An Initial Evaluation of Marine Sediment Dispersion Associated with the Installation of the Islander East Natural Gas Pipeline

Prepared for

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Introduction

The proposed installation of a 24" natural gas pipeline across Long Island Sound between Branford, Connecticut and Wading River, New York (Fig.1) has the potential to introduce quantities of sediment into the adjoining waters. The dispersion of these materials under the combined effects of flow induced advection and gravitational settling can produce short-term alterations in near-bottom suspended material concentrations and longer term changes in the composition and fabric of the sediment-water interface. Evaluation of the effects of these alterations on the local marine resource requires quantitative definition of the area subject to sediment dispersal and specification of the dimensions of the resulting deposit with particular emphasis on vertical thickness. The following report provides a summary of an initial evaluation of these characteristics using a combination of numerical modeling, analytical computation and direct field observations.

Project Characteristics

The installation of the proposed gas pipeline across Long Island Sound will involve the use of a variety of engineering methods. Proceeding south from the Connecticut shoreline (~MP 10.1) the pipeline first will pass through a horizontal directionally drilled (HDD) hole approximately 4140ft in length to exit 20ft below ambient bottom in the vicinity of MilePost 10.9. On exiting the pipe will pass through a transition basin and slowly proceed upwards along a southerly track until it reaches a point approximately 3.0ft below ambient bottom near MilePost 10.95. This transition basin is to be mechanically dredged using a 6yd^3 clamshell bucket mounted on a spud barge. The basin will be approximately 250ft in length with a maximum depth of 20ft and width of 130ft (Fig. 2). From these maxima along its inshore limit, the basin will gradually reduce in cross-section with distance south to MP 10.95. Basin construction is expected to require approximately 7 working days during which time 6500 yds^3 of sediment will be removed and placed around the basin perimeter to form a uniform berm having a base dimension of approximately 65ft and a maximum height of 11ft. Construction is to begin immediately following completion of the HDD pilot hole. The basin will remain open throughout the remaining HDD activities and the subsequent initial pipe laying phase, a period of approximately three (3) months.

From the southerly end of the transition basin at MP 10.95 to MP 12 the pipeline trench will be mechanically dredged applying the same methods used to construct the transition basin. A 6 yds^3 clamshell bucket mounted on a spud barge will remove approximately 44,686 yds^3 over a ten (10) day period forming a trapezoidal trench (Fig 3) with a sidewall slope of 3:1 and a maximum depth of 8ft below ambient bottom. Displaced sediments are to be sidecast along one edge of the trench forming a berm 60ft wide and 10ft high. This trench is to be constructed following completion of the HDD and immediately prior to pullback and the subsequent open water pipelaying operations. It will remain open for a period of approximately 20 days and will be closed by simple mechanical replacement of the dredged materials. The fill sediments are to provide a minimum cover of 3ft over the jacketed pipeline.

Beyond MP 12 pipeline lowering below ambient bottom is to be accomplished by either mechanical plow or hydraulic excavation. Of these, mechanical plowing is the method preferred by Islander East. Both first involve placement of the completed pipeline directly on the seabed. Following the pipeline laying phase the mechanical plow would be placed to straddle the pipe and subsequently pulled at a rate of approximately 400 to 450ft/hr by winches located on an anchored barge. The resulting plowing would displace approximately 504,367 yds^3 of sediment forming a 25 ft wide trapezoidal trench centered on the pipeline and two bordering berms to the right and left each approximately 25ft in width and 2ft high (Fig. 4). Support sufficient to permit this displacement of the sediments found along the proposed route requires an array of 10 anchors distributed along and across a corridor which increases in width from approximately 1200 ft to the east and west of the pipe centerline inshore of the 30 ft water depth contours to 2000 ft either side of the pipe in the open waters of the Sound (~ MP 16.5 to MP 30). As the plow proceeds the anchors are systematically repositioned by supporting small boats resulting in approximately three (3) anchor sets per mile of advance. Examination of the sediment characteristics and distribution along the proposed route indicates that two passes of the mechanical plow will be required to position the pipeline at least 3ft below ambient bottom. Following completion of the lowering phase the blades of the plow will be re-positioned and a third pass initiated sweeping displaced sediments back into the trench covering the pipe and restoring seabed contours to near pre-project conditions. This three (3) pass plan will result in 90 anchor scars per mile of pipe, 45 on either side of the trench. Each scar would be approximately 175 ft^2 in area and 8ft deep.

If the mechanical plow is not available, pipeline lowering will employ hydraulic jetting to excavate underlying sediments. Materials fluidized by downward directed hydraulic jets will be removed by an air lift system and discharged into the water column at a point approximately 10ft above the ambient bottom via two rectangular eductors (10in x 48in in cross-section) located on either side of the support sled (Fig 5). Discharge velocity from each eductor will be approximately 8 ft/sec providing an excavation rate of 500 to 600 ft^3/min of sediment on a rate of advance of 400 to 450 ft/hr. From MP12 to MP 32.15 the plow will displace approximately 662,000 yds^3 of sediment forming a trapezoidal trench 40 ft in width at the surface and 8ft deep (Fig.5). In a manner identical to the mechanical plow, the hydraulic excavator will be positioned to straddle the pipeline and moved along by winches on an anchored barge. In this case it is expected that two passes will be required to lower the pipe to the desired depth below ambient bottom resulting in 60 anchor scars/mile of pipeline. Following lowering infilling of the trench will rely on natural sediment transport processes. There will be no attempt to mechanically backfill the hydraulically excavated trench.

On approach to the Long Island landfall in Wading River, New York plowing will be discontinued in the vicinity of the 20 ft water depth contour (~MP 32.15). From this point shoreward to the 2 ft water depth contour pipeline trenching will again be accomplished by mechanical dredging. Trench dimensions will be identical to those observed along the northern limits of the crossing in Connecticut waters (Fig.3) with material removed using a clamshell bucket and side cast along one side of the trench to form an discrete berm. In the vicinity of MP

32.58, as water depths fall below 8 ft, additional dredging will be required to construct and maintain a flotation basin (Fig.6) sufficient to accommodate the dredge barge. The excavation of this additional material extending over a distance of approximately 320 ft will add substantially to the sediments stored in the bordering berm resulting in an emergent feature subject to wave induced erosion requiring continuing sweeping by the dredge to maintain navigable depths and the desired lowering of the gas pipeline. As a result of this instability the rate of advance will slow from values similar to those achieved in the Connecticut nearshore to less than 50 ft/day requiring close coordination between pipelaying and excavation operations. From the 2ft water depth contour in and across the intertidal zone the pipe will be placed in a sheetpile stabilized trench. Excavated materials will be sidecast in close proximity for reuse as cover following pipe laying operations.

Project Setting

The dispersion of sediments resuspended by pipeline laying operations will vary as a function of engineering protocols, sediment characteristics, and the local flow regime. The engineering methods and procedures, and in particular production rate(s), govern the initial source concentrations and material distributions over the water column and establish the susceptibility of bottom placed materials to long-term erosion and transport. The dispersal of the sediments will ultimately vary as a function of material characteristics including grain size, suspended material concentrations, and critical erosion properties as well as the bulk characteristics of sidecast deposits and the dimensions of the resulting mound. Sampling conducted as part of this project (Haley & Aldrich,2002) indicates that the sediments to be encountered along the proposed route consist primarily of fine sands, silts and clays (Table 1) . With the exception of materials found within the immediate nearshore bordering Long Island (i.e. MP 32-32.9) where sands dominate, all sediments sampled display moderate plasticity indicating that as a class these materials are cohesive. Despite the finer grained composition of the sediments, this characteristic favors the formation of stable deposits of placed dredged materials and the relatively rapid settlement of suspended sediments.

The fine grained sediments dominating the areas in and adjacent to the proposed pipeline route originate within a variety of source areas both inland , alongshore and offshore (Poppe,et.al.,2000). Leaving their respective source areas these materials are distributed along and across the Sound by the combination of tidal currents, density driven flows, winds and wind wave induced velocities. In the deeper waters circulation is controlled primarily by the astronomical tide resulting in regular periodic flow reversals. These patterns are dominated by the M2 component, the semi-diurnal lunar tide, with a period of approximately 12.4 hours and near bottom velocity maxima along the pipeline route of approximately 25 cm/sec (Signell,et.al.,2000). The direction and magnitude of the transport induced by these flows is in large part controlled by the seasonal variations in freshwater discharge entering the Sound and the associated distributions of water densities over the vertical. Within central Long Island Sound velocities associated with this residual circulation average approximately 6-8 cm/sec to the northwest (Signell,2000). Velocity maxima occur in the deeper waters with values progressively decreasing as depths shoal.

Within the near shore shallow water areas bordering the pipeline route flows display significant spatial and temporal variability under the combined effects of water depth and regional topography. Tidal currents continue to dominate the circulation field supplemented by wind driven currents and surface wave induced velocities. Time series observations provided by a network of instruments deployed as part of this investigation (Fig.7) show nearbottom velocity maxima at the offshore station (~MP12.5) of approximately 45 cm/sec with flooding currents typically exceeding the ebb. This asymmetry favors net transport to the northwest at an average speed of approximately 2 cm/sec. At the inshore station, close to the proposed position of the HDD exit hole, the presence of the islands and rocky outcrops favors dominance of the east going ebb tidal currents resulting in a net transport to the northeast at a speed of approximately 4-6 cm/sec. These long term observations also provide clear indication of the importance of wind wave induced velocities in this area with significant wave heights approaching 1m during periods of moderate westerly winds (Figs.8-9). The increase in transport energies due to the combined effects of tidal currents and wind wave induced velocities favor an increased resuspension of bottom sediments producing aperiodic increases in suspended material concentrations throughout the inshore region which persist for several days after the period of peak winds. The wave characteristics and magnitude of the aperiodic resuspension events indicates that the bottom throughout the Connecticut near shore is a dynamic boundary subject to regular physical disruption typically involving the upper 10 mm of the sediment column. This extent of this instability will vary as a function of water depths with maxima inshore and minima in the vicinity of the depth of surface wave influence in approximately 35ft (10m) of water.

Methods and Procedures

The proposed construction of a natural gas pipeline across Long Island Sound has the potential to modify the mass of sediment transported by the local flow field due to the mechanical introduction of materials into the water column by the operating dredge, pipeline plows or anchors and the erosion of sediment deposits placed along and adjacent to the trench including muds associated with directional drilling. Materials introduced from these sources will disperse under the combined effects of local flows, turbulence, and gravitational settling. Each of these factors can be expected to display significant spatial and temporal variability. The effects of this variability are best evaluated using a combination of numerical modeling, analytical computations, and direct observation. For this initial evaluation a numerical model detailing flows throughout the areas bordering the pipeline route was developed. This model consists of two segments, one focused on the Connecticut near shore and the other covering the remainder of Long Island Sound.

The inshore segment of the numerical flow model employs RMA2 a two dimensional depth averaged finite element model specifically designed for the simulation of flow in harbors, estuaries and rivers (King and Norton, 1978). The finite element method uses a network of user defined quadrilateral and triangular elements as the framework for solving the equations of continuity and momentum for turbulent fluid motion. The solution produces the horizontal velocity components (u, v) and depth (h) for each defined point in the flow domain. The finite element method also provides an accurate means of conforming to the spatially varying bathymetry and bottom characteristics typically found in coastal and inland regions. Historically, RMA2 has been the primary tool of the US Army Corps of Engineers as part of the TABS modeling system, and has a broad user base in the academic and consulting industry.

The domain of the RMA simulation was specified using a finite element mesh of 1071 elements and 3176 nodes representing the bathymetry and geometric shape of the nearshore region between Indian Neck and Sachem Head in Branford, Connecticut (Fig.10). The bathymetric data and coastline configuration were digitized from NOAA Nautical Chart #12373. The southern boundary runs east-west approximately 2.5 nautical miles offshore from the northern most location (Juniper Point) of the coastline. The network elements are relatively large (10^5 $yds^{2)}$ in areas where bathymetry is constant and small (10^3 yds^2) where bathymetric gradients are sharp, *e.g.*, in and among the Thimble Islands, along the western boundary at Negro Head Reef, near the eastern boundary at Goose Rock Shoals, and at the southern boundary between Brown's Reef, Wheaton Reef and East Reef. Elements were also refined in selected areas along the pipeline route. The boundary conditions were defined by specifying tidal elevations along the eastern and western limits of the model domain. The tidal elevation data were derived from NOS Tide Tables for Bridgeport and adjusted for the time and height lags using the NOS parameters published for Sachem Head and Indian Neck. The southern boundary was designated as a slip boundary, allowing for parallel flow. The model time stepping was set for 10 minutes. Tidal heights and current observations provided by the inshore array deployed as part of this study (Fig.6) were used to verify model results. Representative model results for the flood and the ebb tide are shown in Figures 11 and 12, respectively.

The offshore model segment extends from Throgs Neck, New York east to the vicinity of Block Island Rhode Island. Tidal flows in this region were modeled using the Long Island Sound Tide Model (LISTide). This model reproduces the sea surface elevation variations due to tidal oscillations by solving the linear shallow-water equations of motion for a single homogeneous layer (Bogden and O'Donnell, 1998). Solution of the equations resolves the vertically averaged horizontal velocities (u, v) and sea-surface displacement (η) throughout Long Island Sound. The model is forced using NOAA tidal predictions along a boundary extending south from Point Judith, Rhode Island to Block Island, R.I to Montauk, N.Y.. The model allows for the specification of a friction coefficient used to minimize errors as the tidal wave propagates through the Sound. The grid spacing used in the model is fixed at approximately 1 km (1094 yds). The bathymetry is derived from USGS data originally obtained every 250 m (273 yds), smoothed and subsampled to fit the larger Long Island Sound grid. The model runs with a fixed internal time step of 10 seconds; the user can specify output at any regular time interval . Ten (10) minutes was specified for this study. An example of LISTide model output for flood and ebb tidal conditions is provided in Figures 13 and 14, respectively.

For this initial evaluation the results of the numerical hydrodynamic models were used in combination with experimental results obtained during previous investigations and the sediment core data obtained as part of this study (Haley & Aldrich,2002) to analytically evaluate the dispersion characteristics of materials resuspended by pipeline construction activities. Particular emphasis was placed on the spatial distributions of sediment introduced into the water column during the proposed dredging of the pipeline trench in nearshore waters and the jet-plow lowering in deeper waters. The mass of material introduced by these activities was supplemented by estimates of mass erosion of placed deposits of dredged materials. These estimates were confined to short periods of time essentially coincident with period of dredging and/or trenching. Long term erosion extending over the life of the project was not considered. This factor with particular emphasis on the effects of aperiodic high energy storm events and the associated wave/current field on mound stability is to be evaluated during the next phase of this investigation .

Results and Conclusions

The influence of the pipeline construction activities on the sediment transport regime active within and adjacent to the proposed route begins will the "punchout" of the horizontal directional drill in the vicinity of MP 10.9. The emergence of the drill head is to occur prior to the construction of the transition trench and as a result will serve to introduce some amount of drill mud along the adjoining bottom. Estimates provided by project engineers indicate that approximately 455 barrels of mud will be discharged. The majority of the mass discharged will be water with less than 5% consisting of bentonite clay and rock fragments. Let's ignore this fact however, and assume that contact of the total mass of drill mud with salt water will favor consolidation/flocculation and retention of the water and that no effort is to be made to mechanically disperse the mud. Allowing local currents to uniformly spread of this material to a depth of 5mm, a value approximating the depth of flow induced disturbance of the sediment water interface, would result in the coverage of a circular area approximately 444 ft in diameter. Dispersal over a larger area would necessarily reduce the deposit thickness. This area is approximately equal to the area involved in the excavation of the transition basin and the placement of the bordering berm of dredged materials. Relative to these operations the dispersal of the drill muds must be considered to represent a negligible influence within the local sediment transport regime.

Following "punchout" the transition basin will be excavated. This mechanical dredging operation as well as the subsequent dredging of the pipeline trench from MP 10.95 to MP 12 will introduce masses of sediment into the water column due to the combined effects of bucket impact with the bottom, leakage during vertical lifting and entrainment during placement. Field observations during a variety of bucket dredging operations indicate that approximately 5% of the dredge materials will be introduced into the adjoining water column. These materials will be dispersed as a function of local flows and settling velocities. Settling velocity will vary as a function of both sediment grain size characteristics and the concentrations of suspended materials. Assuming that within the shallow waters characteristic of much of the Connecticut inshore the sediments introduced by the dredge will be mixed over the entire water column, analyses which combine the flows provided by the numerical model, sediment concentrations based on the assumption of 5% loss during each bucket pass and settling velocities calculated using grain size and concentrations (Burt,1986), indicate that the plume of sediments resuspended by the dredge will for the most part spread laterally to the east and west of the trench centerline due to the dominance of east-west tending tidal currents. Wave induced currents are expected to aperiodically supplement this transport influencing particularly the fraction proceeding to the north and east. Concentrations and grain size favor relatively rapid settling resulting in approximately 80% of the materials suspended during dredging to settle within 66ft (20m) of the dredging point resulting in a primary impact zone paralleling the placed mound (Fig.15). The resulting vertical thickness of deposited materials in this area equals approximately 1.9 cm. The bulk of the remaining mass of resuspended sediments will settle within the next 300 ft (~100m) producing a cover approximately 1.2 mm in thickness in this area. Beyond this secondary impact zone any remaining entrained materials will merge with the background suspended material concentrations, which as shown by the array data (Figs 8 and 9) often exceed 100 mg/l. Given the degree of natural variability within the ambient suspended material field the presence of disbursing dredge resuspended materials beyond the secondary zone will often be difficult to impossible to define.

With the transition trench dredged reaming of the directionally drill hole will proceed to produce an internal diameter of approximately 36in. During the reaming process drill muds will enter the transition basin where they will be recaptured and, to the extent possible, recycled. All reaming muds are to be contained and none will be available for dispersion.

Following reaming, the pipe laying operation will begin with a portion of pipe laid along the seabed to the south of the exit hole. This pipe will be pulled into the drilled hole. During this pullback phase approximately 5000 barrels of drill mud will be introduced into the transition basin. Again , the bulk of this material will be water with small fractions of bentonite clay. In total it's volume equals approximately 1000 yds^3. Since this volume is substantially less than the capacity of the transition trench the released muds will tend to collect in the deep adjoining the exit hole and be effectively sheltered from the ambient flow field. As a result despite the release no far field dispersion of these materials will occur. It is expected that these materials will be mixed with fill materials during closure of the transition basin and adjoining pipeline trench.

Proceeding south and across the Sound beyond MP 12 pipeline lowering is to be accomplished by either mechanical plowing or hydraulic jet excavation. Given the absence of mechanical or hydraulic processes sufficient to induce resuspension and/or entrainment the dispersion of displaced sediments caused by passage of the mechanical plow should be minimal to non-existent. The primary impact zone for this method therefore is confined to the immediate vicinity of the trench (Fig.16). Some far-field dispersion is to be expected due to tidal current induced erosion of the sediment mounds bordering the trench. The amounts of material associated with this dispersion is to be calculated using the full sediment transport model currently under development. Initial estimates using field observations of erosion of sediments placed on the nearby Central Long Island Sound Dredged Material Disposal Area indicate that this transport will remain small with effects confined to the immediate vicinity of the trench.

The use of the mechanical plow will result in a number of discrete scars along a bordering corridor caused by the progressive repositioning of the array of anchors. Given the relatively fine grained nature of the sediments along this corridor (Table 1) and their cohesiveness the transport of materials resuspended during repositioning will be small and confined to the immediate vicinity of the anchor point. It is expected that a significant fraction of the sediment load displaced by the emerging anchor will fall from the anchor as a coherent mass settling on or in the anchor hole. Much of the remainder will adhere to the anchor. Little if any of this material will be washed to form a significant concentration of suspended materials prior to replacement of the anchor. Given these characteristics, anchor handling operations cannot be expected to result in measureable sediment dispersion beyond the immediate vicinity of the anchoring sites.

In contrast to the mechanical plow, the hydraulic jet plow will tend to produce an evident suspended material plume injecting a high concentration of materials upwards to a level of approximately 30ft above ambient bottom. The injected mass will disperse under the combined effects of horizontal flows and gravitational settling resulting in a coherent plume extending downstream from the centerline of the trench over distances in excess 3000 ft (1000m). Given the concentrations of sediments produced by the eductors approximately 90% of the introduced materials will settle within 100ft (30m) of the injection points, to the east and west of the trench (Fig.17). Uniform distribution of this settling mass over this area would result in a layer of sediment approximately 3.8in in thickness. Much of the remaining mass would settle in the secondary zone extending east-west under the influence of the ambient tidal currents, for an additional 300ft (~100m) with a smaller, fine grained fraction perturbing the local suspended material field over an additional 3000ft (~1000m) beyond the secondary zone (Fig.17). The concentrations within the tertiary impact zone would be small but measureable due to the relatively low ambient suspended material concentrations found in this area of Central Long Island Sound (Bohlen, Islander East Data in Analysis).

Beyond MP 32.15 plow operations would be replaced by mechanical dredging. The relatively coarse grained sandy composition of the sediments in this area favors rapid settling of materials resuspended by the clamshell bucket. Analyses of the currents in this area in combination with the settling velocities of the ambient sands indicates minimal dispersion with effects confined to the immediate vicinity of the trench (Fig.18). The mound of placed sediments is however, subject to continuing erosion and transport under the combined effects of tidal currents and wind wave induced velocities. This latter factor becomes of increasing importance on approach to the shoreline and as noted above will require close coordination between the dredge and the pipeline lay barge to affect efficient pipe placement. A quantitative measure of the erosion and displacement of the dredged material mound will be provided following completion of the numerical sediment transport model.

Summary

Analyses using a combination of numerical modeling, analytical computation and direct field observations indicates that majority of sediments resuspended by the proposed installation of the Islander East natural gas pipeline across Long Island Sound will settle rapidly impacting a discrete area within the immediate vicinity of the trench. Within the Connecticut nearshore the limits of this impact zone will be confined to an area extending to the east and west of the trench for distances of approximately 360 ft. Farfield dispersion beyond this area will merge with background concentrations of suspended materials and result in negligible alterations of the mass of sediments transported in this area.

For the offshore region beyond MP 12 the impact zone will be confined to the immediate vicinity of the trench and some ancilliary scars remaining from anchoring operations if mechanical plowing is used to lower the pipeline. The use of hydraulic plowing will substantially increase the dimensions of the impact zone affecting an area extending over distances in excess of 3400ft to the east and west of the trench.

Within the New York nearshore, the coarse grained nature of the sediments favors rapid settlement of resuspended materials. This in combination with the use of mechanical dredging techniques will serve to minimize dispersion and confine resuspension effects to the immediate vicinity of the trench.

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TABLE I
LABORATORY SOIL TEST RESULTS
NATURAL GAS PIPELINE CROSSING
LONG ISLAND SOUND
BRANFORD , CONNECTICUT TO WADING RIVER, NEW YORK

CORE NO.	DESCRIPTION	USCS	DEPTH (FT)	SAMPLE NO.	NAT. WATER CONTENT (%)	ATTERBERG LIMITS (%) LL	PL	PI	SHEAR VANE (PSF) UND(REM)	RESISTIVITY (OHM-CM) (SEE NOTE 1)	pH	AVG. TOTAL UNIT WEIGHT (PCF)	AVG. DRY UNIT WEIGHT (PCF)	ANGLE OF INTERNAL FRICTION (φ, DEG.)	AVG. WATER CONTENT (%)
10aA	Gray lean CLAY to elastic SILT	CL	0.0-1.0	C01	59.9	44.0	25.9	18.1	40(0)	72	7.3	94.9	53.4		77.7
11*		to	1.0-4.0	C02	76.0	58.7	34.2	24.5	80(20)						
		MH	4.0-4.5	S01	79.6	51.7	32.6	19.1	80(20)						
10bA	Black to gray ORG. SILT/CLAY to elastic SILT	OH	0.0-1.0	C01	122.7	76.0	37.2	38.8	40(0)	69	7.6	89.6	45.9		95.2
12		to	1.0-4.0	C02	113.1	70.3	32.0	38.3	60(20)						
		MH	4.0-4.6	S01	77.5	64.4	36.9	27.5	100(40)						
10cA	Dark gray to gray fat CLAY to elastic SILT	CH	0.0-1.0	C01	76.8	62.2	28.0	34.2	80(20)	70	7.5	94.7	52.3		81.1
13		to	1.0-4.0	C02	78.7	67.2	35.3	31.9	100(20)						
		MH	4.0-5.0	S01	83.6	59.6	32.9	26.7	100(40)						
10dA	Black to gray elastic SILT	MH	0.0-1.0	C01	74.7	63.3	32.7	30.6	40(0)	65	7.1	90.8	46.0		97.4
14			1.0-4.0	C02	98.6	66.4	36.7	29.7	60(20)						
			4.0-5.0	S01	96.5	60.0	32.0	28.0	80(40)						
10eA	Dark gray elastic SILT to fat CLAY	MH	0.0-1.0	C01	68.3	59.2	30.7	28.5	40(20)	69	7.5	94.1	51.7		82.0
15		to	1.0-4.0	C02	86.6	64.5	30.4	34.1	40(20)						
		CH	4.0-4.9	S01	77.5	52.4	28.9	23.5	90(20)						
10fA	Dark gray fat CLAY to elastic SILT	CH	0.0-1.0	C01	87.0	62.6	28.8	33.8	60(20)	71	7.5	93.5	49.3		89.7
16		to	1.0-4.0	C02	97.5	70.3	32.4	37.9	60(20)						
		MH	4.0-4.8	S01	82.0	57.6	31.4	26.2	100(20)						
10gA	Dark gray fat CLAY to elastic SILT	CH	0.0-1.0	C01	106.4	67.2	30.5	36.7	40(0)	67	7.1	94.9	41.2		130.3
17		to	1.0-4.0	C02	74.7	64.7	30.2	34.5	100(40)						
		MH	4.2-5.0	S01	185.6	53.7	30.5	23.2	100(40)						
10hA	Dark gray fat CLAY to elastic SILT	CH	0.0-1.0	C01	79.7	65.2	33.9	31.3	40(20)	72	7.1	99.1	57.7		71.8
18		to	1.0-4.0	C02	56.0	52.0	27.9	24.1	100(40)						
		MH	4.0-5.0	S01	83.4	47.9	28.7	19.2	120(40)						
10iA	Black to gray to olive brown fat CLAY to SILT	CH	0.0-1.0	C01	82.6	59.8	30.2	29.6	120(40)	76	7.1	98.8	57.5		71.8
19		to	1.0-4.0	C02	83.9	46.5	27.5	19.0	100(40)						
		ML	3.8-4.3	S01	59.4	50.3	27.7	22.6	120(40)						
10jA	Black to gray fat to lean CLAY to SILT	CH/CL	0.0-1.0	C01	71.3	54.4	27.4	27.0	120(40)	85	6.9	99.2	59.3		67.3
20		to	1.0-4.0	C02	70.3	44.3	24.2	19.9	120(40)	(SEE NOTE 2)					
		ML	4.0-4.9	S01	64.3	41.3	26.5	14.8	120(40)						

* Designates Approximate MilePost MP Locations

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TABLE I (CONTINUED)

CORE NO.	DESCRIPTION	USCS	DEPTH (FT)	SAMPLE NO.	NAT. WATER CONTENT (%)	ATERBERG LIMITS (%) LL	PL	PI	SHEAR VANE (PSF) UND(REM)	RESISTIVITY (OHM-CM)	pH	AVG. TOTAL UNIT WEIGHT (PCF)	AVG. DRY UNIT WEIGHT (PCF)	ANGLE OF INTERNAL FRICTION (ϕ, DEG.)	AVG. WATER CONTENT (%)
10kA 21*	Dark gray to black fat to lean CLAY to SILT	CH/CL to ML	0.0-1.0 1.0-4.0 4.0-4.8	C01 C02 S01	87.4 68.4 63.9	64.8 48.0 47.9	29.6 26.7 28.1	35.2 21.3 19.8	0(0) 80(40) 120(40)	75	6.9	99.7	60.0		66.2
10lA 22	Dark gray to black fat to lean CLAY to SILT	CH/CL to ML	0.0-1.0 1.0-4.0 3.8-4.3	C01 C02	84.6 67.0 59.7	61.8 41.1	28.4 25.5	33.4 15.6	180(40) 120(40) 180(60)	75	7.0	99.2	60.7		63.4
10mC 23	Dark gray to black fat to lean CLAY	CH to CL	0.0-1.0 1.0-4.0 4.0-4.6	C01 C02 S01	100.0 69.6 72.8	73.2 55.4 44.8	31.7 25.5 25.3	41.5 29.9 19.5	80(40) 80(40) 140(60)	80	6.9	96.2	56.2		71.2
10nA 24	Dark gray to gray ORGANIC CLAY to fat to lean CLAY	OH to CH/CL	0.0-1.0 1.0-4.0 4.1-5.0	C01 C02 S01	97.5 81.2 74.5	73.4 55.7 49.2	34.5 27.0 27.1	38.9 28.7 22.1	120(40) 40(0) 80(20)	67	6.9	96.5	54.2		78.0
10oB 25	Dark gray to black ORGANIC SILT to fat CLAY	OH to CH	0.0-1.0 1.0-4.0 4.0-4.5	C01 C02 S01	107.5 93.8 84.3	87.9 73.5 55.9	39.0 30.9 28.2	48.9 42.6 27.7	100(40) 80(20) 80(20)	58	7.0	91.8	48.6		88.9
10pB 26	Dark gray to black ORGANIC CLAY to elastic SILT	OH to MH	0.0-1.0 1.0-4.0 4.0-5.0	C01 C02 S01	113.4 95.6 102.5	86.2 70.9 61.8	35.8 32.5 32.3	50.4 38.4 29.5	120(40) 40(0) 80(20)	66	7.0	92.1	46.3		98.9
10qA 27	Dark gray to black ORGANIC CLAY to elastic SILT	OH to MH	0.0-1.0 1.0-4.0 3.8-4.4	C01 C02 S01	123.6 101.8 98.4	97.9 75.1 70.7	40.7 33.1 34.7	57.2 42.0 36.0	60(0) 40(0) 80(20)	63	7.1	89.8	44.8		100.4
10rB 28	Dark gray to black ORGANIC SILT to fat CLAY	OH to CH	0.0-1.0 1.0-4.0 3.8-4.4	C01 C02 S01	93.2 70.3 76.7	73.4 70.1 50.1	39.0 28.5 25.1	34.4 41.6 25.0	40(0) 40(0) 80(20)	73	6.8	98.7	56.9		73.5
10sA 29	Dark gray to black ORGANIC SILT to elastic SILT	OH to MH	0.0-1.0 1.0-4.0 3.8-4.3	C01 C02 S01	132.4 130.4 108.2	116.7 84.2 74.0	48.1 40.8 37.7	68.6 43.4 36.3	40(0) 20(0) 80(20)	63	7.0	87.6	39.9		119.5
10tA 30	Dark gray ORGANIC CLAY	OH	0.0-1.0 1.0-4.0 4.1-5.0	C01 C02 S01	132.3 124.9 113.6	111.8 101.7 87.8	42.7 41.5 34.0	69.1 60.2 53.8	40(0) 80(20) 120(40)	72	7.0	86.6	39.5		119.2

* Designates Approximate MilePost MP Location

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TABLE I (CONTUNUED)

CORE NO.	DESCRIPTION	USCS	DEPTH (FT)	SAMPLE NO.	NAT. WATER CONTENT (%)	ATTERBERG LIMITS (%) LL	PL	PI	SHEAR VANE (PSF) UND(REM)	RESISTIVITY (OHM-CM)	pH	AVG. TOTAL UNIT WEIGHT (PCF)	AVG. DRY UNIT WEIGHT (PCF)	ANGLE OF INTERNAL FRICTION (ϕ, DEG.)	AVG. WATER CONTENT (%)
10uC 31 *	Dark gray to black ORG. CLAY to ORG. SILT	OH	0.0-1.0	C01	172.9	97.7	40.5	57.2	20(0)	58	6.9	84.5	33.5		152.2
			1.0-4.0	C02	155.9	88.7	37.8	50.9	20(0)						
			4.0-5.0	S01	148.4	93.1	41.4	51.7	40(0)						
10vA 32	Light gray poorly-graded SAND	SP	0.0-1.0	C01	19.2	–	NP	NP	–	283-304 (SEE NOTE 3)	5.6	131.7	111.6	39.5	18.0
			1.0-4.0	C02	18.4	–	NP	NP	–						
			4.0-4.9	S01	17.4	–	NP	NP	–						
10wA 32.9	Light gray poorly-graded SAND	SP	0.0-1.0	C01	3.4	–	NP	NP	–	416-292 (SEE NOTE 4)	4.1	116.8	106.8	34.0	9.4
			1.0-4.0	C02	4.0	–	NP	NP	–						
			4.0-4.9	S01	14.6	–	NP	NP	–						
12aA	Dark gray to black ORGANIC CLAY to elastic SILT	OH to MH	0.0-1.0		106.4				80(20)	78	7.1	94.3	52.5		79.6
			1.0-4.0		79.0				100(40)						
			4.0-4.5	S01	80.0	53.4	29.2	24.2	80(20)						
12bA	Dark gray to black ORG. CLAY to ORG. SILT	OH	0.0-1.0		171.7				0(0)	58	7.3	87.0	41.3		110.7
			1.0-4.0		124.9				60(0)						
			4.0-4.5	S01	96.7	69.1	34.1	35.0	40(0)						
12c	Dark gray to black ORGANIC CLAY to fat CLAY	OH to CH	0.0-1.0		86.1				40(0)	63	6.9	91.5	43.8		108.9
			1.0-4.0		103.5				60(20)						
			4.0-4.5	S01	114.6	59.8	30.4	29.4	60(20)						
12d	Dark gray to gray ORGANIC CLAY	OH	0.0-1.0		166.3				20(0)	58	7.0	84.0	37.8		122.2
			1.0-4.0		125.0				80(20)						
			4.0-4.5	S01	119.9	85.6	35.3	50.3	60(20)						
12e	Light gray poorly-graded SAND	SP	0.0-1.0		2.3	–	NP	NP	–	107,721-18,440 (SEE NOTE 5)	5.8	124.2	109.1	36.0	13.8
			1.0-4.0		12.1										
			4.0-5.0	S01	15.8										

NOTES: * Designates Approximate MilePost MP Location

1. Soil saturated as received; the as-tested and saturated resistivity values are the same.
2. Resistivity at as-test water content (55.0%) = 85; resistivity at saturated water content (66.4%) = 84.
3. Resistivity at as-test water content (16.4%) = 283; resistivity at saturated water content (29.8%) = 304.
4. Resistivity at as-test water content (11.6%) = 416; resistivity at saturated water content (23.7%) = 292.
5. Resistivity at as-test water content (3.1%) = 107,721; resistivity at saturated water content (28.1%) = 18,440.

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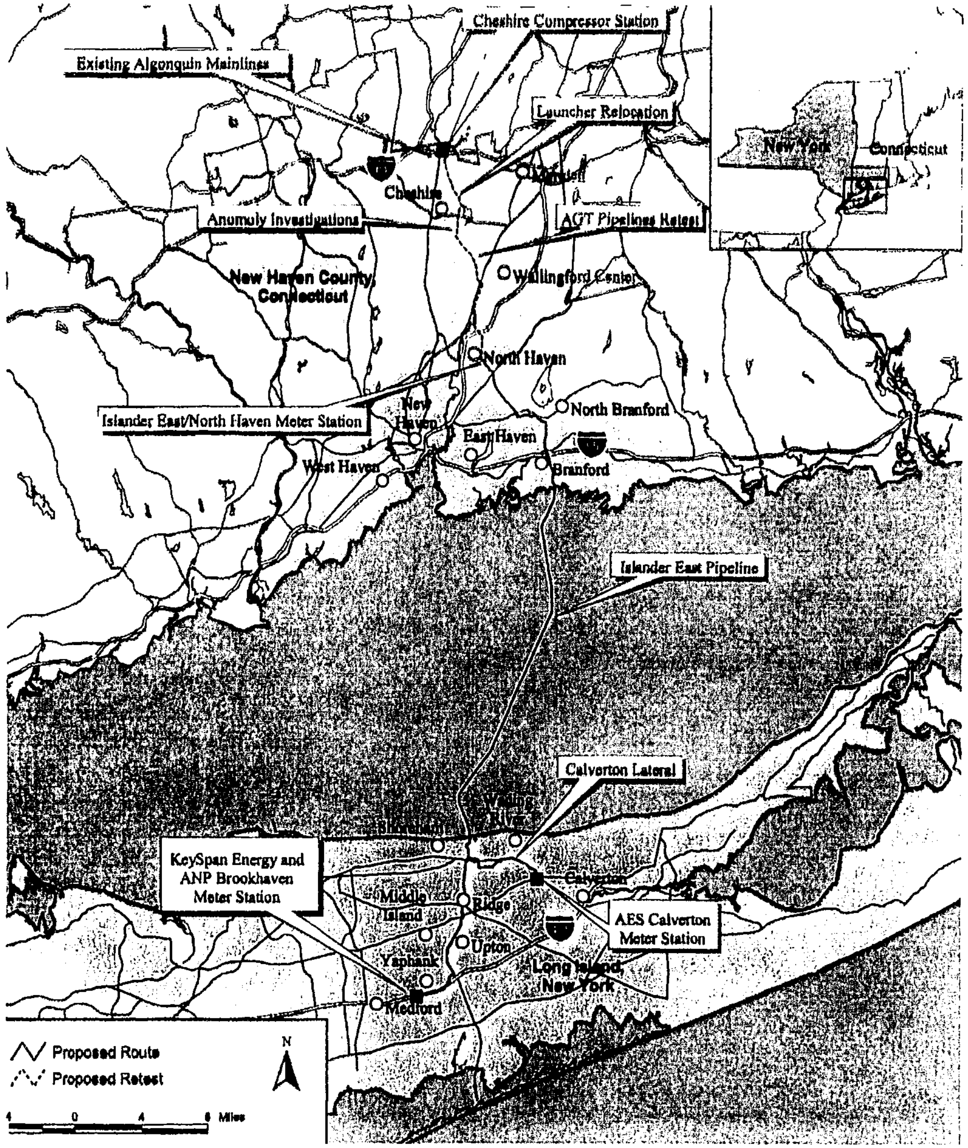


Figure 1. Project location.

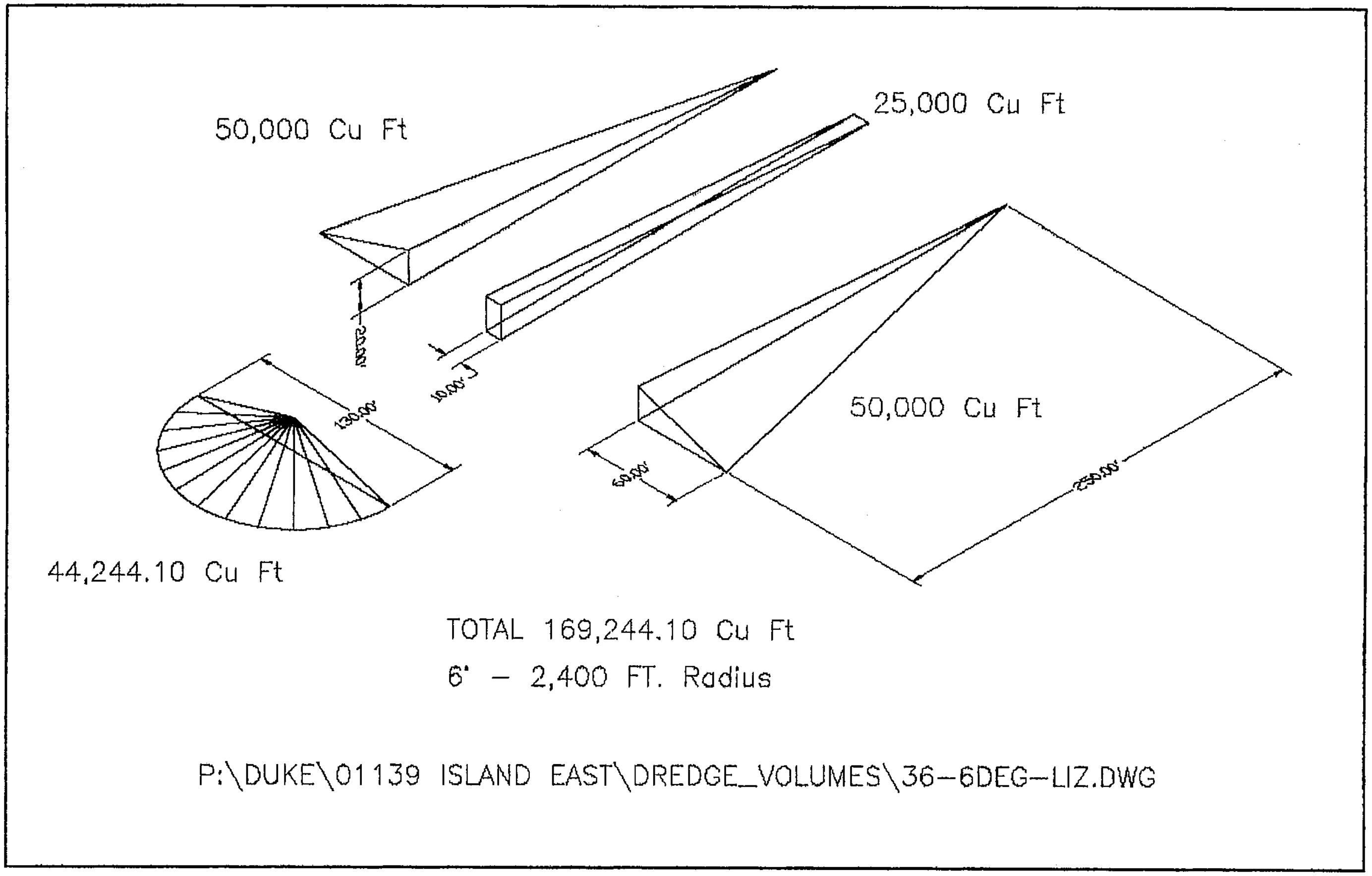


Figure 2. HDD transition basin.

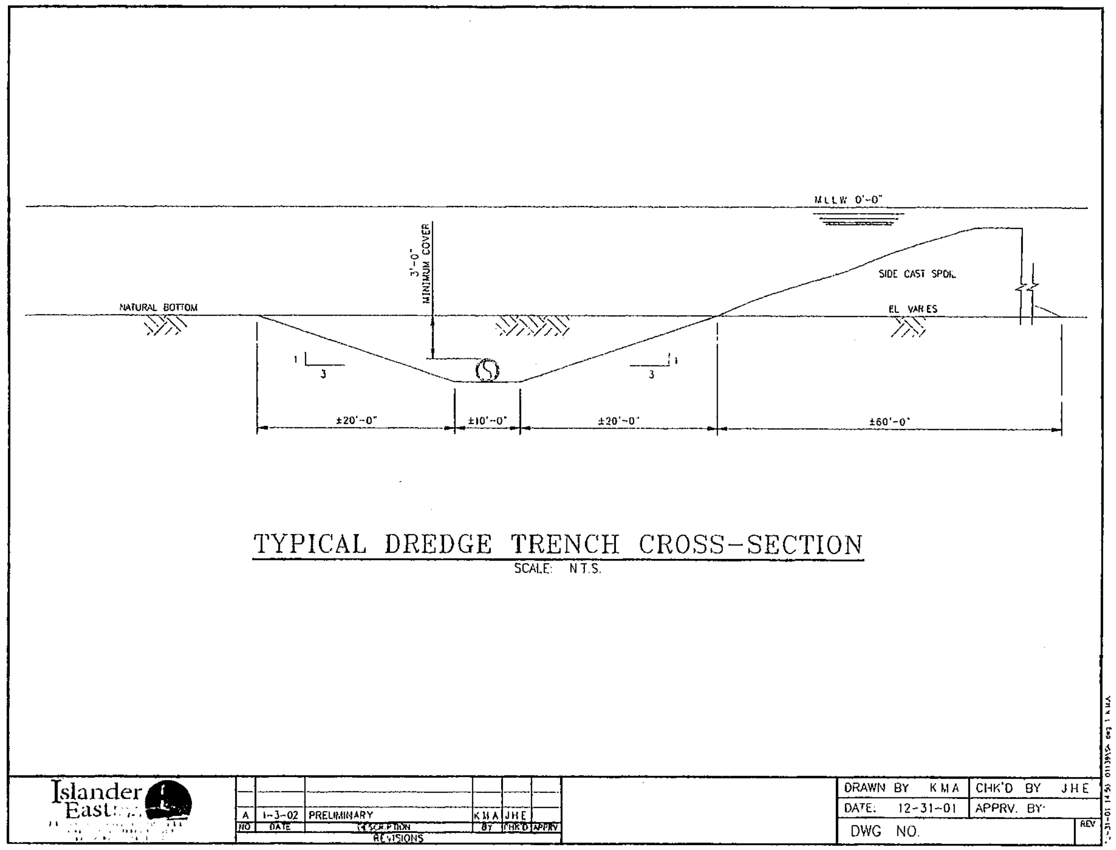


Figure 3. Dredged trench configuration.

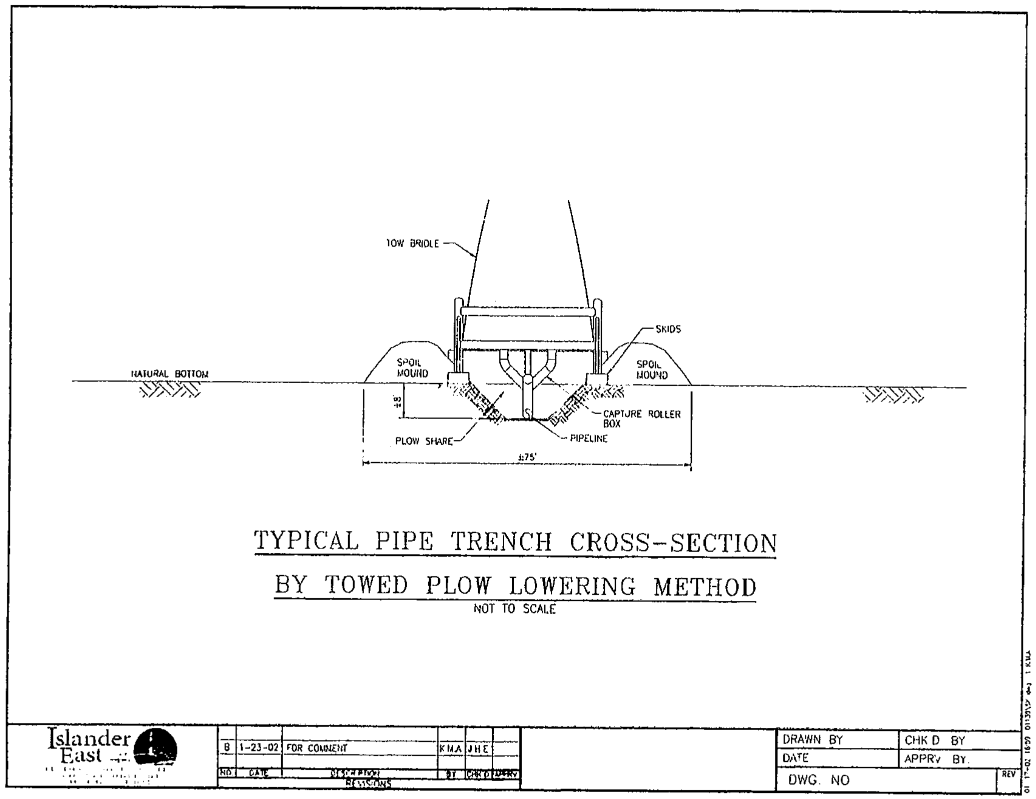


Figure 4. Plowed trench configuration.

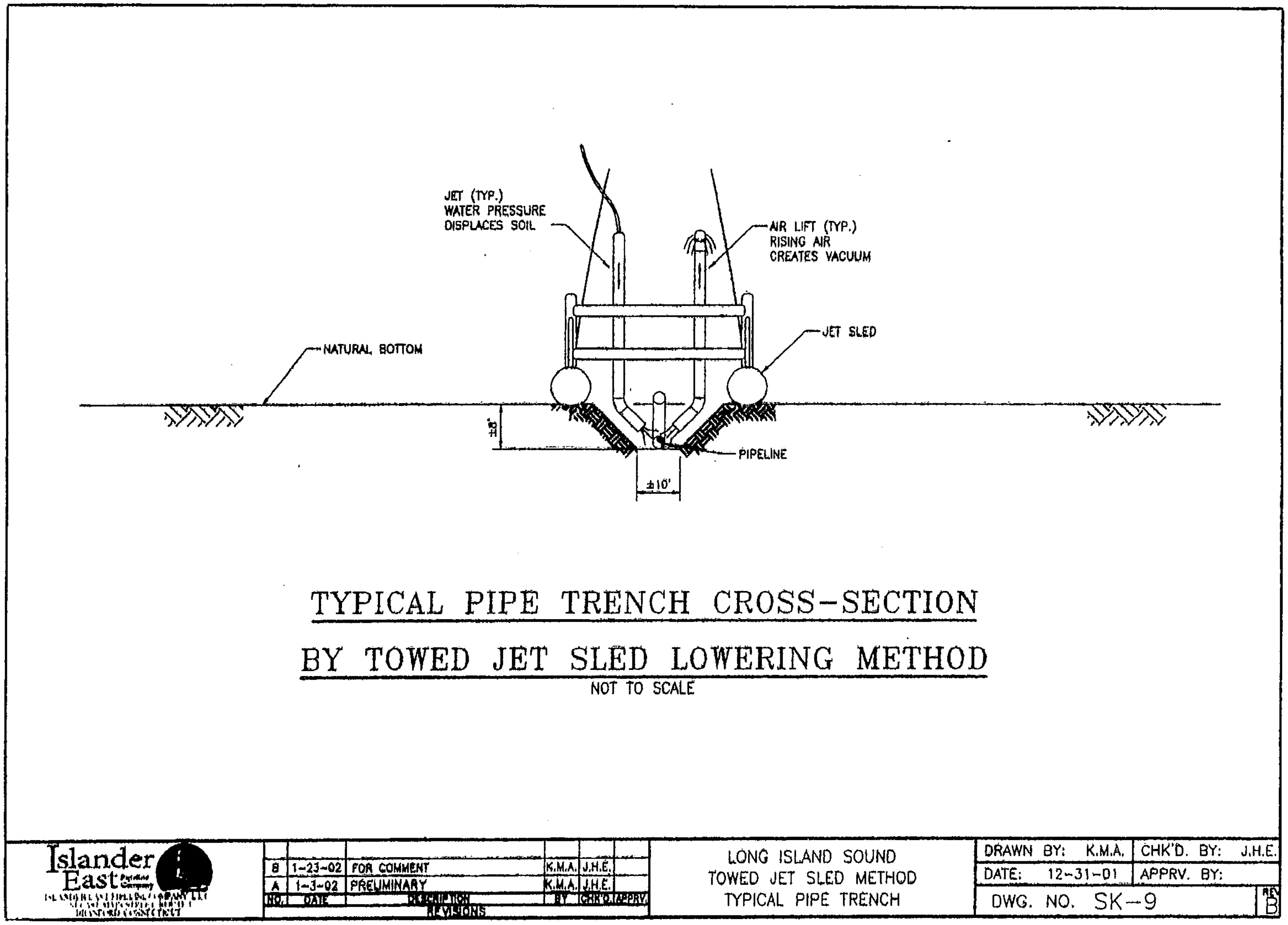


Figure 5. Jet plow and trench.

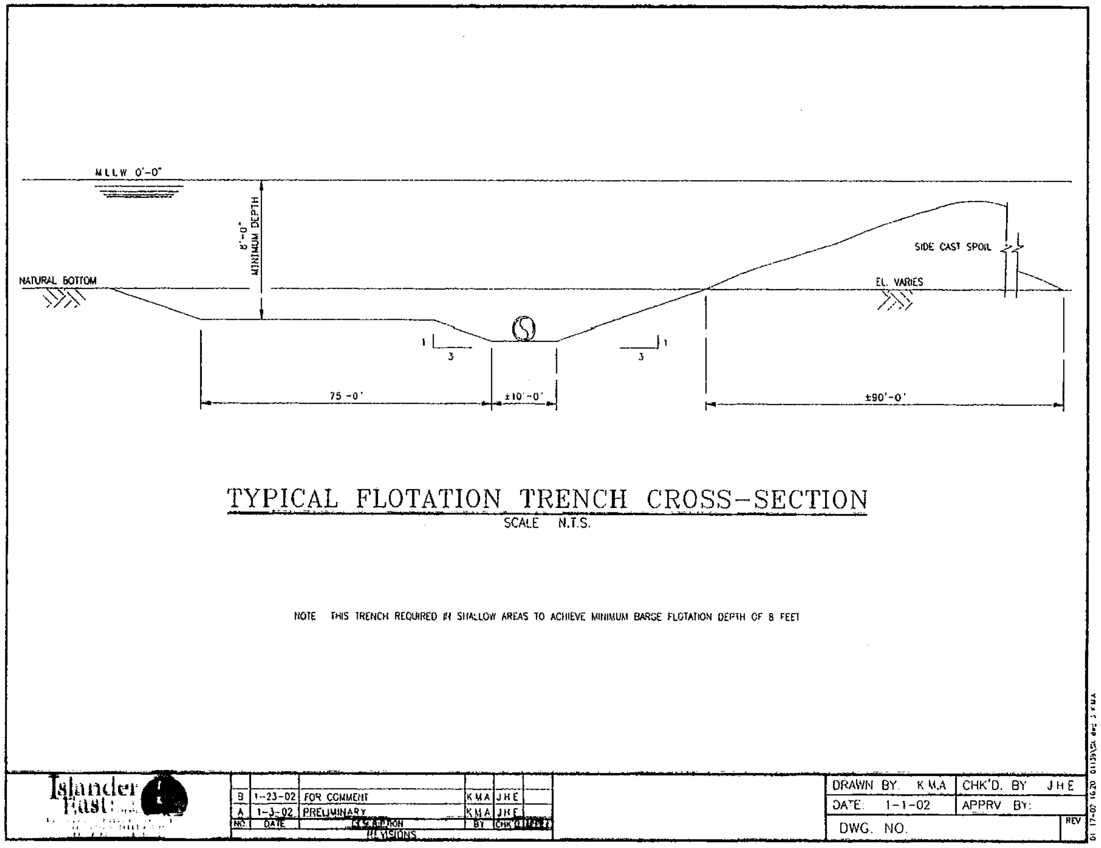


Figure 6. Floatation trench.

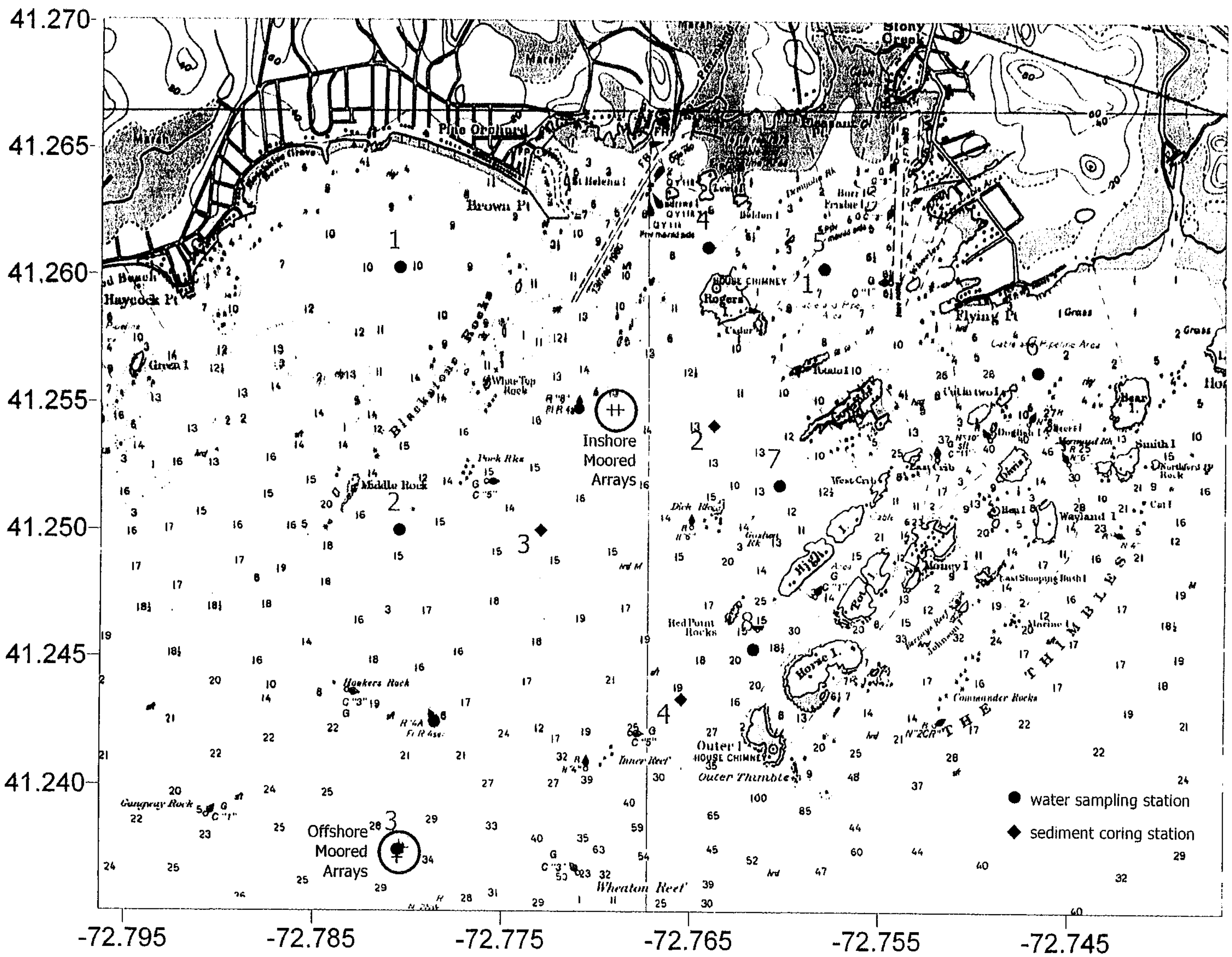


Figure 7. Location of moored arrays, water sampling and sediment coring stations.

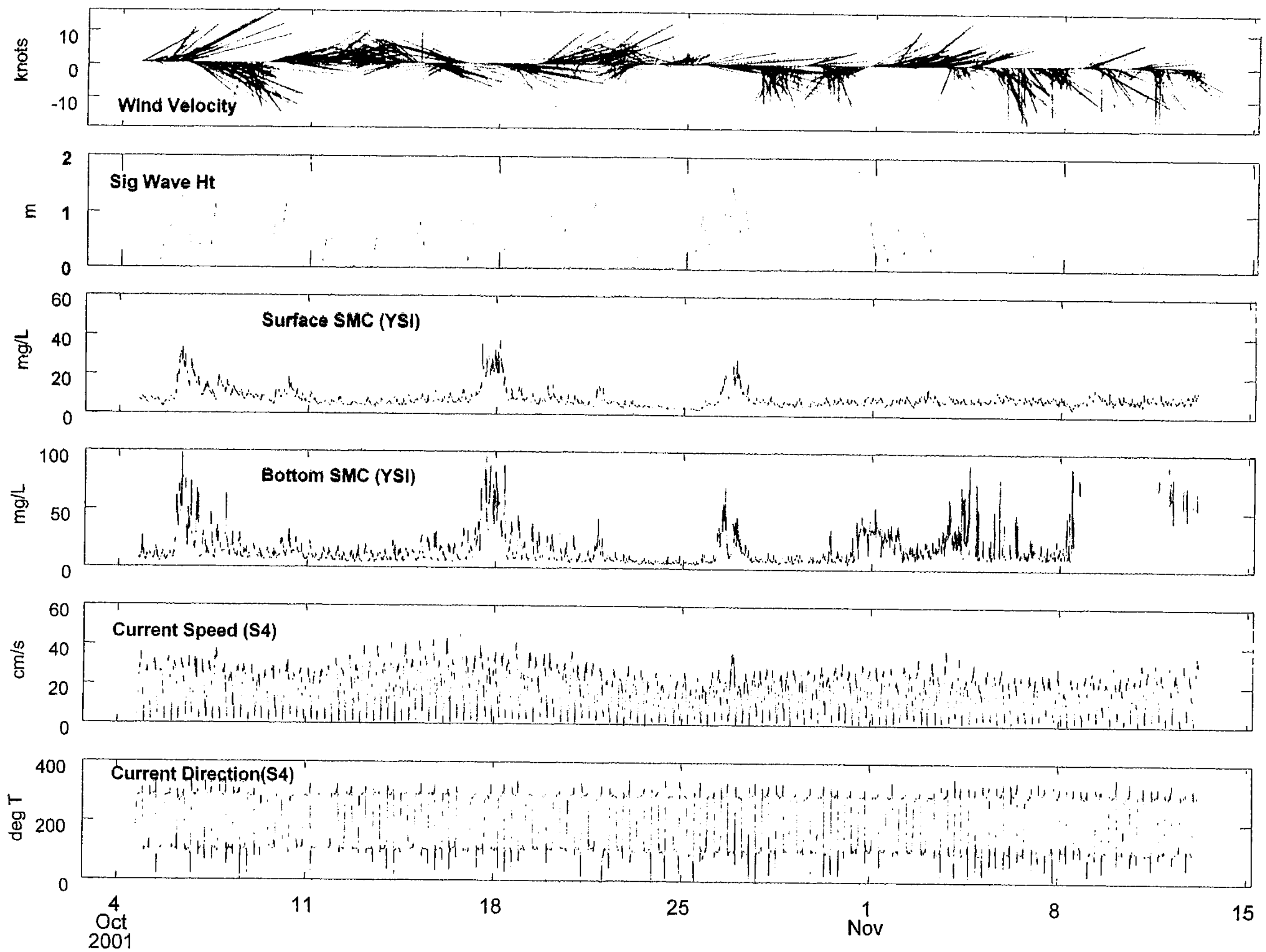


Figure 8. Representative time series data from the Branford offshore station.

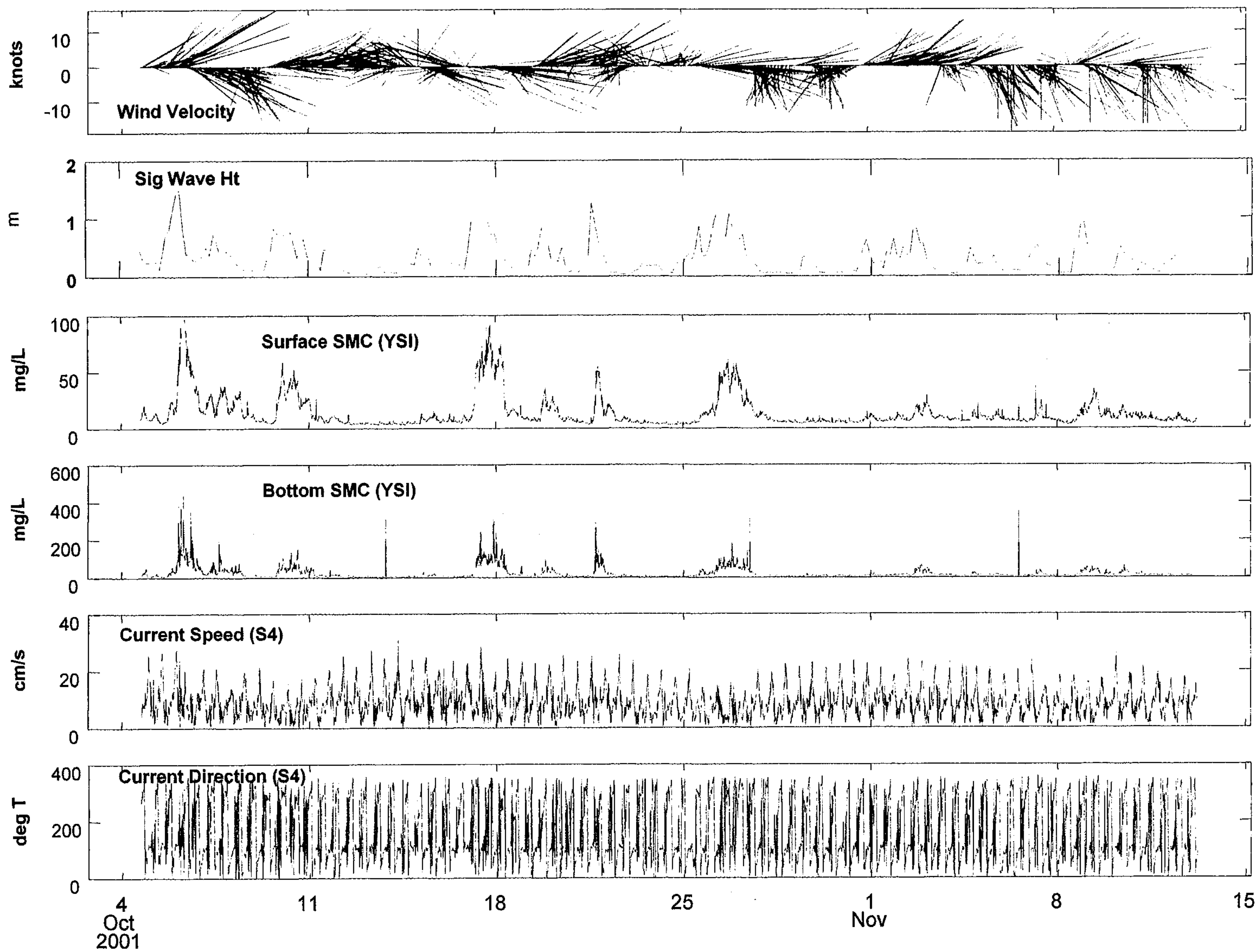


Figure 9. Representative time series data from the Branford inshore station.

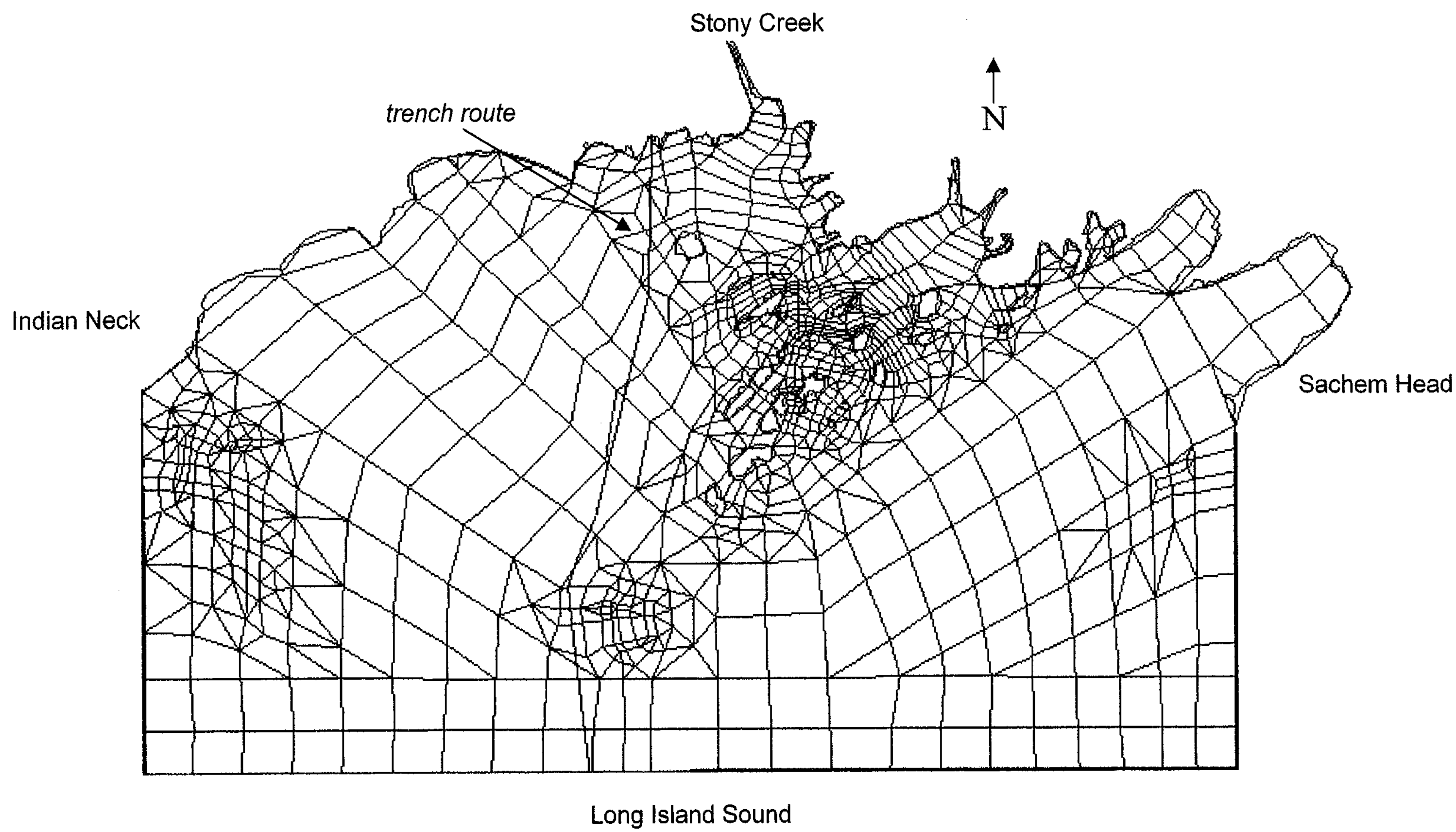


Figure 10. Inshore model domain and network schematization.

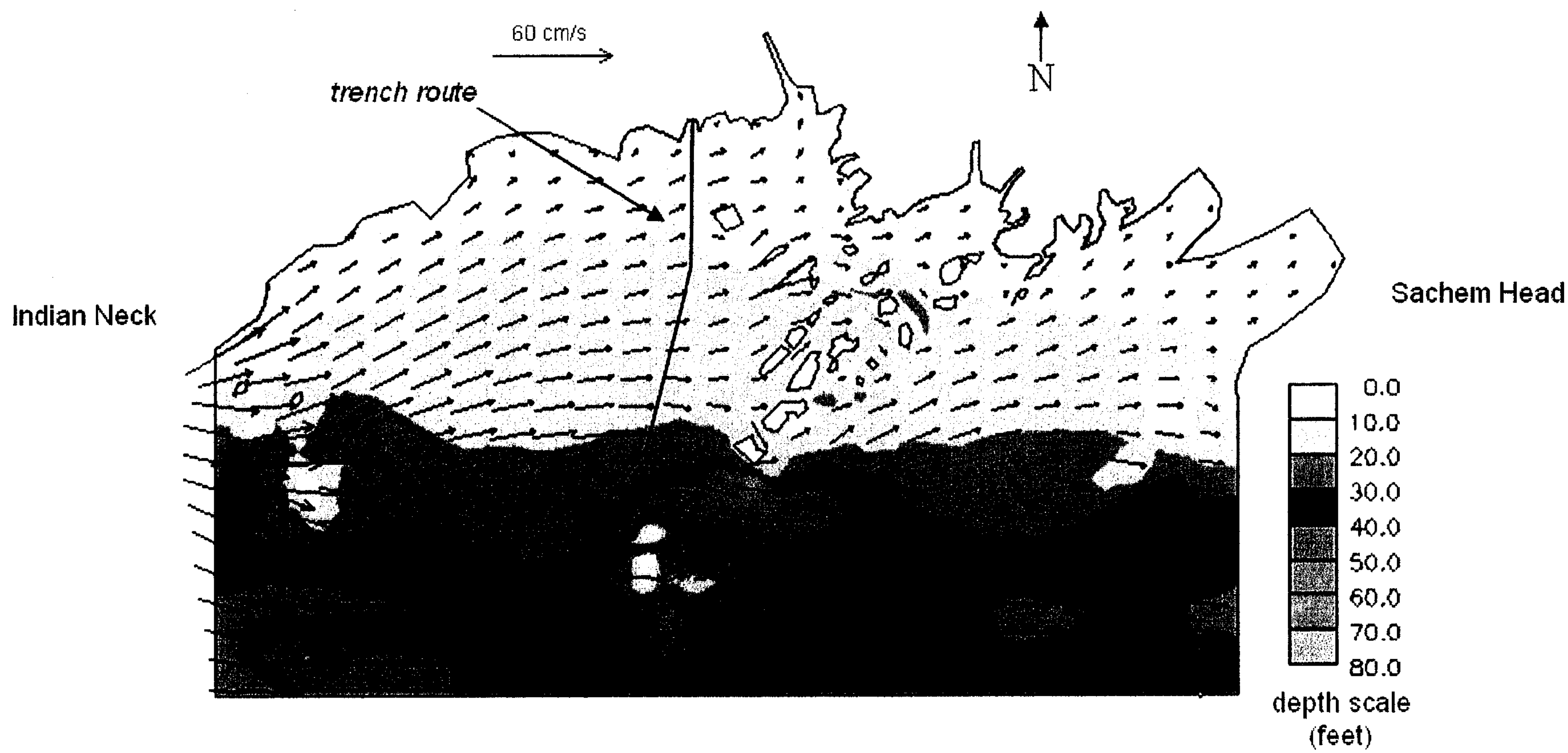


Figure 11. Representative modeled inshore currents, ebb tide - hour 6, year day 61.

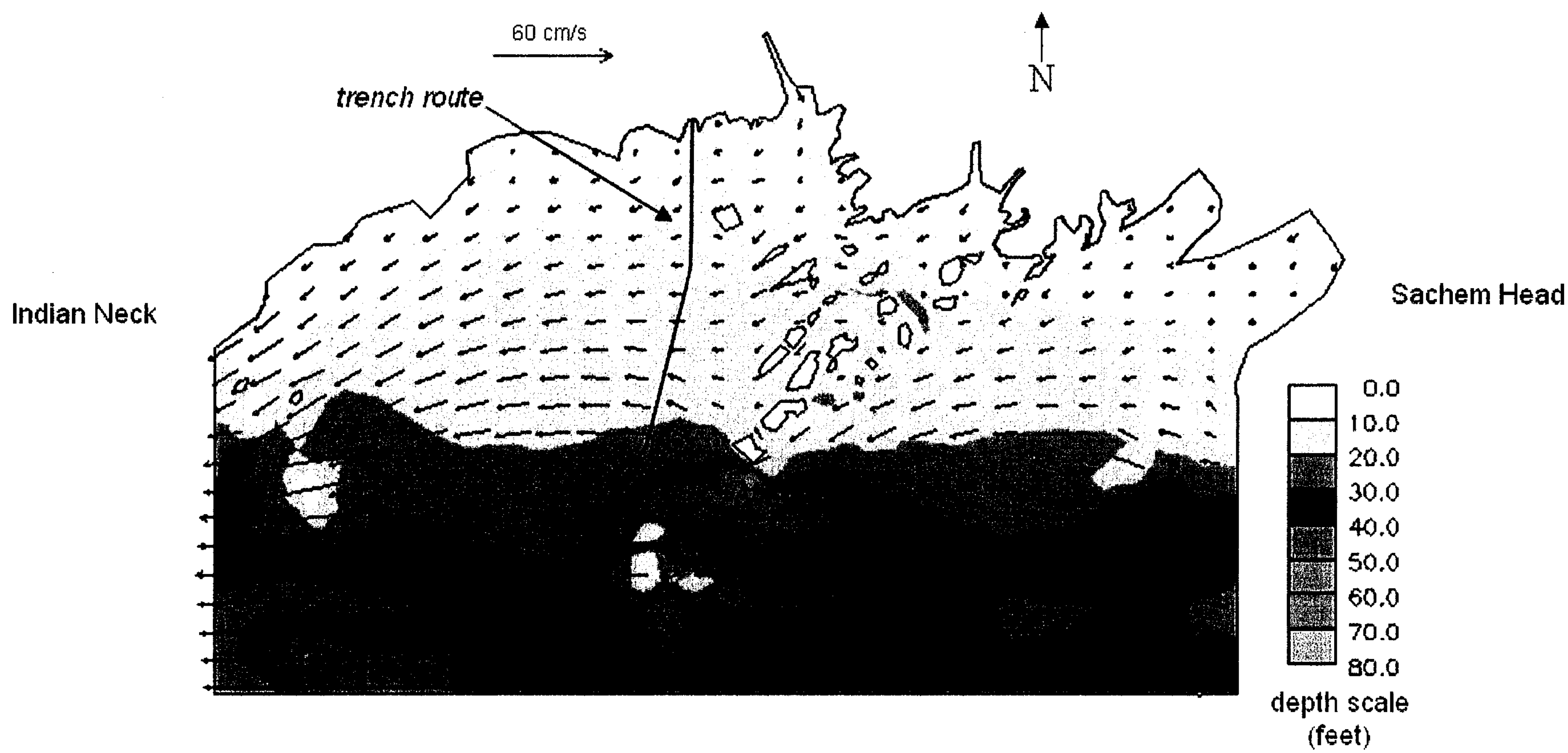


Figure 12. Representative modeled inshore currents, flood tide - hour 0, year day 61.

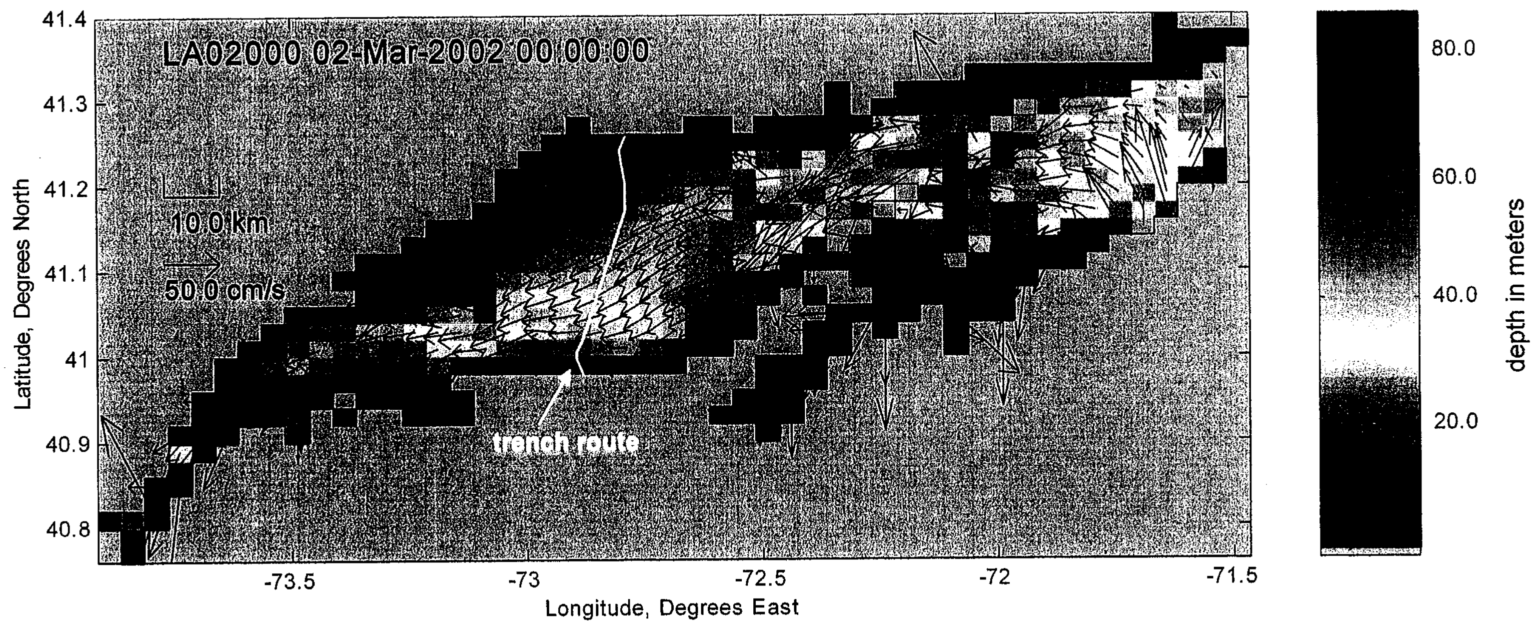


Figure 13. Representative LISTide modeled offshore currents, flood tide - hour 0, year day 61.

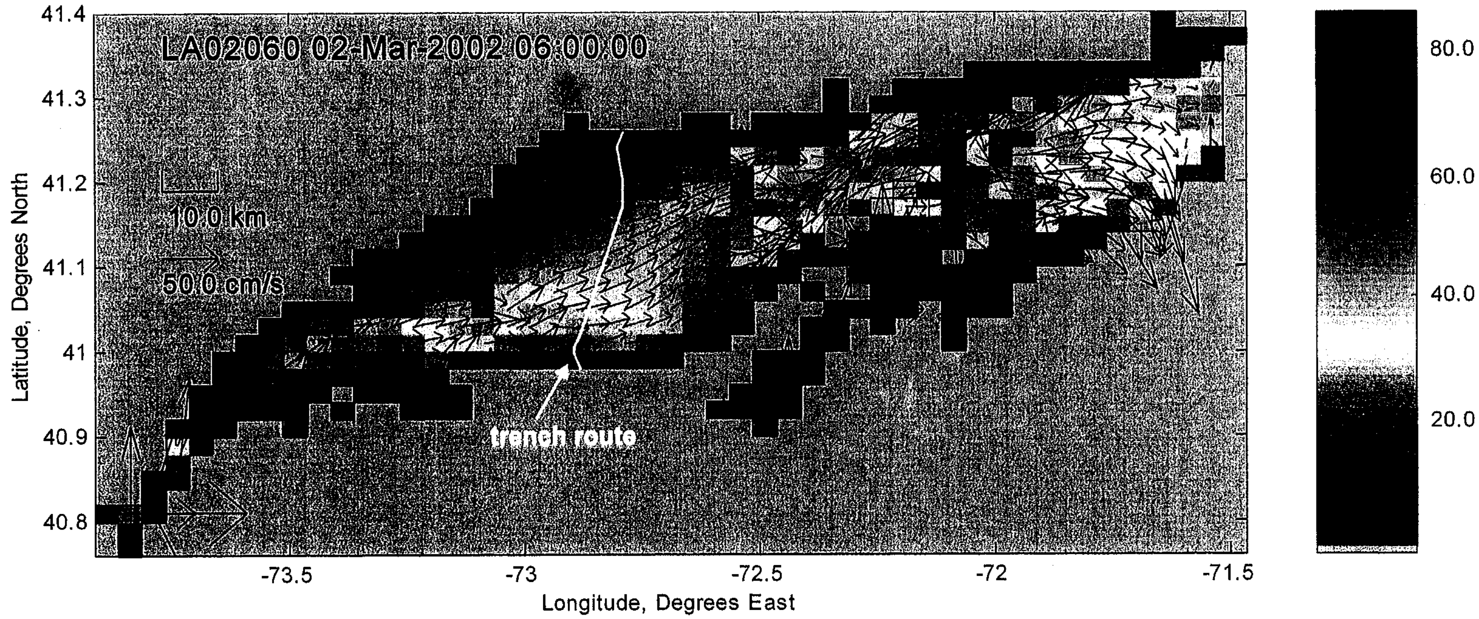
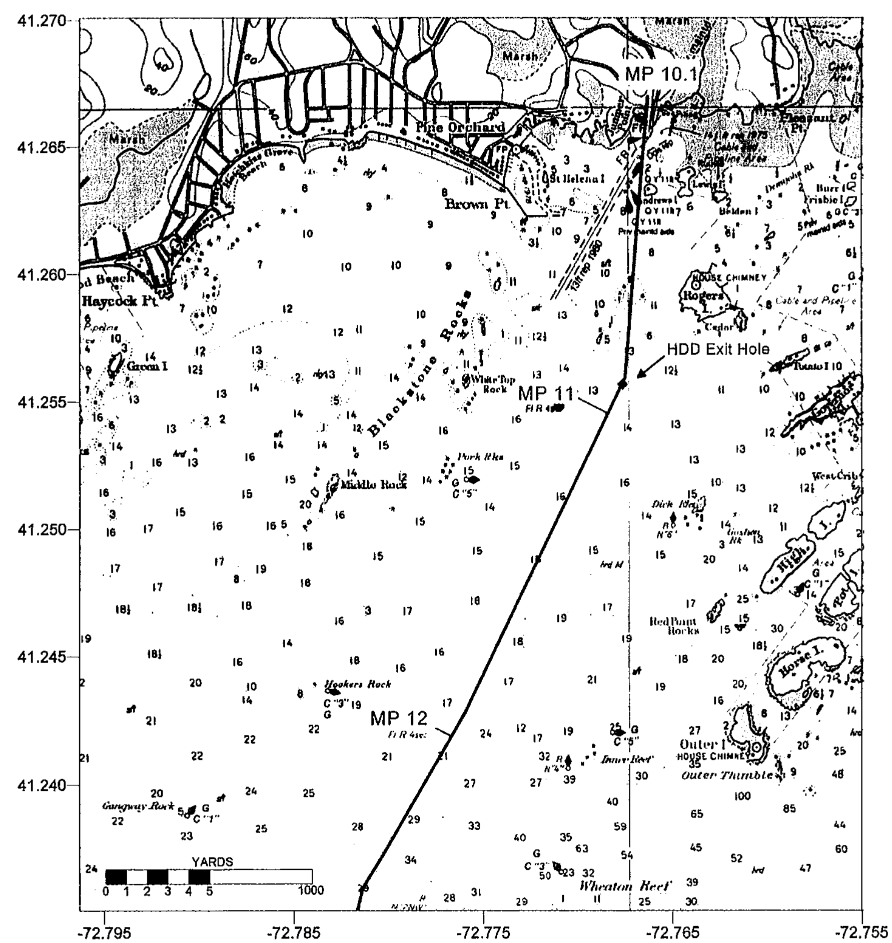


Figure 14. Representative LISTide modeled inshore currents, flood tide - hour 6, year day 61.



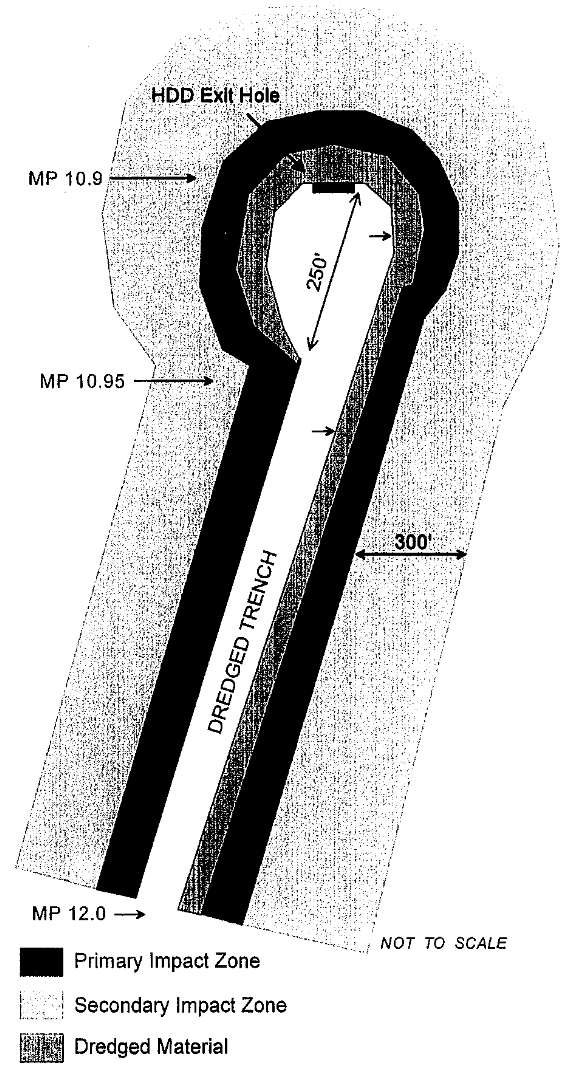


Figure 15. Sediment dispersion patterns, Branford inshore.

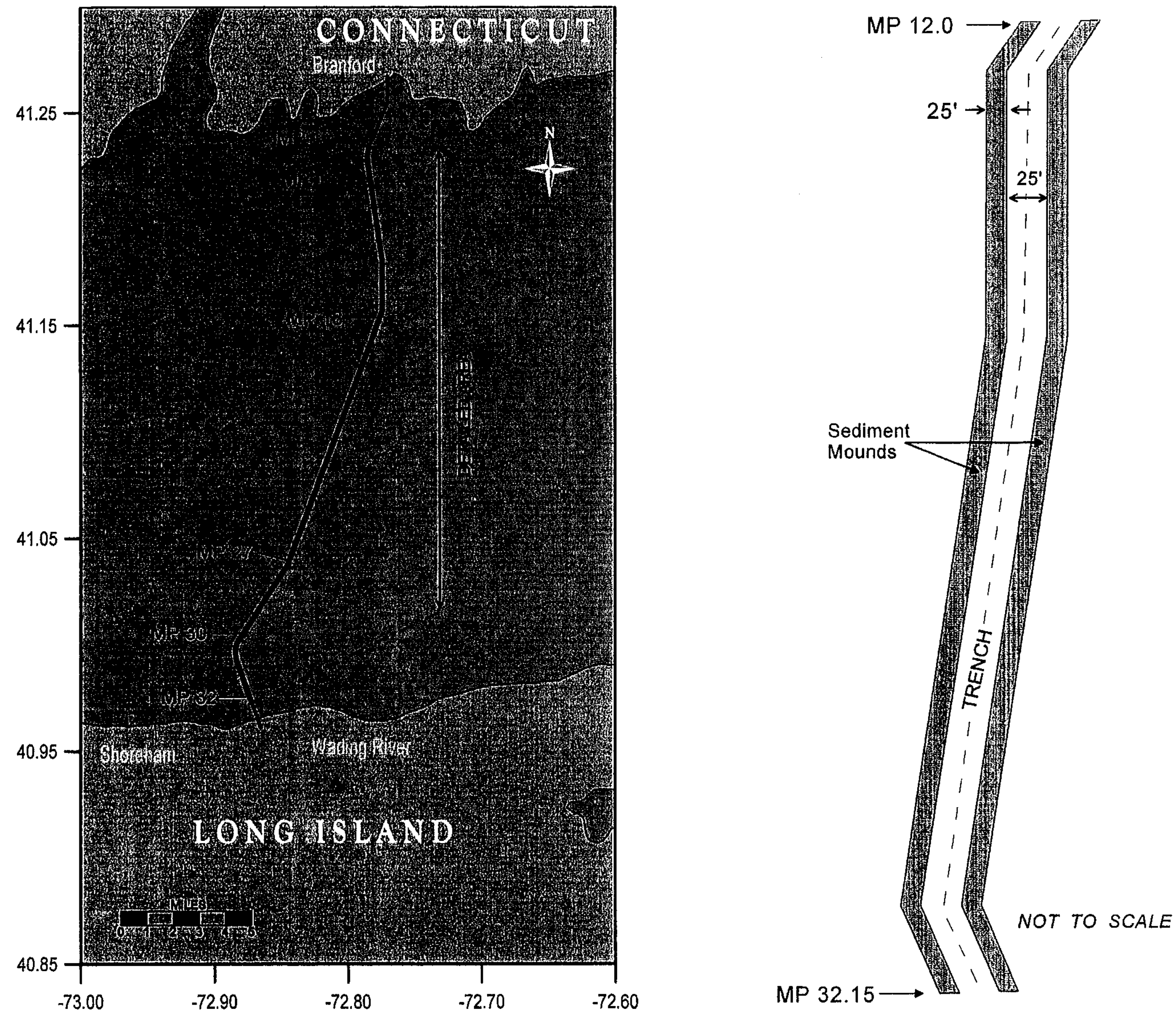


Figure 16. Sediment dispersion patterns, mechanical plow.

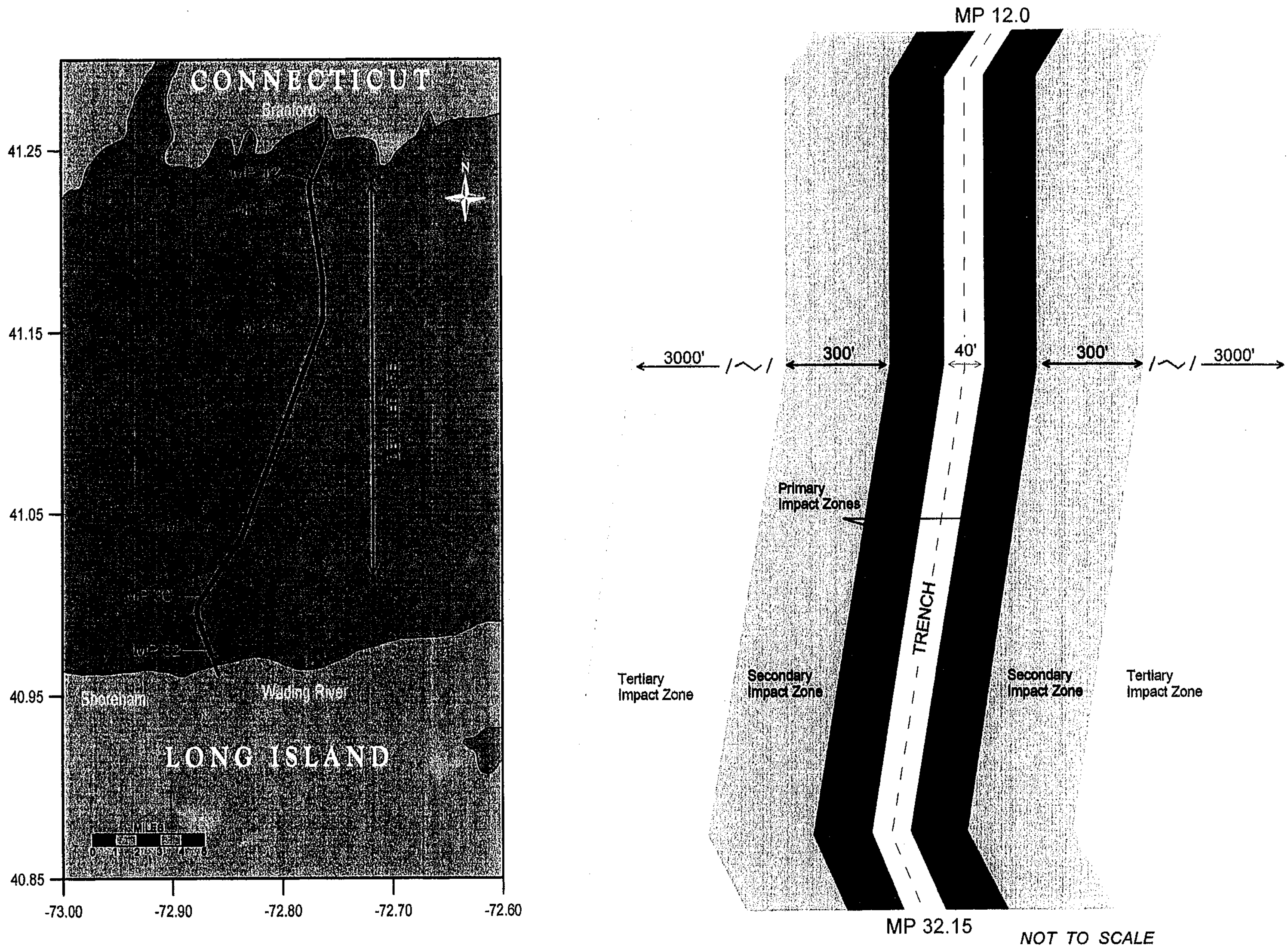


Figure 17. Sediment dispersion patterns, jet plow.

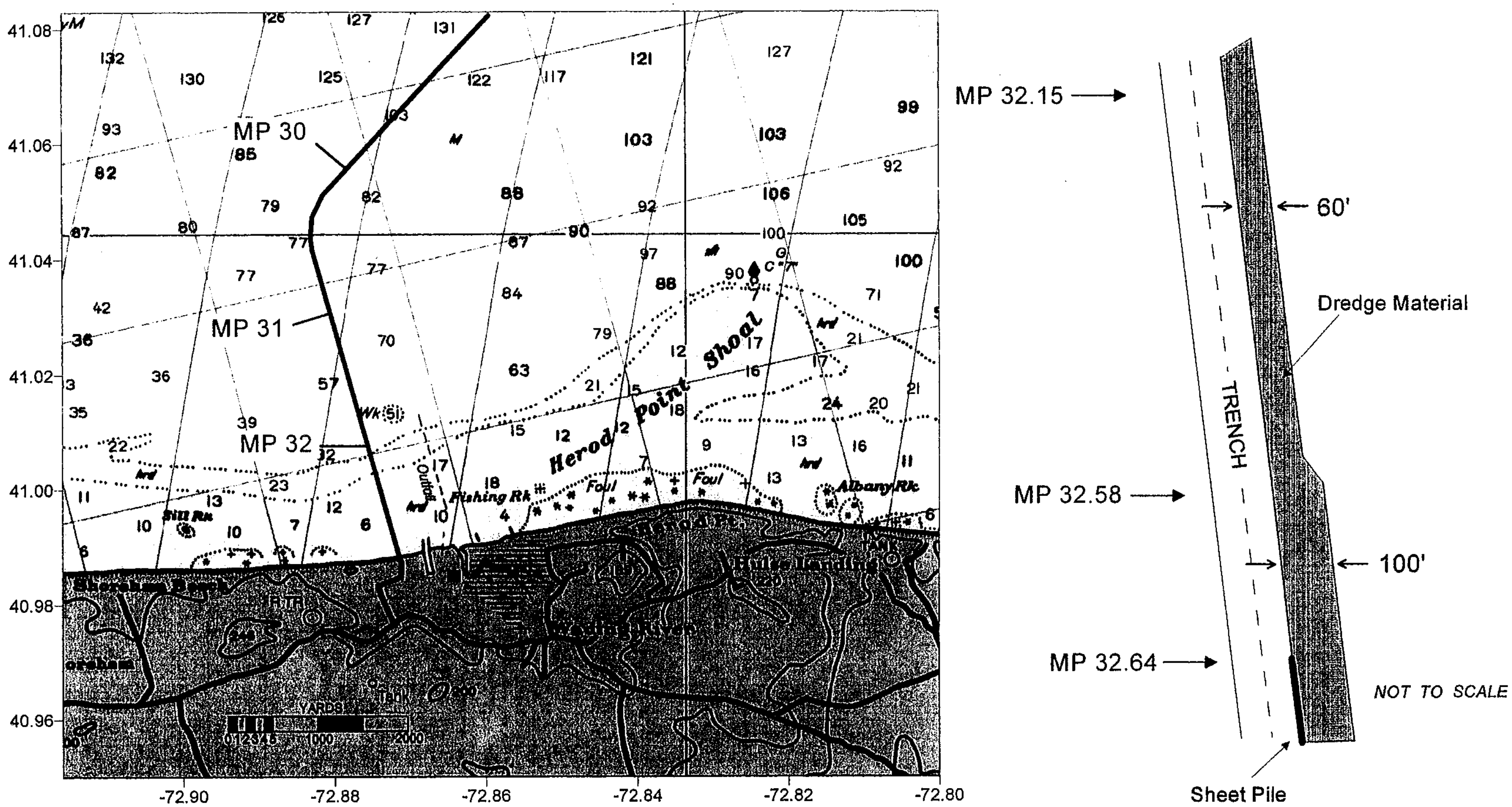


Figure 18. Sediment dispersion patterns, New York nearshore.