(I) INTRODUCTION

This Benthic Mapping data package produced by Lamont-Doherty Earth Observatory of Columbia University and SUNY Stony Brook presents the geophysical data from the Piermont, Haverstraw Bay, Hudson Highlands and Catskill Creek reaches of the river. The main body of the report includes the description of the data collection, data reduction, image generation and the sediment classification work. The supplementary material, including images, mosaics, tables and other detailed information are presented in the appendices.

The data is delivered on 7 DVDs. A readme.txt file on each DVD described the contents. DVD1 contains the GIS data and the report. Five DVDs (DVD2-7) contain the seismic data in SEGY format. DVD1 has three main folders:

MAIN FOLDERS	Contents
MAPS- The maps folder contains ArcGIS/ArcMap map documents for letter-size maps and letter size pdfs of the maps. The naming convention is xxx_letter_xxx.mxd.	ArcGIS map documents pdf-files of single maps
REPORT - The report folder contains this report in pdf format with one file for each chapter and each appendix.	Digital version of the report
DIGITAL - The digital data contains subdirectories as noted in the chart below.	Digital data

The digital data contains subdirectories for each data type as follows:

Digital Data Folders	Contents	Files/Subdirectories
CORES	Data from sampling	Subdirectories descriptions (text) grain_size (tables) photos (jpeg and text files) physprops (ASCII data) Shapefiles 2001_cores.xxx 2001_cores_grabes_components.xxx 2001_grabs.xxx 2001-cores-and-grabs.csv (table) 2001_grabs_sed_type.lyr (legend) cores_grabs_simple.lyr (legend) grab_components.lyr(legend) pie_chart.lyr (legend)

INTERPRETATION	Interpretation	Shapefiles grainsize_interpretation- anthropogenic habitat morphology sediment_environment
MB_BACKSCATTER	Multi-beam backscatter 2m tiles	For Each Area: mosaic (*.tif), world-file (*.tfw), ArcGIS auxiliary files (*.aux, *.rrd)
MB_BACKSCATTER_1M	Multi-beam backscatter 1m tiles	For Each Area: mosaic (*.tif), world-file (*.tfw), ArcGIS auxiliary files (*.aux, *.rrd)
MB_DEM	Multi-beam bathymetry 2m tiles	Arc\Info grids b2mb_dem_2m b3mb_dem_2m b4n_dem_2m b4s_dem_2m b7n_dem_2m b7s_mb_dem_2m Arc\Info table info for grid data Layer file b3mb_dem_2m.lyr b3mb_dem_2m.lyr
MB_DEM_1M	Multi-beam bathymetry 1m tiles	
MB_SUN_1M	Multi-beam sun-illuminated bathymetry 1m tiles	mosaic (*.tif), world-file (*.tfw), ArcGIS auxiliary files (*.aux, *.rrd) for each area with 1m resolution.
MB_SUNILLU	Multi-beam sun-illuminated bathymetry 2m tiles	mosaic (*.tif), world-file (*.tfw), ArcGIS auxiliary files (*.aux, *.rrd) for each area with 2m resolution.
METADATA_MASTER	metadata files	mb_backscatter_1m_meta.txt mb_backscatter_meta.txt

		mb_dem_2m_meta.txt mb_sun_1m_meta.txt mb_sun_2m_meta.txt seismic_track_meta.txt sidescan_1m_meta.txt sidescan_2m_meta.txt singlebeam_bathymetry_meta.txt tile_meta.txt
PICTURES	Lamont Logo	
SEISMIC	seismic tracks, shotpoints and images	B2 - data of area B2 B3 - data of area B3 B4 - data of area B4 B7 - data of area B5 Each of these subdirectories has the following structure: Images gif-images of each seismic profile nav Text-file of shotpoint (profiles) Text file of navigation (profiles) Shapefiles of every 25th shotpoint Shapefiles of lines (east-west, north-south, turns)
SHORELINE	shoreline used for the maps (combined DEC and NOAA data	dec_noaa_poly.xxx - shapefile of shoreline
SIDESCAN100_1M	100kHz side-scan mosaics 1m tiles	For each area: mosaic (*.tif), world-file (*.tfw), ArcGIS auxiliary files (*.aux, *.rrd)
SIDESCAN100_2M	100kHz side-scan mosaics 2m tiles	For each area: mosaic (*.tif), world-file (*.tfw), ArcGIS auxiliary files (*.aux, *.rrd)
SIDESCAN384_1M	384kHz side-scan mosaics 1m tiles	For each area: mosaic (*.tif), world-file (*.tfw), ArcGIS auxiliary files (*.aux, *.rrd)

SIDESCAN384_2M	384kHz side-scan mosaics 2m tiles	For each area: mosaic (*.tif), world-file (*.tfw), ArcGIS auxiliary files (*.aux, *.rrd)
SINGLEBEAM	single-beam data	Arc\Info grids b2sb_dem (Piermont) b3sb_dem (Haverstraw) Arc\Info table info
TILES_EXTEND	Tile boundaries	shapefile (polygon) of ~1 min tiles

(II) DATA COLLECTION, REDUCTION AND IMAGE GENERATION

(A) Bathymetry

(1) Instrumentation

Echosounding - A multibeam system operates by transmitting sound beams perpendicular to the ship track, and then processing the returned sonar data to determine a number of depths across the ship track. The SimRad EM 3000 operated in a single-head mode forms up to 120 echosounder beams, each nominally 1.5° wide and spaced 0.9° apart. These beams are transmitted in a swath width that is four times the water depth. The maximum ping rate is 20 times a second, decreasing to 13 times a second as water depth increases to 10 m. In water depths of 10 m and at a speed of 8 kts, the bathymetric and backscatter data has an along-track and across track spacing of as little as 30 cm. The manufacture's specified accuracy of each depth measurement is 0.05 -0.10 m. This resolution is sufficient to map medium to large-scale bed forms and other features with dimensions of about 1 meter. The EM 3000 also collects a side scan sonar (backscatter) record at 300 kHz, which is very similar to the traditional sidescan sonar system also used in this program. The sound beams in the EM-3000 system are directed down more than a sidescan sonar system and the backscatter record is processed with a knowledge of seafloor bathymetry. The improved navigation and the near vertical nature of the sound beams results in improved positioning of the backscatter measurements.

Navigation - In addition to the beam forming instrumentation the EM-3000 requires accurate navigation and orientation data to produce high quality bathymetric measurement. The POS/MV attitude sensor uses three accelerometers and three gyroscopes to correct the multibeam data for heading, roll, pitch and heave. A differential GPS system (supplemented by inertial navigation; also part of the POS/MV system) determines position to within 1 meter. The real time differential corrections were provided by Omnistar.

Other system components include: a separate display to guide the boat along precise survey lines; a CTD for determining the sound velocity profile; a tide gauge for determining local sea-level changes during a survey; Sun and SGI computers (with 36" wide and page-size printers) for logging, storing, processing and displaying the data; and multibeam processing software. Near-final survey products can be generated within a short time after the survey is completed, and our products generally meet hydrographic mapping standards. The EM 3000 multibeam system was mounted on the R/V Donald W. Pritchard, a research vessel operated by MSRC at SUNY Stony Brook, and multibeam data can be collected at speeds up to 8 knots.

Table 1: Summary of Multibeam Survey Operations (2001)

2001 (only weekday work)	**first day**	**last day**
Area B2 survey	06/11/01	06/22/01
Area B3 survey	06/22/01	06/29/01
Area B4 survey	10/22/01	10/29/01

transit to B7	10/29/01	
Area B7 survey	10/30/01	11/07/01
transit to B4	11/08/01	
Area B4 survey (cont.)	11/08/01	11/08/01

Multibeam Survey - The multibeam survey was designed to optimize the ship time while fulfilling the goal of 100% coverage of the river in water depths greater than 5 m (15'). Swath width depends on water depth, thus ship tracks need to be closer together in shallower water and farther apart in deeper water. The mapping strategy was therefore to follow the river contours rather than to run parallel ship tracks. The navigation display on the bridge provides the ship's captain with real time guidance on the portion of the river that has been successfully surveyed and the regions that need to be traversed so that the ship could be directed to an unsurveyed area. CTD casts were conducted about every 90 minutes. The CTD profiles were converted to sound velocity profiles and integrated into the data acquisition to provide correction for ray bending and thus precise depth determinations.

Real Time Quality Control - The real time quality control for the multibeam system includes operator monitoring of the navigation and the ping returns. The surveying is stopped when the broadcast differential GPS correction is unavailable. The real time quality control also permits the operators to monitor for bad pings. Survey lines with excessive bad pings were resurveyed.

(2) Data Reduction and DTM/DEM Production

Editing - After the acquisition of the multibeam data several major steps are required to produce the final digital terrain maps and backscatter maps. The first step is the editing of the navigation and the ping files for erroneous values. There are manual and automatic stages to both these editing tasks. Backscatter records were also reviewed for anomalous data, but data anomalies were generally not removed from the data. In particular, there are often low-backscatter (black on the multibeam backscatter images) lines that go across individual tracks, caused by a brief loss of bottom tracking, that do not represent river-bed features.

Automatic Navigation Editing - The navigation plots are reviewed in detail to identify any positioning errors. The automatic navigation editing process identifies times when the number of satellites was insufficient, the HDOP (the Horizontal Dilution of Precision) was excessive, or there was no differential correction. Pings which fail the navigation criteria are masked from the final data product if the time interval with poor navigation was too long (greater than about 30 seconds). For shorter time intervals, navigation was linearly interpolated between good fixes.

Manual Editing - The manual component of the ping editing involved viewing the depth data from approximately 80 pings at a time (about 8,000 to 9,000 depth determinations are viewed at one time). The operator reviews both the depth and the backscatter data simultaneously. Outliers in depth data sets were flagged as bad data and not used in the final map. For a typical screen of data, from 5 to 50 pings are flagged as bad (less than 1%). We carefully reviewed our ping editing to ensure we had not removed any feature of the riverbed due to excessive editing, and pings incorrectly flagged as bad were restored.

Tidal Fluctuation correction - The next stage of processing was to produce bathymetric and backscatter maps using the depth measurements, with depth measurements being corrected for predicted tidal data. The goal of this step was to identify any remaining anomalies in the data set. The final major step in the processing is to correct the depth data for the actual tidal fluctuations during the survey. Predicted tides in the Hudson are good to better than 1 meter, but to reach the target of 30 cm, actual tidal measurements are necessary. In general, we surveyed between two tide gauges, and water elevations at the ship location were determined by calculating a river slope from the gauge data and then calculating a water elevation for the ship position. If data from only one gauge was available a model of river slope vs. tide phase, determined when two gauges were deployed, was used to determine water level for each survey. During data gaps in the LDEO/MSRC instruments we used the USGS tide gauges. The improved tide model, incorporating the observed tide, reduced the error in the multibeam maps to ~10 cm. Depths are reported relative to NAVD88. Thus water depths shown are about ~1 m greater than depths reported relative to MLLW (mean lower low water) displayed on nautical charts.

Digital Terrain Map - After these corrections, the depth data was gridded at an appropriate interval (usually 1 m) to create a digital terrain map (DTM). This DTM was averaged to 4 m spacing before being contoured at 1 m to show regional bathymetric patterns. A sun-illuminated image was routinely created by shining a synthetic sun across the DTM. This step provided a remarkable image of the seabed, and small bathymetric features difficult to resolve on contoured bathymetry, are clearly visible on the sun-illuminated image. The sun-illuminated images shown for this report are created by shining a sun from the northwest. The image data was also gridded to provide an image of the backscatter, an acoustical property linked to bottom roughness and distinct from topography. The 1 m bathymetric and backscatter data were averaged to 2 m spacing and combined to give the 5' maps. We applied a beam correction to the backscatter data to enhance the backscatter imagery and stretched the resulting data to display the backscatter features. The backscatter data is consistent through the four areas and can be compared between areas.

An appendix of Multibeam Images is included with detailed images from each area (Appendix III).

(B) Side-scan Sonar

(1) Instrumentation

Towed Equipment - The towed side-scan system used for this program was the Edge Tech DF-1000 dual frequency sonar with an ISIS data acquisition topside. The system is designed to acquire data at two frequencies 100 kHz and 384 kHz. The six foot tow fish was deployed from a boom off the bow of the ship to place the system in quiet water for optimal instrument performance. The fish was towed at a depth of 1.5 m. The fish has transducers and receivers on either side of the tow fish. The transducers transmit and receive both frequencies simultaneously. The acoustic signals are digitized in the tow fish and transmitted with a high-speed digital uplink to the onboard acquisition system. The tow cable is a single coaxial cable. A swath width of 200 m to each side was used so that together a total width of 400 m of riverbed was surveyed with a single survey track.

Topside Equipment - The topside unit was an ISIS data acquisition supported by Triton Elic. The side-scan data was time tagged in the ISIS system and recorded to hard disk. The Triton Elic system also recorded several auxiliary data streams including: the ship's compass heading, the single-beam bathymetry and the real time navigation. The LDEO ship compass was mounted in magnetically quiet location of the boat. The navigation data recorded in the ISIS system was differential GPS positions received by a Trimble AG-132 unit.

(2) Survey Design

Naming Convention - The survey design was targeted at full insonification of the river at 85 m line spacing in the north-south orientation and 180 m in the east-west orientation. The data were generally recorded into separate files for each profile. The naming convention for the side-scan files includes an area identifier, the direction of the track (i.e. east-west or north-south), and an indicator for the number of times the line was shot. During turns, data was recorded into a file using the naming convention of the just completed line with an B3 suffix. For example, B3N001B is the filename for the Area B3 filed acquired in the north-south orientation along the track designated #1 for the second time as indicated by the b. For example, B3N001A1 is the filename for the Area B3 file acquired during the turn after B3N001A was complete.

North-South – East-West - In area B2 and B3 north-south and east-west lines are collected in this directions. In areas B4 and B7 the north-south lines are partially river-parallel. The river in area B7 is too narrow to collect useful east-west lines a zig-zag pattern was used instead.

Table 2: Summary of Survey 2000

2000 Surveying	DATES	OPERATIONS	
Preparation	*December 4, 2000 -*		
B2	*December 5, 2000 -* *December 11, 2000*	*55 east-west lines* *20 north-south lines*	

Table 3: Summary of Survey 2001

2001 Surveying	DATES	OPERATIONS	
Preparation	*April 9, 2001*		
A2	*April 30, 2001* *May 4, 2001*	*East west lines – reshoot*	
A3	*May 3, 2001*	*East west and east west lines* *reshoot*	
A1	*May 15, 2001*	*Reshoot lines*	
B2	*April 26, 2001* *May 15, 2001*	*Reshoot 4 east-west* *10 north-south*	
B3	*April 10, 2001 – April 25, 2001* *May 9, 2001 reshoots*	*55 East-West Lines* *88 North-South Lines*	
B4	*April 25, 2001* *May 7, 2001- May 8, 2001,* *May 10, 2001*	*6 North south lines broken into ~3 segments* *east west lines south of Bear Mountain Bridge*	
B7	*May 1, 2001- May 2, 2001*		
B1/B0 – Manhattan	*May 16, 2001*	*Lines over Vema Cores and Circum Manhattan Data*	
TRANSISTS	*April 30, 2001*		
Maggie Calibration	*April 27, 2001*		

(3) Quality Control

Overview - After each day of acquisition the data was returned to LDEO for overnight quality control. For the side-scan data the goal was to ensure the proper number of bits were present in the data, that the navigation and time tagging was appropriate and that the preliminary imagery was correct. The goal was to identify any corrupt track while it was still possible to re-shoot the data. The side-scan quality control for each track included a page of text containing the critical acquisition parameters and a track plot of both the 100 and 384 kHz data. The track plot included an overlay of the ships heading and depth from the single beam. These products were reviewed by a project scientist early the next day. Summaries of the quality control results were transmitted to the field crew to enable acquisition of repeat data as necessary.

Quality - Data quality was in general excellent. Field conditions which introduced noise into the sidescan data included stratification of the water column in shallow water during calm, hot days, excessive ship's motion, turbulent water due to boat wakes, and sonar fish vibration due to build up of vegetation on the towing cable.

(4) Navigation Merge

The processing included demultiplexing of raw data, correcting for layback and merging track data to produce final mosaics.

Demultiplexing -The raw data files recorded with the ISIS system contain both frequencies and data from the different serial channels. In a first step both frequencies and the additional data were split into separate files. The data values were converted into a range of 0 (high-backscatter) to 255 (low- backscatter).

Correction for Laybacks - The corrections for layback, i.e. the difference between GPS antenna position and the position of the side-scan fish, was calculated as part of the navigation processing. The corrected navigation is merged with the side-scan data.

Merging Track Data - We have chosen the philosophy of providing minimally processed backscatter data in the final mosaics. This ensured the preservation of the maximum information. We have implemented a slant range correction for the data. All the mosaicking routines assume a flat bottom. The major corrections incorporated into the mosaicking routine are the removal of the nadir and to systematically seam the data. The nadir central stripe produces a final product which is difficult to interpret. Our survey design ensured that the nadir from one line could be filled with the outer beam data from the adjacent line. In the mosaic we have filled the nadir with the adjacent line data wherever possible. We evaluated in detail the utility of correcting the side-scan sonar for the heading of the fish, which can differ from the heading of the boat. We concluded that an empirically derived correction of 0°-10° depending on area (i.e. areas with strong currents like the highlands needed a larger correction) reduced the swath to swath mismatch of riverbed features and improved the final mosaic.

Generate Final Images - Mosaics were generated at 2 m and 1 m pixel resolution for 5‘ tiles of the river representing 5 nautical miles. For each tile four mosaics were produced using different azimuth and different frequency data. These four mosaics are a north-south 100 kHz mosaics, an east-west 100 kHz mosaic, a north-south 384 kHz mosaic and an east-west 384 kHz mosaic.

An appendix of Sidescan Sonar Images is included with detailed images from each area (Appendix II).

(C) Chirp

(1) Instrument

System - Subbottom data were acquired using the X-Star II topside data acquisition unit and the SB 4_24 tow fish, both manufactured by Edge Tech of Boca Raton, Florida. This is a Chirp or swept frequency sonar system, which emits a broadband FM source pulse with low frequencies providing depth penetration into the subbottom and higher frequencies providing high vertical resolution. The X-Star II acquisition unit controls all data transmission, recording and signal processing including Analogue to Digital (A to D) conversion, compression of the FM pulse and spherical divergence correction. The recorded signal is the output of the correlation filter used for pulse compression and is stored in SEG-Y format.

Rate & Frequency - Data were acquired at a transmission rate of 5-6 pings/second. At survey speeds of 5 knots these transmission rates provide one trace for each 0.83 m of ship motion. Transmit pulse length was 10 msec. Pulse power was set at 50-60% of maximum available output in order to avoid ringing and generation of cross-talk interference with the sidescan sonar data. The SB 4_24 tow vehicle offers the ability to transmit a variety of pulses with a frequency range from 4 to 24 kHz. After comparison of data quality obtained with the range of pulse options, we chose the lowest frequency sweep pulse (4 to 16 KHz) to obtain maximum possible penetration with this fish.

The Chirp vehicle was towed from the stern starboard corner using a towline to keep the fish to the side. Tow points for the subbottom fish were surveyed in, so that layback corrections could be applied during post-processing. Real time GPS navigation was passed directly to the acquisition unit via an RS-232 serial port.

Table 4: Chirp Acquisition Parameters

Area Survey year	**Frequency range of source pulse (kHz)**	**Sampling frequency (kHz)**	**AtoD sample interval (microsec)**	**Trace duration (millisec)**
B2 2000, day 340, 341 (partial)	4-16	32	31.25	64.0
B2/B3/B4/B7, 2001 B2, 2000, rest of data	4-16	50	20.0	64.0

(2) Survey Design

Gas Migration - The Chirp data were collected simultaneously with the towed sidescan data on the same generally orthogonal survey grid. A complete survey of area B2 was carried out in December 2000. During this survey we discovered that our subbottom penetration was significantly less than had been obtained in the adjoining Tappan Zee area to the north (~1-2 m compared with ~4 m). Upon further investigation we discovered that the more limited penetration was due to seasonal gas migration within the shallow sediments. Research in other estuarine regimes has shown seasonal migration with gas moving in and out of solution within the sediment pore fluids due to changes in bottom temperature. As a result of this more limited penetration, we decided to reshoot a portion of the B2 data set in 2001 and 2002. All even EW lines and most even north-south lines have been reshot.

Table 5: Summary of Chirp Subbottom Tracklines

Area	N-S	E-W	Notes
Area B2 Piermont	B2n001-55	B2w001-55	Reshot in 2001/2002: B2w001, 02-54 (all even) B2n012, 14, 15, 18, 20, 30, 32, 36, 38, 40 (full lines), B2n004, 5, 7, 21, 22, 24, 26, 28 (partial)
Area B3 Haverstraw Bay	B3n01-84	B3w01-55	B3w001 missing B3n019, 42, 53 not shot B3n034 (partial line)
Area B4 Hudson Highlands	B4n01-19	B4w1-119	B4n011 – partial line only B4w050, 52, 54, 56, 58 not shot
Area B7 Catskills	9	B7w1-	E-W lines acquired at an oblique angle

(3) Quality Control

Dropouts - During acquisition, data dropouts were observed at ship speeds above ~5.5 knots, during turns, and when intersecting large ship wakes. Dropouts were easily controlled by keeping tow speeds under 5.5 knots and slowing in other instances when they became common. Instances of data dropouts affect less than 1% of the total data set.

Weather influence - During rough weather days, a roll induced heave was occasionally present within the data. This swell-induced noise produced two effects; high frequency undulations of the riverbed and lower resolution of subbottom layers. These weather related artifacts affect a significant percentage of the Chirp data acquired in area B2 in December 2000 and contributed to our decision to reshoot these data.

Coding - All processing was carried out using a combination of in-house code for reading the raw data files and the Seismic Unix package maintained by the Colorado School of Mines (a listing of processing programs and scripts is included in Appendix II). Initial processing involved several steps. The raw data stored by the system manufacturer are pairs of short integers corresponding with the real and imaginary components of the deconvolved received signal. These values are combined and scaled during initial processing to output the envelope amplitude for each sample. During demux, statistics for each profile are determined for quality control and output to a summary text file. The demux SEGY file is written and a gif image is produced to allow immediate assessment of data quality. Real time navigation is extracted for each profile and initial track charts are made.

4) Navigation Merge

Overview - Final processing included updating the navigation information within the SEGY trace headers for post-processed layback corrected final navigation (longitude, latitude, and easting, northing in UTM coordinates projection zone 18 referenced to the NAD83 datum). With the exception of occasional data drop outs and swell artifacts on a few rough weather days, the data are remarkably noise-free and no post-acquisition filtering was required. Chirp technology incorporates signal-processing techniques into the control units that automatically deconvolves the wide-band signal pulse during data acquisition. Hence deconvolution for pulse compression is not needed as a post-processing step. Spherical divergence corrections are also applied within the data acquisition unit.

Data Presentation - Tests of both AGC and PGC methods were conducted to determine optimal gain parameters for data presentation. Application of AGC was ruled out as this method does not preserve relative amplitudes. Exponential and power law gains subdue data amplitudes at shallow levels and gain them at depth to produce a more uniform grey level across the trace. Because acoustic penetration is confined to shallow levels for most of our data, these schemes were inappropriate for uniform application to the entire data set. However, along the occasional line where deeper penetration is observed, they may provide some improvement in data display. The results of our experiments indicate that a fixed gain was the best choice for application to the entire data set. All imaged structure can be detected and relative amplitudes are preserved.

(5) Generate Final Images (Profiles)

Images are provided in GIF format and are all included with the digital data. For each line the total data range is scaled to 256 grey levels, and the grey level legend is displayed on the right hand side of each image. Data values range over 1 order of magnitude for most lines. Images are annotated with trace number, time, latitude, longitude, easting and northing in UTM zone 18 coordinates. All images except for turns are oriented with west and south to the left. Names for final SEGY files, nav and gif images include a NSEW indicator denoting the geographic location of the beginning of the line. Data are plotted in seconds two-way travel time (twtt). Assuming a sound velocity of 1500 m/s, 0.005 sec twtt is equivalent to 3.75 m.

An appendix of Chirp Data is included (Appendix IV).

(D) Core Samples

(1) Sample Acquisition

Coring - The R/V Walford operated by the New Jersey Marine Science Consortium at Sandy Hook was used for the coring program. Sediment cores were recovered from areas B2, B3 and B4. Only grab samples were obtained from B7 area because the sediment was thought to be dominated by sand. In sand dominated environments coring is not an effective sampling technique.

A gravity corer with a weight of 750 lbs was used to penetrate the sediment. The core liners are 4” in inside diameter providing more sediment volume for sampling than the traditional 2.5” diameter cores. The longest core is 200 cm although recovery typically ranged between 1-2 m. All cores and grab samples are being curated at the LDEO Core Laboratory under the support of the National Science Foundation.

(2) Site Selection

The siting of the sample locations was based on the review of the preliminary mosaics, bathymetry and the Chirp subbottom data. The sampling strategy was to ensure we sampled the major structures observed in the geophysics. The time lag between the coring and geophysical surveys allowed us to optimally plan the sediment-sampling program after examination of the geophysical data.

(3) Core Processing

The processing of the cores included the following steps: physical properties on the unsplit cores including magnetic susceptibility, bulk density and p-wave velocity, split and photograph the cores, describe the cores, grain size analysis of the core tops and archive the core at Lamont's Core Archive

We acquired cores for 108 locations. Multiple cores were acquired at 11 locations due to either no initial core recovery or overpenetration and missing core tops. For some samples material was only recovered within the core catcher, or the core was < 10 cm long. These samples were bagged and grain size analysis carried out but no photographs taken. Physical properties were only acquired on those cores longer than 1 m unless they were deemed to be of high priority based on analysis of the geophysical data.

Table 6: Core sampling program

CORE AREA	DATE - Vessel OPERATIONS	Number of Cores
B2 – Piermont Area 58 attempted 54 cores	9/05/2001 Walford W. Ryan	21 cores LWB2-1 to LWB2-20 2 Over-penetrated: LWB2-2, 7 1 duplicate LWB2-2, 2B No core recovery LWB2-21
	9/8/2001 Walford A. Slagle	37 cores LWB2-22 to 51B 3 Over-penetrated LWB2-35, LWB2-44, LWB2-49 3 No Intact Core (Bagged Samples) LWB2-36, 39,48 5 duplicate: LWB2-22,22B,28,28B,32,32B,36, 36B, 51, 51B 2 No Recovery LWB2-25,51B
B3 – Haverstraw 53 core attempts	9/06/2001 Walford W. Ryan, A Slagle	30 cores LWB3-1 to LWB3-30 6 Over-penetrated LWB3-2, 7, 14, 16, 22, 25, 26
	9/07/2001 Walford A Slagle	23 cores LWB3-31 to LWB3-49 3 Duplicate: LWB3-32,32B, 42,42B, 48,48B, 48C 8 Over-penetrated LWB3-32, 40, 42, 43, 46,47, 48, 48B Bagged Sample – LWB3-36
B4 - Hudson Highlands	9/09/2001 Walford W. Ryan	11 cores LWB4-1 to 10 Bagged sample LWB4-11

Table 7: Core Analysis

Area	# cores	Grain size analyses	Descriptions	Photos	Physical properties
B2 51 core locations	49 total (5 recore) 2 cores failed (LWB2-21, 25)	48	45	45	36
	No analysis (bagged sample, core too short, missing core)	LWB2-30	LWB2-3, 15, 2B, 48, 30	LWB2-3, 15, 1, 2B, 12, 48, 30	LWB2-3, 6, 13, 15, 22, 26, 39B, 47, 1, 2B, 12, 48, 30
B3 49 core locations	48 total (4 recore) 1 core failed (LWB3-36)	49	50	49	42
	No analysis (bagged sample, core too short)		LW3-20, 29	LW3-20, 29	LW3-20, 29, 1,18, 21, 37
B4 11 core locations	11 total	11	10	10	10
	No analysis (bagged sample)		LWB4-11	LWB4-11	LWB4-11
Total	108	108	105	104	88

Table 8: Detailed summary of core recovery

Area		Total Number	
B2			
	Overpenetration, no recore	3	LWB2-7, 44, 49
	Overpenetration, recore	2	LWB2-2, 35
	No/poor recovery, recore	6	LWB2-2, 22, 28,32,36,39
	No core recovery	2	LWB2-21, 25
	Bagged or core catcher only	4	LWB2-2B, 3, 15, 48
	Missing core	1	LWB2-30
B3			
	Overpenetration, no recore	11	LWB3-2, 7, 14, 16, 22, 25, 26, 40, 43, 46, 47
	Overpenetration, recore	4	LWB3-32, 42, 48, 48B
	No core recovery	1	LWB3-36
	Bagged or core catcher only	2	LWB3-20, 29
B4			
	Bagged or core catcher only	1	LWB4-11

(a) Physical Properties

Overview - Wet bulk density, magnetic susceptibility and p-wave velocity measurements were made on each unsplit core using the GeoTEK multisensor track core logger at the LDEO Core Laboratory . A description of the calibration and measurement process follows. Both P-wave velocity and magnetic susceptibility measurements are sensitive to temperature, so cores are maintained at room temperature for the duration of data collection.

Wet bulk density measurements - were obtained using a 137-Cs gamma source and gamma detector. Calibration of the logger was conducted on an empty core liner. The internal diameter and wall thickness of the empty core liner were measured. The liner was cleaned and two calibrations conducted. During the first calibration the liner was filled with distilled water, and for the second calibration the liner was filled with an aluminum standard, a piece of aluminum of known thickness. Readings of gamma attenuation counts were recorded for the liner with water and each thickness of aluminum. The numbers were inserted into a calibration spreadsheet. A gamma calibration curve was created in a standard spreadsheet, and the slope and intercept was used in the core logger program to correct for liner diameter and wall thickness. After this calibration procedure wet bulk density was calculated for each core taking into account sediment thickness, Compton attenuation coefficient, gamma source intensity and measured intensity through the sample. The gamma-ray attenuation porosity instrument measured wet bulk density at 1-cm intervals. The data was recorded as gm/cc.

Magnetic susceptibility - was measured using a Bartington loop sensor. The sensor measures absolute magnetic susceptibility and these values are then corrected for the size of the core and the size of the sensor. Prior to logging, operation of the sensor is validated with a calibration sample of known magnetic susceptibility. The calibration measurements recorded did not deviate by more than 5% of known value. The loop diameter of 125 mm was used for the cores. The exact fit of our cores into this loop minimized the instrumentation error. The operating frequency of the coil was .565kHz and the magnetic field strength was 80 amperes/meter. The magnetic susceptibility measurements are recorded in SI units.

P-wave velocities - were measured with ceramic piezo-electric transducers spring-loaded against the core, to detect the travel time of an ultrasonic pulse through the sediments. The calculation of P-wave velocity was based on the measured thickness of sediments in the core liner as well as the total measured travel time of the pulse.

(b) Core Description

Each core was visually described including lithology, color, deformation, accessories and physical structures. Digital photos of all cores, with reference color bars, were obtained at 30 cm-long intervals.

Wentworth Scale - The lithology of each core is described based on grain size divisions according to those of the Wentworth scale (Wentworth, 1922)[1]. The relative proportions of each component determine the main name of the sediment: clay, silt, sand, or gravel. The component that is most abundant determines the name of the sample. For example if the main component is sand the sample is labeled as sand. If sand is the main component and silt is minor the sample is called silty sand. Major and minor modifiers are listed in order of decreasing abundance to the left of the principal name. If the component is less than 10% it is not listed as part of the sediment name. For example a sandy, clayey silt would be a sample that is 10% sand, 20% clay and 70% silt while a clayey silt might contain 5% sand, 20% clay and 75% silt.

Munsell Soil Color Charts - The color of each sample was preserved both with the digital photograph acquired upon splitting and by visual comparison. The visual determinations of the hue and chroma attributes of core color used the Munsell Soil Color Charts (Munsell, 1990)[2].

A detailed description of the core description procedure follows:

Macro -- describe overall appearance – color, texture, lithology, structures, deformations, accessories (shells, pebbles). Lithology broken down into 'units' based on color and/or texture (grain size); these are based on Munsell color chart and Wentworth scale, respectively. 1cc samples and smear slides are taken from each 'unit'. 1cc samples are dried, weighed, washed thru 63um sieve, dried and reweighed to get percentage of coarse fracture.

Micro-smear slide - looked at with petrographic scope and c.f. looked at with binoc. scope to determine mineralogy. 'Name' (i.e. Biocalcareous Clay) based on mineralogy / microfossil assemblage (most abundant component makes up first part of name) and percentage of coarse fracture (clay or sand). (If sedigraph analysis done, include silt as

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[1] Wenthworth, C. K., 1922. A scale of grade and class terms of clastic sediments. Journal of Geology, 30, 377-392.

[2] Munsell Color Company Inc., 1990. Munsell Soil Color Charts: Baltimore, MD (Munsell).

option.) Secondary descriptor (i.e. Biocalcareous (Terrigenous) Clay) based on second most abundant component. More specific name (i.e. [Foram Ooze]) found under broader name.

Description layout:
Latitude:
Longitude:
Corr. depth:
PDR depth:
Date taken:
Date opened:
Date described:
Date photographed:
Described by:
Station number:
Core length:
Flow-in:

General notes about core. Overall description of entire core (if can be generalized).

‘unit interval’ cm Dominant component (secondary component) clay/sand [specific name], munsell color (color code); lithology, including colors, mottles, bioturbations, etc.; approximate moisture content and sediment firmness. Carbonate content based on microfossil content and possible minerals, high, moderate or low. Coarse fraction % consists of abundant; common; rare; trace components (trace includes smear slide). (Not all categories will be filled.) Basal contact description (unless end of core). Sampling interval.

(c) Grain Size Analysis

The upper 5-cm of the cores were sampled and mixed for grain size analyses. The grain size data represent percentages of the whole sample. The coarse (> 63 um) and fine (< 63 um) fractions are separated with the coarse fraction analyzed with a sonic sifter, and the fine fraction on the sedigraph.

Detailed description of the analysis procedure is included below.

1. Sample grab or core. Two samples need to be taken, one 10-15 cc wet bulk for grain size (put into tared beaker), another 1.5 cc wet bulk for density analysis on pycnometer. Samples higher in clay/silt content can be smaller if necessary. Coarser samples need to be a little larger to give enough fine fraction to run on the sedigraph.
2. Weigh the grain size sample while wet.
3. Freeze dry both samples.
4. Weigh dried grain size samples to determine water content.
5. Washing the grain size sample: Wash sample with distilled water thru a 63 um sieve. Collect fine fraction in a beaker.

6. Allow the fine fraction to completely settle out.
7. Once settled, the supernatant is carefully poured or siphoned off and discarded. Transfer the sediment to large weigh dishes to dry under heat lamps.
8. Weigh dried fine fraction and store until sedigraph analysis.
9. The coarse fraction is dried under heat lamps (in the sieve) and brushed into separate containers for upper phi scale analysis.

Coarse fraction – sonic sifter

1. Coarse fraction is weighed and 'initial weight' recorded.
2. Sample is carefully brushed into top of sonic sifter sieve stack and placed in sifter.
3. Allow sample to sift for approx. 5 minutes depending on sample size and clumping, etc.
4. Remove sieves. Beginning with the top sieve, brush contents out and weigh them (individually). The contents of the latex bottom pan are also brushed out and weighed.
5. For particles or grains larger than 4 mm the pieces should be separated out of the top sieve and weighed in groups (4-8mm, 8-16mm, 16-32mm, >32mm).

Fine fraction – sedigraph analysis

1. The pycnometer sample is ground into a powder and run on the pycnometer prior to sedigraph analysis.
2. The rinse jug for the sedigraph should be filled with distilled water.
3. All sample cups should be labeled.
4. Densities (from pycnometer) and corresponding sample names should be entered and sample files created.
5. A 0.5% sodium hexametaphosphate solution is prepared with distilled water.
6. Dried fine fraction is added to the sample cups and mixed with 60-80 mL of the sodium hexametaphosphate solution.
7. A baseline of the sodium hexametaphosphate solution is run in the first sample cup.

(E) Grab Samples

(1) Sample Acquisition

Grab sampling was carried out in two phases; aboard the R/V Lionel Walford using a Smyth-McIntyre grab on Sept 07/09, 2001 and on October 16/17, 2001 aboard the R/V Pritchard using a Shipeck grab sampler. A total of 115 grab samples were acquired. Of these, 7 grabs recovered rocks or shells but no sediment and hence no grain size analysis was possible.

The grab sample acquisition and analysis is summarized in the table below.

Table 9: Grab sample operations

Grab AREA	**Date Vessel**	**Number of Grabs**
B2 - 21 total 21 DP	*10/16/2001 Pritchard,* E. Ayers, S. Chillrud	21 grabs DPB2-G35- DPB2-55
B3 - Haverstraw 50 total 13 LW 37 DP	*9/7/2001 Walford*	13 grabs LWB3-1 - LWB3-13
	10/16/2001 Pritchard, E. Ayers, S. Chillrud	27 grabs DPB3-G1- DPB3-G27
	10/17/2001 Pritchard E. Ayers, S. Chillrud	10 grabs DPB3-G28- DPB3-G37
B4 - Hudson Highlands 44 total 24 LW 20 DP	*9/09/2001 Walford,* C, Major	24 grabs LWB4-G1 to LWB4-25
	10/17/2001 Pritchard, E. Ayers, S. Chillrud	*20 grabs* DPB4-G1- DPB4-G3

Table 10: Grab Sample Analysis Summary

Location	**Number of Grabs Acquired**	**Grain Size Analysis**	
Area B2 - Piermont Pier	21	19	No sediment (DPB2-44, 55)
Area B3 - Haverstraw Bay	50	45	9 analysis No sediment (LWB3-4, 9, 10, 13, ***DPB3-13***)
Area B4 - Hudson Highlands	44	44	
TOTAL	115	108	

Procedure - Upon recovery of each grab sample, a field description of the grab, the grab location and the presence of major components (e.g. slag, zebra mussels, oysters and wood) were recorded in a field log sheet. The grab positions were not layback corrected (offset distance between the GPS antennae and the A-Frame). The grab sample was sealed in a zip lock bag and sent to Lamont for grain size analysis and archiving.

(2) Site Selection

The general strategy of the grab sample program was to acquire transects along the main axis of the channel and to sample major reflectivity and morphologic terrains. Other factors considered in developing the sampling strategy included local geology, location of tributaries, wetlands, and anthropogenic structures.

(3) Grab grain size analysis

The grain size analysis procedure for the grabs was the same as that used for the cores (described above).

An appendix of Core & Grab Data with detailed information and maps from each area is included (Appendices VII and VIII).

(III) SEDIMENT CLASSIFICATION FRAMEWORK AND INTERPRETATION

(A) Sediment Classification Framework

We have five major groups of interpretations based on our experience in the Phase 1 of the Benthic Mapping Project and other interpretive efforts in the Hudson River. These major interpretations include:

(1) Sedimentary Environments
(2) Grain Size
(3) Morphology
(4) Anthropogenic
(5) Habitats

For each of these major interpretations we have developed 3-5 categories.

(1) Sedimentary Environments

Sedimentary environments are based on the evaluation of the Chirp data in conjunction with the backscatter and bathymetry data.

(a) Depositional

Depositional environmental are identified as regions with low backscatter which optimally can be seen overlying other strata. A clear example of a depositional environment is the site off Hook Mountain (A1) where Cesium measurements have confirmed the interpretation of recent sedimentation. This also includes the high backscatter deposits associated with tributary mouths (A2, A3).

We have developed 4 distinct depositional subclasses:

Table 11: Deposition Subclassifications

Deposition Subclasses
Deposition – Thin accumulation (<50 cm)
Deposition – Thick accumulation (>50 cm)
Deposition – Drape Over Bedrock
Deposition – Thickness Unknown

(b) Erosional/Non Depositional

Erosional/Non depositional is defined as sites with clearly truncated bedding in the Chirp data, outcrops of bedrock as in the Hudson Highlands or where other information, stratigraphic or radionuclide indicate non-depositional.

We have developed 3 distinct erosional/non depositional subclasses:

Table 12: Erosional/Non Depositional Subclasses

Erosional/non Depositional Subclasses
Erosional – truncated layers
Erosional - bedrock
Erosional/Non Depostional – other (stratigraphic evidence or radionuclides)

(c) Dynamic

The identification of dynamic environments is based on the morphology and the backscatter data. Within the dynamic regions it is possible that both erosional and depositional processes are active. A clear example of a dynamic environment is the sediment waves/dunes prominent in the upper reaches of the Hudson. As these features migrate both deposition and erosion are active.

We have identified six subclasses for the dynamic environment:

Table 13: Dynamic Environment Subclasses

Dynamic Environment Subclasses	
Dynamic Waves	Regions with waves imaged with multibeam or sidescan
Dynamic Scour	Typically located around obstacles such as bridge abutments.
Dynamic Lineations	These are bedforms which are parallel to the current in contrast to the waves/dunes which are typically aligned perpendicular to the current. Examples of lineations with distinct topographic relief are found in the Highlands.
Dynamic Drift	Regions characterized by deposition in the lee of obstacles. Often scour is also evident along the edges of the obstacle so that regions of dynamic drift are characterized by both deposition and erosion.
Dynamic Streaks	Features visible in the backscatter are aligned along the current but have no evident topographic relief. Examples of these features are associated with the Newburg Beacon Bridge (A2).
Dynamic Slumps	Features which are found a few times in the interpretation for example the slump structure along the edge of the channel adjacent to Catskill Creek and the slide off of Stony Point.

(d) Unknown

Significant fractions of the riverbed are difficult to resolve either due to poor penetration of the Chirp data or the absence of clear stratification. Some of the areas were too shallow to survey. These regions have been interpreted as unknown.

We have identified 2 major subclasses for the dynamic environment:

Table 14: Unknown Classifications

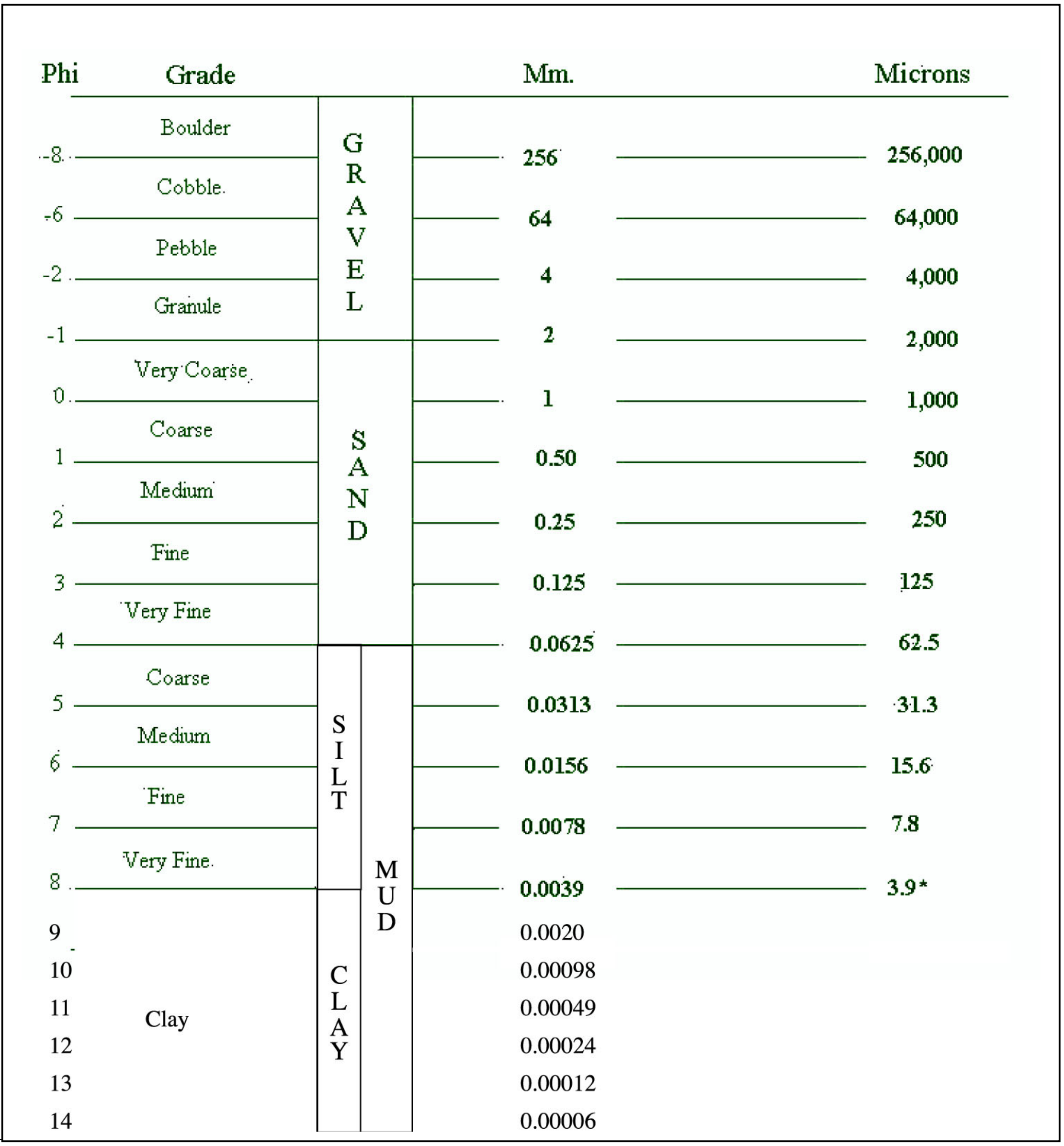
Unknown Classification	
No data	These regions are not classified due to lack of data coverage. These are generally the shallow regions which were not surveyed.
Uncertain	These regions are classified uncertain due to ambiguity in the data sets.

(2) Sediment Type

Interpretation - The sediment type interpretation is base on the grain size analysis of the cores and grabs with some guidance from the backscatter data. The SPI data has also been used to supplement these interpretations. Since the first guide in developing this interpretation is contouring the results of the grain size interpretation there is deviation from the sidescan images. An example of this deviation is off Croton Point where two regions of high backscatter are not evident in the grain size analysis. The northern arcuate region is an oyster reef and the southern region is a broad area of scour, scour evident in the chirp data but not in the grain size.

In most research on sediments, grain-size data is given in phi (ϕ) intervals rather than in microns, millimeters, or inches. One phi unit is equal to one Udden-Wentworth grade[3]. Phi diameter is computed by taking the negative log of the diameter in millimeters. A table of the Wentworth Phi scale has been included here for reference.

Table 15:Phi Scale



Phi	Grade			Mm.	Microns
	Boulder	GRAVEL			
-8				256	256,000
	Cobble				
-6				64	64,000
	Pebble				
-2				4	4,000
	Granule				
-1				2	2,000
	Very Coarse	SAND			
0				1	1,000
	Coarse				
1				0.50	500
	Medium				
2				0.25	250
	Fine				
3				0.125	125
	Very Fine				
4				0.0625	62.5
	Coarse	SILT	MUD		
5				0.0313	31.3
	Medium				
6				0.0156	15.6
	Fine				
7				0.0078	7.8
	Very Fine				
8				0.0039	3.9*
9	Clay	CLAY		0.0020	
10				0.00098	
11				0.00049	
12				0.00024	
13				0.00012	
14				0.00006	

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[3] Wentworth, C. K., 1922. A scale of grade and class terms for clastic sediments; Journal of Geology, 30: 377-392.

We have identified 7 major classes of sediment based on the Wentworth classification:

Table 16: Sediment Classifications

Sediment Classification	
Mud	> 90% mud (silt and clay)
Sandy Mud	Mud with > 10% sand
Muddy Sand	Sand with >10% mud
Gravel	> 90% gravel
Sandy Gravel	Gravel with >10% sand
Gravely Sand	Sand with > 10% gravel
Bedrock	

(3) Morphology

The proposed morphology interpretation framework characterizes the major regions of the river based on depth ranges and slopes. We have defined 4 major morphologic units for

(a) Channel

The channel floor is the deep portion of the river and bounded by steep slopes.

We have identified four distinct subclasses to the channel:

Table 17: Channel Subclasses

Channel Subclasses	
Channel Floor	the generally level center region of the channel
Channel Axis	the line which defines the deepest portion of the channel
Channel Wall	the steeply sloping regions abutting the channel floor
Channel Terrace	an intermediate depth, gently sloping region

(b) Margins

The margins of the river include the variable morphology of the shallow portions of the river.

We have identified three major subclasses for the river margins:

Table 18: Margins Subclasses

Margins Subclasses	
Marginal Flats	Shallow, low gradient regions – Tappan Zee
Marginal Ramps	Edge of the Highlands
Marginal Pools	Enclosed Basins

(c) Other

A number of distinctive morphologic structure have been identified in the river which do not simply fit into either the marginal or channel classification.

The subclasses we have identified include:

Table 19: Other Subclasses

Other Subclasses	
Banks	The river bank, the edge of the river where imaged in the geophysical data
Bar	The shallow regions, often separating multiple channel in the upper river. Examples include the Flats and the Hogsback.
Pinnacles	In the Tappan Zee region and southern Haverstraw Bay the isolated peaks elevated 4 m about the channel floor have been classified as pinnacles.

(d) Unsurveyed

Portions of the river shallower than 2 m were not covered in our survey. These regions are classified as unsurveyed.

(4) Anthropogenic

The interpretation of the Anthropogenic material is based on the multibeam data, the backscatter data and the chirp data.

We have four major categories identified.

Table 20: Anthropogenic Categories:

Anthropogenic Categories		
Possible Cultural Resources	Instead of specifically identifying features as we did during the first phase of the project we have developed a broader theme. This theme will include the shipwrecks, fish weir and Cheveaux de Frise themes from earlier projects.	
Constructions	Many structure visible on the riverbed in the benthic mapping data have been constructed in the past 75 years. Often these are well documented on the NOAA charts. These include the bridge footings (A2,A3), the water intakes (A2), the cable crossings (A2) and the pipelines (A3). We have identified:	Identified Structures Trenches Bridges Cables Pilings Intakes Navigational Aids
Dredged Areas	The dredged channels are clearly visible in the multibeam data (A3). Often these regions also have a distinct character in the Chirp data as well (B3).	
Debris Fields/Dredge Spoils	We have identified both regions of debris field (aka doughnuts, A1, A2) and clear dredge spoil deposits (A4).	

(5) Habitats

Although much of the correlation between the geophysical data and the benthic habitats is a point of research we have identified several well defined habitats which we include as themes.

Table 21: Habitat Categories

Habitat Categories	
Shell Beds	The exposed fossil shell beds in the Tappan Zee (A1, B2, B3) are confirmed to be oyster beds by the SPI photography.
Submerged Aquatic Vegetation	The root structure of the submerged aquatic vegetation appears to make a distinctive pocked structure in the backscatter data (A2,A3,A4).

(B) Detailed Sediment Classification Areas Piermont, Haverstraw Bay, Hudson Highlands and Catskill Creek Reaches (B2,B3,B4,B7*)*

(1) Piermont – B2

(a) Morphology

The morphology of the Piermont region is characterized by broad marginal flats along the western shoreline surrounding the Piermont Marsh, a linear channel and narrow marginal flats along the eastern shoreline. A distinct channel terrace is formed along the western channel wall becoming up to 800m wide off the Piermont Pier.

(b) Sediment Type

The Piermont region sediment type is based on the interpretation of the grain size analysis of the core tops of 47 cores and 21 grabs. In general the marginal flats along both margins are characterized by mud, An arcuate region centered on the Piermont pier is generally sandy mud. A similar arcuate feature, consisting of sandy mud, extends from South Nyack to the channel 1 km south of the Tappan Zee Bridge. The axis of the channel is characterized by ~100m wide stripe of gravel. A three km long deposit of gravel is located south of the bridge. A second 2 km long gravel deposit is located off of Sneden’s Landing and a third is found north of the bridge. These gravel features are bounded by similar elongate but sandy north-south trending deposits. The remainder of the channel floor and wall are characterized by sandy mud with the exception of a muddy deposit along the western channel wall off of Piermont.

(c) Depositional Environment

The marginal flats range in depth from 4m close to the channel to less than 2 m west of the Piermont Pier. Deposition in this region of mud is evidenced by low backscatter and a thin drape both south and north of the pier. South of the Pier a 300m wide swath of deposition extends to the southern edge of the Piermont (B2) study area. A similar region of thin drape and low backscatter characterizes the shallow regions northwest of the pier. This depositional region is disrupted in several locations by erosional and dynamic features. South of the Tappan Zee Bridge, along the western shore off of Grandview, a localized strip of erosion ~100m wide has developed. This narrow strip of erosional or non-deposition is associated with a pinching out of the thin drape to the east. The Tappan Zee Bridge with its closely spaced supports is associated with an east-west trending region of dynamic scour which extends across the river from shore to shore. Beginning about 1 km from the western shore this dynamic scour is accompanied by a region of dynamic drift extending both north and south of the bridge. These sediment drifts have significant topography with the north-south trending ridges having elevations of up to 2m. The deposition environment is terminated in the north by the east-west trending exposed oyster beds off South Nyack about 500m north of the Tappan Zee Bridge. On the western side of the river the marginal flats north of the oyster beds are non-depositional with the exception of a 400m wide north-south trending region along the edge of the channel where thin deposition is evident in the Chirp data. This deposition may be the northern extent of the bridge associated drift and deposition.

The deposition on the marginal flats is bounded to the east by an extensive erosional/nondeposition region extending from 200m south of the Tappan Zee Bridge to just north of the gas pipeline crossing at Snedens Landing. This region is generally characterized by sandy mud. The 5.5 km long arcuate region of erosion and non-deposition is over 1100m wide in the north and narrows to ~200m in the south. The locus of erosion is a 2.5 km long region centered at the Piermont Pier. In much of this region truncated reflectors are evident in the chirp data and the multibeam bathymetry is dominated by outcropping beds trending southwest-northeast. This region is interpreted as erosional based on the truncated reflectors while the northern and southern extents are classified as erosion/nondeposition based on the morphology and the high backscatter. This extensive erosional region centered on the Piermont Pier is a result of the changed flow caused by the construction of the Pier in the 1840's. Two narrow strips of deposition cross cut this broad erosional region which are associated with the channels dredged into the Pier.

The channel of the Piermont region is dominated by flow-perpendicular sediment waves in the channel and along the channel walls. These extensive regions of sediment waves have sediment types which range from gravel along the channel axis north of the bridge, from the southern extent of the Dynamic drift associated with the Tappan Zee Bridge to the Piermont Pier and for a 2 km stretch of the channel off of Hastings. These axial gravel are surrounded by sand deposits. The remained of the channel, the channel walls and terrace are sandy mud. This extensive region of sediment waves is interrupted by the pipeline crossing at Sneden's Landing and the Tappan Zee Bridge. The pipeline has little topographic expression along the western channel wall but is associated with a deep trench across the channel floor. Dynamic scour is evident in the backscatter data along the pipeline across the width of the river. Dynamic streaks, regions of low backscatter with no morphologic relief, extend both north and south of the pipeline along the western channel wall.

The eastern margin of the Piermont area is generally mud and low backscatter. Between Kings Point and the Tappan Zee Bridge marginal flats are characterized by low backscatter and thin drape in the chirp data. A region of non-deposition, characterized by high backscatter is found along the steep channel walls between the dynamic waves of the channel and the thin deposition of the eastern marginal flats.

(d) Anthropogenic

The anthropogenic features in the Piermont region are associated with the major construction projects in the region, the cable crossing off Kingsland Point, the Tappan Zee Bridge, the dredge channels into the Piermont Pier, and the El Paso Pipeline at Tallman Park. Over 40 individual dredge spoil deposits were identified along the channel and the channel walls. Over 30 possible cultural resource sites were identified.

(e) Habitats

Oyster reefs have been mapped in the Piermont region, both exposed, as evidenced by high backscatter, and buried, as imaged in the chirp data. A 500m wide exposed bed extends from South Nyack over 2 km to the east. This oyster bed continues up to 500 m further to the north under sediments. Two smaller oyster bed, primarily buried were mapped in the center of the Piermont Flats, south of the Tappan Zee Bridge. Distinct pinnacles, interpreted as eroded oyster bed, were mapped along the eastern edge of the channel 500m south of the Tappan Zee Bridge.

(2) Haverstraw – B3

(a)Morphology

Haverstraw Bay is separated into two major morphologic units: A large up to 4 km wide shallow marginal flat region dominates the east whereas the major broad channel is the principal feature of the west. The broad channel is up to 2 km wide, although the river cross section narrows at both the northern and southern end of the Bay.

(b)Sediment Type

The Haverstraw region sediment type is based on the interpretation of the grain size analysis of the core tops of 53 cores and 50 grabs. In general the marginal flats in enclosed portions of the Haverstraw region are characterized by mud. Close to the channel the sediment type becomes sandy mud. This sandy mud deposit extends from the southern tip of Croton Point to western edge of the channel margin and north to Montrose Point. The sandy mud includes both the western edge of the marginal flats and the eastern channel wall. Along the northeastern side of Haverstraw Bay sandy mud and sand are associated with the promontories, including Georges Island and Oscawana. Similar elongate deposits of sandy mud are associated with the Stony Point and Grassy Point promontories. The dredged portion of the channel in Haverstraw Bay is characterized by mud. As the river cross section decreases both to the north and south the sandy mud is found in the channel and thin strips of sand.

(c)Sedimentary Environments

In Haverstraw Bay the majority of the shallow (~3m) marginal flats area is covered by a thick layer of unconsolidated mud. In some locations an underlying reflection indicates a thickness of about 1-2 m. Although this reflection occasionally becomes shallower, the whole area has been classified as thick deposition. The age of the deposition is unknown although an uncorrected C14 age of 3795 ± 35 years on an oyster shell from 229 cm depth in vibracore CD02-05 in the Haverstraw Bay marginal flats supports the concept that this region is depositional. Along the northeastern edge of Haverstraw Bay, from Georges Island to 2 km east of Oscawna, three finger-like features up to 1500m long and 200-300 m wide extend south into the marginal flats. These features are characterized by high backscatter and coarser, sandy material. The coarser material and the high backscatter indicate these features are the result of scour or possibly related to coarse sediment inputs from Furnace Brook and other small tributaries. Towards the south the thick deposition unit is bounded by an elevated fossil oyster bed which extends from the northern tip of Croton Point to edge of the channel. This bed is generally 2.5m deep, 50 cm above the marginal flats to the north, and is characterized by a strong backscatter signal. Grab samples of this area yield abundant shell material although no live oysters were recovered. A second high backscatter region is found south of the elevated shell bed. Truncated reflectors and the absence of a recent drape indicate predominantly erosional processes although the grain size analysis indicates the material is similar to the depositional marginal flats to the north. The high backscatter in this region is a result of truncated bed exposed at the surface.

The broad Haverstraw Bay channel is on average 2 km wide. The center of the channel was dredged as recently as in the 1980s but has been subsequently re-filled with mud. Most of the channel floor and parts of the channel wall and terraces are covered by a thin mud drape visible in the Chirp data and associated with low backscatter values. In some locations a gas layer is present close to the surface of this mud drape producing high backscatter values in this generally low backscatter depositional unit. These high backscatter regions have also been classified as deposition-thin. The steep channel walls are characterized by scouring and erosion. For example, off of Montrose Point along the east side of the channel contains many incisions, isolated blocks and other signs of erosion. This erosion is focused along the boundary between the channel and the marginal flats. This region has been characterized as erosional.

At both the north and south end of Haverstraw Bay the general cross-section of the river decreases, the flow velocities increase. Associated with the changing cross section the channel forms elongated depressions. The eastern channel walls of both these depressions are characterized by patches of sediment waves. Some of these sediment waves are covered by mud. Therefore it is unclear, which of these waves are active presently. The west sides of both depressions and the axis of the southern pool are also dominated by scouring and winnowing and therefore are categorized as dynamic.

The narrow shallow marginal flats along of the western edge of Haverstraw Bay are mainly depositional with varying thickness. The marginal flats are segmented by two dredged channels, one into the town of Haverstraw and one into a marina south of Grassy Point. The bottom around these dredged channels appears to be mainly scoured. Stony Point and Grassy Point, two rock promontories that extend into the channel, are associated with scouring around their bases. The river bottom near Stony Point is covered by gravel and rock debris that could either have been eroded from the outcrop or resulted from a rock slump or slide from the steep slope.

(d)Anthropogenic

Dredge channels are evident into the Haverstraw Marina and at an outfall just north of Bowline Point. Major debris fields were identified along the channel wall east of Tellers Point, off the quarry in south Haverstraw and at Tompkins Cove. Evidence of a pipeline is seen in the channel just south of Stony Point. About 10 individual dredge spoil deposits were identified along the channel and the channel walls. Approximately 30 possible cultural resource sites were identified.

(e) Habitats

A fossil oyster bed was mapped extending over 2 km northwest from the northern end of Croton Point. The fossil bed is 800m wide in the east and thins towards the channel in the west. Several grabs over this feature were empty although one grab recovered abundant oyster shells. Several pinnacles were identified in the deep water area off Croton Point. These could be the remnants of old oyster reefs.

(3)Hudson Highlands – B4

(a)Morphology

The Hudson Highlands are characterized by a deep channel with very steep, often bedrock, channel walls. Marginal flats are developed at the mouths of creeks including Peekskill Cove, Iona Marsh and Constitution Marsh. Deep pools tend to develop adjacent to bedrock promontories such as Little Stony Point and Con Hook as well at sharp bend in the river such as Worlds End at West Point, the bend at Bear Mountain and the bend off of Jones Point and Dunderburg Mountain. The depths shoal from Jones Point south towards Haverstraw Bay. A new kind of morphological feature has been identified in this section of the river. A lobe is a large cone-shaped sediment deposit, generally with its apex at the shoreline and near a marsh or river. These lobes may represent deposits created by sediment delivered to the river, but the deposits could have been created at an earlier time, certainly before the construction of the railroad and perhaps in pre-historic time. Lobes may develop in this part of the river because of its great depth.

(b) Sediment Type

The Hudson Highlands region sediment type is based on the interpretation of the grain size analysis of the core tops of 11 cores and 45 grabs. The dominant sediment type of the Highland is mud. The mud deposits are generally located in the deep pools at the river bends and adjacent to promontories. Sandy mud and in one instance sand, is located along shallow saddle between the deep pools, adjacent to tributaries and where the channel wall has a gentle slope. For example off of Jones Point the saddle between the deep Bear Mountain pool and the Jones Point pool is characterized by sand and sandy mud. Similar sandy mud deposits are found on the saddle between the Jones Point pool and the pool at the northern end of Haverstraw Bay, the saddle both between the Bear Mountain pool and the Con Hook pool and on the saddle between the Con Hook pool and West Point. Tributary deposits, sandy mud, are found at the mounts of the Poplopen Creek just north of the Bear Mountain Bridge and Cooper Creek adjacent to Manitou Marsh in Garrison.

(c) Sedimentary Environments

The sedimentary environment of the Hudson Highlands stretch is primarily dynamic, characterized by fields of bedforms, river-parallel bands of scour and streaks as well as regions of thin mud deposition. Both flow-parallel and flow-perpendicular bedforms are observed. The flow-parallel bedforms are categorized as dynamic –

lineated bedforms and the flow-perpendicular features are categorized as dynamic – waves. The nature of the bedforms closely linked to sediment type; flow-parallel bedforms are found within muddy sediments and flow-perpendicular bedforms within sandy-muds. The abundance of thin deposits of mud within the region is striking given the dynamic flow regime through this narrow bedrock controlled portion of the river.

From north of Peekskill Bay to Cold Spring/Foundry Cove, exposed bedrock outcrops are found along the channel walls. The bedrock exposures are categorized as erosion – bedrock. Within this same stretch of the river, a thin drape of sediment blankets bedrock along the channel walls and across the channel floor within the deep channel bend at West Point, World's End. These regions of sediment drape over bedrock is categorized as deposition – bedrock drape. Local elongated deposits of mud associated with bedrock obstructions are also common within this stretch of the river and are categorized as deposition – drifts.

Active erosion of older sedimentary layers is evident from Chirp data in three distinct locations, all of which are associated with local shoals along the channel margins. The regions of truncated reflectors and high backscatter are categorized as erosion – truncated layers. In all cases, Chirp data show dipping layers which are truncated by the modern river bottom. These regions are coincident with local shoals suggesting that the river is currently downcutting former depositional sites. The three locations are along the eastern shore off of Peekskill Bay, along the eastern shore in Garrison just north of Arden Point, and along the western shore adjacent to Storm King Mountain north of Target Point. The truncated dipping sediments found at the outside channel bend off Peekskill Bay may reflect cutting of a new channel into a former point-bar deposit.

Thick (> 50 cm) deposits of muds are found within shallow regions near the riverbanks both north and south of the narrow, bedrock-dominated portion of the river. These low backscatter deposits, categorized as deposition thick, are found on the west edge of the river south of Dunderburg Mountain/Jones Point, and between Target Point and Storm King Mountain. Along the eastern shore thick depostional units are located along the eastern margin at Peekskill Bay and between Foundry Cove and Little Stony Point.

Large regions of dynamic scour and dynamic streaks are found along the channel floor throughout this stretch of the river. Areas classified as dynamic streaks are comprised of thin layers of mud, typically not discernable in the Chirp data, which are streaked out along the river bottom parallel to the flow direction. These regions are characterized as alternating bands or "streaks" of low and moderate backscatter. This sediment class appears to be a transitional class often adjoining areas of scour and thin deposition. The nearby areas of thin deposition may be the sediment source for the thin muds within the streak areas.

(d) Anthropogenic

Three large debris fields were identified along the channel and the channel walls. One large field extends over 1500m from Iona Island to Jones Point and is up to 500m wide. Two smaller fields were identified between Tompkins Cove and Verplank. Seven individual deposits were also identified between Iona Island and Verplank. No debris fields of dredge spoils were identified north of Iona Island. Over 50 possible cultural resource sites were identified, most found north of Iona Island. Two outfall pipes were identified on the east side of the river in Peekskill. The pipeline crossing just south of Indian Point, consisting of at least three cuts, is evident in the data. This feature is being covered by a sediment deposit on the west side of the channel.

(e) Habitats

No habitats were imaged in the geophysical data in the Hudson Highlands.

(4)Catskill Creek– B7

(a) Morphology

The Catskill Creek region is characterized by large bars, narrow channels and broad marginal flats. The southern Catskill Creek region has two distinct channels, formed on either side of the central bars. The shipping channel has been dredged for much of this section of the river, although there has not been dredging recently. The central bars are Green Flat off Malden-on-Hudson and Upper or Livingston Flats off West Camp and an unnamed shoal between Silver Point and Duck Cove on the western shore and Twin Islands on the eastern shore. The northern Catskill Creek region is characterized by a single channel whose location is appears to be strongly influenced by the deposits associated with the numerous tributaries entering the river along this stretch.

(b)Sediment Type

Sampling has not been conducted on the upper river so to date there is no grain size data and no sediment type interpretation

(c)Sedimentary Environments

The Catskill Creek reach is characterized by large field of waves/dunes and dynamic scour that dominate the channels while the river margins and the central bars are characterized by deposition. Dynamic scour is evident along the channel, adjacent to bridge abutments and navigational aids.

The southern Catskill Creek region has two distinct channels, formed on either side of the central bars. The central bars are Green Flat off Malden-on-Hudson and Upper or Livingston Flats off West Camp and an unnamed shoal between Silver Point and Duck Cove on the western shore and Twin Islands on the eastern shore. The channels are characterized by scour and sediment waves of a range of sizes. The waves are found principally along the axis of the eastern Livingston Channel, along the western flanks the central bars (Green Flats, Upper Flats and the Twin Island Bar) and along the northern ends of the Upper Flat and the Twin Island Bar. The shallow margins are characterized by low backscatter and are interpreted to the depositional although we cannot determine the thickness of these deposits. The central bars or flats are also characterized by thin deposition in the chirp data. The northern and western edges of the flats are defined by high backscatter region of scour.

The northern Catskill Creek region is characterized by a single channel whose location is appears to be strongly influenced by the deposits associated with the numerous tributaries entering the river along this stretch. Along the edge of Inobocht Bay the channel is characterized by scour while an extensive sediment wave field forms along the eastern channel wall. The outer walls of the channels tend to have higher backscatter than the inner walls in river bends. Just to the north where extensive shoals develop off the Roeliff Jansen Kill on the east side of the river, scour is found along the channel floor adjacent to the tributary deposit and the sediment waves develop along the western channel wall. This field of sediment waves is well developed along the western channel margin from the Roeliff Jansen Kill to the mouth of Catskill Creek. The channel along the eastern shore is characterized by dynamic scour. The mouth of the Catskill Creek is characterized by thin deposition with the exception of a possible slump feature evident along the northern margin of the Creek. North of Catskill Creek the channel is characterized by extensive wave fields and some scour. The river margins are generally low backscatter and interpreted to be thin deposition. Scour is evident around the Rip Van Winkle Bridge abutments west of Rogers Island. The small bar west of Rogers Island is interpreted to be thin deposition. In the very northern portion of this region, just east the Hudson Light and west of the South Bay an older channel is observed in two chirp lines. This older channel is now covered by sediment waves.

(d) Anthropogenic

The anthropogenic features in the Catskill region are associated with the extensive dredging in the region. The prominent anthropogenic influence in the Catskill Creek reach is the dredge spoil fields along the eastern channel just north of Saugerties and off of the southern tip of Rogers Island and along both sides of the channel 2 km north of Saugerties. Over 20 possible cultural resource sites were identified. Several constructions, including a cable crossing at the northern end, and navigational aids are present in the channel north of the mouth of Catskill Creek.

(e) Habitats

No habitats were identified in the data. We believe that the submerged aquatic vegetation identified in the Phase 1 is only imaged seasonally. This data was acquired in the spring when it appears that there is not simple acoustic signature of submerged aquatic vegetation beds.

An appendix of Interpretive Maps is included with detailed morphological, sedimentary, anthropogenic and habitat information from each area (Appendix VIII).