	3	8:00		25773.6	44272.7						1386		X	30	8				X	X	Same as above.
			eol				42.36907	-70.77926	794771	499710		07:15:56									
17	3	8:50	EOL	25773.6	44272.8						1413	7:16:29	X	30	8				X	X	Same as above. End of line.

STA	TAPE	EL.TIME		TD X	TD Y	TD W	LAT	LON	SP X	SP Y	TAPE DIST	24hrTIME	% GRVL	MAX	MEAN	CS	MS	FS	SLT	CLAY	COMMENTS
18	3	0:00	SOL	25787.0	44282.4						1492		X				X	X	X		The bottom sediment is medium to fine sand. Some shell fragments and a very light scattering of rocks are present. There are sand waves.
18	3			25786.8	44282.2						1552		X				X	X	X		Sand waves are no longer present. The bottom patchy with gravel areas and areas of fine grained sediment. The fine grained areas have burrow holes. The gravel has growth on it.
18	3	2:00		25786.9	44282.4						1555		X				X	X	X		Same as above.
18	3										1594	8:36:00	X				X	X	X		Same as above.
18	3	4:00		25786.6	44282.3						1616		X				X	X	X		Same as above.
18	3			25786.6	44282.1						1636	8:37:00	X				X	X	X		Same as above.
18	3	6:00		25786.5	44282.1						1677		X				X	X	X		Same as above.
18	3	7:50	EOL	25786.4	44282.0						1730		X				X	X	X		Same as above. End of line.
19	4	0:00	SOL	25796.7	44285.6						0114		100%	72	48						The bottom sediment is boulders. The average size is 4' in diameter. There is growth on the boulders, it looks like kelp. The boulders are dark red in color.
			sol				42.39634	-70.81167	785935	509575		09:20:34									
19	4	2:00		25796.7	44285.5						0205		100%	72	48						Same as above.
19	4	4:00		25796.7	44285.6						0295		100%	72	48						Same as above.
19	4	6:00		25796.7	44285.6						0382		100%	72	48						Same as above.
			Mol				42.39639	-70.81171	785923	509593		09:27:34									
19	4	8:00		25796.7	44285.6						0466		100%	72	48						Same as above.
19	4	10:00		25796.7	44285.7						0548		100%	72	48						Same as above.
19	4	12:00		25796.7	44285.6						0629		100%	72	48						Same as above.
			eol				42.39651	-70.81154	785967	509638		09:36:04									
19	4	12:20	EOL	25796.7	44285.6						0643		100%	72	48						Same as above. End of line.

STA	TAPE	EL.TIME	TD X	TD Y	TD W	LAT	LON	SP X	SP Y	TAPE DIST	24hrTIME	% GRVL	MAX	MEAN	CS	MS	FS	SLT	CLAY	COMMENTS
20	4	0:00	SOL 25778.9	44276.3						0747		98%	6	3				X	X	The bottom texture is gravel. The gravel has growth and a light dusting
			sol			42.37812	-70.78403	793455	502998		10:06:03									*of fines on it. The fines can be resuspended but it is difficult.*
20	4	2:00	25779.0	44276.3						0823		98%	6	3				X	X	Same as above.
20	4		25779.0	44276.3						0861	10:09:00	98%	6	3				X	X	Same as above.
20	4	4:00	25779.0	44276.3						0897		98%	6	3				X	X	Same as above.
20	4	6:00	25779.0	44276.4						0970		98%	6	3				X	X	Same as above.
			Mol			42.37826	-70.78434	793372	503045		10:12:03									
20	4	8:00	25779.0	44276.4						1042	10:14:00	98%	6	3				X	X	Same as above.
20	4	10:00	25779.1	44276.4						1112		98%	6	3				X	X	Same as above.
20	4	12:00	25779.2	44276.4						1161		98%	6	3				X	X	Same as above.
			eol			42.37632	-70.78457	793308	503068		10:19:33									
20	4	13:30	EOL 25779.1	44276.5						1229		98% .	6	3				X	X	Same as above. End of line.
21	4	0:00	SOL 25778.9	44276.5						1279		98%	8	4				X	X	The bottom texture is gravel with a coating of fines. The fines are
			sol			42.37860	-70.78369	793545	503173		10:39:33									resuspendable.
21	4	2:00	25779.0	44276.4						1345		98%	8	4				X	X	Same as above.
			Mol			42.37855	-70.78422	793403	503154		10:43:03									
21	4	4:00	25779.1	44276.5						1410		98%	8	4				X	X	Same as above.
21	4		25779.2	44276.5						1432	10:44:00	98%	8	4				X	X	Same as above.
			eol			42.37860	-70.78491	793217	503170		10:47:03									
21	4	5:05	EOL 25779.1	44276.5						1443		98%	8	4				X	X	Same as above. End of line.

STA	TAPE	EL.TIME		TD X	TD Y	TD W	LAT	LON	SP X	SP Y	TAPE DIST	24hrTIME	% GRVL	MAX	MEAN	CS	MS	FS	SLT	CLAY	COMMENTS
22	4	0:00	SOL								1507		99%	6	4				X	X	The bottom is all gravel with a coating of fine grained sediment. The fine sediment is easily resuspended. The gravel has growth on it.
			sol				42.37717	-70.77821	795032	502664		11:01:33									
22	4										1543	11:03:00	99%	6	4				X	X	Same as above.
22	4	2:00		25775.9	44275.1						1568		99%	6	4				X	X	Same as above.
			Mol				42.37656	-70.77829	795012	502439		11:05:03									
22	4	4:00		25775.9	44275.1						1630		99%	6	4				X	X	Same as above.
22	4	6:00		25775.9	44275.1						1691		99%	6	4				X	X	Same as above.
			eol				42.37623	-70.77862	794923	502321		11:09:33									
22	4	7:00	EOL	25775.9	44275.0						1723		99%	6	4				X	X	Same as above. *End of line.*