NWRI - Technical Note
TN05-005

Environment Canada Environnement Canada

Canada

AQUATIC SUBSTRATE MAPPING IN SUPPORT OF CONSERVATION STRATEGIES FOR HURON BAY, LAKE SUPERIOR

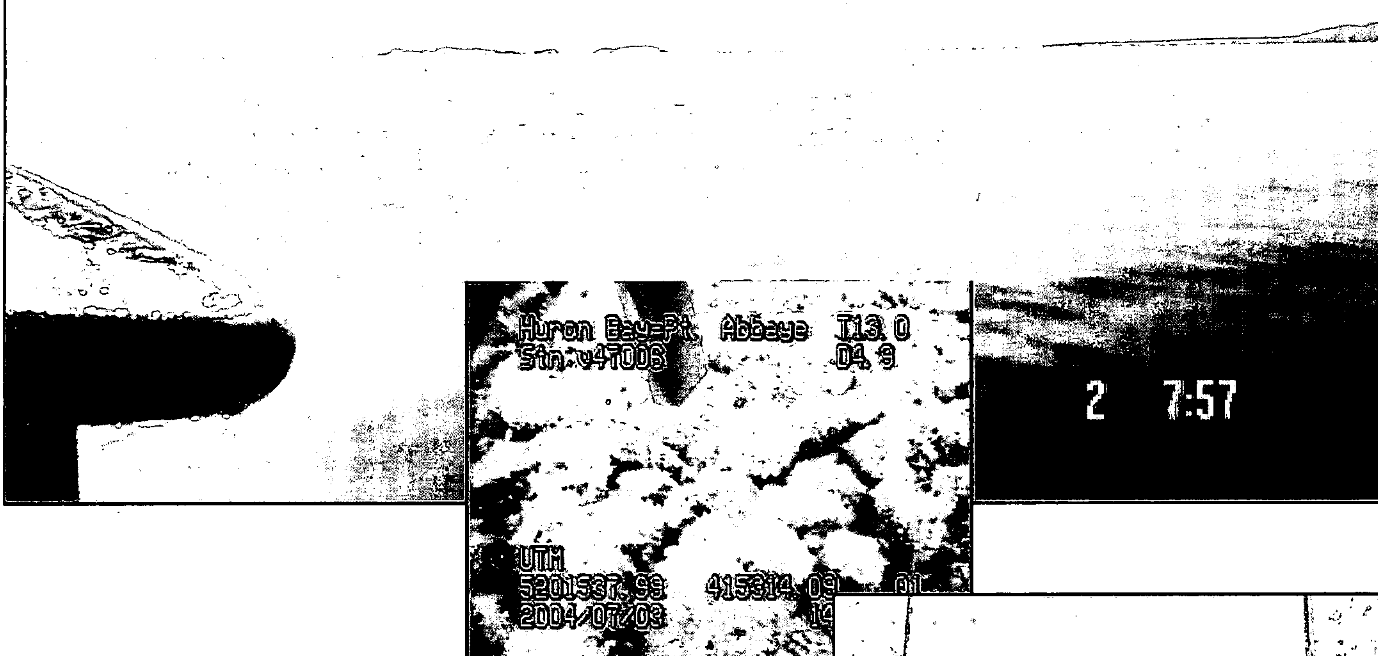
J. Biberhofer and C.M. Prokopec

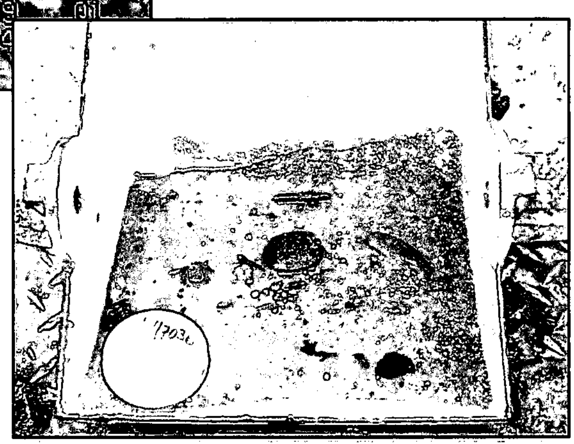
NWRI Technical Note No. AEMRB-TN05-005

NATIONAL WATER ... H INSTITUTE
... NATIONAL DE ... E SUR LES EAUX

Locator No: WQMS05-002
[redacted]

Aquatic Substrate Mapping in Support of Conservation Strategies for Huron Bay, Lake Superior.





Prepared by:
J. Biberhofer and
C.M. Prokopec

Environment Canada
National Water Research Institute

NWRI Technical Note No. AEMRB-TN05-005

Introduction:

The determination of the quality and quantity of aquatic habitat is an essential component of conservation management. The types of habitat required for particular fish species changes through the life history of the fish. The opportunity for the fish to exploit successive habitats is often a function of the connectivity or habitat corridors available to the fish. The quality of these habitats can often be impacted by land-based activities or the extraction of submerged resources that have become either integrated with or are co-located with particular habitats. A key objective of conservation management is to protect critical habitats and their corridors from degradation, disturbance or exploitation. Delineation of these habitats is an important element in the management and conservation of these resources.

The Keweenaw Bay Indian Community (KBIC) has management responsibilities for natural resources including the waters of Keweenaw Bay and Huron Bay of Lake Superior. Members of the Natural Resources staff are active in both regional conservation management initiatives as well as participating in broader Lake Superior basin programs. KBIC aquatic programs include an established fisheries monitoring program in Keweenaw Bay and operation a fish hatchery using native brood stock.

The National Water Research Institute (NWRI) of Environment Canada has successfully used an acoustic seabed classification system to map the distribution of aquatic substrates for a range of program objectives including the distribution of contaminated sediment deposits, sediment geometry and fisheries habitat. There is an ongoing research effort into refining procedures and developing technologies to improve the robustness of the measurements.

This report summarizes the methods employed by NWRI staff and the results achieved from an acoustic mapping survey of aquatic substrate. This study was the result of a scientific partnership initiated by the KBIC Natural Resources Department in support of their conservation management objectives.

Study Area:

The study area is located in the waters of the Huron Bay, Lake Superior in the Upper Peninsula of Michigan (Figure 1). Adjacent to the south west shore of the Bay are the lands of the Keweenaw Bay Indian Community. Forested land and cottages border most of the remaining shoreline. The marina in Skanee, Mi was used as a base of operations for the survey. The study area extended from navigable limits of the southern portion of the bay north to include Finlander Bay the crest and in-shore region of the Point Abbaye Reef. Three study zones were identified prior to the survey, Zone 1 – Southern Extent, Zone 2 - Middle Bay and Zone 3 - Outer Bay (Figure 2).

The survey effort for substrate classification, was limited to a water depth range of 2 m - 40 m. Additional soundings were collected in deeper waters (> 40 m) to develop a bathymetry model for the bay. The bathymetry data is of particular interest with respect to the steep slopes rising from the deep water of the bay. Primary spawning sites are often the littoral areas that suitable habitat which are immediately adjacent to steep slopes (J. Fitzsimons, personal comm.).

Survey Schedule

The study took place from June 29, 2004 to July 6, 2004. The first half-day was dedicated to launching the boat and system setup. Acoustic mapping started in the afternoon of June 29, 2002 and continued each day up to and including July 04, 2004. There was a break in the acoustic mapping on the afternoon of July 03, 2004 when underwater video was collected along the Point Abbaye Reef and Finlander Bay to take advantage of the good weather conditions. Weather was generally favourable with the exception of afternoon of July 02, 2004 when data collection was suspended due to unsuitable sea states. A total of 616.1 km of acoustic data was logged (Table 1).

Underwater video work was done on the afternoon of July 3, 2004 in the Pont Abbaye area (18 sites) and all day on July 05, 2004 in Huron Bay (57 sites). Sediment samples were collected at 26 sites on July 6th, 2004.

Field Procedures

Positioning

A NovAtel 3151W differential Global Positioning System (DGPS) with a 2 carrier signal antenna was used to collect position data for the soundings, underwater video and sediment sampling. The DGPS was enabled to include real-time Wide Area Augmentation System (WAAS) corrections as part of the DGPS solution. Position accuracy was monitored throughout the survey effort by recording the NMEA GPGST output string from the DGPS at 10 second intervals. The GPGST sting reports the standard deviation of the longitude and latitude of the DGPS solution.

Survey lines and target positions were created and displayed in Hypack © version 2.12 navigation software. The software provides a left-right indicator and target proximity information for the boat driver. Tracklines were generally run within 10 m or better of the planned lines and positioning for video and sediment sampling were usually within 2 m of target position.

Substrate Mapping - RoxAnn

Acoustic mapping of surface sediment with a RoxAnn™ seabed-classification system (Rukavina 1998, Rukavina and Cadell 1997) has been used at a number of sites in the Great Lakes basin to investigate the distribution of substrate types. This technology has recently been applied to map aquatic substrate to identify and quantify critical fish habitat in Lake Superior (Biberhofer 2004, Biberhofer 2003, Biberhofer, 2002).

The RoxAnn surveys were conducted between June 29, 2004 and July 05, 2004. The survey vessel Puffin, a 7 m aluminium launch, was equipped with a dual-frequency (50 kHz and 200 kHz) digital Knudsen sounder (Model 320M) with in-hull transducers. The return signal from each frequency of the sounder transmit was measured and processed with a dedicated RoxAnn seabed-classification system unit. This study will report only on the high-frequency data.

The RoxAnn output signal, G1 (roughness) and G2 (hardness), was converted to acoustic labels by Microplot™ survey software running on a dedicated rack-mount computer. Microplot logged the labels and the corresponding water depth and DGPS positions at 1-second intervals and displayed them in real time on a geo-referenced map (Figure 3). Survey lines were initially run at 100 m and 200 m offsets. The density of mapping was increased in nearshore areas with water depths less than 40 m. (Figure 4).

The RoxAnn readings, as measured by the response to a simulated sounder transmit, were logged at the beginning and end of each survey day to confirm equipment integrity and stability. The system was stable throughout the survey period.

Underwater video

An underwater camera mounted on a weighted tripod was used to collect underwater video records of the substrate at 71 sites (Table 2, Figure 5). The legs of the tripod have 10 cm colour gradations useful for comparing substrate size and depth of penetration when the camera is lowered onto the substrate. A DGPS antenna was mounted on the davit used for lowering the camera (Figure 6). At fixed target sites efforts were made to keep the boat stationary or at very low speeds to optimize the vertical and position accuracy between the antenna and the camera lowered in the water. Station information and real-time position data output, combined using custom software, was overlaid on the video signal from the camera by integrating the two inputs with a VideoStamp ™ processor (Figure 7). During the first series of video sites depth and water temperature data from an in-house sonde was also recorded. On the second day of video, the sonde malfunctioned. Depth data from the sounder were used for the station information for the remainder of the stations.

At some sites, particularly those sites that transitioned from sand to cobble or at sites where the substrate was heterogeneous due to debris, it was useful to record video transects as the boat drifted or moved slowly under power. During some instances, the position information was degraded up to 3 metres due to the slope of the line from the davit to the camera's tripod.

The video was recorded in a digital format on 8mm tape. Selected segments of the video were then extracted as computer images and computer video files for portability as well as to be included in a Geographic Information System (GIS) project.

Sediment Sampling

Sediment samples were collected at 26 sites (Table 3, Figure 8) with a Shipek sampler, which is very effective at collecting surface sediment. This layer of sediment has the most effect on the characteristics of the high-frequency return echo recorded with the RoxAnn seabed classification system. The sampler was deployed from a winch and davit setup on the launch with a GPS antenna mounted on the davit, similar to the setup for the underwater video. The collected sediment was described, photographed and sub-sampled for particle size analyses (Duncan and LaHaie, 1979).

Data Analysis

Bathymetric data

The water depth data can be collected over a wider range of vessel speeds and depths than the RoxAnn measurements. The bathymetric dataset included all the data collected for RoxAnn measurements, the depth data logged during video and sediment sampling, and during transit when the vessel speed was less than 8 $m.s^{-1}$. Additional track lines were run in deeper waters (>40 m) specifically for bathymetric data. The water depth data was adjusted to International Great Lakes Datum (IGLD) 1985 based on records from the water-level gauging station located at Marquette, MI (Station 9099018 Marquette C.G., MI, Northing 5154673.15 Easting 470993.74 Zone 16N) using a six-minute interval and time referenced to Eastern Standard Time.

A spatial raster model of the bathymetric data was generated using the nearest neighbour algorithm of the 3D Analyst extension of ArcGIS © (Environmental Systems Research Institute Inc (ESRI)) (Figure 9). The 3D model provides both a spatial context for the substrate data as well as identifying submarine topographical features that may modify the expected acoustic return data.

Substrate Mapping – RoxAnn

RoxAnn data were edited using spreadsheet macros to remove records for which the actual water depths were less than 2 m or when the boat speeds were less than 2 $m.s^{-1}$ and greater than 5 $m.s^{-1}$. Two meters is the shallow-water limit of the high-frequency RoxAnn system. Boat speeds outside the 2 to 5 $m.s^{-1}$ range result in shifts of RoxAnn labels to coarser and harder sediment classes than are actually present (N. Rukavina, personal comm.). Air bubbles or eddies under the vessel's hull compromise the RoxAnn signal integrity and are sometimes encountered when the velocities exceed the upper limit of speed range or when the seas are too rough. This processing resulted in a dataset of in 128125 soundings.

The dataset was further edited to remove soundings when the standard deviation of DGPS position solution, as reported by the GPGST string, was greater than 5.0 m for either the latitude or longitude coordinate (Figure 10). As the position data was recorded every second and the quality of the DGPS solution was logged every 10 seconds the data was edited in GIS rather than eliminating matching records. The GPGST dataset was edited to only include positions that had a position standard deviation greater than 5.0 m. A buffer was created around each position of the selected GPGST points that overlapped along the direction of the track line. Soundings that were included within the buffer (n=1067) were deleted from the dataset.

The final edited data for substrate mapping had 128125 soundings. The dataset was imported into Systat ® (Version 11, Systat Software Inc.) a Windows based statistical software package. To expedite testing for the most appropriate classification scheme, a subset of approximately 50% (64107 records) of the original dataset were randomly selected with an algorithm included in Systat. The test records were then clustered using the Systat K-means procedure with Euclidean as the distance metric and number of iterations set to 20. Several combinations were tested using G1, G2 as the variables and the number of clusters was varied using 6, 7 and 8.

The dataset and the cluster identifier file were merged and exported into an ArcGIS ArcMap © (Environmental Systems Research Institute Inc (ESRI)) readable format. The cluster identifier was then mapped as a substrate class in an ArcMap GIS project. The substrate label was determined by comparing substrate class with the images of the substrate, which were extracted from the underwater video records. The video sites selected, 60 of 71 visited, were matched with the nearest RoxAnn soundings that were within 5 m. The ArcMap "Hyperlink" feature was used to make direct visual comparisons of the substrate label and the substrate image (Figure 11). The grain size analysis from the 26 sediment samples (Appendix 1) was also compared with the substrate labels and the images.

Generally, there was fairly good correspondence between the range of the RoxAnn signals and the substrate type observed. To further improve the correspondence, the G1 and G2 values were transformed to $\log_{10}$ and natural log values. These variables were then reanalyzed with the K-means procedure. The best agreement with the video sites and sediment samples was the $\log_{10}$ transformed data 6 cluster dataset (Figure 12). The dataset was further processed to determine if discrimination of the cobble substrate class could be improved by extracting the cluster associated with coarse gravel and cobble. The cluster was processed separately by applying the K-means analysis to subdivide the data into 2 groups. There was no improvement in substrate classification when the results were mapped with the ground-truth data. Therefore, the substrate classification is based on six substrate type clusters that were discriminated based on the log (G1) and log (G2) values of the RoxAnn soundings.

Spatial analysis

To quantify the areal distribution of the substrates, the classified RoxAnn data was ingressed into MapViewer © (Golden Software Inc.) as the data source for generating Thiessen polygons. The procedure creates boundaries from point data so that a region is drawn around each point and that every position in the region around that point is closer to that point than to any of the other points. The polygons were then assigned the substrate classification of the associated point data. The boundaries of the analysis were limited to the nearshore extents of the edited soundings. This was to avoid implying a substrate type to the shoreline, as the distance from the closest sounding to the shore might be considerable, such as the eastern shore of Zone 1 that was too shallow to map.

As the extent of an individual Thiessen polygon is an extrapolation to the boundary of the adjacent polygon, the accuracy of the substrate area estimates can be affected by distance offset between track lines and the degree of natural variability of the underwater features. Areas such as the mud and muddy sand regions in the deeper waters tend to be uniform over large areas and are well represented with the Thiessen polygon procedure. The nearshore areas are often more heterogeneous which is often captured with tighter survey patterns and hence smaller polygons and shorter distances to extrapolate. It is possible that there may be features that were not detected, but based on the sounding coverage from this survey, the Thiessen polygon method should provide a reliable estimate of the distribution of the substrate types based on the classification techniques employed.

Results and Discussion

Bathymetry of the Bay

The bay is characterized by a deep central trough that tapers to a narrow but well defined submerged channel which is outlined by the 20 m contour in figure 13. This channel continues along the west side of the bay to Bendry Point. The wide littoral areas of the outer bay become narrow sills on both the east and west sides of the bay at Reeds point. The littoral area then expands on the east shore, south of Lighthouse Point but remains narrow along the west edge of the bay. South of Bendry Point the littoral zone is narrow until the southern extent where the bay is a shallow plateau. Throughout the bay, steep slopes are characteristic of the transition from the littoral zone to the deeper waters (Figure 13).

Substrate Classification

After comparing all the data, the best description of the substrate types was with 6 clusters or classes. These classes represent the substrate groups:

1. mud / sandy mud
2. muddy sand
3. sand
4. compact sand or fine-grained material on hard substrate (S-FOH)
5. gravel and cobble
6. bedrock and fractured bedrock

The muddy sand is a transition class from the mud / sandy muds to sand. The sand class is generally clean sand waves in lower energy zones. This contrasts with the compact sand or fine-grained material on hard substrate (S-FOH) class which tends to be in higher energy zones, typically along the edges of the steep slopes or in the littoral zones. A number of attempts were made to discriminate between the gravel and cobble classes with limited success in certain areas but not throughout the study zone. A review of underwater video shows that gravel areas tend to border cobble fields as a transition from the sand substrate. This apparent close proximity of the gravel to the cobble probably results in overlap of substrate types being sonified by the echo sounder pulse resulting in a modified acoustic return. This averaged echo mutes any boundary value that can be used for discrimination of the differences. The final substrate class, bedrock and fractured bedrock, is exclusive to the outer bay in the area of Finlander Bay and Point Abbaye Reef. Figure 14 illustrates examples of the six substrate types.

Zone 1 – Southern Extent

Zone 1 has the smallest area of the study zones and only half the area could be mapped due to the shallow water and dense macrophyte coverage in the south end of the bay. The substrate is predominately S-FOH with sand in the central portion of the zone. Muddy sand was mapped in the south east extent of the area that was sounded. The substrate transitions to sand and then hardens to S-FOH in the south central area of the zone. Harder and coarser substrate, gravel and cobble, was found along the edges of the slopes on the east and west banks (Figure 15). The hard substrate on the east bank may be in part debris from a derelict wharf that extended into the bay near the mouth of Slate River. An interesting artefact was detected from the sounding and was identified with the underwater video as an old sunken barge adjacent to this wreck (Figure 16).

Zone 2 – Middle Bay

The middle bay is the most complicated of the three zones due in part to variability of submarine topography. The constriction imposed by Bendry Point divides the area into 2 separate basins. The southern basin has a fairly consistent bathymetric profile with fine-grained substrates, muds through muddy sands, covering most of the area. The shallower littoral areas are typical of exposure to higher energy with sand and S-FOH mapped in these areas. In the central area of the southern basin there is an area that mapped as S-FOH that has a sand buffer around it and appears to be an extension of the substrate from the west shore.

There is a distinct zone of gravel or cobble at the south end of the southern basin that is adjacent the delta of the Ravine River. This cobble field may be the result of river wash carrying cobble and rock into the bay, similar to the cobble fields associated with the tributaries in Keweenaw Bay (Biberhofer 2002) (Figure 17).

At Bendry Point the variations in the substrate corresponds with the changes in the bathymetric features. The sill appears to be an extension of the point and forms the southern boundary of the trough that extends out to Lake Superior. The top of the sill has a combination of S-FOH and gravel and cobble. Immediately south of the sill there was a depression and the substrate rapidly changes to muddy sand and then mud. There was a less distinct ridge mapped on the south side of the depression and the top of the ridge transitioned to a narrow band of gravel and cobble (Figure 18).

The northern basin of Zone 2 had a more consistent pattern of substrate distribution, where muds and muddy sand dominant the deep basin. There is a rapid transition to coarser substrates along the tops of the slopes and into the littoral zones. There was a cobble patch on the west side, north of Bendry Point that extends into the littoral area. There were indications of gravel/cobble substrate along the fringes of the west shore of the survey area and rock outcrops were frequently visible from the boat but were generally inside the 2 m operational boundary for RoxAnn soundings (Figure 19).

One acoustic anomaly that was confirmed with underwater video was the small zone immediately south of Lighthouse Point and was one of the few areas of survey where the launch would have approached perpendicular to the aspect of the slope. This zone mapped as coarse gravel and cobble but the ground-truth data confirmed that it was predominately fine-grained sediment (Figure 20). This hardening of the signal has been described previously in acoustic mapping and is an artefact of compounding of the echoes when a steep slope is encountered (T. Eagan, personal comm.). The arc of hard substrate that follows the contour of the slope edge north northwest of Bendry Point may also have been the result of this phenomenon.

Zone 3 – Outer Bay

The southern extent of Zone 3 continues substrate distribution consistent with the northern extent of Zone 2. As the bay widens, the trough deepens and the steepness of the slopes becomes more pronounced. The littoral zone widens north of Reeds Point and continues to Finlander Bay and then becomes Point Abbaye Reef. Bedrock and fractured bedrock were exclusive to these areas. The rock was scoured and for the most part clean of any algae or other vegetation. On the lee side of the reef and in towards Finlander Bay there was a large area of cobble which comprised of both rounded and angular rock. The edges of the slopes to the trough were cobble and bedrock whereas the toe of the slope and to the depths surveyed, sand and compact sand was found (Figure 21).

The eastern littoral area had comparable substrate distribution to the west shore south of Finlander Bay. A zone of cobble and fractured bedrock extending out from the shore was mapped and confirmed using underwater video.

Spatial Analysis

The Thiessen polygon matrix provides an estimate of the quantity of substrate types as defined in this study (Figures 22, 23). The data included in table 4 summarizes the distribution of the substrate type by study zone areas. Each substrate classes were well represented in the bay as a whole, but each of the study zones had unique distributions.

Summary

The substrate distribution of the Huron Bay study area appears to be primarily a function of the bathymetric features of the bay. These features focus fine-grained material in the deep trough that extends from Bendry Point to Lake Superior. The higher energy zones along the shallower littoral areas are predominately sands, compact sands and thin layers of fine-grained material overlying a hard substrate. The sands are probably sorted by wave action and the veneer of fine-grained material may be transitory and displaced during higher energy events.

The sill projecting from Bendry Point represents the southern end of the deep trough from the lake and divides Zone 2 into 2 distinct basins. There were rapid transitions to different substrate types in the proximity of the sill. It was interesting to note that this was the only area during the survey where there was noticeable water current and the current flowed north to south. South of the sill and continuing into Zone 1 the submarine topography was moderate, lacking the steep slopes occurring north of the sill. Gravel and cobble were mapped at the mouths of the Slate and Ravine Rivers and could be the result of river transport to the bay. Some of the cobble mapped offshore the Slate River may also be the remains of a derelict crib pier.

The upper extent of Zone 2 and Zone 3 is dominated by the central deep water trough and basin. The northern extent of the west shore of the basin is sheltered by Point Abbaye and the reef that extends out from the point. There is a large area of cobble located in the lee of the point that extends the edge of the slope to the basin. This type of feature, cobble at the edge of a steep slope, has been described as potential primary spawning habitat for lake trout (J. Fitzsimons, personal comm.).

References:

Biberhofer, J. 2004. Aquatic substrate distribution in Michipicoten Bay, Lake Superior. Draft Report. National Water Research Institute, Environment Canada.

Biberhofer, J. 2003. Spatial Analysis of Substrate Classification Data for 2002 Keweenaw Bay Survey. Supplemental Report.

Biberhofer, J. 2002. Aquatic Substrate Mapping in Support of the Keweenaw Bay Indian Community Conservation Management Objectives. National Water Research Institute, Environment Canada.

Duncan, G.A. and LaHaie, G.G. 1979. Size analysis Procedures Used in the Sedimentology Section. NWRI. Hydraulics Division Manual, September 1979.

Marsden, J.E., Casselman, J.M., Edsall, T.A., Elliot, R.F., Fitzsimons, J.D., Horns, W.H., Manny, B.A., McAughey, S.C., Sly, P.G., and Swanson, B.L. 1995. Lake Trout Habitat – A Review of Current Knowledge. J. Great Lakes Res. 21(Supplemental):487-497

Rukavina, N.A. 1998. Experience with a single-beam seabed-classification system in environmental surveys of river and lake sediments. *In* Proceeding, Canadian Hydrographic Conference, Victoria BC, March 1998

Rukavina, N.A. and Caddell, S.E. 1997. Applications of an acoustic sed-bed classification system to freshwater environmental research and remediation in Canada. *In* Proceeding, 4th Conference on Remote Sensing for Marine and Coastal Environments, Orlando, Fls., March 1997.

Acknowledgements

Michael Donofrio, of the Keweenaw Bay Indian Community Natural Resources Department, was instrumental in initiating this project and provided direction for the study design and objectives. Mike Sladewski provided base map layers that were useful in the study design and also assumed the role of project coordinator in the final stages of the study.

The field crew appreciated the hospitality and support of the staff at the Keweenaw Bay Indian Community Natural Resources field office.

The extra effort made by the staff of Witz Marina in Skanne MI, which was our base of field operations, was most appreciated.

NWRI's Technical Operations Section provided the launch and staff support for field operations. Steve Smith of NWRI's Technical Operation Section provided direct support to field studies by Environment Canada.

Brian Trapp, NWRI, AEMRB was responsible for post-processing the video data.

This study was funded in part through a grant received by the Keweenaw Bay Indian Community from the United States Environmental Protection Agency – Great Lakes National Program Office.

Tables:

Table 1: Summary of Acoustic Survey Effort.

RoxAnn Sounding Tracks								
Collection Date	Raw Start Time	Raw Finish Time	Number of Records			Distance Covered (km)		
			Raw	RoxAnn Edited	Bathymetry Edited	Raw	RoxAnn Edited	Bathymetry Edited
29/06/2004	14:43:58	17:46:20	9608	9377	9533	41.7	40.9	41.4
30/06/2004	7:55:30	17:55:18	28719	24542	26876	121.4	103.6	111.2
01/07/2004	8:29:14	17:58:08	24441	23543	24158	104.3	100.7	102.8
02/07/2004	7:55:58	13:52:52	18705	17469	18553	83.8	79.1	83.0
03/07/2004	8:04:38	21:31:50	32829	31222	32681	144.5	134.0	140.8
04/07/2004	8:00:14	17:01:08	25788	23039	25478	120.8	101.9	113.9
		Total:	140090	129192	137279	616.5	560.2	593.1

Note: Sounding was suspended on July 03,2004 from 13:27 till 16:15 while underwater video was being conducted on Point Abbaye Reef and in Finlander Bay.

Table 2: Location of Underwater Video Sites.

Site	Date	Easting	Northing		Site	Date	Easting	Northing
V47001	2004-07-03	413863.0	5199482.5		V47040	2004-07-05	404947.5	5191830.6
V47002	2004-07-03	413880.3	5199936.0		V47043	2004-07-05	404931.7	5191893.7
V47003	2004-07-03	414310.9	5200983.4		V47044	2004-07-05	405224.5	5192402.4
V47004	2004-07-03	414820.6	5201753.1		V47045	2004-07-05	405452.5	5192290.5
V47005	2004-07-03	416355.9	5201992.9		V47046	2004-07-05	405317.9	5192355.9
V47006	2004-07-03	415314.1	5201538.0		V47047	2004-07-05	405352.3	5192410.9
V47007	2004-07-03	413954.1	5201932.2		V47048	2004-07-05	406007.6	5192042.5
V47008	2004-07-03	413176.8	5201029.7		V47049	2004-07-05	405929.7	5191928.3
V47009	2004-07-03	416288.0	5202752.6		V47050	2004-07-05	406767.9	5192574.0
V47011	2004-07-03	414877.1	5199519.3		V47051	2004-07-05	406378.9	5194096.5
V47012	2004-07-03	415932.7	5200175.1		V47053	2004-07-05	406131.8	5194162.4
V47013	2004-07-03	416305.5	5200102.8		V47054	2004-07-05	407345.9	5193662.2
V47014	2004-07-03	415387.6	5199987.2		V47055	2004-07-05	407520.7	5193462.4
V47015	2004-07-03	415386.7	5200312.1		V47056	2004-07-05	406596.4	5194656.2
V47016	2004-07-03	414816.4	5200019.6		V47059	2004-07-05	407125.5	5195191.7
V47017	2004-07-03	414333.8	5199482.5		V47061	2004-07-05	409373.2	5195162.9
V47018	2004-07-03	417962.2	5201517.1		V47062	2004-07-05	408841.6	5194792.4
V47021	2004-07-05	403957.0	5188577.9		V47063	2004-07-05	409075.9	5194957.7
V47022	2004-07-05	403809.0	5188512.0		V47064	2004-07-05	409582.2	5196506.0
V47023	2004-07-05	403351.3	5188087.3		V47065	2004-07-05	409973.6	5196927.8
V47024	2004-07-05	402991.1	5187746.9		V47066	2004-07-05	410167.4	5197181.8
V47025	2004-07-05	403961.0	5189003.7		V47067	2004-07-05	410328.8	5197159.7
V47026	2004-07-05	403721.6	5188867.5		V47068	2004-07-05	410507.0	5197172.8
V47027	2004-07-05	404288.0	5189108.5		V47069	2004-07-05	413973.7	5196273.4
V47028	2004-07-05	404314.1	5189453.6		V47070	2004-07-05	414434.8	5196430.9
V47029	2004-07-05	404209.5	5189589.6		V47071	2004-07-05	413133.9	5196408.2
V47030	2004-07-05	404297.3	5188663.8		V47072	2004-07-05	414766.4	5196961.7
V47031	2004-07-05	404553.0	5189041.0		V470724	2004-07-05	415472.6	5197322.5
V47032	2004-07-05	404394.3	5189713.5		V47073	2004-07-05	415469.7	5196808.1
V47033	2004-07-05	404579.5	5190414.5		V47075	2004-07-05	406797.5	5193023.8
V47034	2004-07-05	404721.3	5190520.2		V47076	2004-07-05	406994.1	5193047.3
V47035	2004-07-05	404758.5	5190907.9		V47077	2004-07-05	405592.7	5192633.3
V47036	2004-07-05	404808.8	5190979.9		V47092	2004-07-05	411383.3	5195456.0
V47037	2004-07-05	404892.9	5190313.7		V47095	2004-07-05	412934.8	5199476.2
V47038	2004-07-05	404995.8	5190618.5		V47101	2004-07-05	412799.5	5199779.8
V47039	2004-07-05	405011.4	5190934.0		Wreck	2004-07-05	403406.7	5187840.7

Table 3: Location of Sediment Sample Sites.

Site	Easting	Northing
s47001	405786.0	5192582.0
s47002	406068.0	5192457.0
s47003	406334.0	5192416.0
s47022	403808.0	5188516.6
s47026	403721.2	5188870.2
s47031	404552.7	5189043.1
s47032	404395.1	5189713.1
s47033	404579.7	5190415.3
s47034	404721.6	5190519.6
s47035	404756.6	5190907.4
s47036	404808.1	5190982.0
s47038	404996.0	5190618.1
s47040	404950.1	5191833.0
s47043	404935.4	5191896.0
s47044	405222.9	5192402.4
s47045	405453.5	5192289.8
s47046	405351.9	5192413.5
s47050	406771.5	5192573.0
s47051	406384.0	5194098.4
s47062	408845.3	5194792.8
s47063	409073.9	5194955.4
s47065	409973.8	5196925.8
s47068	410514.4	5197174.7
s47071	413134.4	5196407.4
s47077	405595.1	5192632.5
s47092	411385.1	5195455.0

Table 4: Areal Coverage of Substrate Classes

Substrate Class	Surface Area (hectares)			
	Lower Area	Middle Area	Upper Area	Total
Muds / Sandy mud	0.0	235.1	321.9	**557.0**
Muddy Sand	5.2	170.5	215.8	**391.5**
Sand	38.6	159.0	709.4	**907.0**
Sand compact or fine on hard	53.9	159.8	579.7	**793.4**
Coarse gravel and cobble	8.5	22.0	923.3	**953.9**
Bedrock and fractured bedrock	0.0	0.9	958.7	**959.6**
Total Area Surveyed	**106.2**	**747.3**	**3708.8**	**4562.3**

Figures:

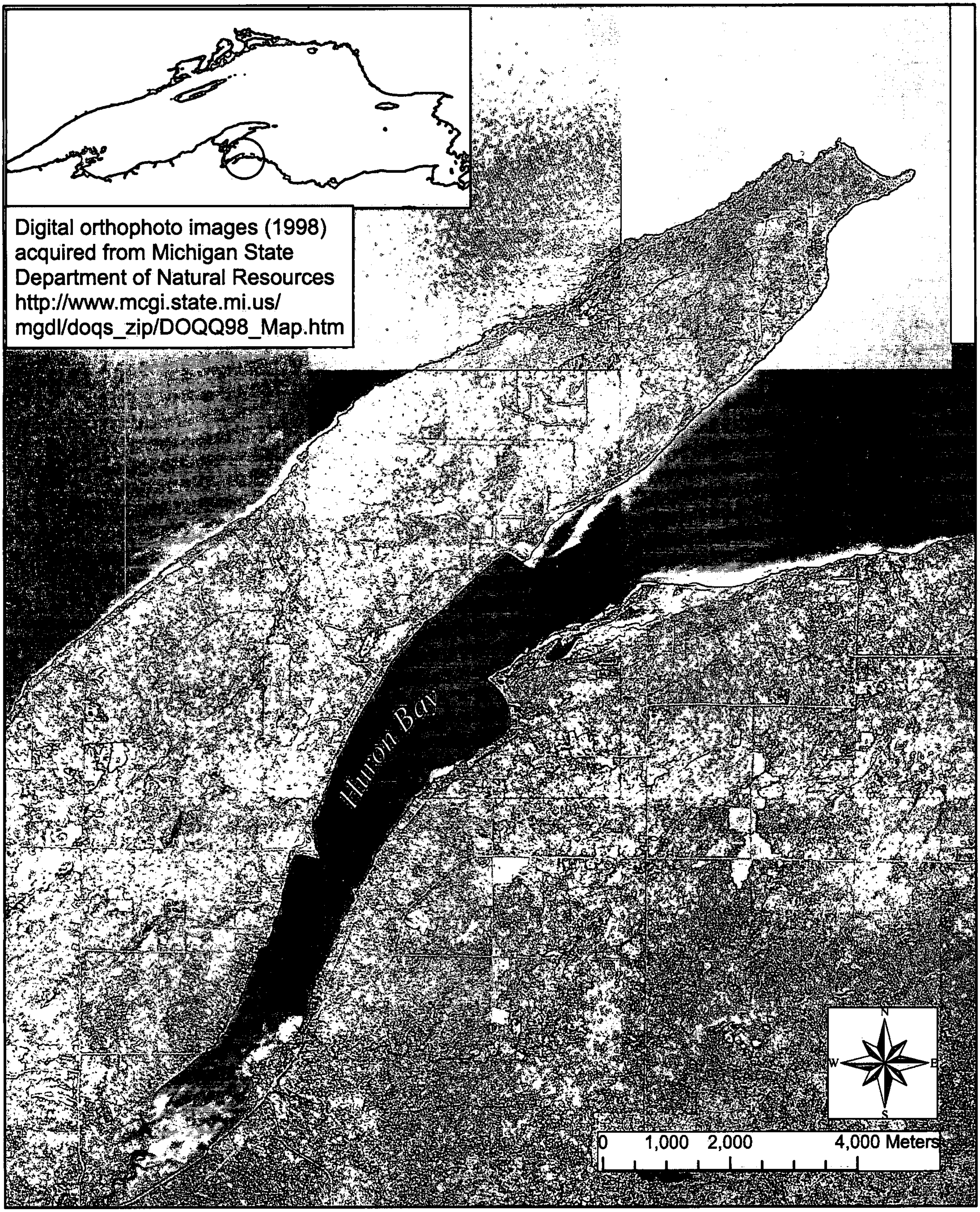


Figure 1: Huron Bay, Lake Superior.

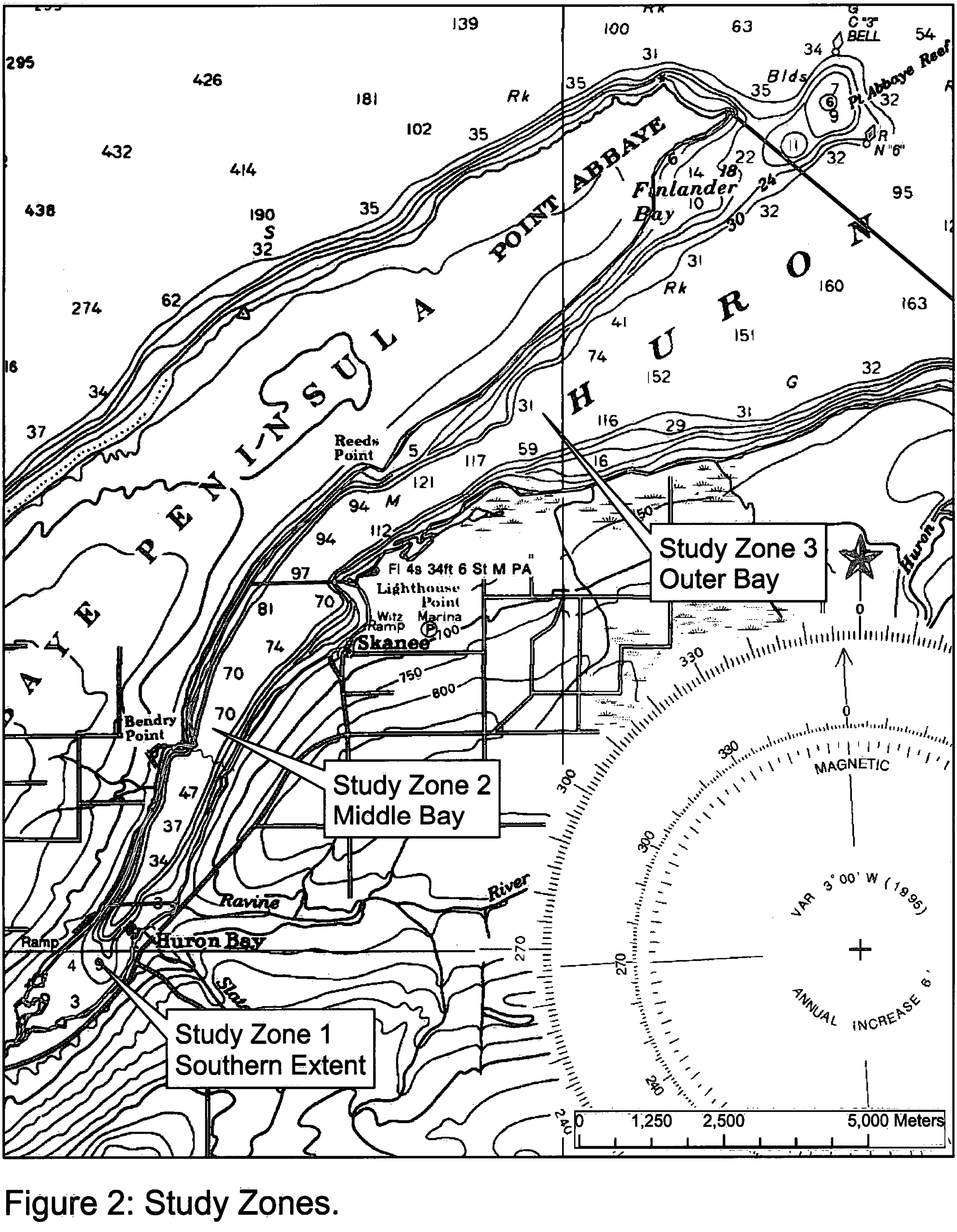


Figure 2: Study Zones.

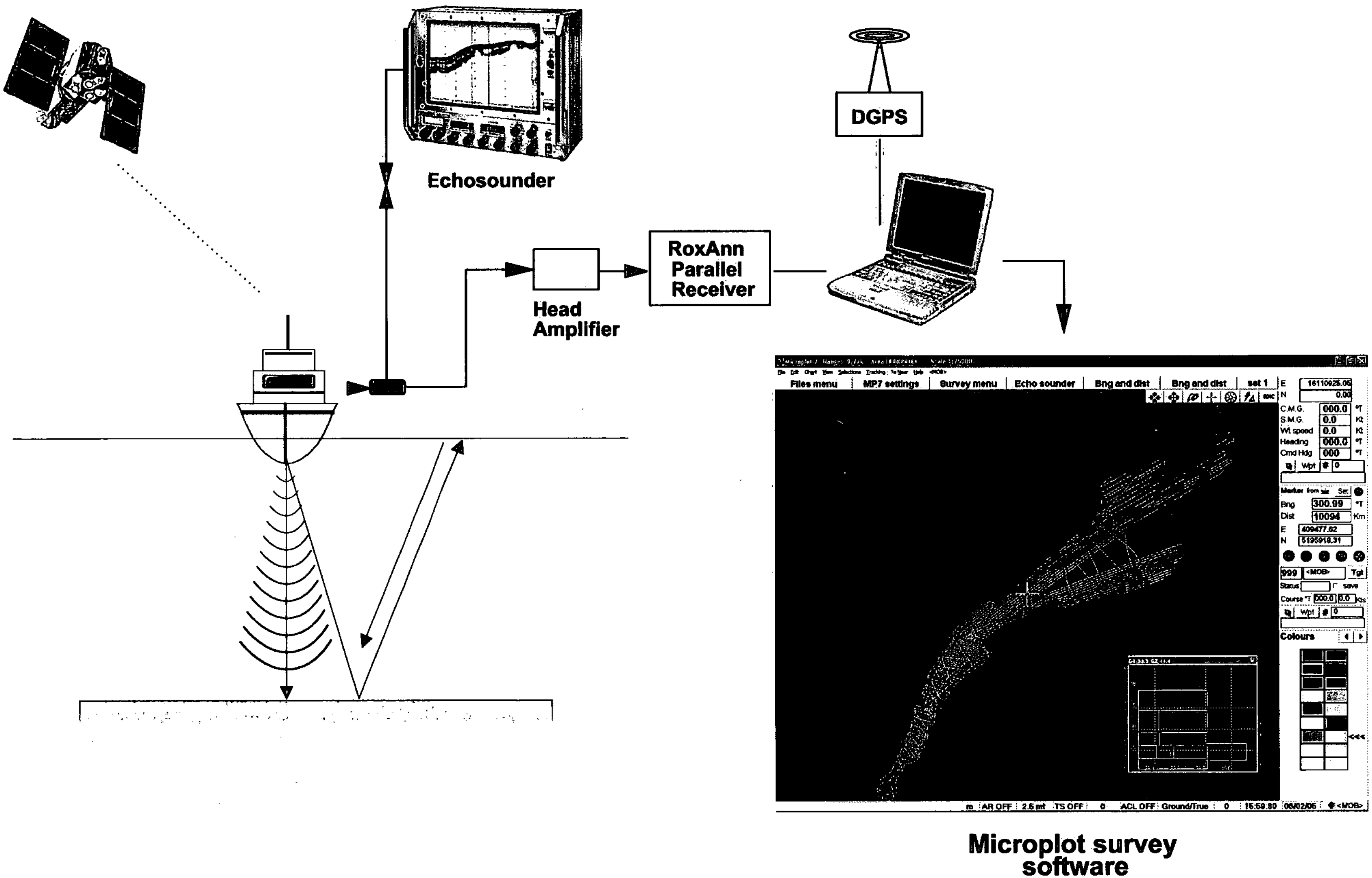


Figure 3: RoxAnn Schematic

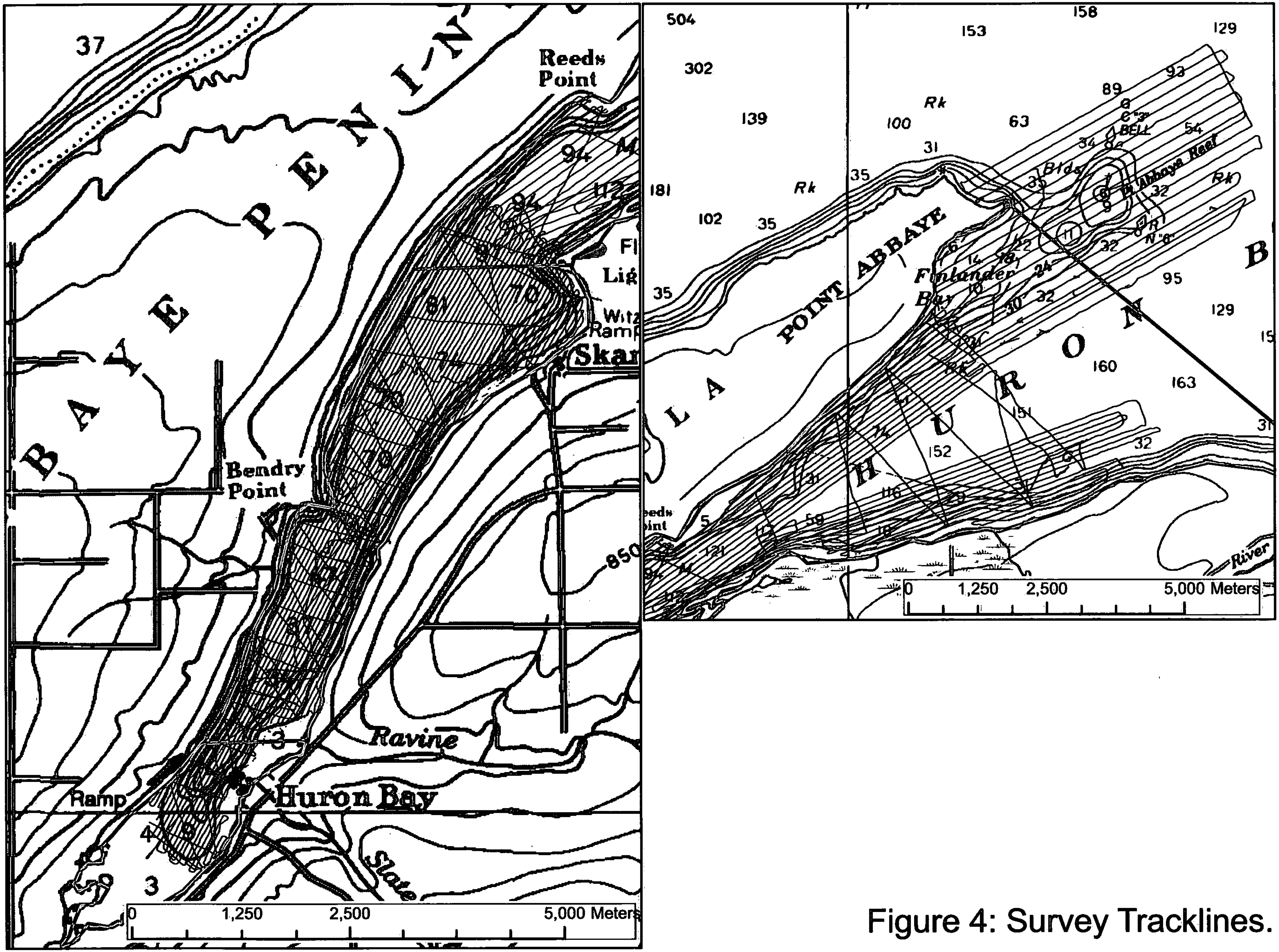


Figure 4: Survey Tracklines.

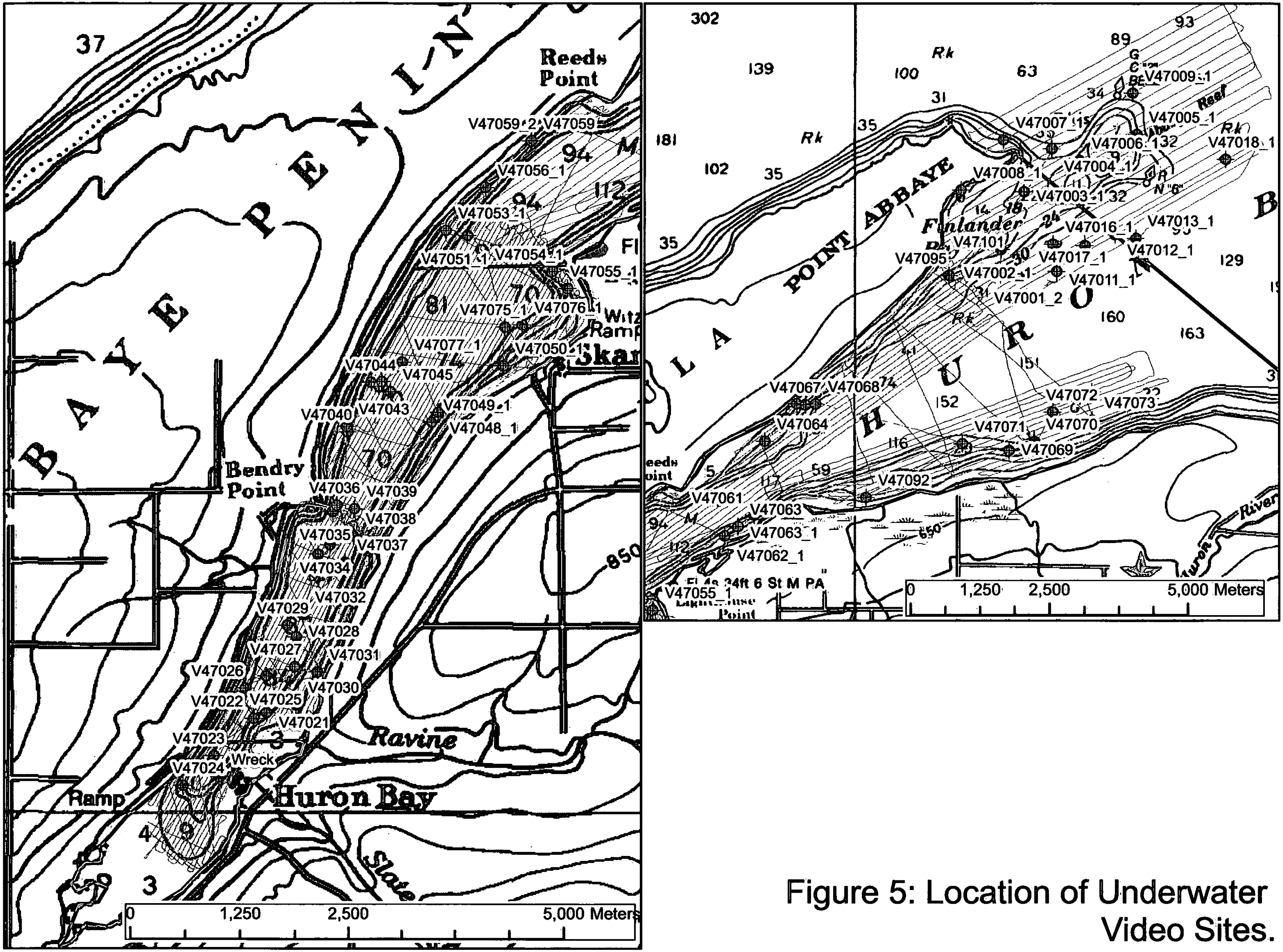
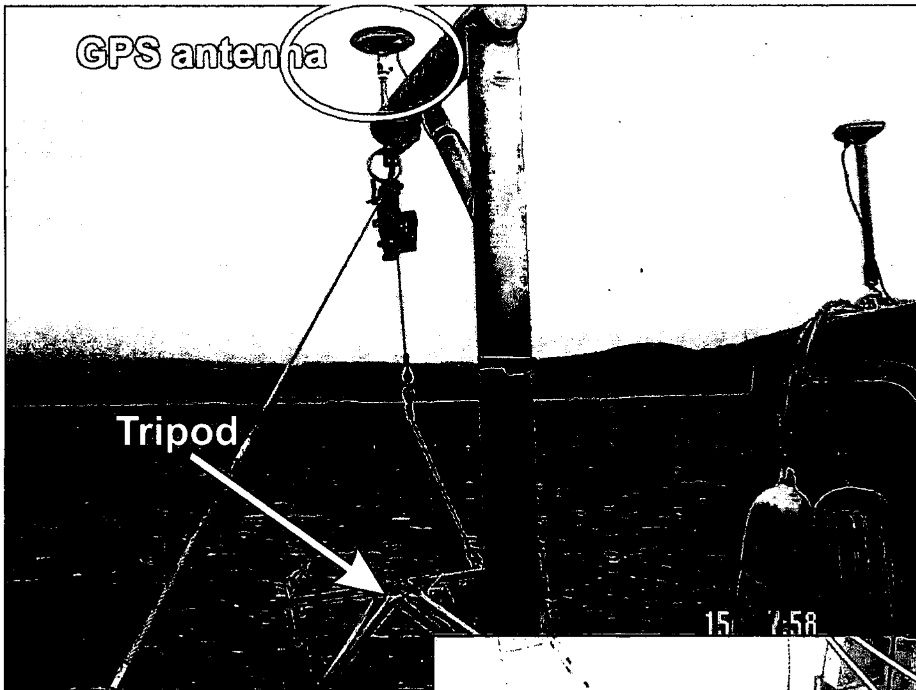
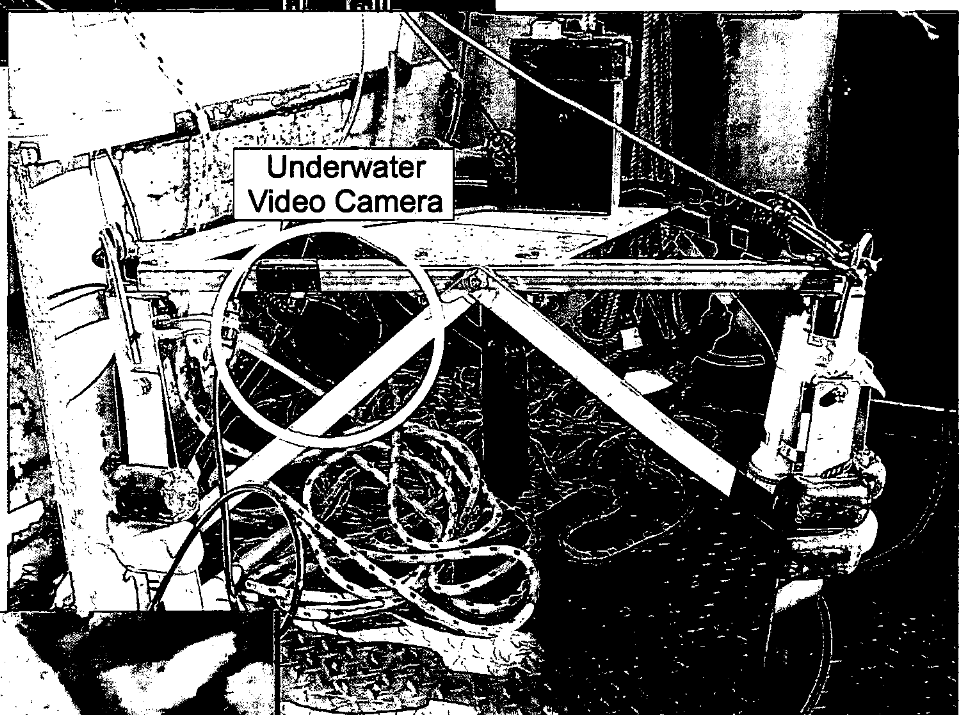


Figure 5: Location of Underwater Video Sites.



Davit setup on Puffin

Camera tripod



Video overlay

Figure 6: Underwater Video Camera Configuration.

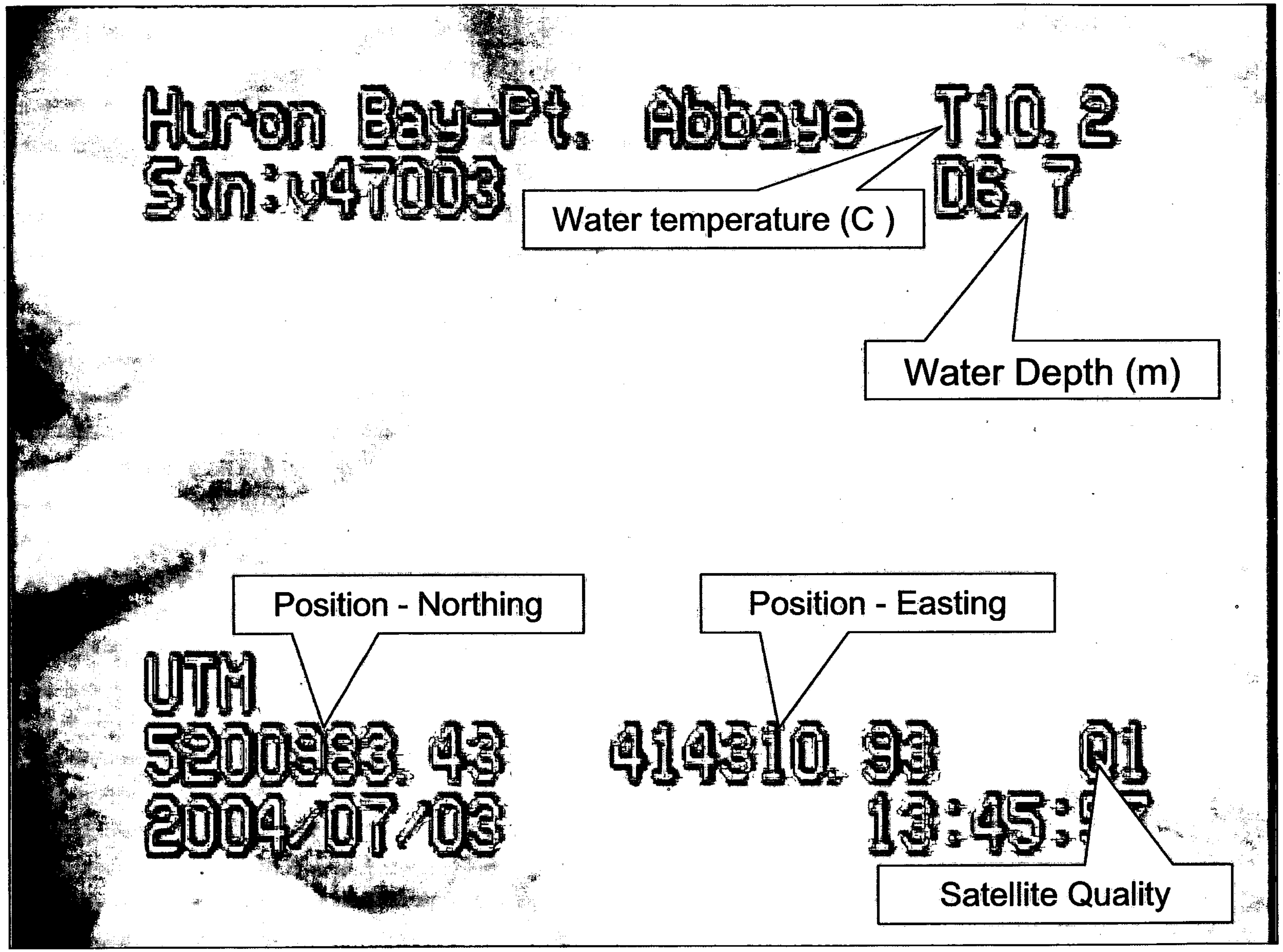


Figure 7: Example of Site Data Included with Underwater Video.

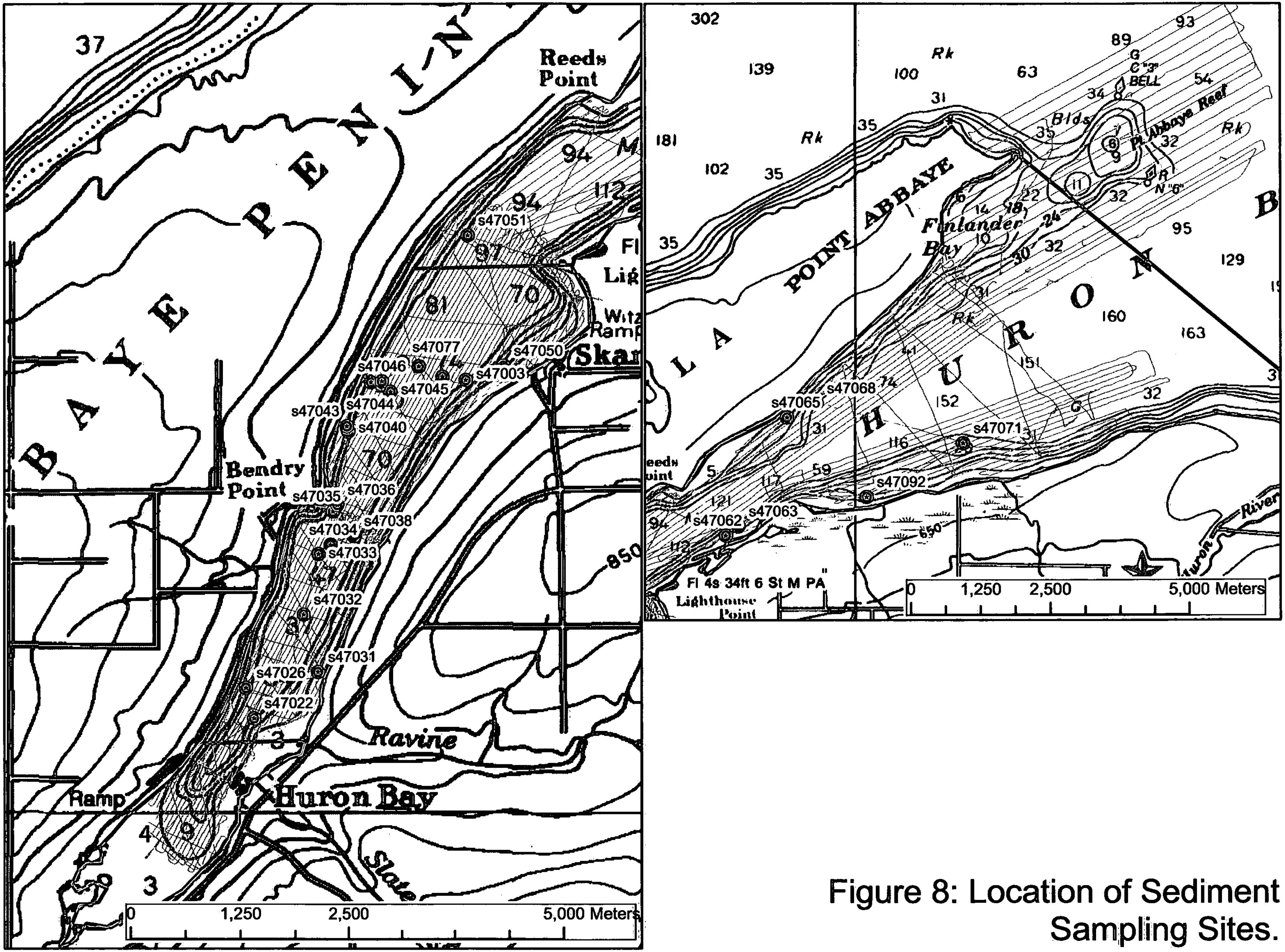


Figure 8: Location of Sediment Sampling Sites.

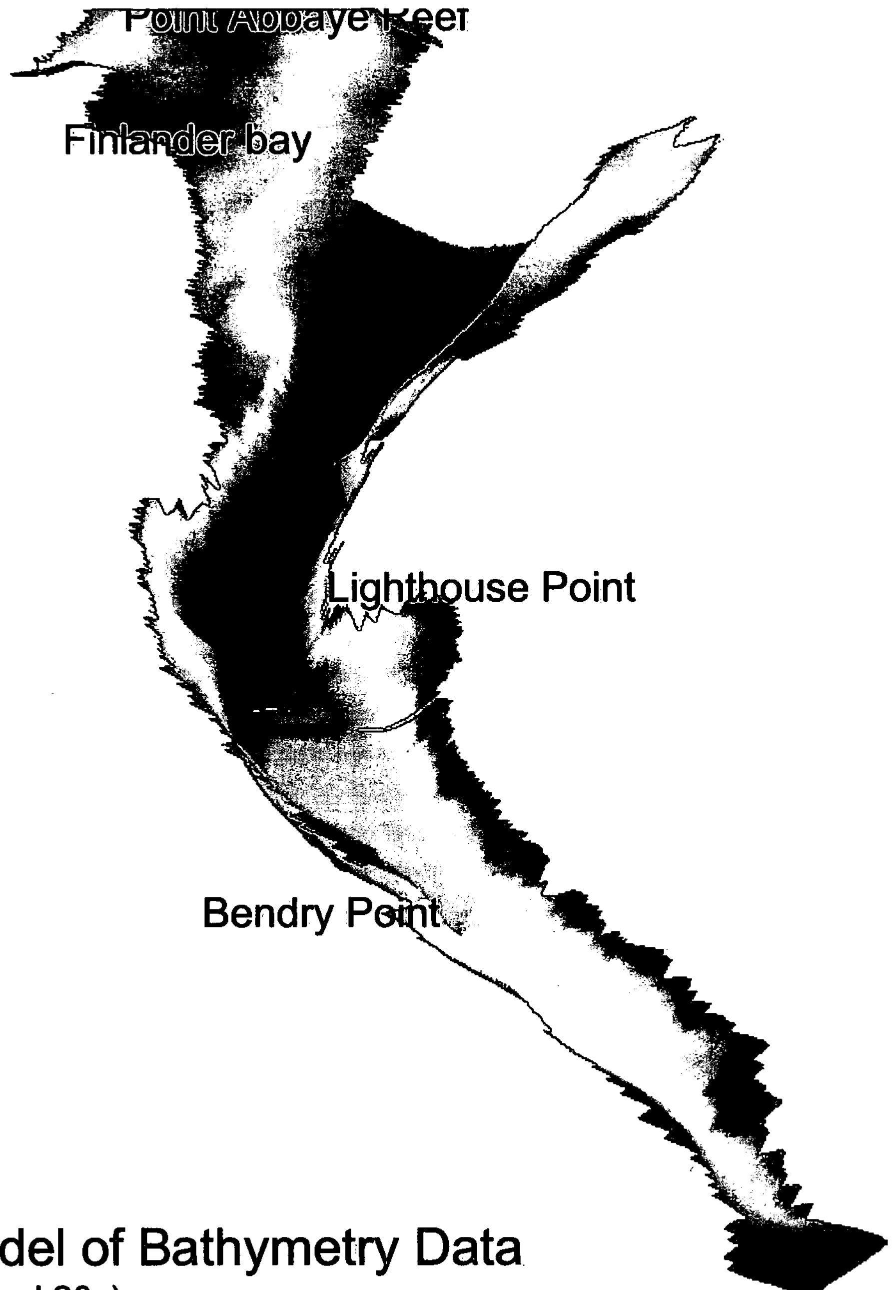


Figure 9: 3D Model of Bathymetry Data
(Depth value exaggerated 20x)

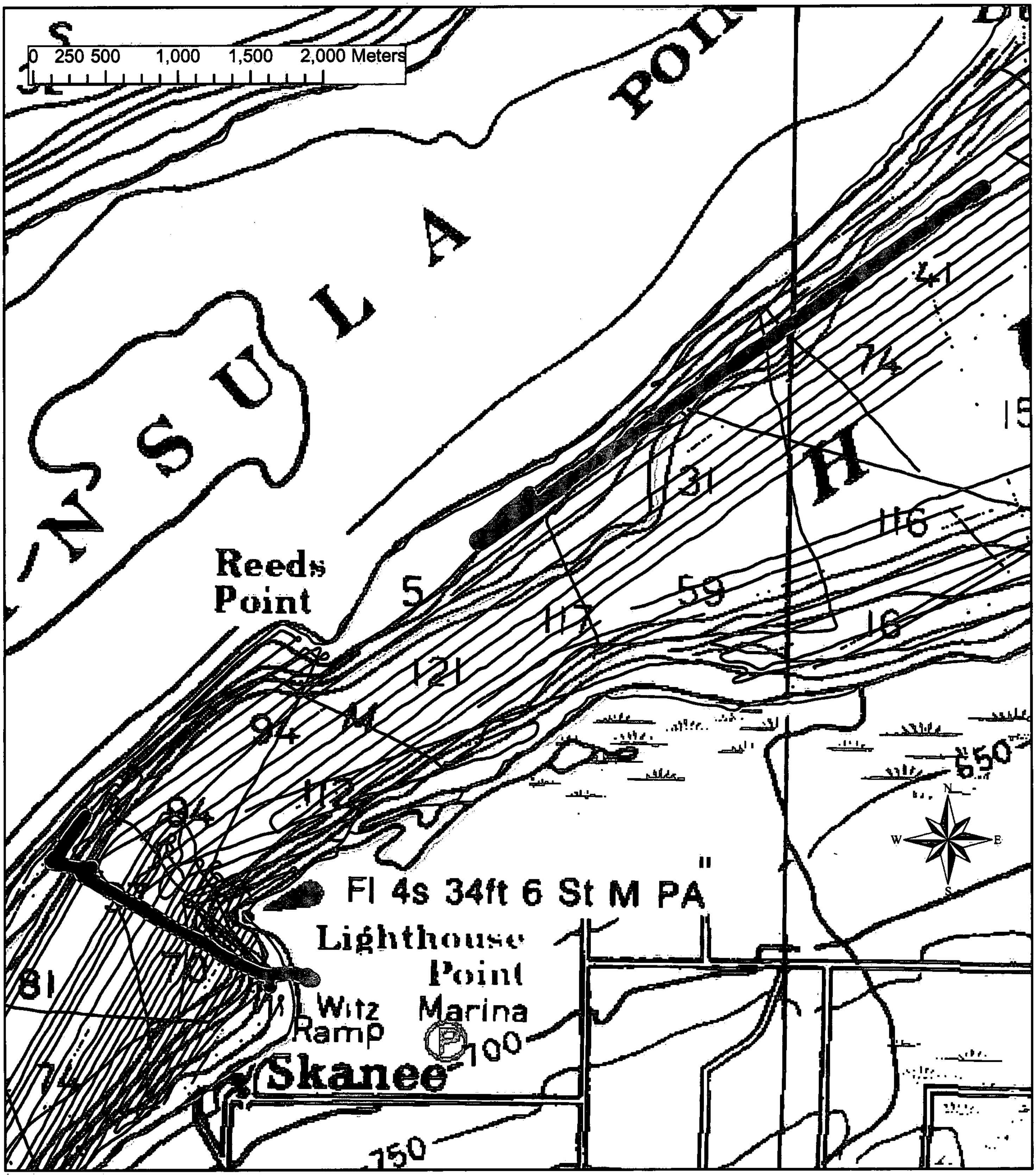


Figure 10: Location of Position Data with Standard Deviation > 5 m.

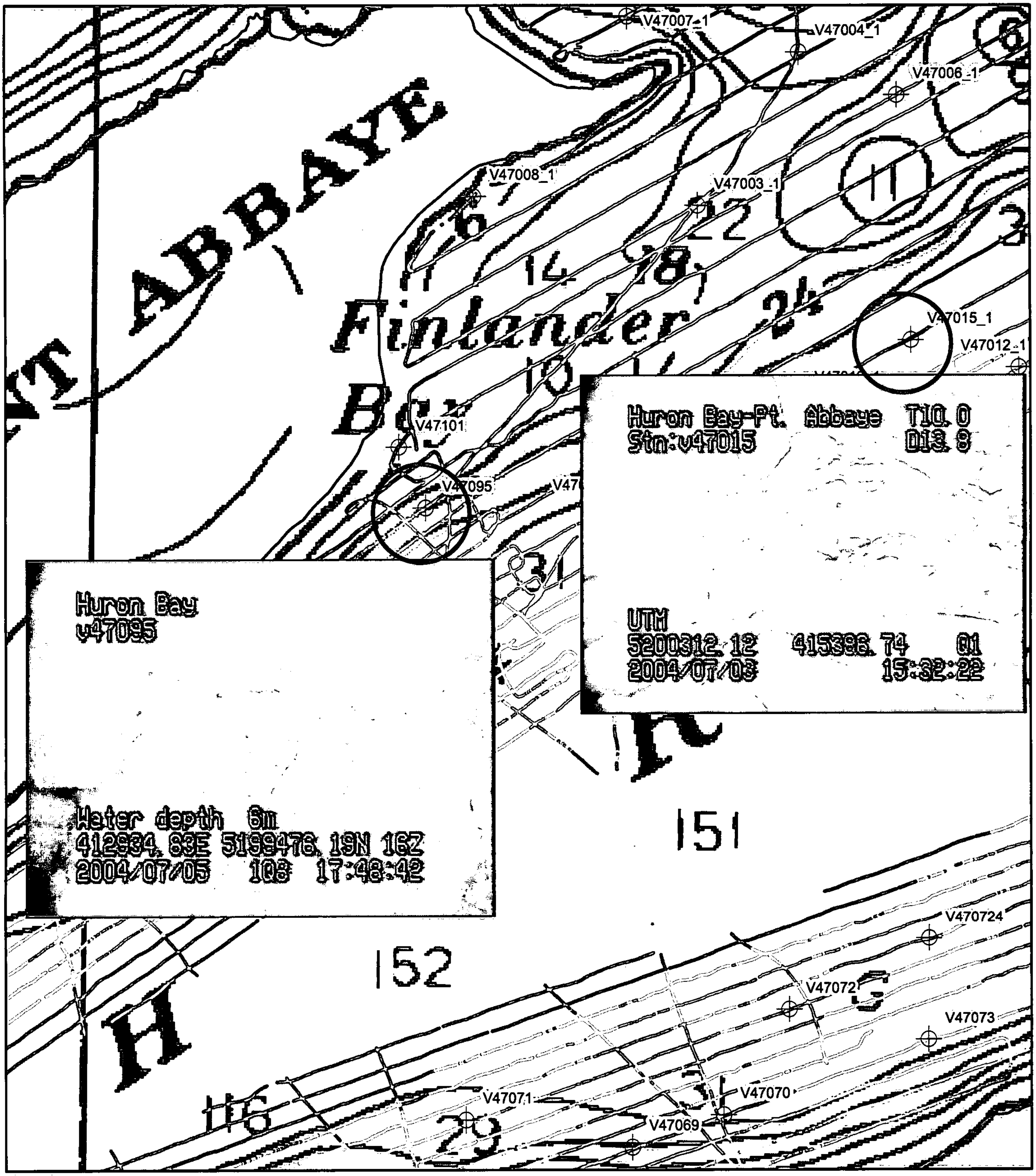


Figure 11: Example of Comparing Ground-truth Data to Verify RoxAnn Classification.

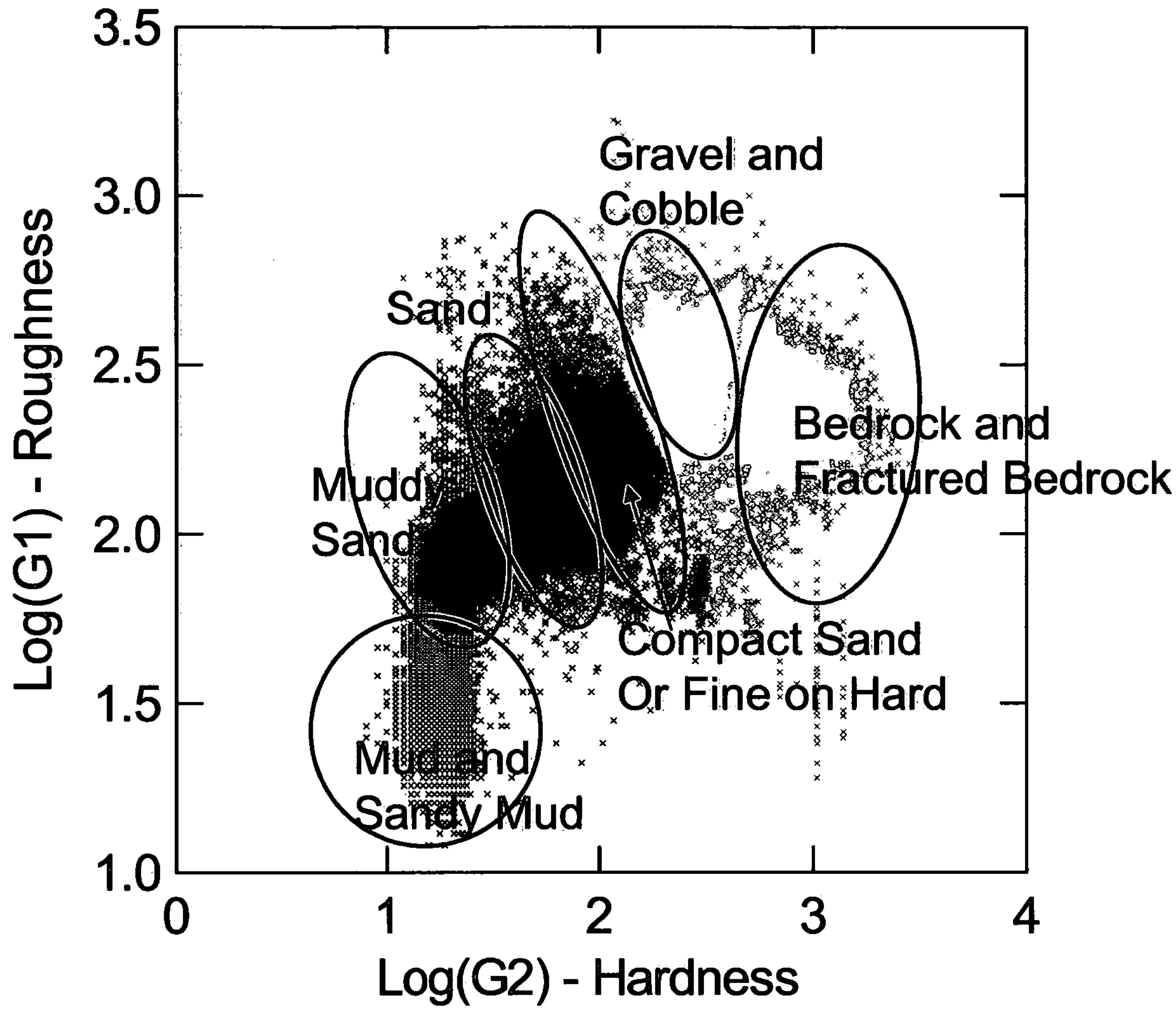


Figure 12: Results of Kmeans classification of G1 and G2 values.

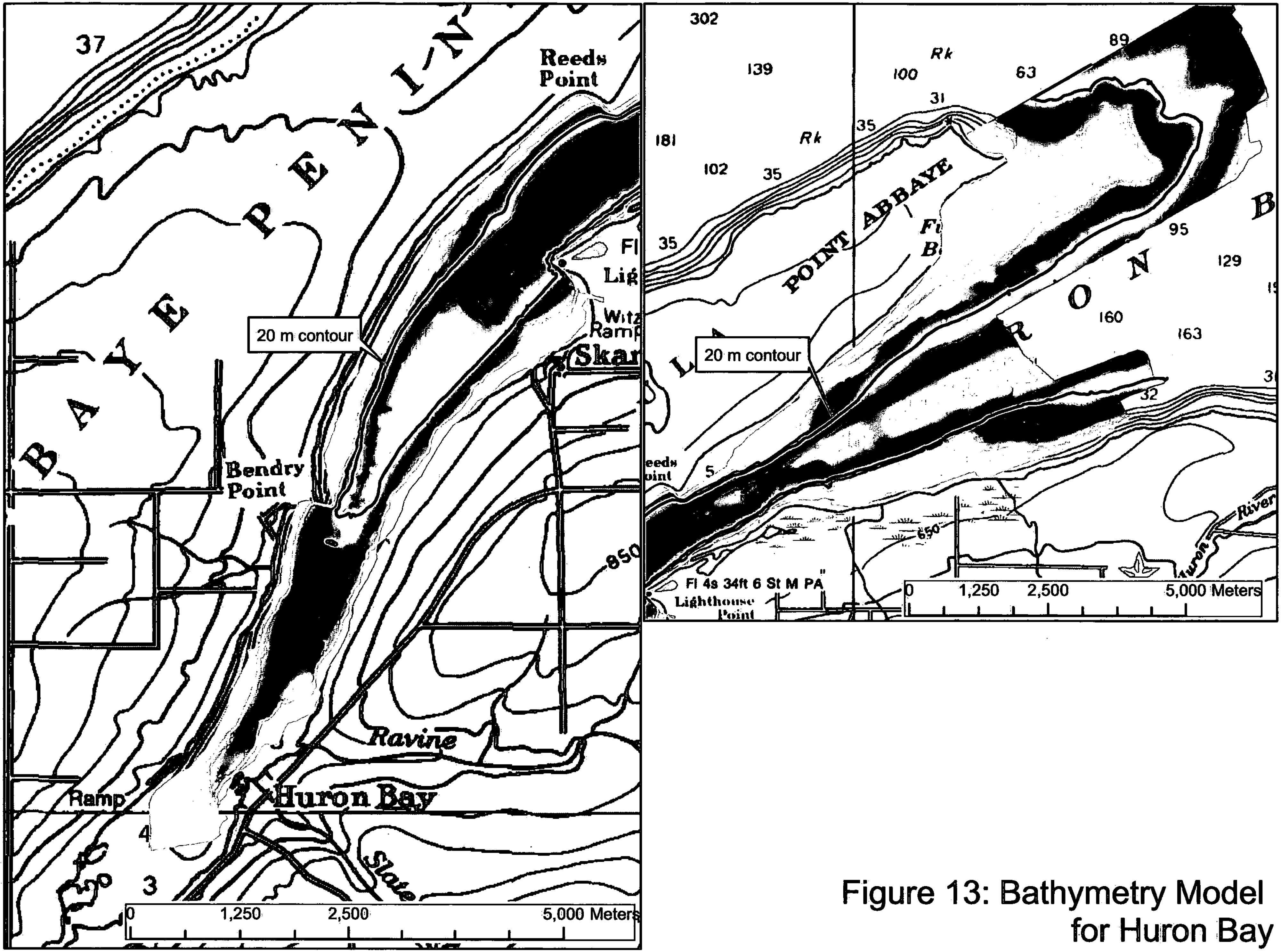
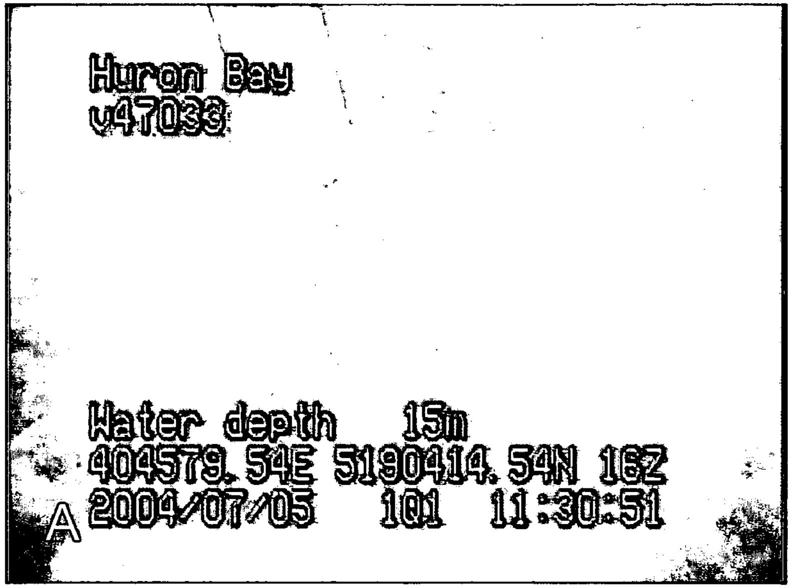
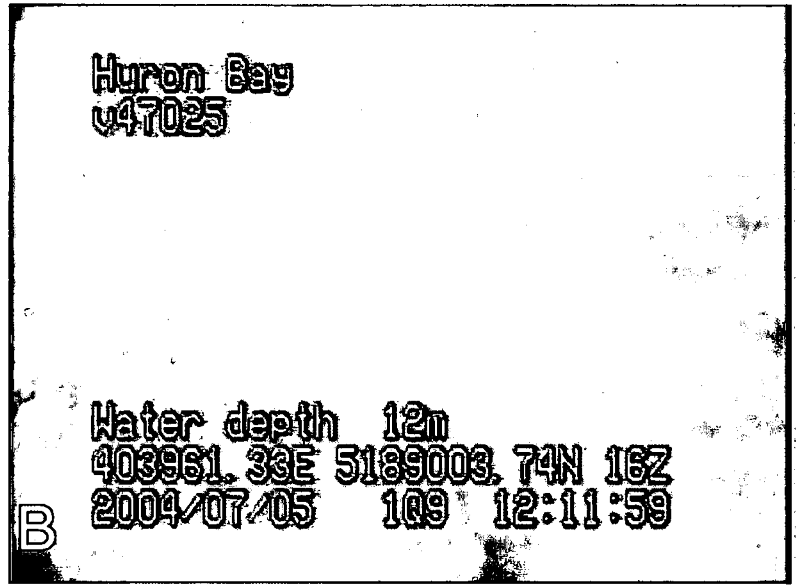
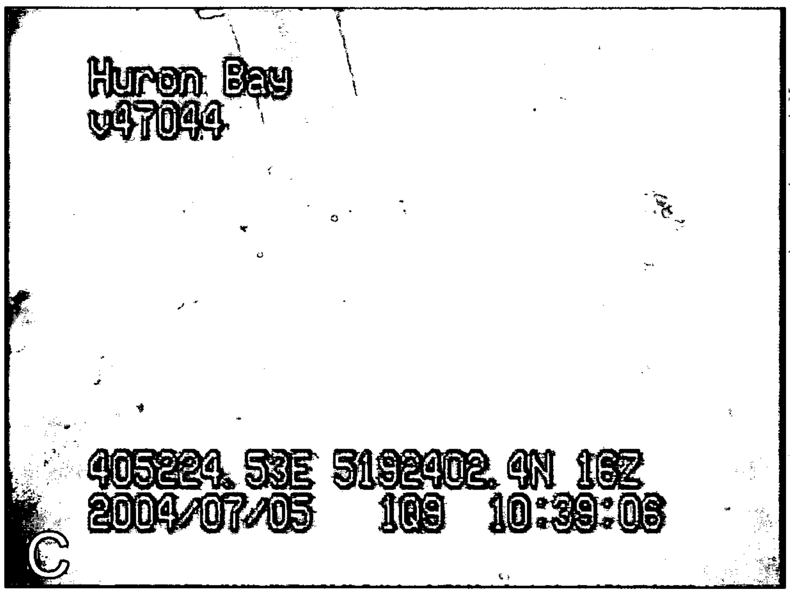


Figure 13: Bathymetry Model for Huron Bay

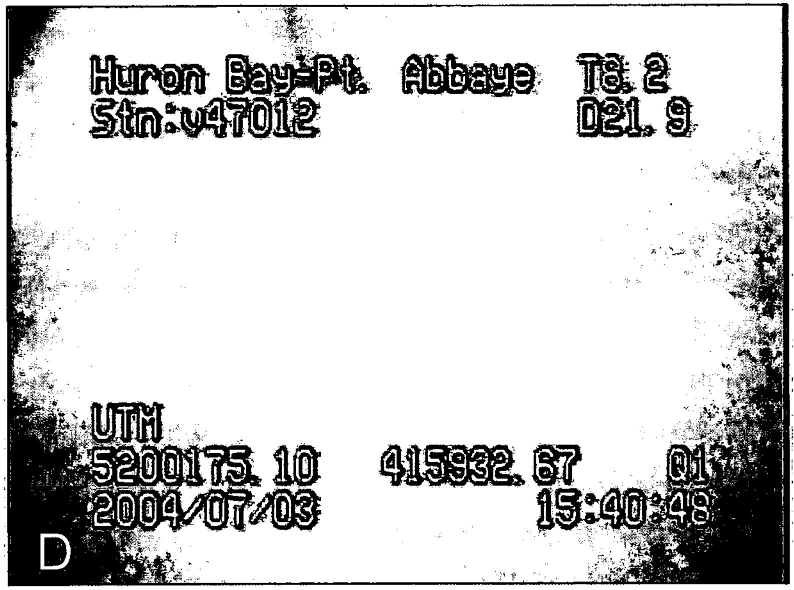


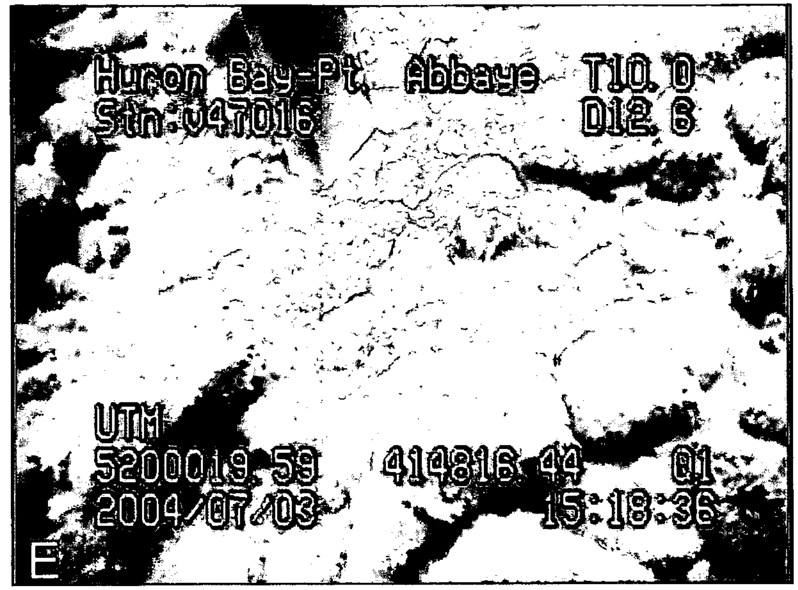


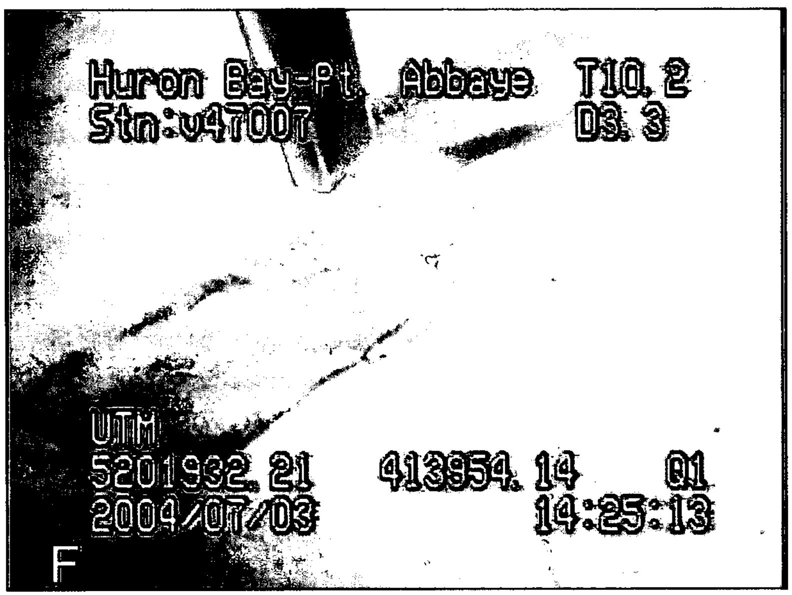


A - Mud / Sandy Mud
B - Sandy Mud
C - Sand

Figure 14: Images of Substrate Types.







D – compact sand
E – cobble
F – bedrock

Figure 14: Images of Substrate Types (continued).

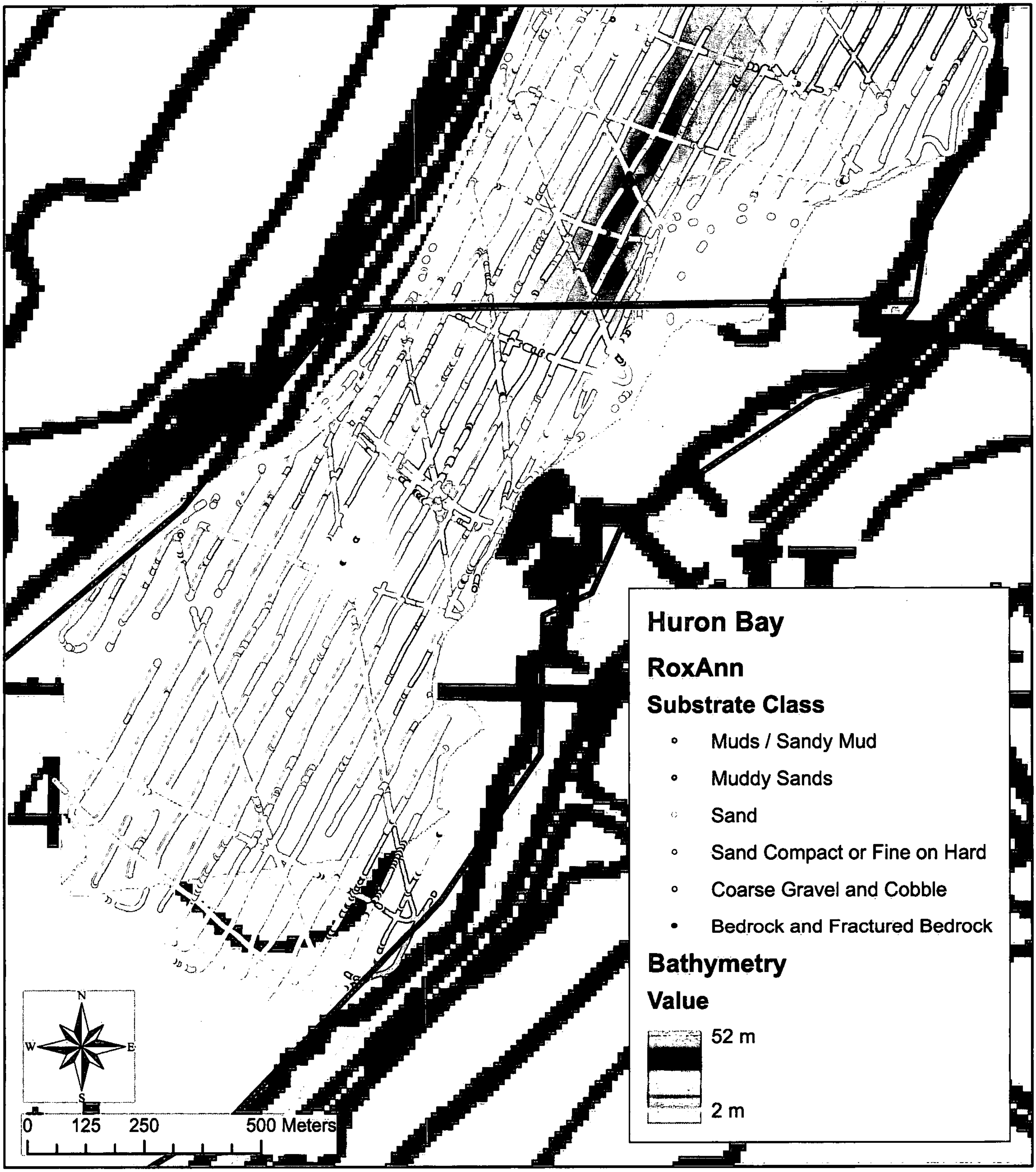


Figure 15: Zone 1 - Substrate Classification.

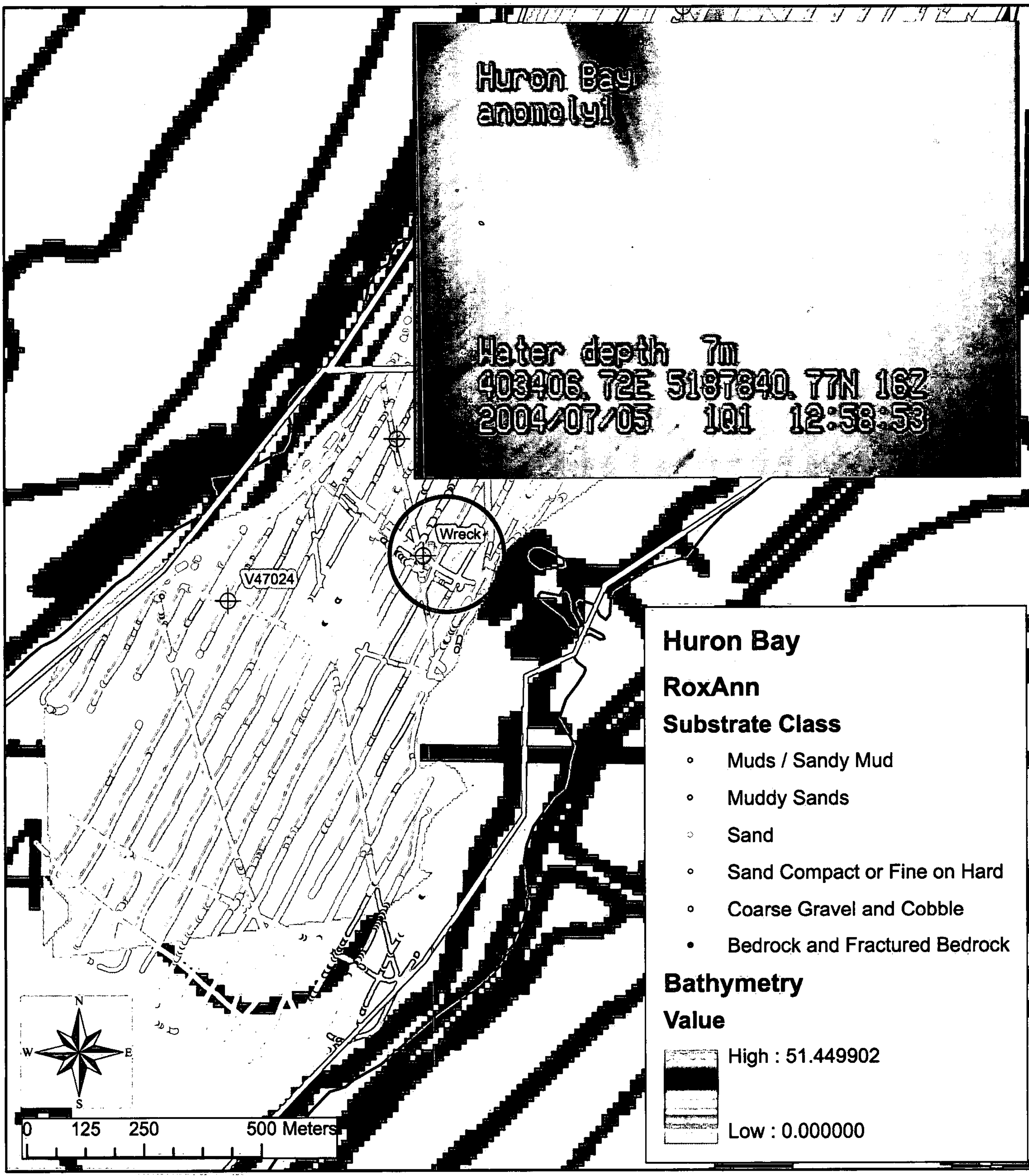


Figure 16: Location and Image of Submerged Wooden Barge.

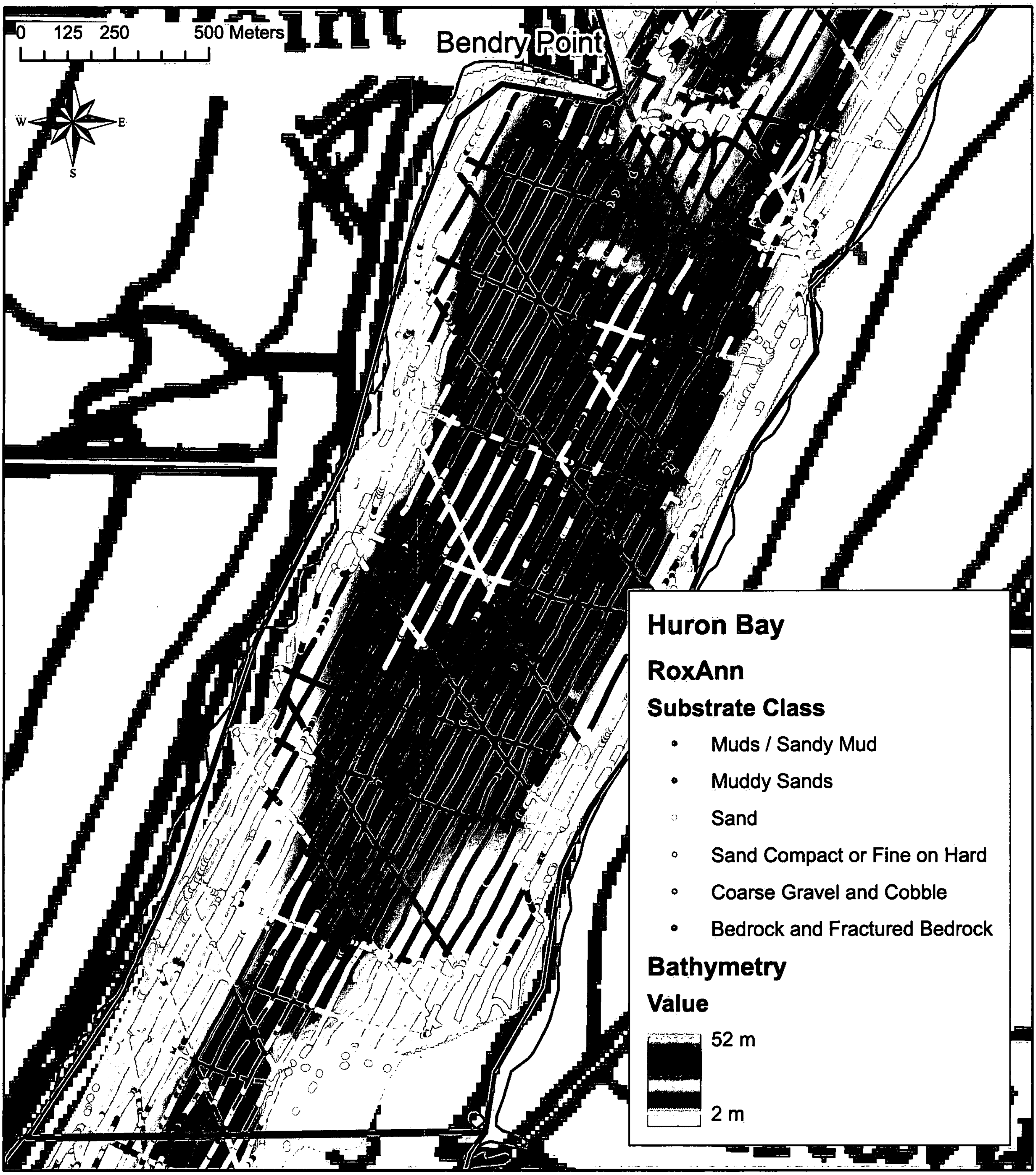


Figure 17: Southern Portion of Zone 2 - Middle Bay.

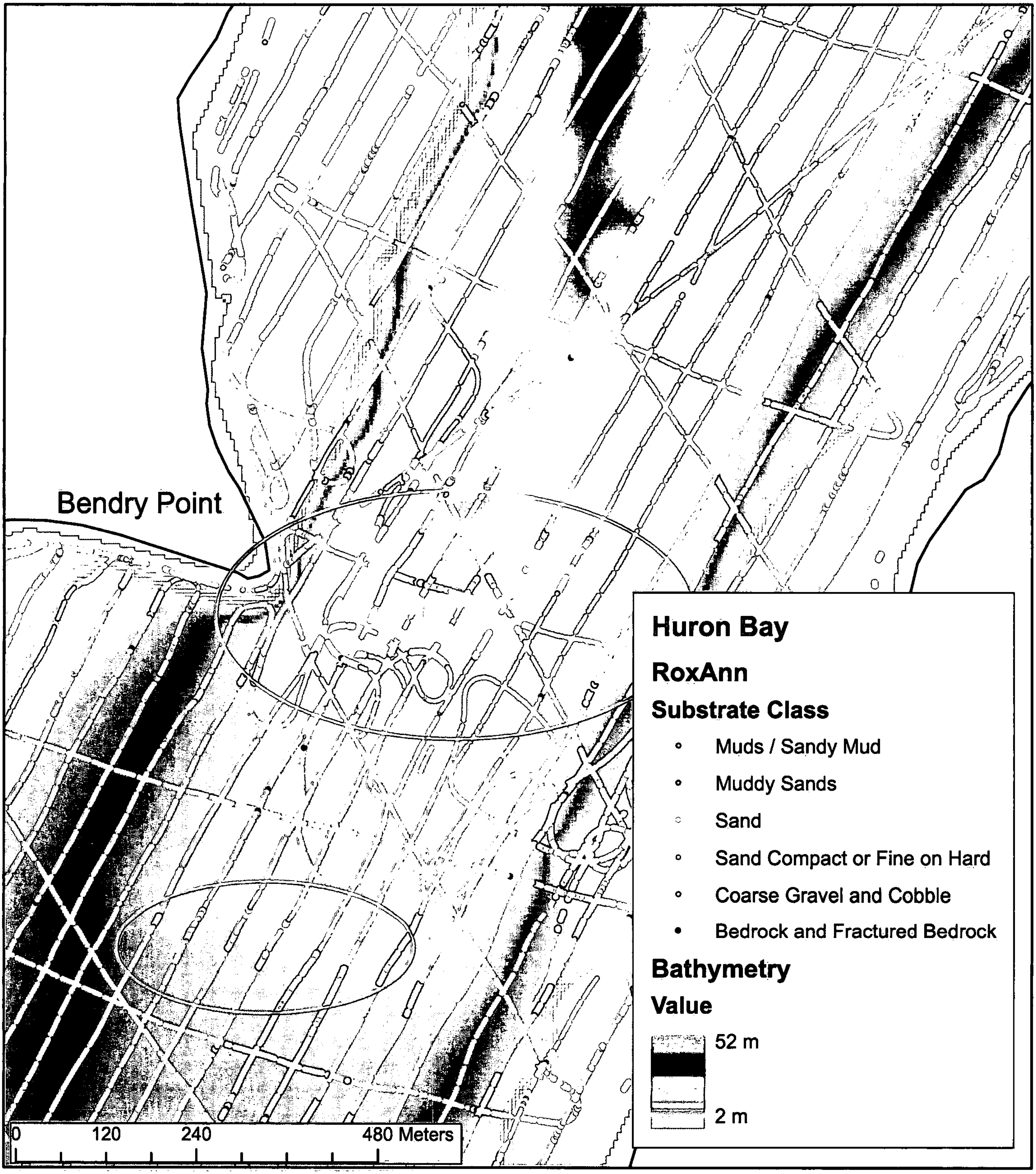


Figure 18: Substrate Atrributes on and Adjacent to the Sill at Bendry Point.

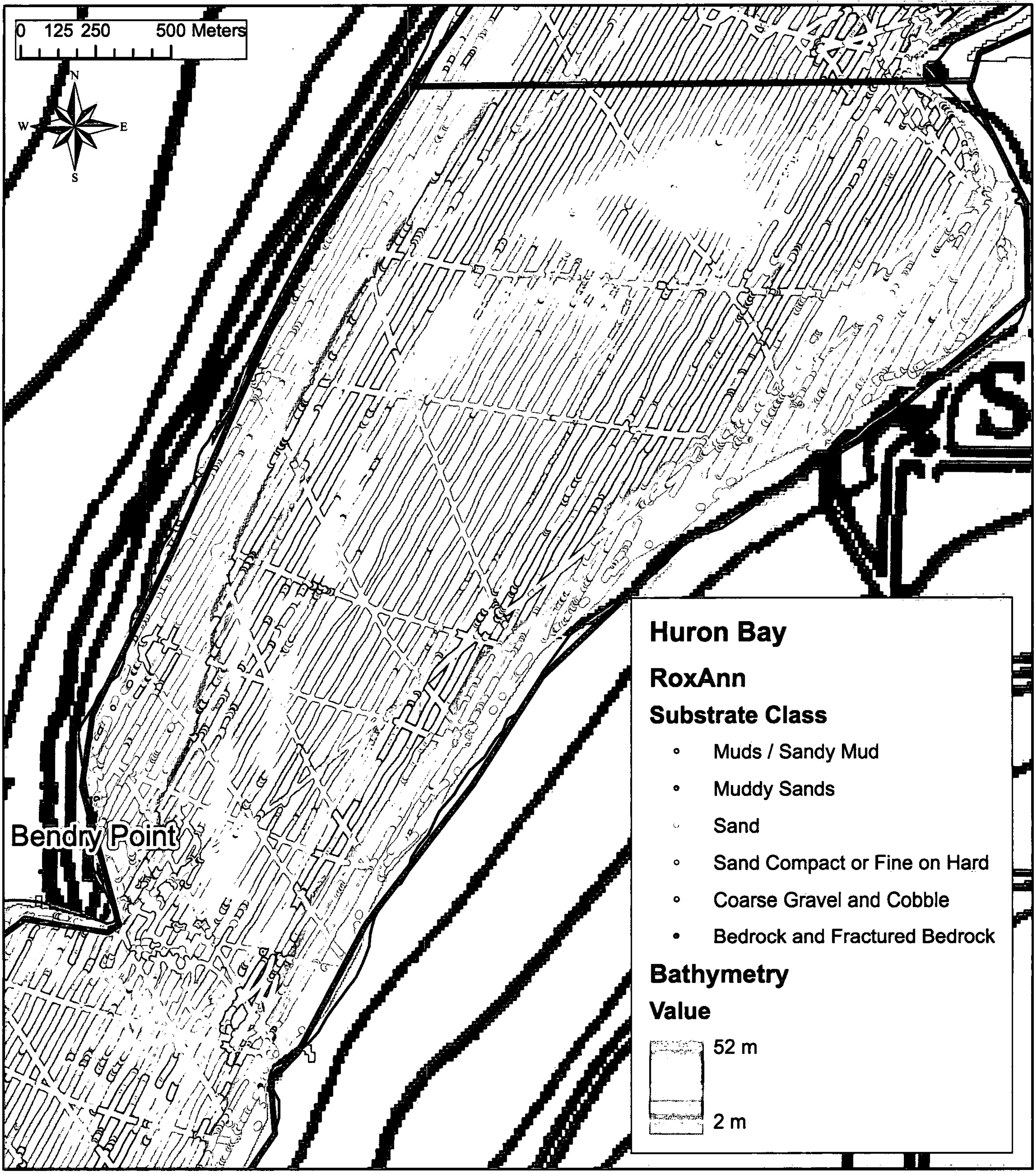


Figure 19: Northern Portion of Zone 2 - Middle Bay.

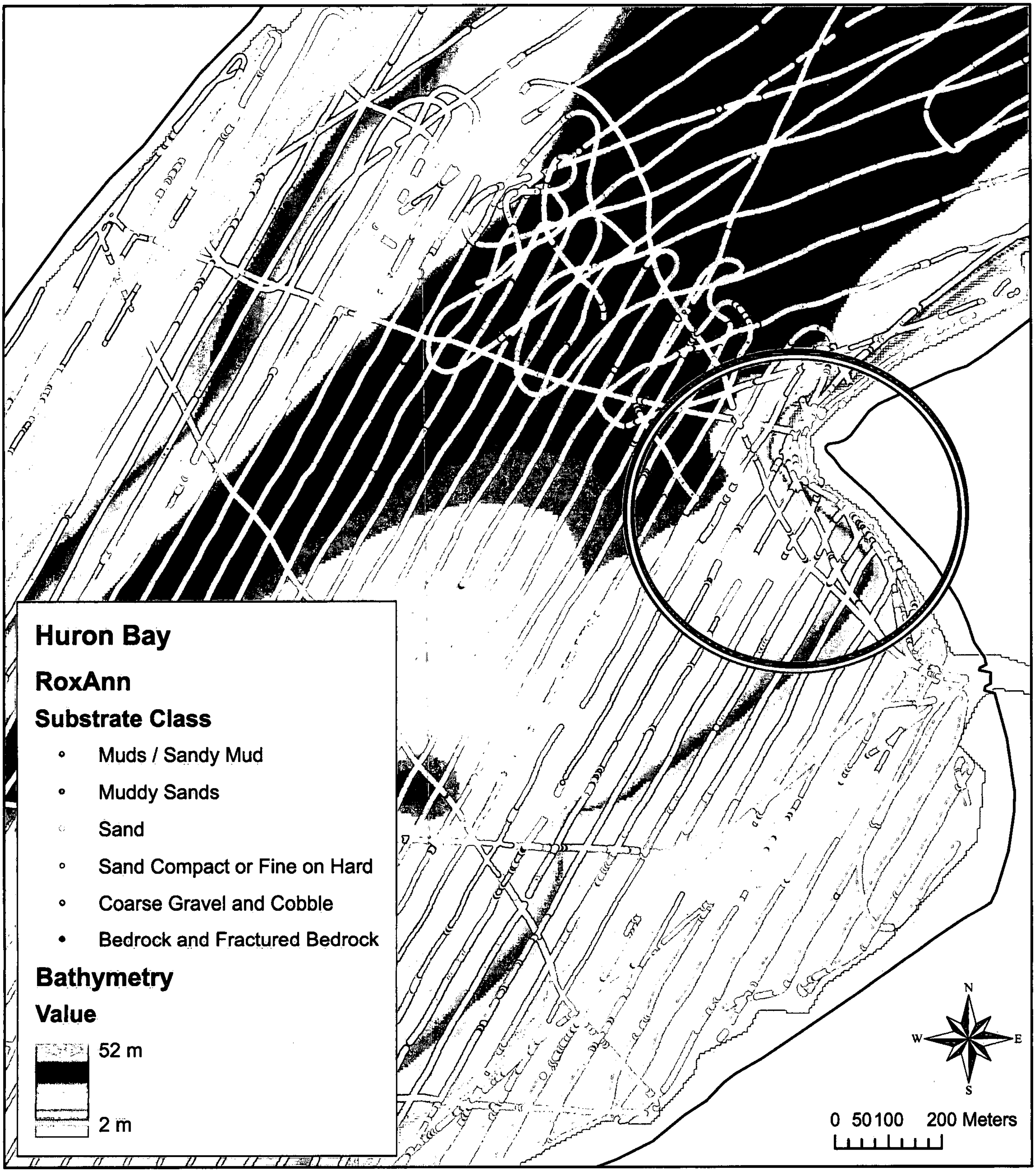


Figure 20: Acoustic Hardening Due to Slope.

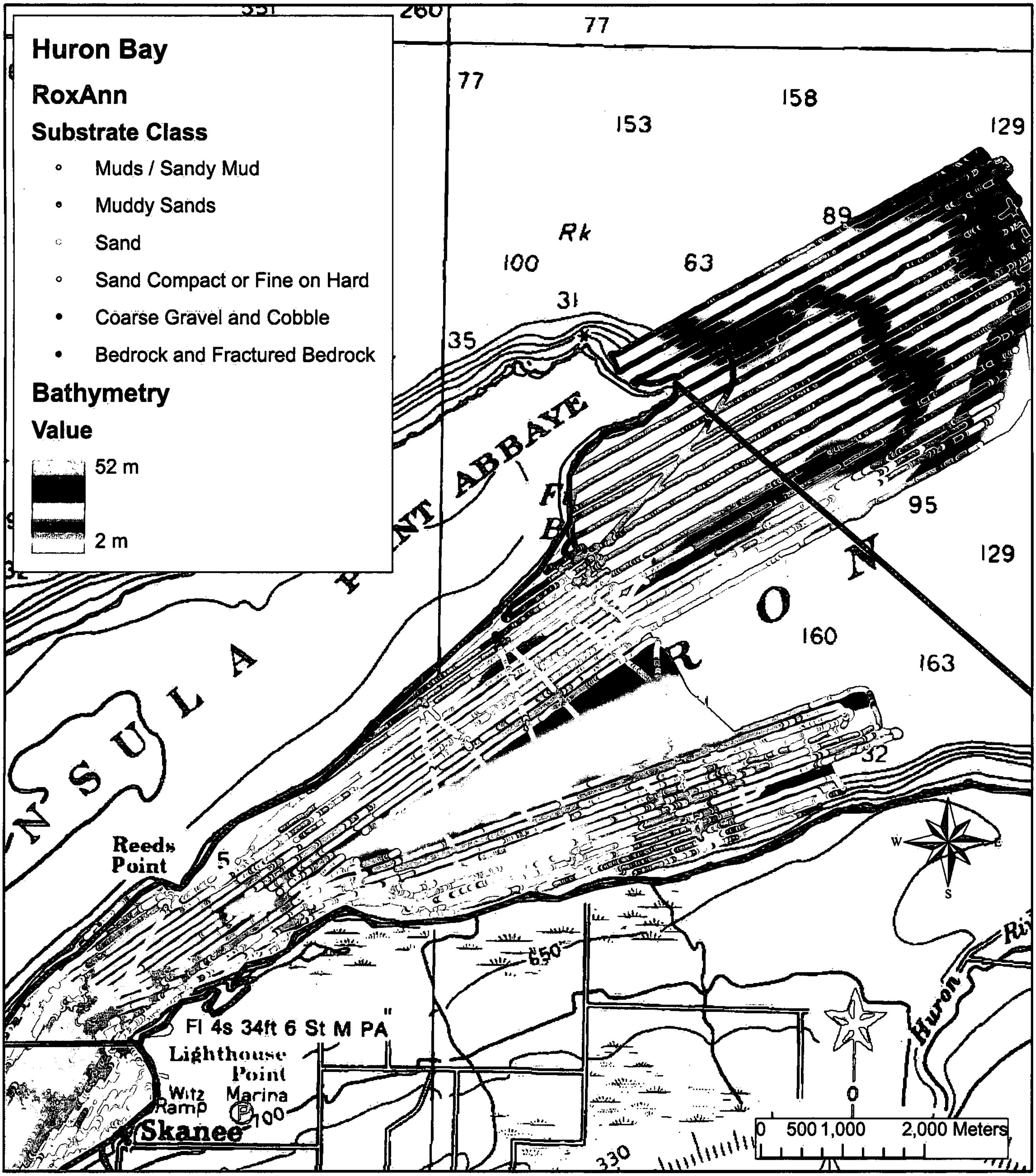


Figure 21: Zone 3- Outer Bay

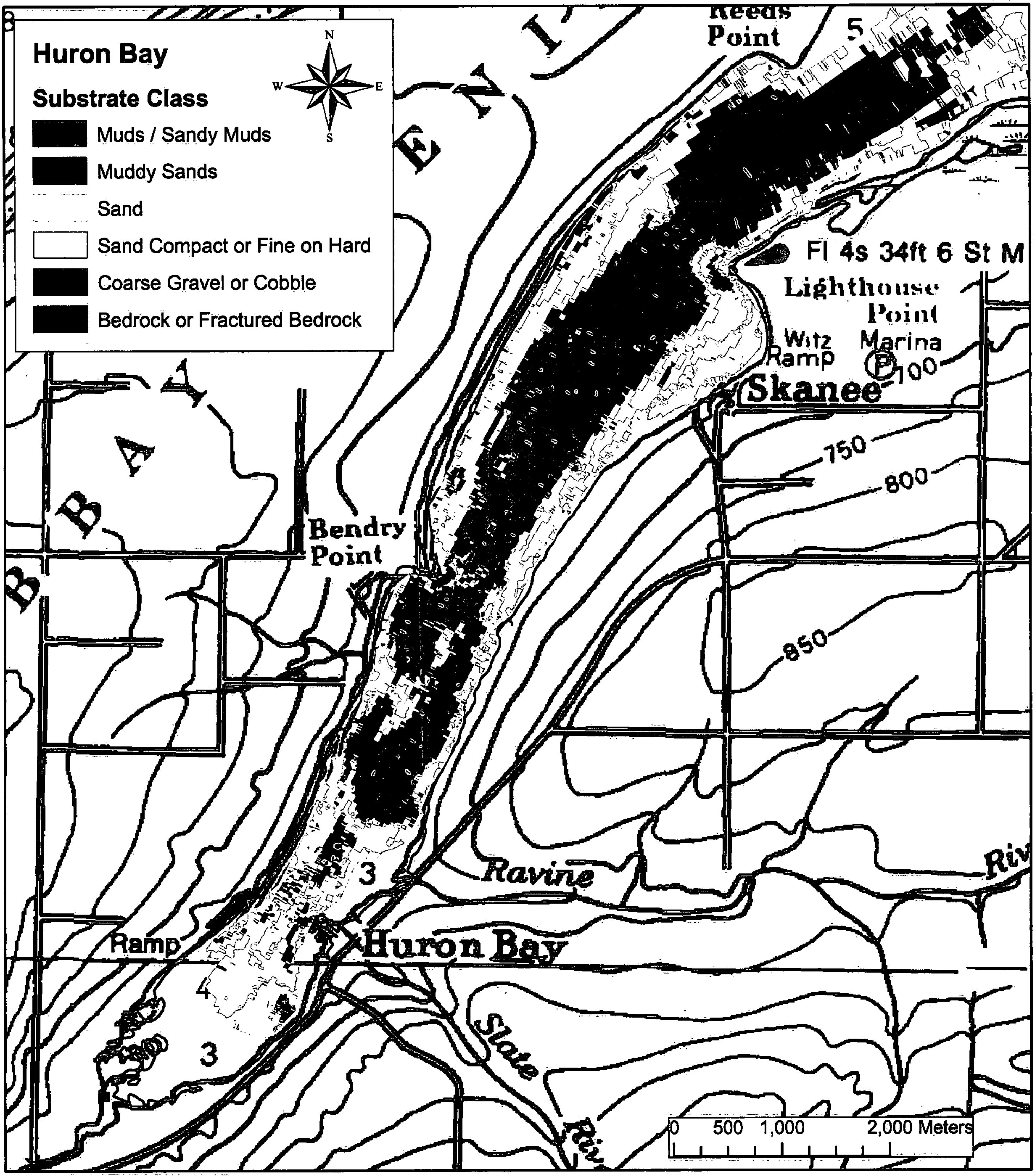


Figure 22: Thiessen Polygon of Substrate Classes Southern Portion of Bay.

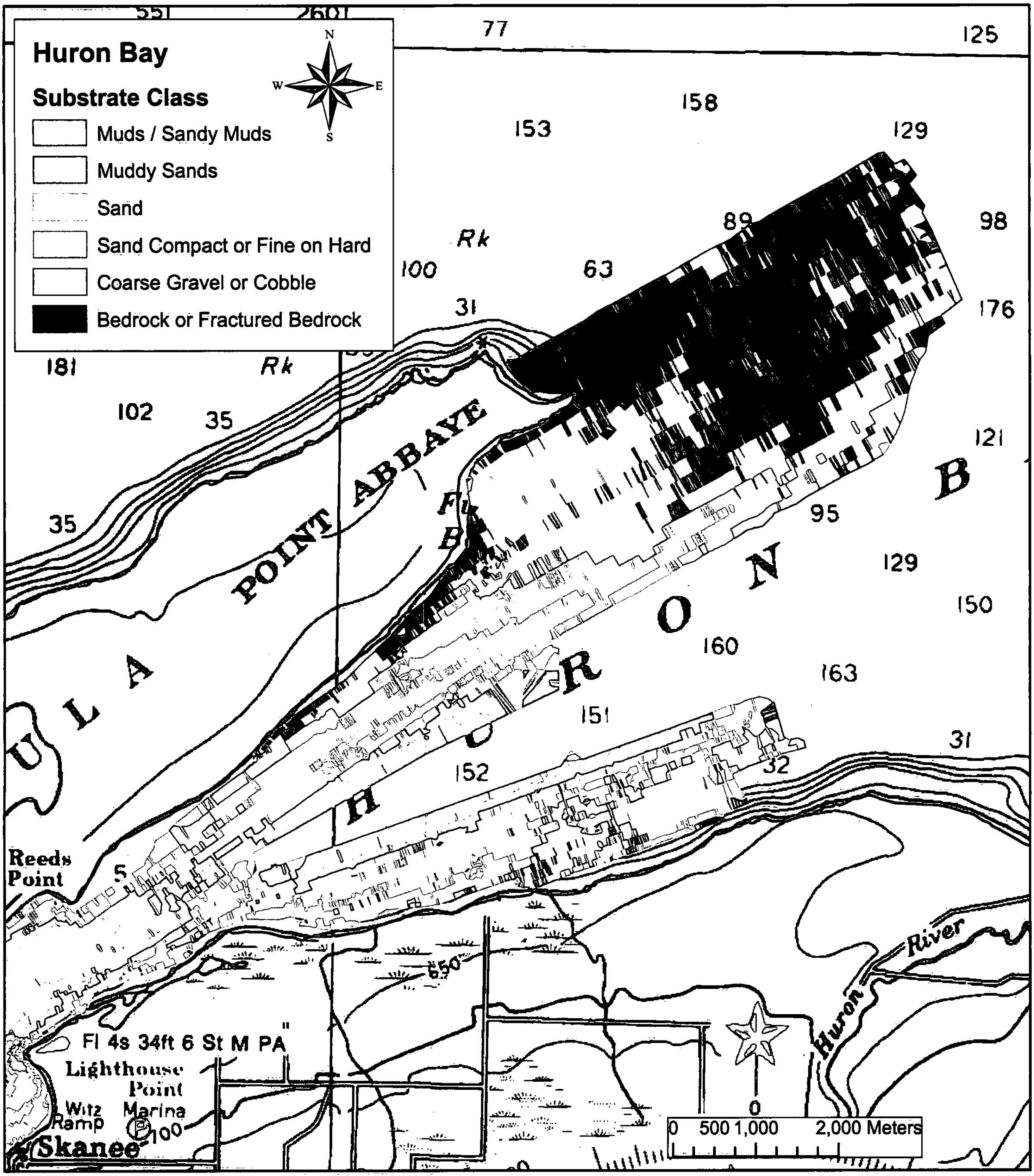
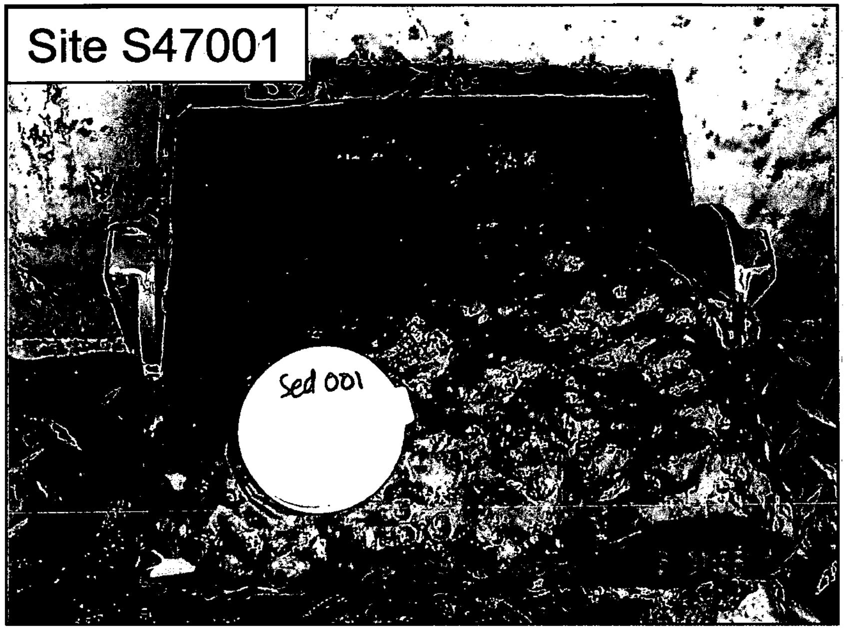
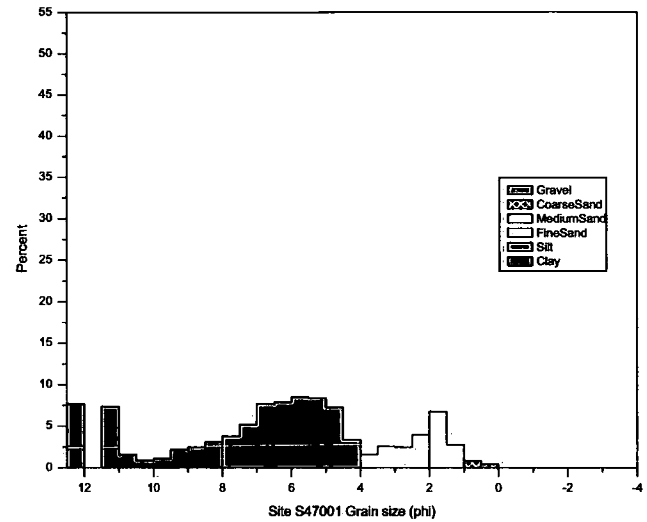
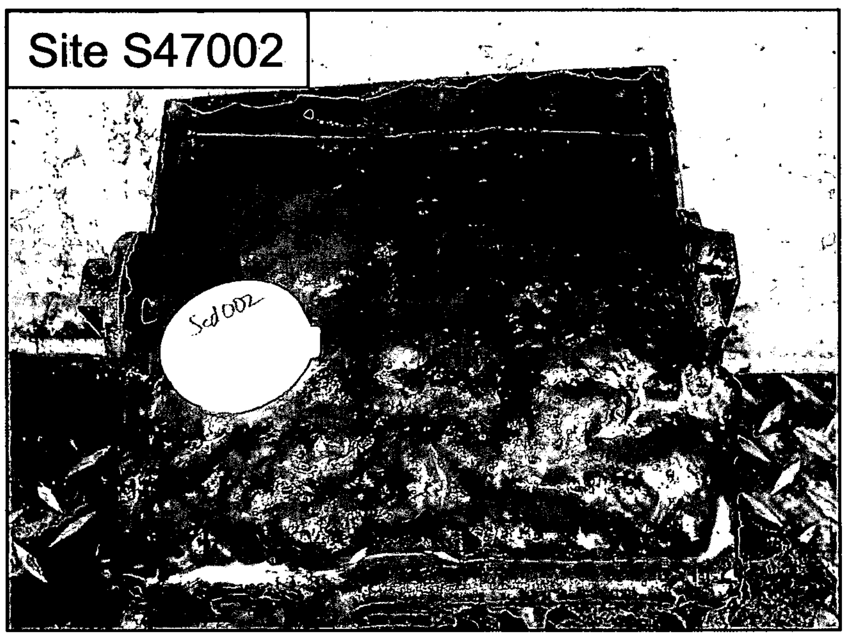


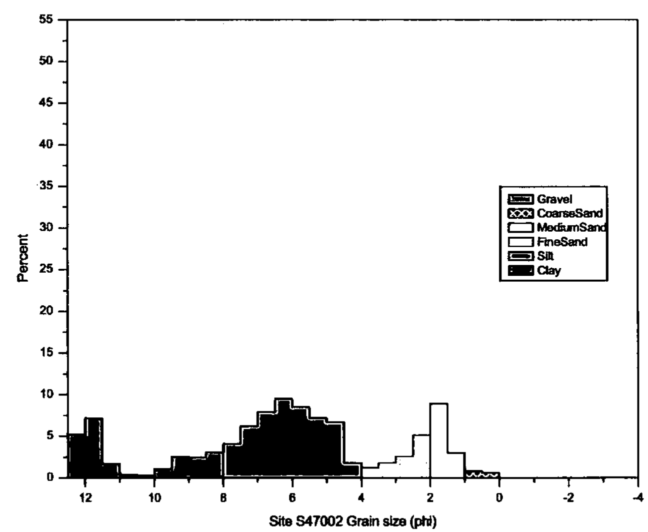
Figure 23: Thiessen Polygon of Substrate Classes Northern Portion of Bay.

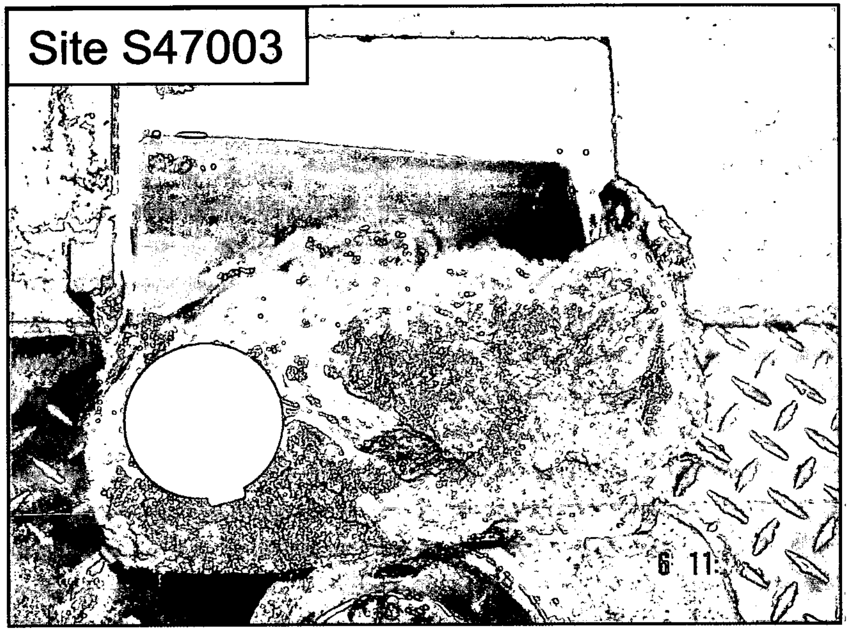
Appendix 1: Sediment Samples

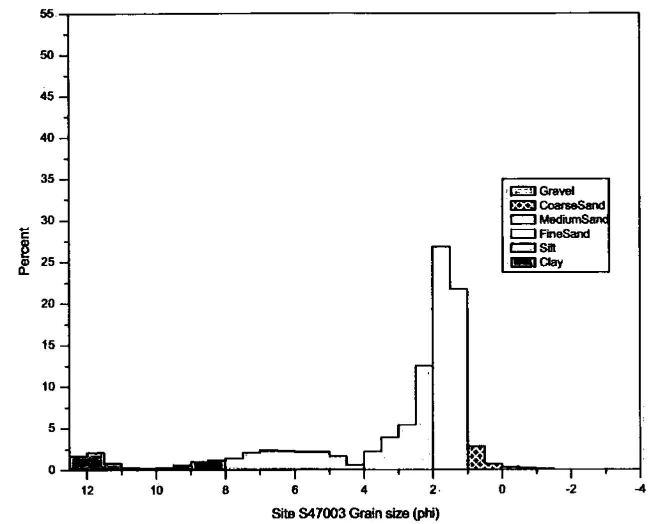

Site S47001
Sed 001

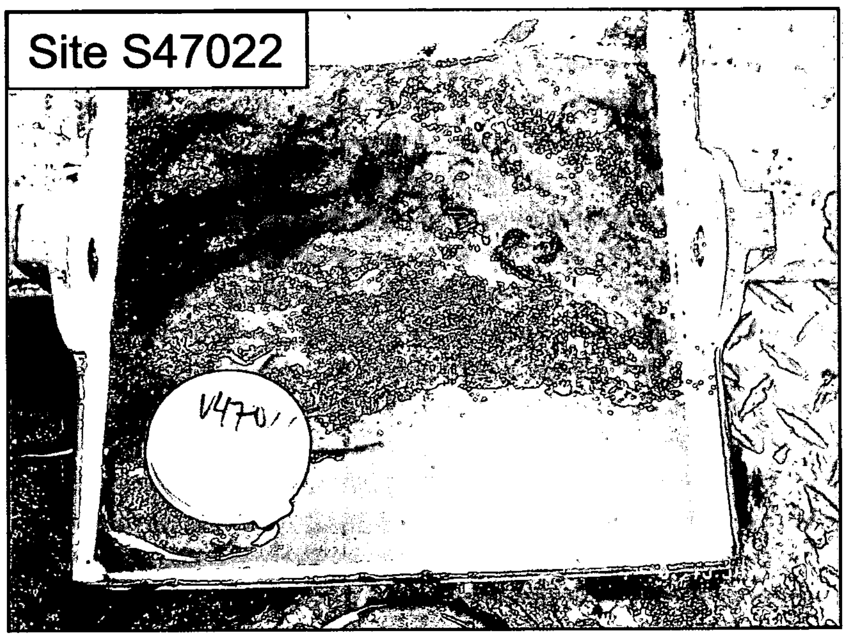

Percent
55
50
45
40
35
30
25
20
15
10
5
0
12
10
8
6
4
2
0
-2
-4
Gravel
CoarseSand
MediumSand
FineSand
Silt
Clay
Site S47001 Grain size (phi)

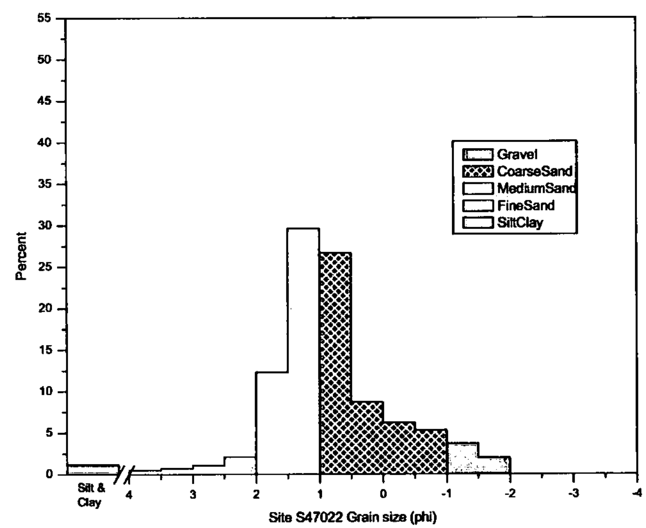

Site S47002
Sed 002


Percent
55
50
45
40
35
30
25
20
15
10
5
0
12
10
8
6
4
2
0
-2
-4
Gravel
CoarseSand
MediumSand
FineSand
Silt
Clay
Site S47002 Grain size (phi)

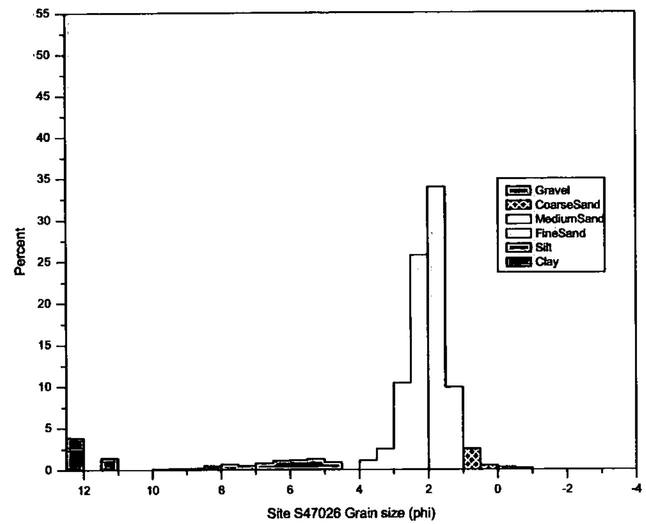

Site S47003

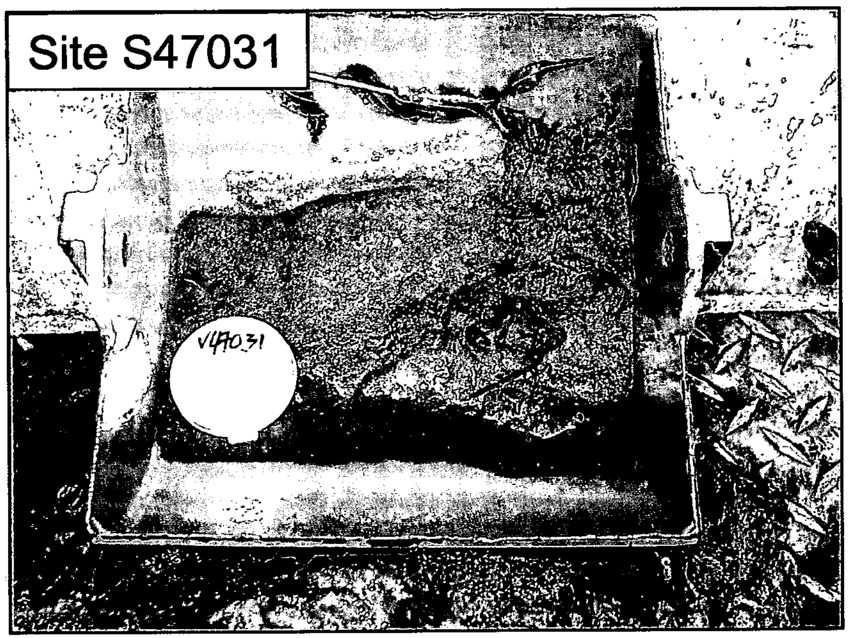

Gravel
CoarseSand
MediumSand
FineSand
Silt
Clay
Percent
Site S47003 Grain size (phi)

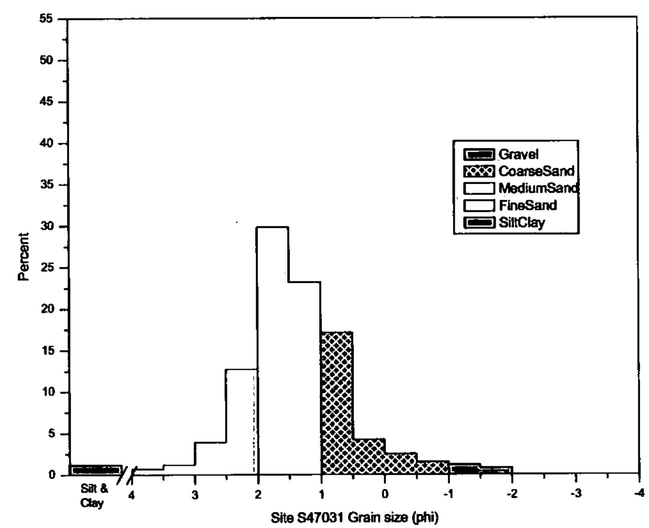

Site S47022

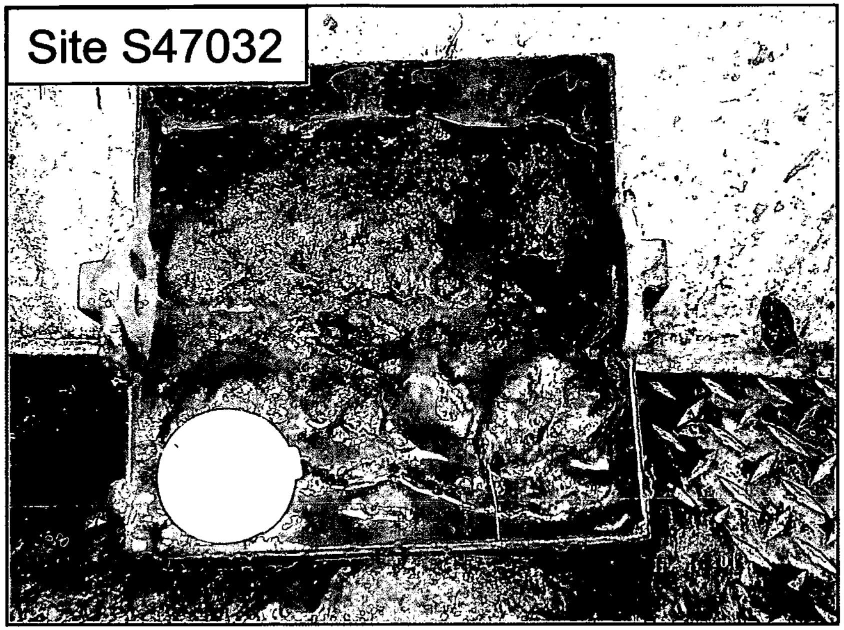

Gravel
CoarseSand
MediumSand
FineSand
SiltClay
Percent
Silt & Clay
Site S47022 Grain size (phi)

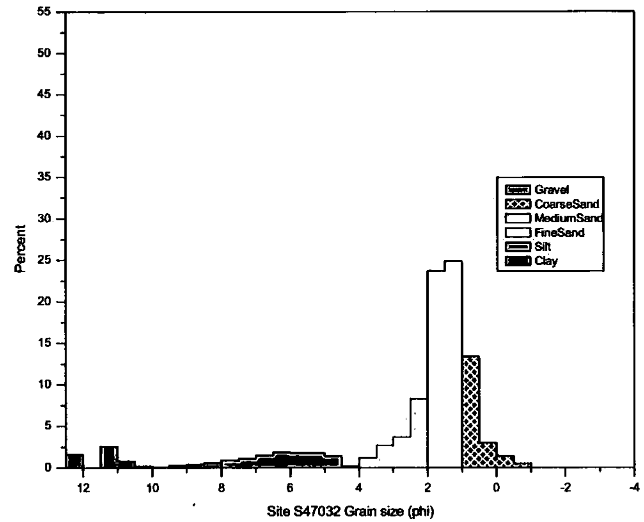

Site S47026


Percent
Gravel
CoarseSand
MediumSand
FineSand
Silt
Clay
Site S47026 Grain size (phi)

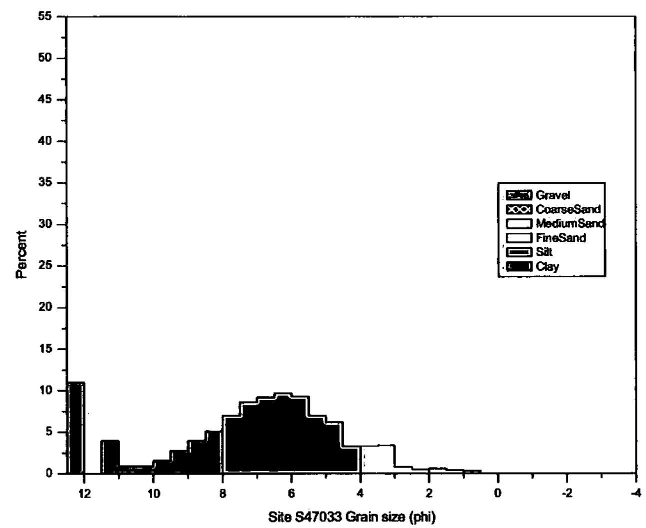

Site S47031


Percent
Gravel
CoarseSand
MediumSand
FineSand
SiltClay
Silt &
Clay
Site S47031 Grain size (phi)

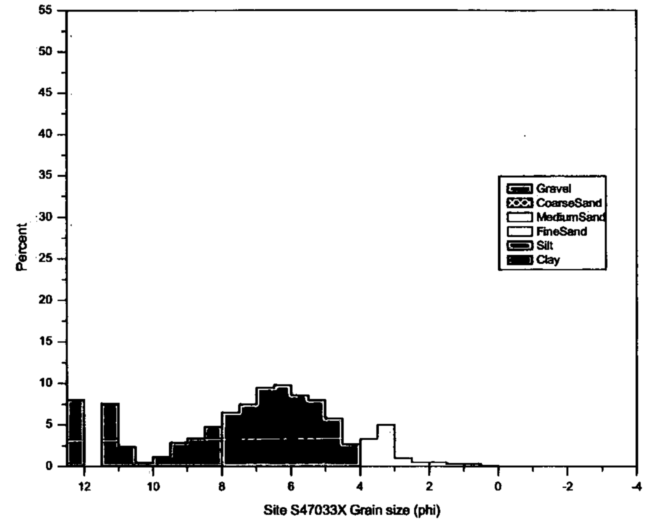

Site S47032

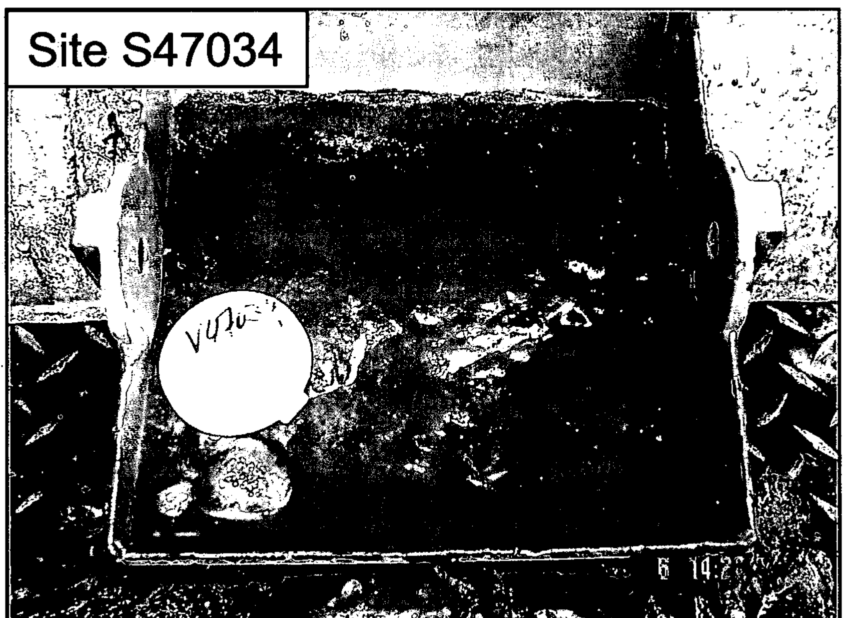

Gravel
CoarseSand
MediumSand
FineSand
Silt
Clay
Percent
Site S47032 Grain size (phi)

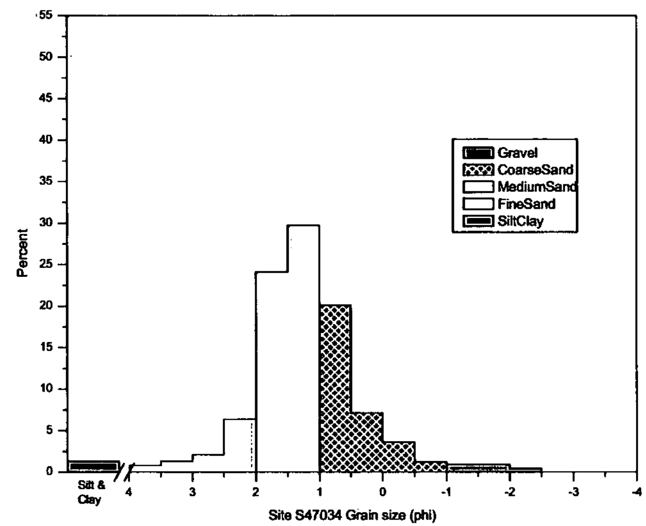

Site S47033

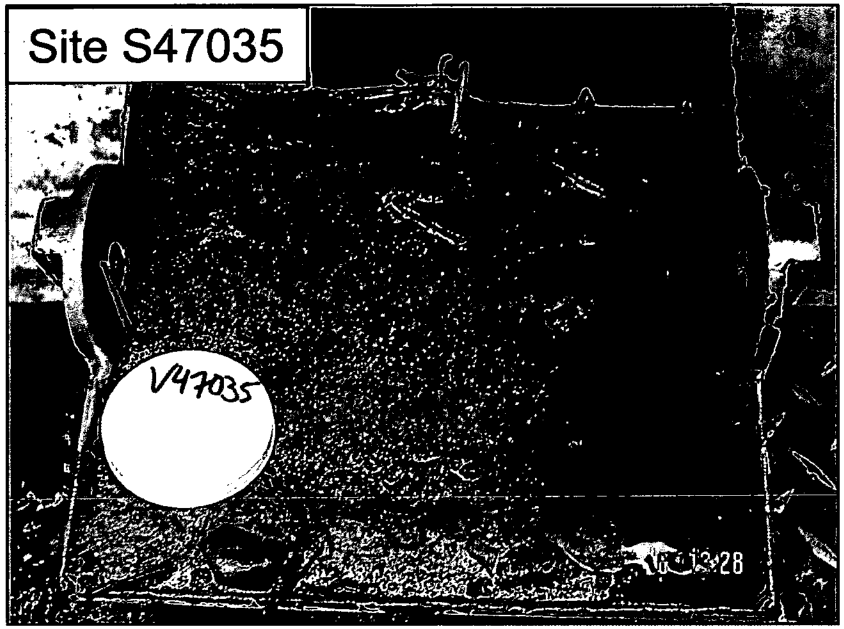

Gravel
CoarseSand
MediumSand
FineSand
Silt
Clay
Percent
Site S47033 Grain size (phi)


Site S47033x

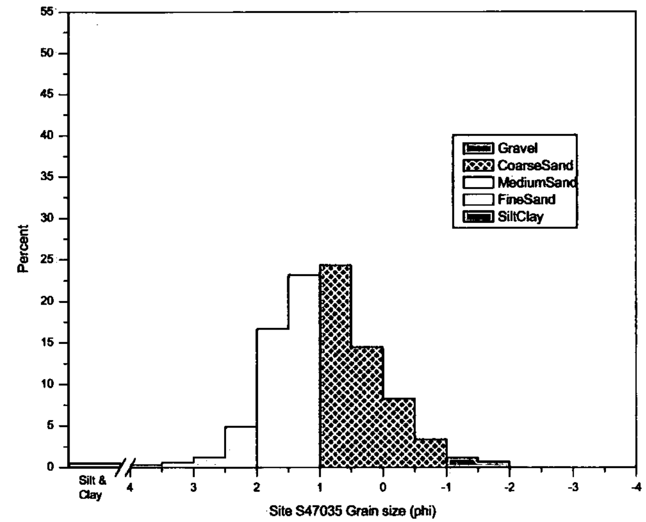

Percent
Gravel
CoarseSand
MediumSand
FineSand
Silt
Clay
Site S47033X Grain size (phi)

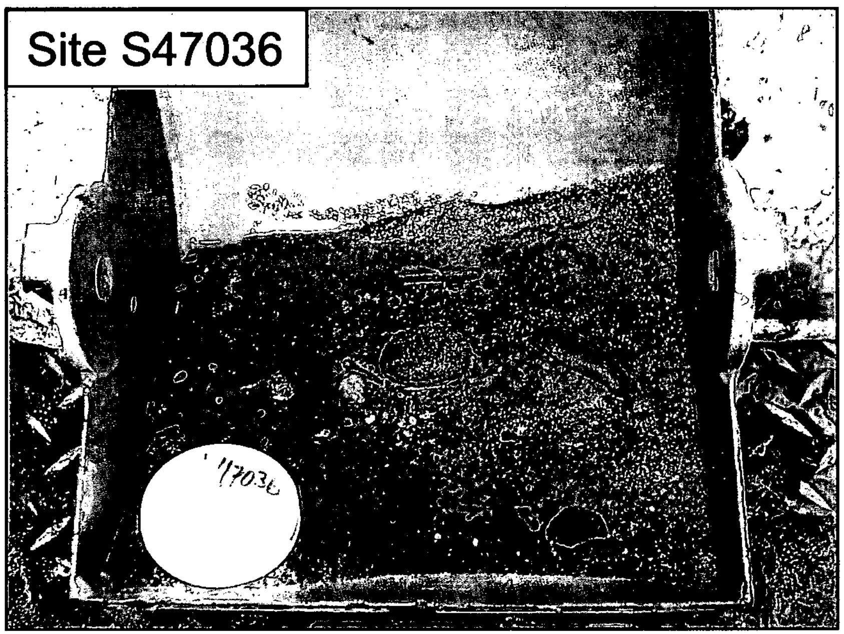

Site S47034


Percent
Gravel
CoarseSand
MediumSand
FineSand
SiltClay
Silt & Clay
Site S47034 Grain size (phi)

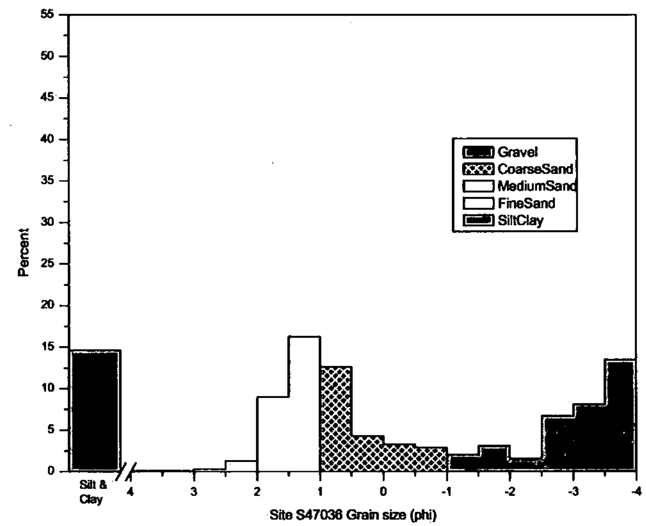


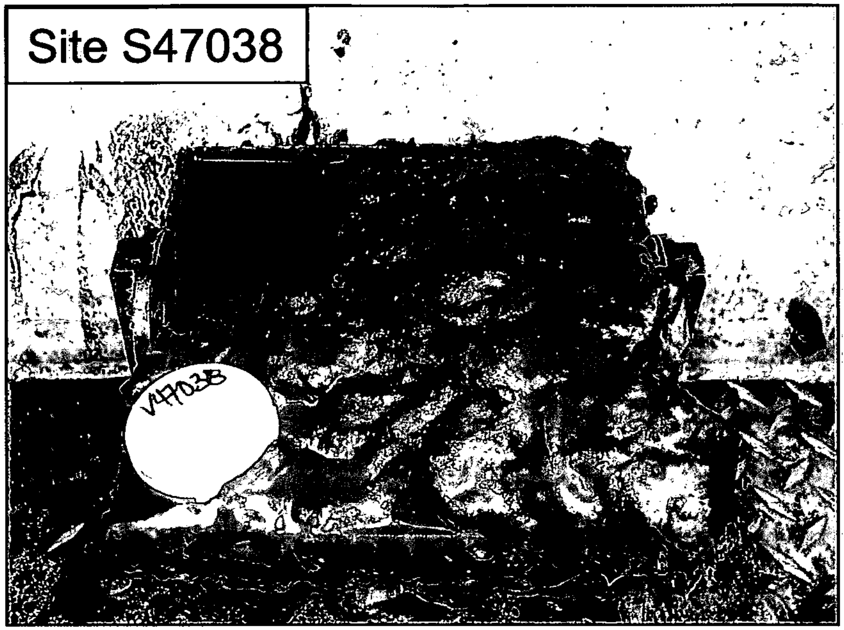
Site S47035

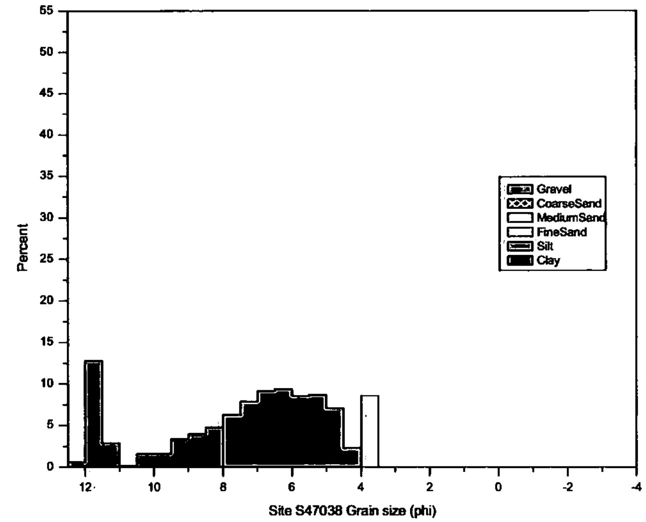




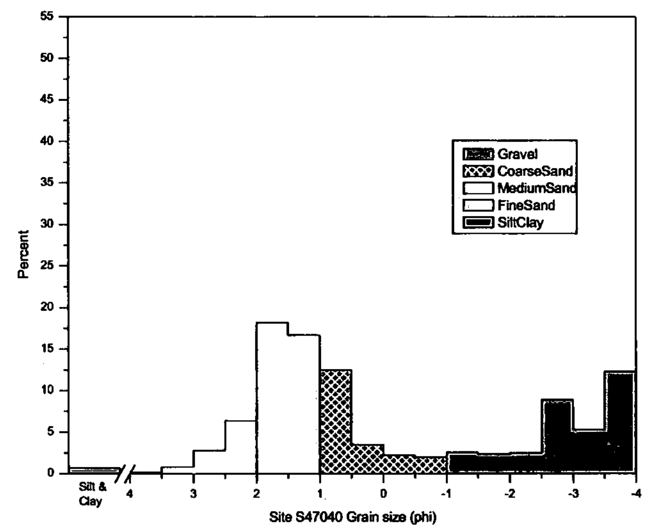
Site S47036

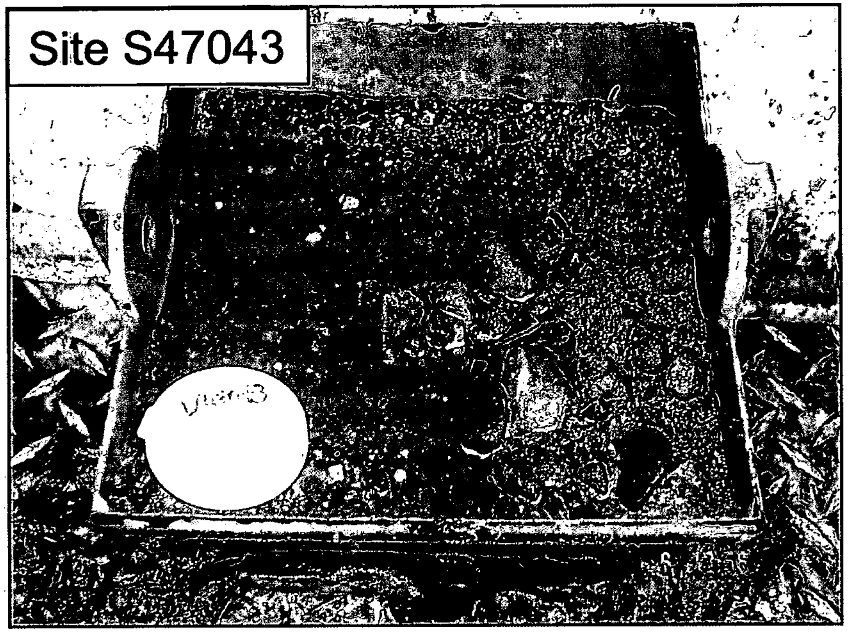


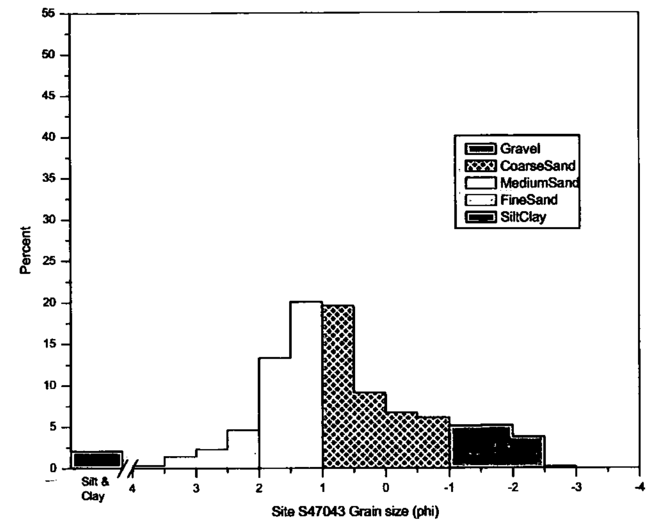

Site S47038

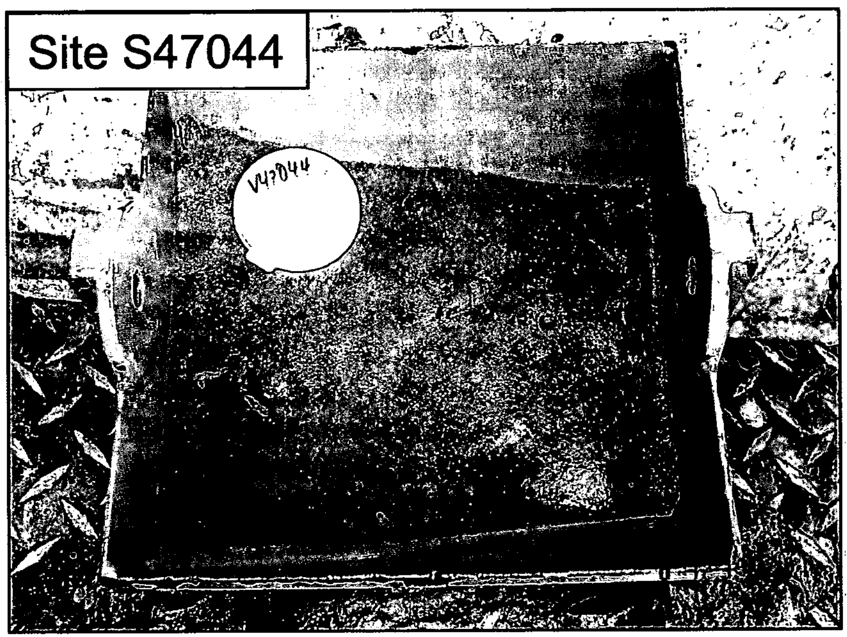

Percent
55
50
45
40
35
30
25
20
15
10
5
0
Gravel
CoarseSand
MediumSand
FineSand
Silt
Clay
12
10
8
6
4
2
0
-2
-4
Site S47038 Grain size (phi)

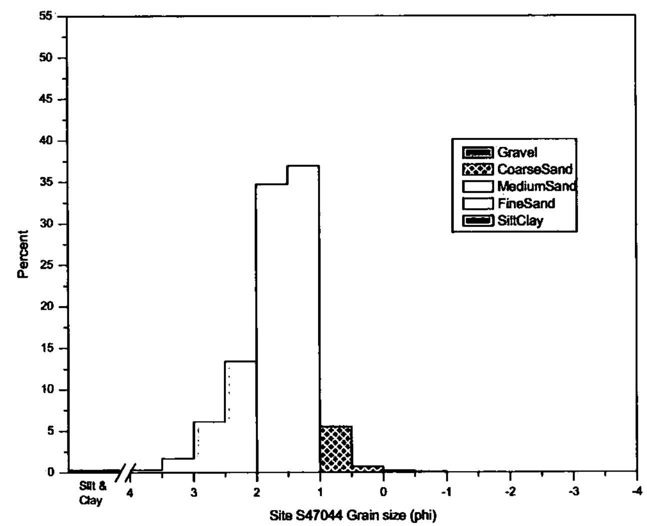

Site S47040

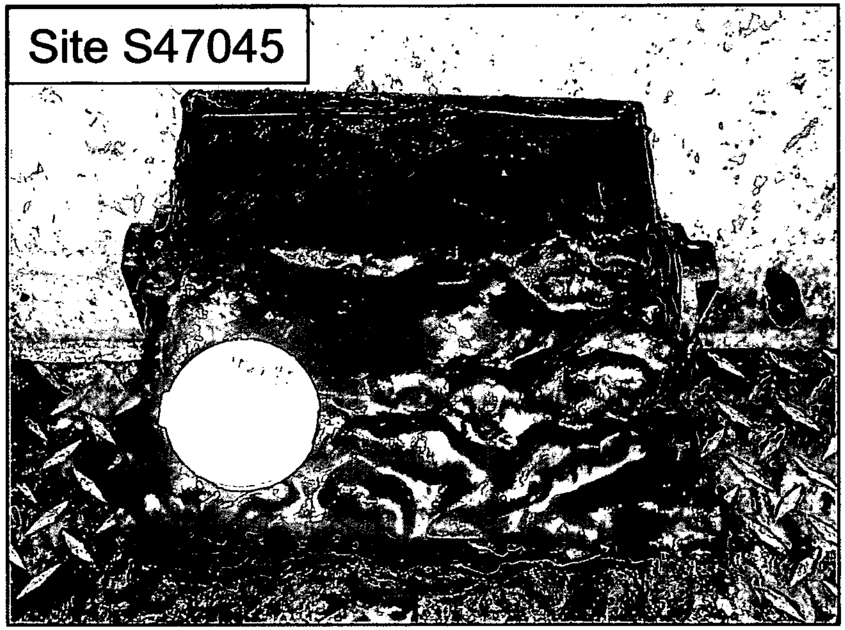

Percent
55
50
45
40
35
30
25
20
15
10
5
0
Gravel
CoarseSand
MediumSand
FineSand
SiltClay
Silt & Clay
4
3
2
1
0
-1
-2
-3
-4
Site S47040 Grain size (phi)

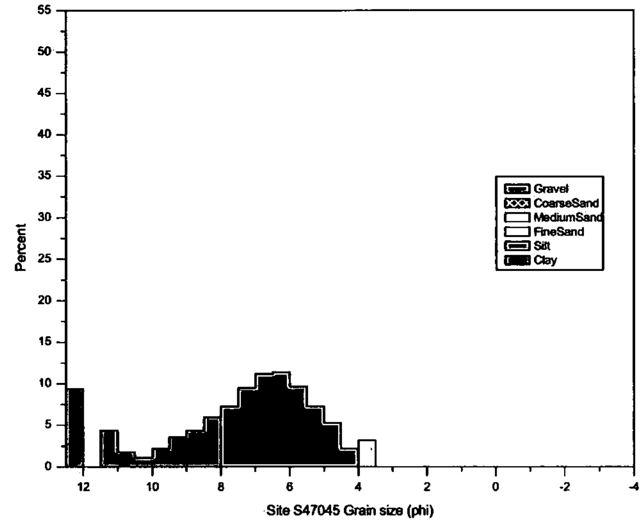

Site S47043

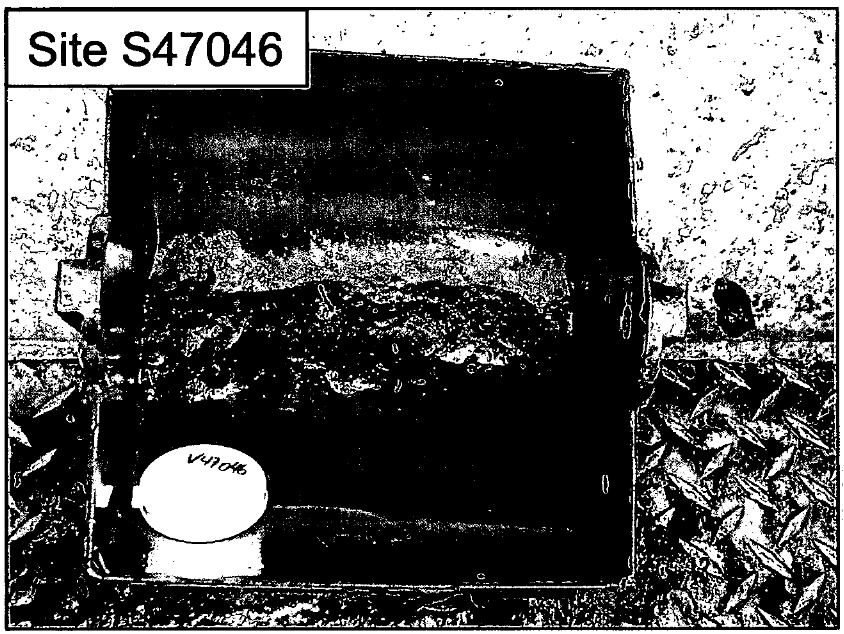

Percent
Gravel
CoarseSand
MediumSand
FineSand
SiltClay
Silt &
Clay
Site S47043 Grain size (phi)

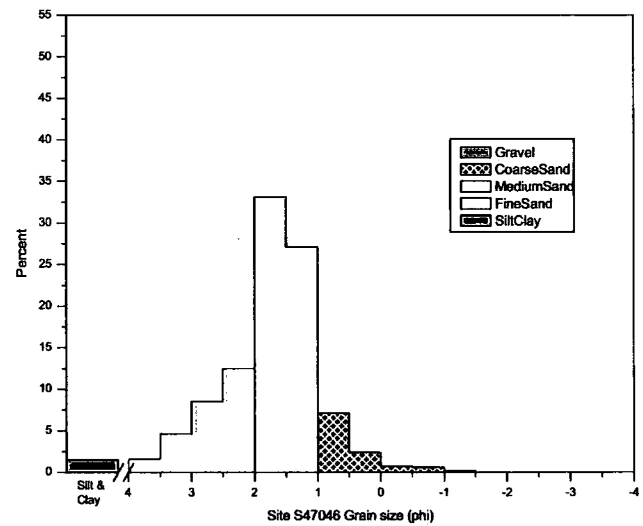

Site S47044
V47044

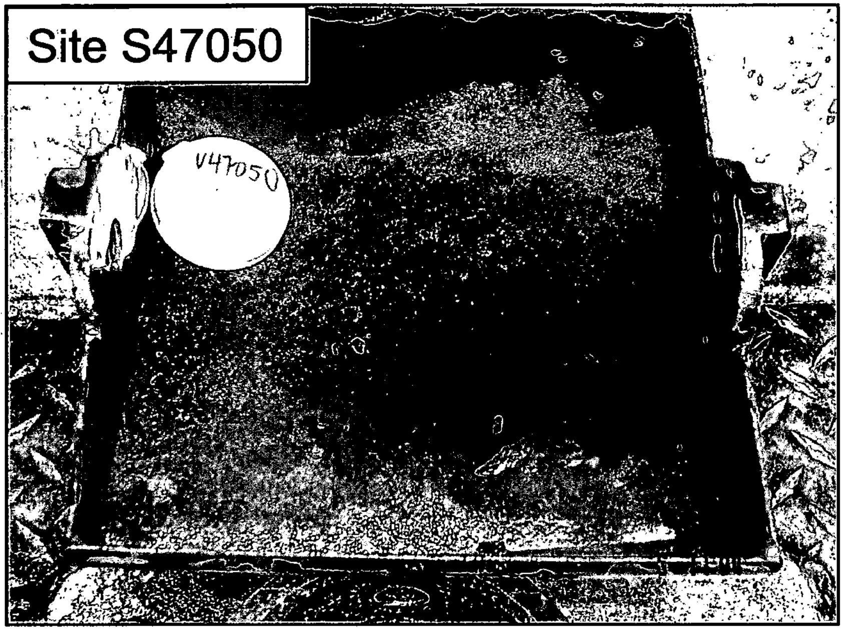

Percent
Gravel
CoarseSand
MediumSand
FineSand
SiltClay
Silt &
Clay
Site S47044 Grain size (phi)

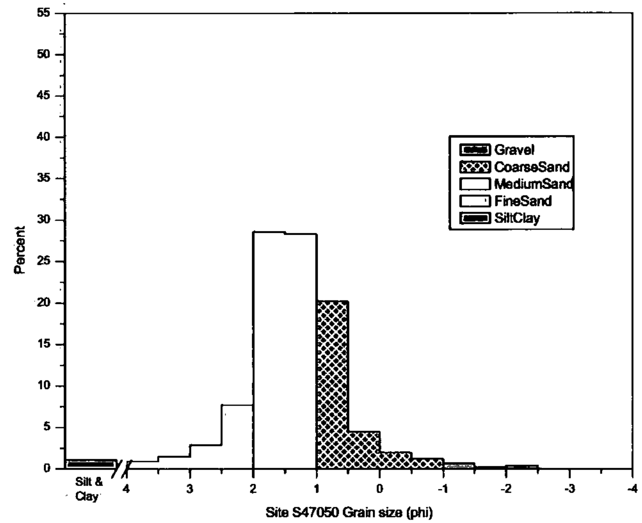

Site S47045

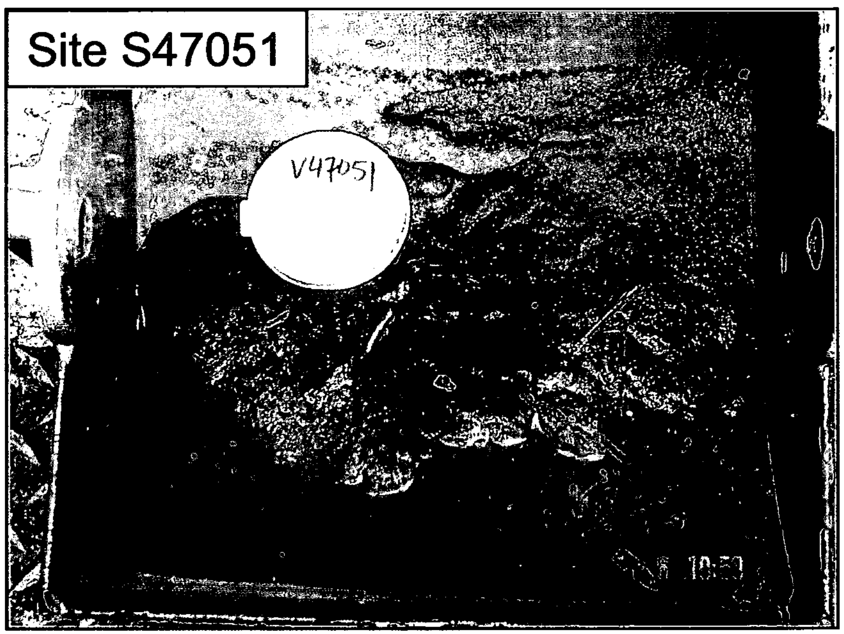

Gravel
CoarseSand
MediumSand
FineSand
Silt
Clay
Percent
Site S47045 Grain size (phi)

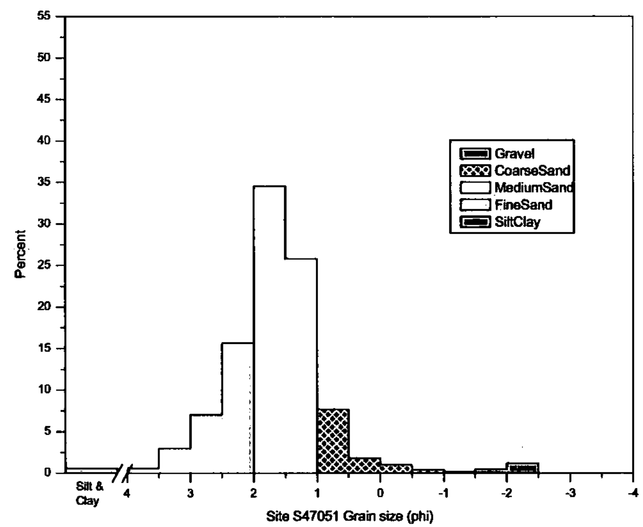

Site S47046

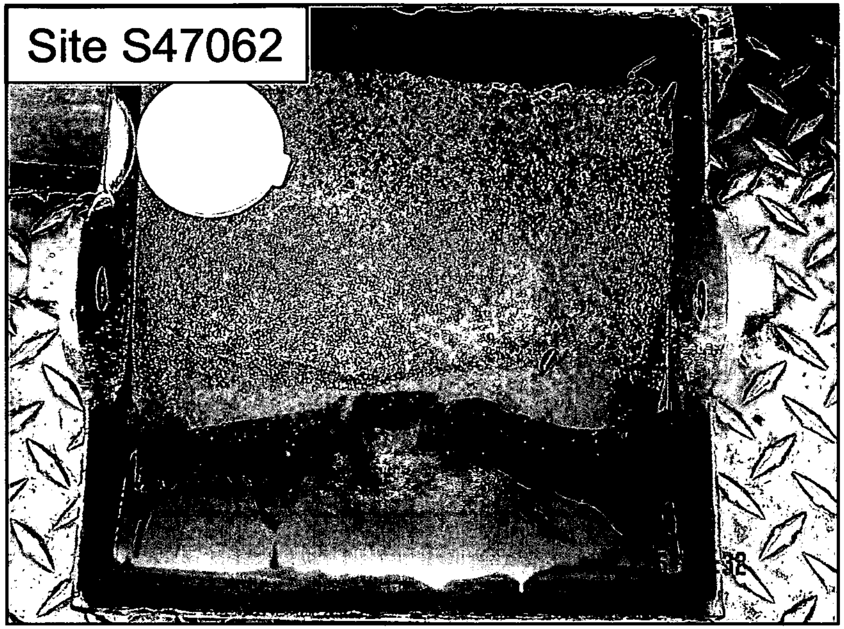

Gravel
CoarseSand
MediumSand
FineSand
SiltClay
Percent
Silt & Clay
Site S47046 Grain size (phi)

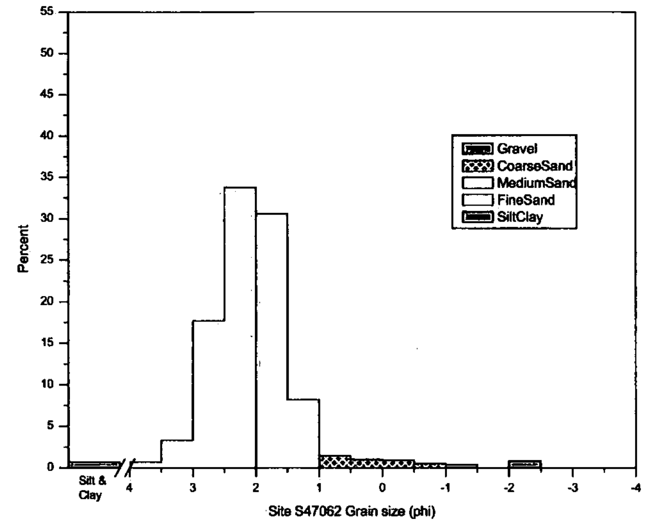

Site S47050
V47050

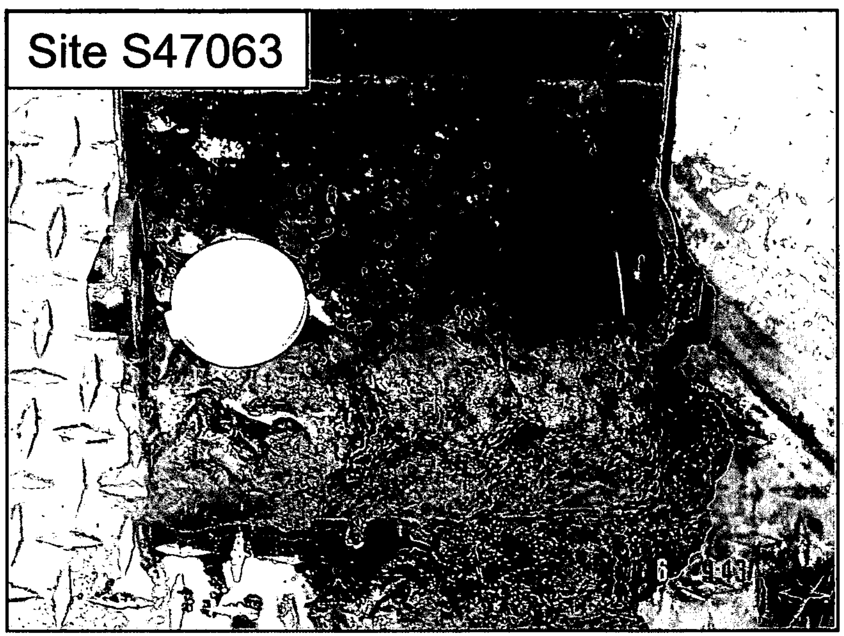

Percent
Gravel
CoarseSand
MediumSand
FineSand
SiltClay
Silt & Clay
4 3 2 1 0 -1 -2 -3 -4
Site S47050 Grain size (phi)

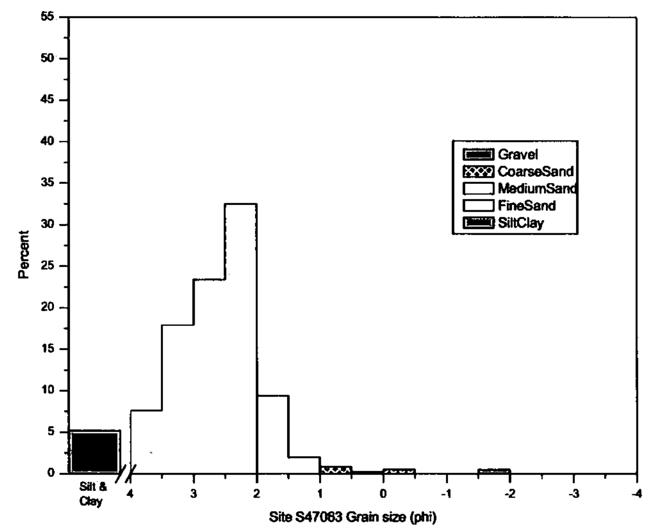

Site S47051
V47051

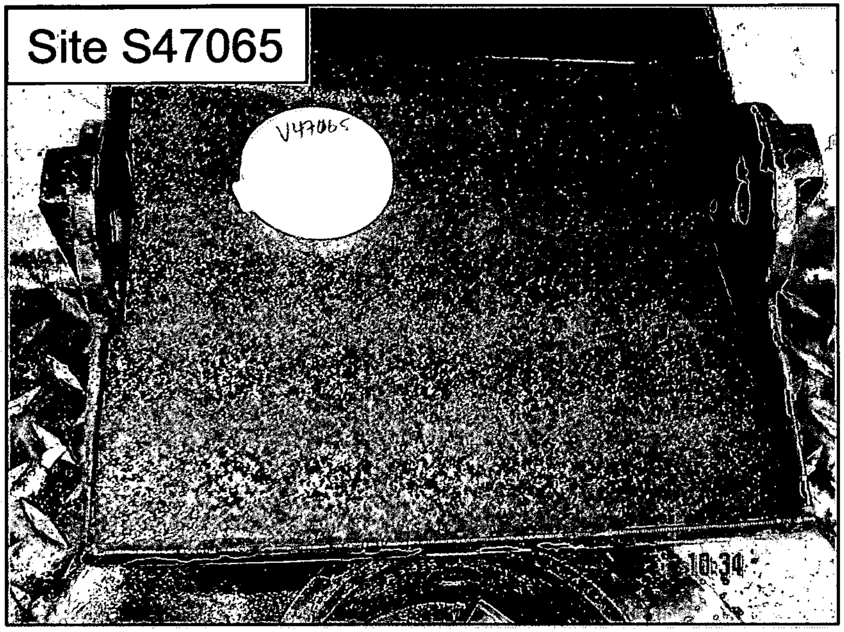

Percent
Gravel
CoarseSand
MediumSand
FineSand
SiltClay
Silt & Clay
4 3 2 1 0 -1 -2 -3 -4
Site S47051 Grain size (phi)

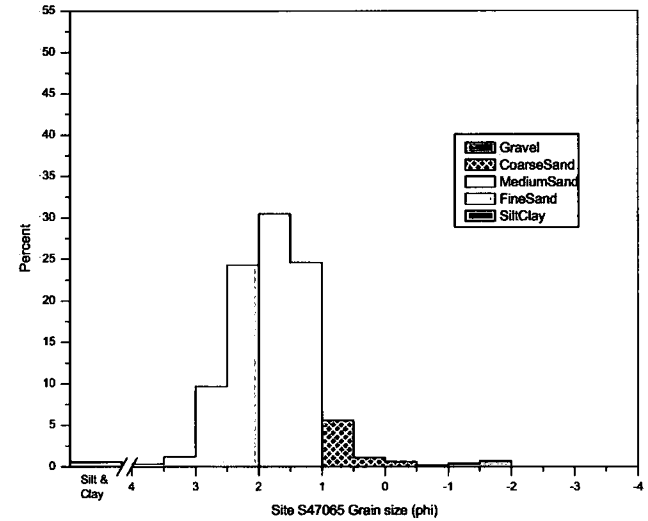

Site S47062

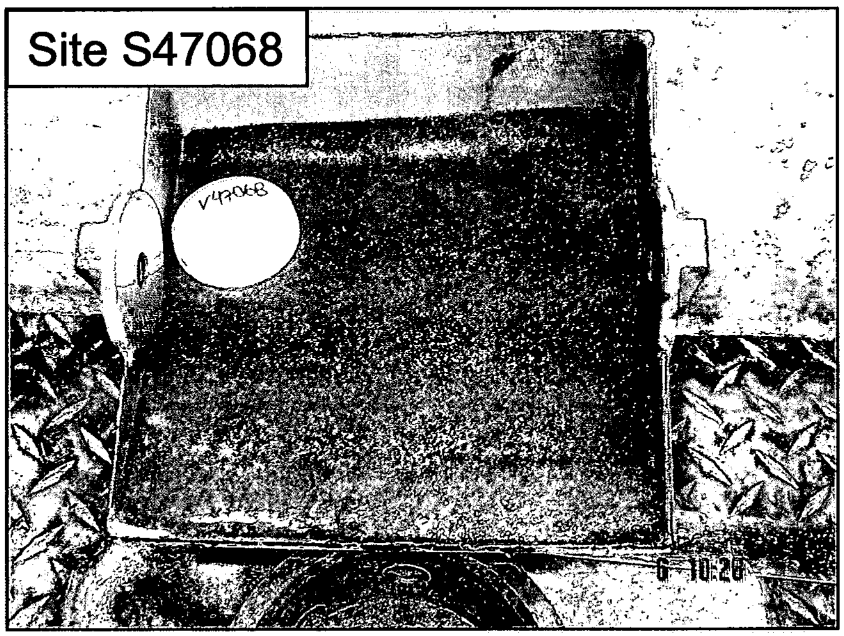

Percent
Gravel
CoarseSand
MediumSand
FineSand
SiltClay
Silt & Clay
Site S47062 Grain size (phi)

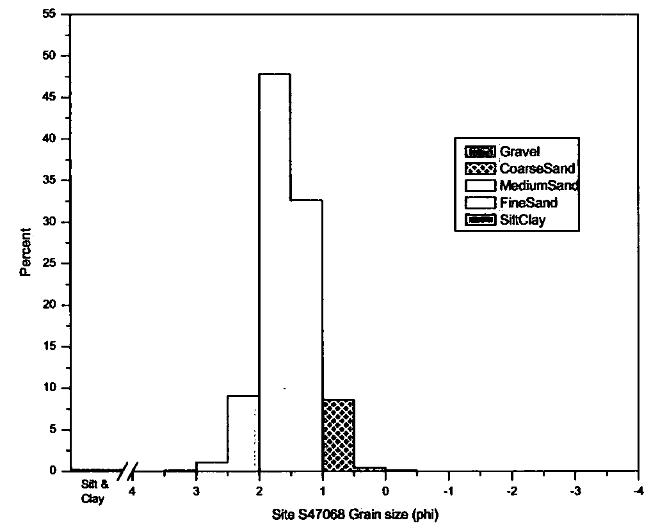

Site S47063

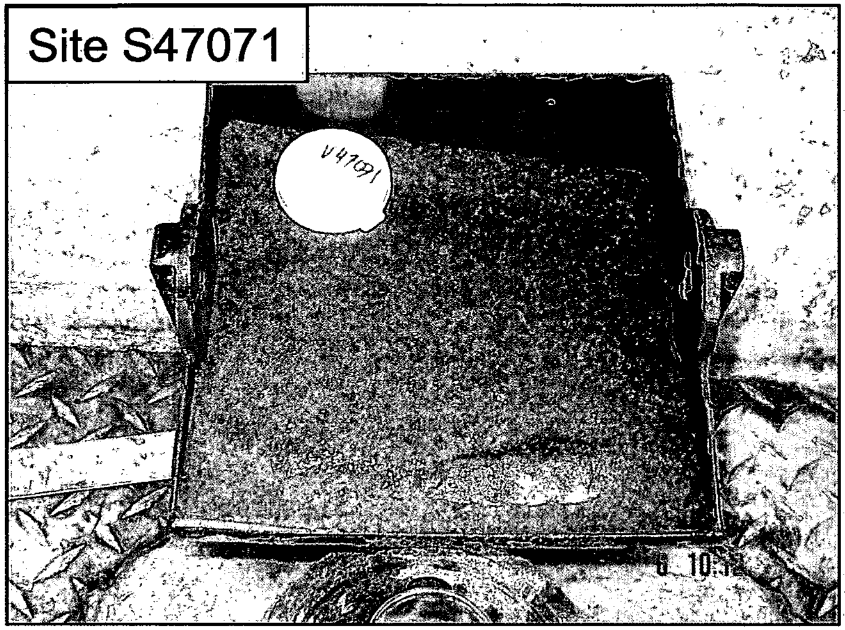

Percent
Gravel
CoarseSand
MediumSand
FineSand
SiltClay
Silt & Clay
Site S47063 Grain size (phi)

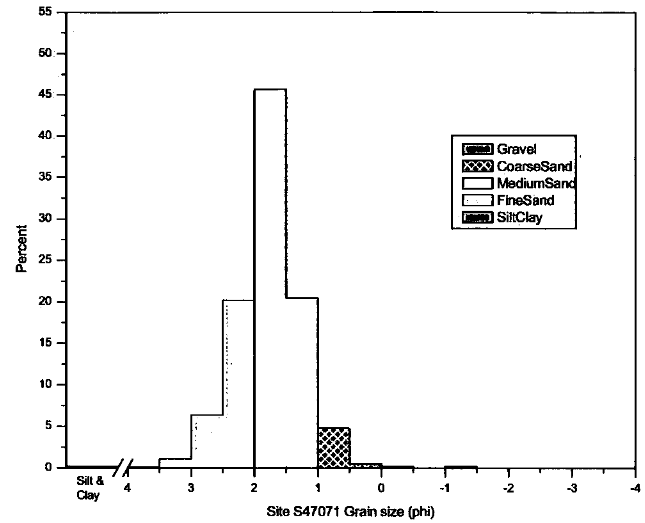

Site S47065

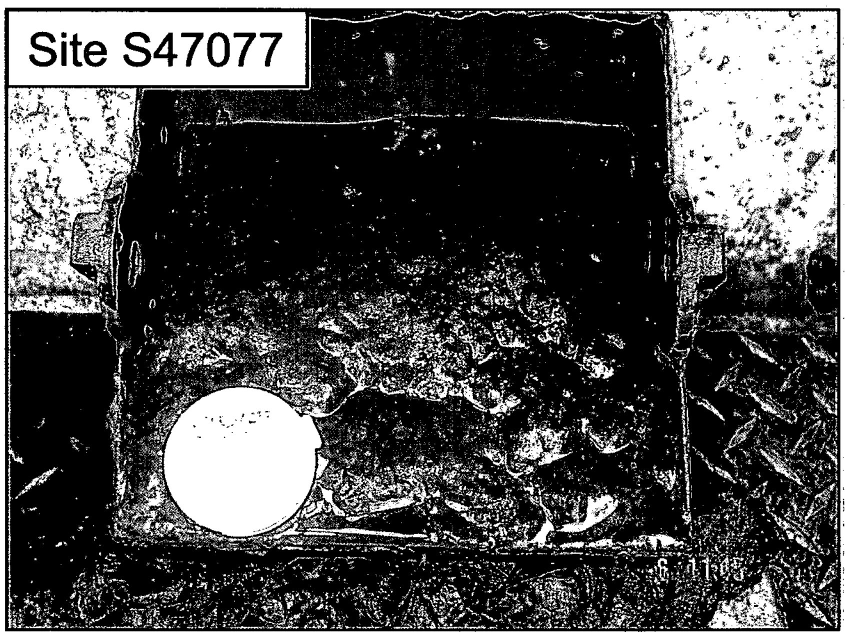

Percent
55
50
45
40
35
30
25
20
15
10
5
0
Silt & Clay
4
3
2
1
0
-1
-2
-3
-4
Site S47065 Grain size (phi)
Gravel
CoarseSand
MediumSand
FineSand
SiltClay

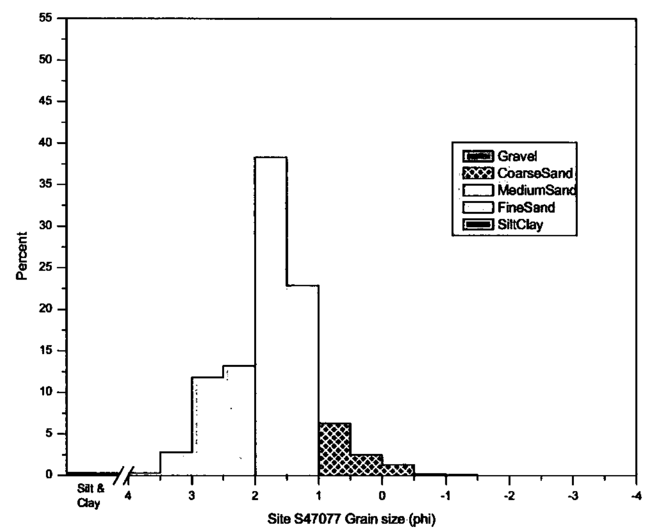

Site S47068

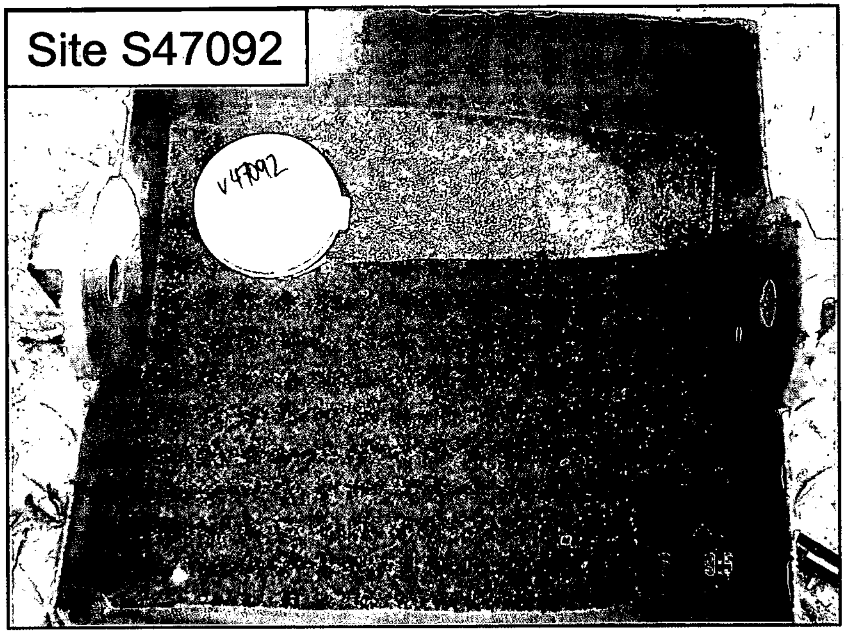

Percent
55
50
45
40
35
30
25
20
15
10
5
0
Silt & Clay
4
3
2
1
0
-1
-2
-3
-4
Site S47068 Grain size (phi)
Gravel
CoarseSand
MediumSand
FineSand
SiltClay

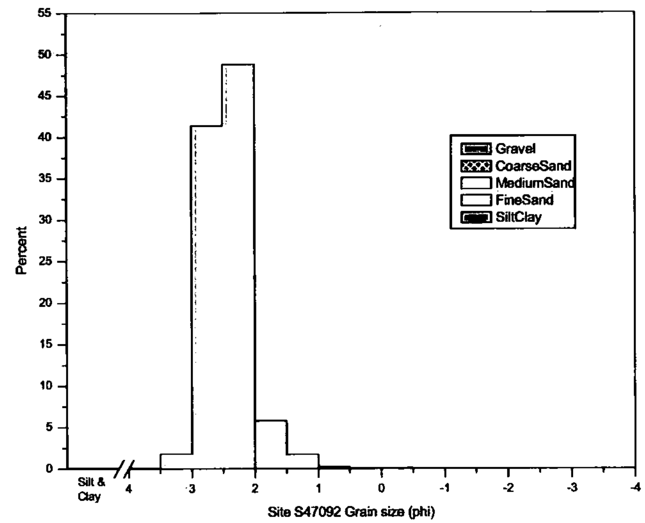

Site S47071
V47071


Percent
55
50
45
40
35
30
25
20
15
10
5
0
Gravel
CoarseSand
MediumSand
FineSand
SiltClay
Silt & Clay
4
3
2
1
0
-1
-2
-3
-4
Site S47071 Grain size (phi)


Site S47077


Percent
55
50
45
40
35
30
25
20
15
10
5
0
Gravel
CoarseSand
MediumSand
FineSand
SiltClay
Silt & Clay
4
3
2
1
0
-1
-2
-3
-4
Site S47077 Grain size (phi)


Site S47092
V47092


Percent
Gravel
CoarseSand
MediumSand
FineSand
SiltClay
Silt &
Clay
Site S47092 Grain size (phi)

PRINTED IN CANADA ON RECYCLED PAPER
IMPRIMÉ AU CANADA SUR DU PAPIER RECYCLÉ

National Water Research Institute
Environment Canada
Canada Centre for Inland Waters
P.O. Box 5050
867 Lakeshore Road
Burlington, Ontario
L7R 4A6 Canada

National Hydrology Research Centre
11 Innovation Boulevard
Saskatoon, Saskatchewan
S7N 3H5 Canada

NATIONAL WATER RESEARCH INSTITUTE
INSTITUT NATIONAL DE RECHERCHE SUR LES EAUX

Institut national de recherche sur les eaux
Environnement Canada
Centre canadien des eaux intérieures
Case postale 5050
867, chemin Lakeshore
Burlington, Ontario
L7R 4A6 Canada

Centre national de recherche en hydrologie
11, boul. Innovation
Saskatoon, Saskatchewan
S7N 3H5 Canada

Environment Canada Environnement Canada

Canada