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ACOUSTIC SURVEYS OF BOTTOM-SEDIMENT TYPE AND BATHYMETRY IN THE GRAND RIVER, GRAND HAVEN, MICHIGAN

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ACOUSTIC SURVEYS OF BOTTOM-SEDIMENT TYPE AND BATHYMETRY IN THE GRAND RIVER, GRAND HAVEN, MICHIGAN

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MANAGEMENT PERSPECTIVE

This survey of the bottom sediments of the Grand River at Grand Haven, Michigan, is part of an EPA study of acoustic procedures for mapping contaminated sediments. The specific objective of the study is to map the sediment type and thickness of four contaminated areas in the Grand River and to measure their erodibility. The more general objective is to contribute to the development of procedures for mapping freshwater contaminated sediments in general.

This report describes an acoustic study of the bottom sediments and morphology of Grand River sediments conducted by Environment Canada's National Water Research Institute with the seabed-classification system, RoxAnn™. RoxAnn surveys in October 1998 were used to map the bottom types and morphology of four contaminated sites. The survey results include GIS maps of bottom-sediment types and bathymetry, areal coverage of the types, and sample and penetrometer data on sediment type and thickness.

The current study will be completed as of June 1999. Future work will depend upon EPA's interest in further collaboration with NWRI and the availability of funding to do so.

Abstract

Environment Canada's National Water Research Institute (NWRI) is collaborating with the Michigan EPA on an acoustic study of contaminated sediments in the Grand River at Grand Haven, Michigan. Both NWRI's RoxAnn seabed-classification system and an acoustic system provided by an EPA contractor were used to map the distribution of bottom-sediment type and thickness and the bathymetry of four areas of the river. Part of the study involved a comparison of the results from the two approaches. Another participant in the investigation was the University of California at Santa Barbara which measured the erodibility of contaminated-sediment cores.

NWRI's component of the study consisted of RoxAnn mapping of sediment types and bathymetry, collection of surface samples as groundtruth data, and penetrometer measurements of soft-sediment thickness. The study also included a trial of the use of dual-frequency data from RoxAnn surveys for estimates of the relative thickness of riverbed sediments. All study data were imported into a GIS to generate sediment and depth maps and data on the areal coverage of sediment types. The surveys were successful in identifying a variety of bottom types and in delimiting the areas of fine-grained sediments with which contaminants were most likely to be associated.

1. Introduction

The Grand River at Grand Haven, Michigan, is known from previous studies (Water Resources Institute, Grand Valley State University, unpublished data) to have contaminated bed sediments at several sites within the city of Grand Haven. EPA, Michigan, selected the area as a test site to continue development and trials of a sophisticated acoustic system developed by Caulfield Engineering for mapping the type and thickness of contaminated sediments and for estimating their degree of contamination. NWRI was invited to participate in the sediment study and to use its RoxAnn acoustic seabed-classification system as an alternative mapping approach. Another part of the study consisted of flume measurements of the erodibility of riverbed sediments by a team from the University of California at Santa Barbara (UCSB). This report deals with only the NWRI portion of the project.

RoxAnn surveys were run in October 1998 at four sites designated by the EPA, two of which were also investigated by Caulfield Engineering and UCSB. Independent data on surface-sediment type were collected at all four sites with a grab sampler and sediment thickness was measured at the Caulfield and UCSB sites with the NWRI tripod penetrometer. RoxAnn and sample data were compared and RoxAnn acoustic labels were adjusted to conform with the physical data. Data on bottom type and water depth were then imported into a GIS for mapping and areal analysis. An attempt was also made to estimate sediment thickness from the differences in the parameters of the high- and low-frequency RoxAnn returns and results were compared with the direct measurements of thickness.

The study results include maps of sediment type, acoustic parameters and bathymetry and data on the areal coverage of the sediment types. The RoxAnn mapping was successful in delineating the areas of fine-grained sediments with which contaminants are most likely to be associated.

2. Study Site

The study area is the lower reach of the Grand River within Grand Haven, Michigan, on the east shore of Lake Michigan (Figure 1). Bed-sediment properties are known from a suite of 23 cores collected and analysed by the Water Resources Institute of Grand Valley State University in 1997 (unpublished). Sediments are primarily silts and organic silts ranging in thickness from 0.3 to 2.8 m and averaging 1.3 m. Cores from several sites have elevated levels of metals, PAHs and pcbs to depths of as much as 2.8 m. EPA selected four of the contaminated sites for the RoxAnn survey- Delta, Sag, Spring Lake and Brass and specified the 10-m track lines to be run. The Delta and Sag sites were also surveyed by Caulfield and UCSB.

3. Survey Procedure

The survey equipment used was RoxAnn, an acoustic sea-bed classification system capable of recording detailed data on bottom-sediment type and water depth at survey speeds (Rukavina and Caddell 1997, Rukavina 1998). RoxAnn connects to an echo sounder and uses the properties of its first and second echoes from the bottom as a measure of its acoustic roughness and hardness. It then combines these parameters to produce an acoustic classification of bottom-sediment type. RoxAnn's default classification scheme for NWRI surveys can discriminate 8 acoustic types: mud, muddy sand, sand, coarse sand, gravel, boulders/hard, weeds on soft and weeds on hard. Figure 2, the RoxAnn record for site Brass, is an example of the computer display of acoustic bottom types available as the survey proceeds. Independent data on sediment properties are needed to convert these acoustic labels to physical sediment types.

RoxAnn surveys were run from October 14-16, 1998 from the NWRI launch Puffin. Traverses followed the 10-m track lines designated by EPA (Figure 1) as closely as possible but not all tracks could be completed because of depths less than 2m, the minimal operating depth for RoxAnn. Navigation was by differential GPS in datum NAD83 with corrections provided by the Milwaukee beacon. Some difficulty with positioning was experienced early in the survey because the RoxAnn survey software could not handle the state-plane coordinates used by EPA. This was resolved by collecting data in state plane and then post-processing in UTM coordinates. Static checks of GPS accuracy at a local benchmark (STAND) indicated that it was within 2 m for differential readings and about 50 m for non-differential readings. Only non-differential data were available during part of the sampling survey on the morning of October 16 because the beacon was not operational. Details of the survey schedule are shown in the log in Appendix 1.

The survey sounder used was the Atlas Deso 10 hydrographic sounder, a two-transducer system operating at frequencies of 210kHz and 30kHz. Both frequencies are used because they provide data on different parts of the sediment column. High-frequency penetration of surface sediments ranges from a few cm to about 50 cm depending on sediment type and porosity ; the low-frequency data represent the integrated response from about the top 1-2 m of the sediment column. By comparing depths and acoustic roughness and hardness for the two frequencies, it is often possible to distinguish areas of relatively thin and thick sediments.

The high and low-frequency data were fed to two RoxAnn systems and recorded on notebook computers by the survey program, Microplot™. Microplot logs RoxAnn data and associated GPS positions at one-second intervals or at about 2-3 m intervals for the standard survey speeds of 2-3 m/s.

RoxAnn requires independent data on bottom-sediment type from samples or diver or underwater-television observations to convert its acoustic sediment labels to physical bottom types. The expectation was that these data would be available from cores collected by the other study teams but, in fact, they were able to provide only limited data for portions of the Sag and Delta sites. Supplemental data were obtained from the 1997 coring survey mentioned previously and from mini-Shipek samples (Mawhinney and Bisutti 1987) of the top 5 cm of bed sediments collected at 33 sites (Figure 3). Particle size of the grab samples was estimated visually. Sample and size data are listed in Appendix 2. Underwater-television surveys which are generally used to record both bottom type and sediment thickness could not be used in this case because of poor visibility.

Sediment thickness to refusal was measured at 24 locations in the Sag and Delta sites with an acoustic/video tripod developed in-house at NWRI. The tripod is a stainless-steel frame 2.5 m high with an underwater video camera and lights on its frame and an echo-sounder transducer installed on its top plate. Weight of the system can be adjusted by adding diver weights to holders on the legs. The total submerged weight of the tripod used for this survey was 47.6 kg. The frame was developed to measure the thickness of soft water-rich sediments most likely to be remobilized by waves or currents. In this case it was only able to record the upper part of the unconsolidated-sediment layer which the earlier coring studies had shown extended to depths of more than 2.8 m.

Sediment thickness was measured by positioning the launch Puffin over each site with differential GPS and then lowering the tripod slowly into the bottom sediment to refusal. Because visibility was extremely poor, the measurements were made acoustically rather than with an underwater video camera. The echo-sounder transducer on the top plate of the tripod measured the distance to the sediment-water interface and the difference between this distance and the tripod height was the depth to refusal. The depths were recorded on a Lowrance X-16 dry-paper recorder at a scale which permitted depth to be read reliably to the nearest ±3 cm. All tripod and core thickness data are listed in Appendix 3 and plotted in Figure 4.

4. Data Analysis

A map of all the RoxAnn data collected during the survey is shown in Figure 5. This is a screen capture of the survey program with labels superimposed to identify the bottom types. The light blue and yellow track lines represent muddy and sandy deposits and the brown and red tracks coarser sediments and boulders or hard bottom. Raw survey maps of this type can be used as soon as the survey is complete to locate depositional areas of soft sediments for more detailed surveys or for selection of sample and core sites. The normal post-processing includes confirmation of bottom types with independent data and GIS analysis to determine sediment boundaries and areas.

To prepare the RoxAnn file for GIS analysis, all the data were checked and fixes with poor GPS quality were removed. No attempt was made to adjust RoxAnn depth data to IGLD85 because water-level data were not available. The edited file was then imported into an Arc/Info™ GIS for voronoi-polygon analysis of the RoxAnn bottom types. This type of analysis produces a chloropleth map by first associating with each data point an area (polygon) extending half the distance to surrounding data points, and then grouping areas of the same type (Rukavina and Delorme 1992). The result is a map with georeferenced boundaries of acoustic bottom types and a table of areas of coverage of each type. Arc/Info was also used to produce chloropleth maps of the RoxAnn parameters acoustic roughness and hardness.

RoxAnn acoustic bottom types must be compared with independent sediment data to confirm their accuracy. In this case groundtruth data were limited and of poor quality. The data available consisted of grain-size data from the 1997 cores for which the positions were of uncertain accuracy, EPA/UCSB cores from the current survey positioned with a different GPS, and visual estimates of grain size from the grab samples. Size data were reduced to three classes- sand (>67% sand), muddy sand (33-67% sand), and mud (<33% sand)- for comparison with the RoxAnn labels. The RoxAnn data corresponding to a sample site were located in the survey program using the criterion that RoxAnn and sample locations had to be within 4 m of each other. If the RoxAnn labels fell within the same size class as their matched sample, they were rated as good, if one size class removed fair, and otherwise poor. Where no size data were available because the sediments were too coarse or weedy, the sample description was used to decide on the goodness of fit with other RoxAnn classes. The accuracy of the RoxAnn classification determined in this fashion in previous surveys varied from site to site but was typically about 50% good, 30% fair and 20% poor. Appendix 4 lists the results for this survey. Identification was good for 53% of the tests, fair for 34% and poor for 13%. Where the results were fair or poor, the RoxAnn label tended to be harder or rougher than the groundtruth data, and it is possible that a better fit could be obtained by adjusting the RoxAnn class boundaries. This was not attempted because of the limited groundtruth data, the non-differential GPS positions for some of the sites, and the uncertainty as to the significance of the weeds on soft class discussed below.

The bottom type, weeds on soft, covered about 10% of the area of the deposits at the Delta, Sag and Brass sites but no weeds were recovered in the Minishipek samples and the echo patterns characteristic of bottom weeds were missing from the hardcopy sounder records. Weeds on soft is a bottom type with a high acoustic roughness and low hardness. In this case, it likely represents mud with a high roughness value because of dispersed gas bubbles. Gas bubbles were observed during drops of the tripod and the recovery of grab samples at both the Sag and Delta sites.

The depth data recorded by RoxAnn were also imported into Arc/Info for processing. Depth was contoured at 5-m intervals to produce a bathymetric map and the areas within the contour intervals were computed to determine the depth distribution. Depth data were also used in Surfer™ to prepare 3-D maps of the site morphology. All maps were generated by kriging using the program's default values.

Previous trials of thickness mapping with dual-frequency surveys have shown fair correlation of the depth difference ($depth_{low}$-$depth_{high}$) and the roughness ratio (E_{1low}/E_{1high}) with direct measurements of sediment thickness for depths greater than 4 m, the minimal depth for which low-frequency data are valid. In this case, no local relationship could be developed because of the limited control data. Thickness data from 1997 and 1998 cores and tripod penetration were available at 24 sites in the four study areas, only 3 of which were at depths greater than 4 m.

5. Results and Discussion

General

The results of GIS areal analysis of RoxAnn bottom type and depth are listed in Appendix 5. Each site is described below in terms of sediment type and bathymetry. Data from tripod penetration and cores collected in 1997 and 1998 have been used to estimate the relative sediment thickness. Neither the tripod nor the cores provide the total thickness of unconsolidated sediment.

Brass

Brass is a small linear basin between the shoreline and an offshore shoal and island area in the southeast part of the study area (Figure 1). Maximum depth is 6 m along the axis of the basin (Figures 6, 7). The basin sediment is muddy sand flanked by sand and gravel on the inshore slope and the offshore shoal area (Figure 8). Boulders and hard bottom some of which consists of concrete slabs occur along the shoreline and offshore in the southeastern part of the area. Muddy sand (44%) is the dominant bottom type followed by gravel (25%), sand (17%), weed on soft (8%) and boulders or hard bottom (6%). Data on sediment thickness are available at only 3 sites from cores collected in 1997. Thickness ranges from 0.3-1.4 m.

Delta

The Delta site straddles the river channel at the point where it separates into north and south arms (Figure 1). Figures 9, 10, and 11 are maps of RoxAnn bathymetry, morphology and bottom type. The site consists of two bathymetric regimes: the main channel of the river with maximum depths of 8-9 m on the west and a shallower shelf area opposite the island ranging in depth from 2-6 m. The main channel is floored with muddy sand at depth and sand and gravel on the inshore slope. The shelf area is more complex consisting of a mix of soft (weed on soft and sand) and hard bottom (gravel and boulders) inshore and muddy sand offshore. Muddy sand (68%) is again the dominant type, sand and weed on soft account for 11% each, and gravel and boulders 8% and 1% respectively. Thickness data are available at 25 sites concentrated in the eastern end of the area opposite the island and in the south arm of the river. Thickness in that area ranges from 0-2.6 m and averages 0.81 m.

Sag

The Sag site occupies a large shallow embayment off the north arm of the river (Figure 1) with depths restricted to less than 3 m within the embayment and then dropping off quickly to 8-9 m in the main channel to the southeast (Figure 12, 13). Only the central part of the deposit was accessible because of shallow depth, and data are available only for that area. Most of the shallow flat and the channel slope and bed is covered with muddy sand and smaller amounts of weed on soft (Figure 14). Sand, gravel and weed on soft are the slope deposits. Muddy sand is the dominant type at 74% and there are roughly equal amounts of weed on soft (11%), sand (8%) and gravel (7%). Thickness data are available at 21 sites. Thickness ranges from 0.1-2.8 m and averages 0.81 m.

Spring Lake

The Spring Lake site occurs on the south shore of an embayment in the northeast corner of the study area (Figure 1). Depth increases gradually subparallel to the shoreline from 2-3 m at its southwest end to more than 9 m at its northeast end (Figures 15, 16). Bottom types show no relationship to depth (Figure 17). Most of the area is a muddy-sand deposit except for the inshore margin where mud occurs along the central part of the area and coarser sediments ranging from sand through boulders at the northeast and southwest limits. Muddy sand is by far the dominant type (83%), mud is an important component at 12% and the remaining types account for less than 1% each. Data on sediment thickness are available at only one site cored in 1997. Core length was 1.9 m.

6. Conclusions

RoxAnn seabed-classification surveys have been used to map the distribution of bottom-sediment types and to delineate the areas of fine-grained sediments at four areas in the lower Grand River at Grand Haven, Michigan. The surveys were completed in a period of four days with the 10-m line coverage specified by the contractor.

RoxAnn was successful in discriminating 8 bottom types: mud, muddy sand, sand, coarse sand, gravel, boulders/hard, weeds on hard and weeds on soft (gassy mud?). Comparison of the acoustic labels with qualitative and quantitative size data from grab samples and cores showed good to fair agreement at 87 percent of the ground-truth sites.

GIS analysis of RoxAnn bottom-type and depth data was used to generate chloropleth maps of sediment type and contour maps of bathymetry and to compute the areas of coverage of the bottom types and of the depth intervals. The fine-grained sediment types with which contaminants are most likely to be associated range from a minumum of 53 percent of the deposit at the Brass site to a maximum of 97 percent at the Spring Lake site.

Thickness of the soft-sediment deposits was estimated from the lengths of cores collected in 1997 and during the current survey and from penetration measurements with NWRI's tripod penetrometer. Data are limited and insufficient for an isopach map or an estimate of sediment volume. The maximum thickness recorded was 2.8 m in a core at the Sag site.

7. Recommendations for additional work

The RoxAnn bottom maps delineate the areas of fine-grained sediments but the available data on sediment thickness from the NWRI and other surveys are inadequate to map the geometry of the contaminated deposits or to estimate their volume. Additional penetrometer, coring or acoustic-coring surveys would be required to complete the data set needed for 3-D mapping. The 1997 core data suggest that contamination is limited to the upper 2.8 m of the sediment column and it is unlikely that data below this level would be necessary. In our experience, collecting cores longer than about 1.5 m with a Benthos type of corer is difficult because internal friction limits recovery. Longer and less disturbed cores can be recovered with a small vibrocorer like the Meta-Probe™.

The RoxAnn surveys provide a snapshot of sediment distribution at the time of the survey. If there is concern about changing sediment patterns because of seasonal changes in water level or flow rates, then a survey of this type should be repeated to determine the extent of the change and the possibility of erosion and export of contaminated sediments. Early-spring surveys in particular would be useful to minimize the effect of both weeds and gas on the acoustic results.

It was not possible to use the RoxAnn dual-frequency data to estimate sediment thickness at the Delta and Sag sites because ground-truth data from cores were limited and depths were too shallow for operation of the low-frequency RoxAnn. Both the Brass and Spring Lake sites had depths high enough to permit the thickness estimates but only 4 cores were available as control data. If more detailed surveys of these sites are intended in the future, they would provide the opportunity for a proper evaluation of RoxAnn for discriminating between areas of relatively thick and thin sediments. A successful survey of this type could be used to optimize the selection of coring sites and improve sampling efficiency.

8. Acknowledgements

Dr. John Filkins of EPA, Grosse Ile, coordinated the study. Dave Gilroy of NWRI's Technical Operations group was the coxswain for the survey and assisted in the reduction of the RoxAnn data. Brian Trapp (AERB/NWRI) operated the RoxAnn system and compared the high and low frequency results. Jerry Ford of NWRI's Engineering Services Group advised on the acoustic aspects of the study and reviewed the report. He was also present during one of the Caulfield surveys as an observer. Contractor Marilyn Dunnett assisted with data processing and computer graphics. Contractor Carolyn Bakelaar provided the GIS analysis of the RoxAnn data. The study was funded by EPA's Great Lakes National Program Office with Marc Tuchman of the Chicago office as coordinator.

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Figures

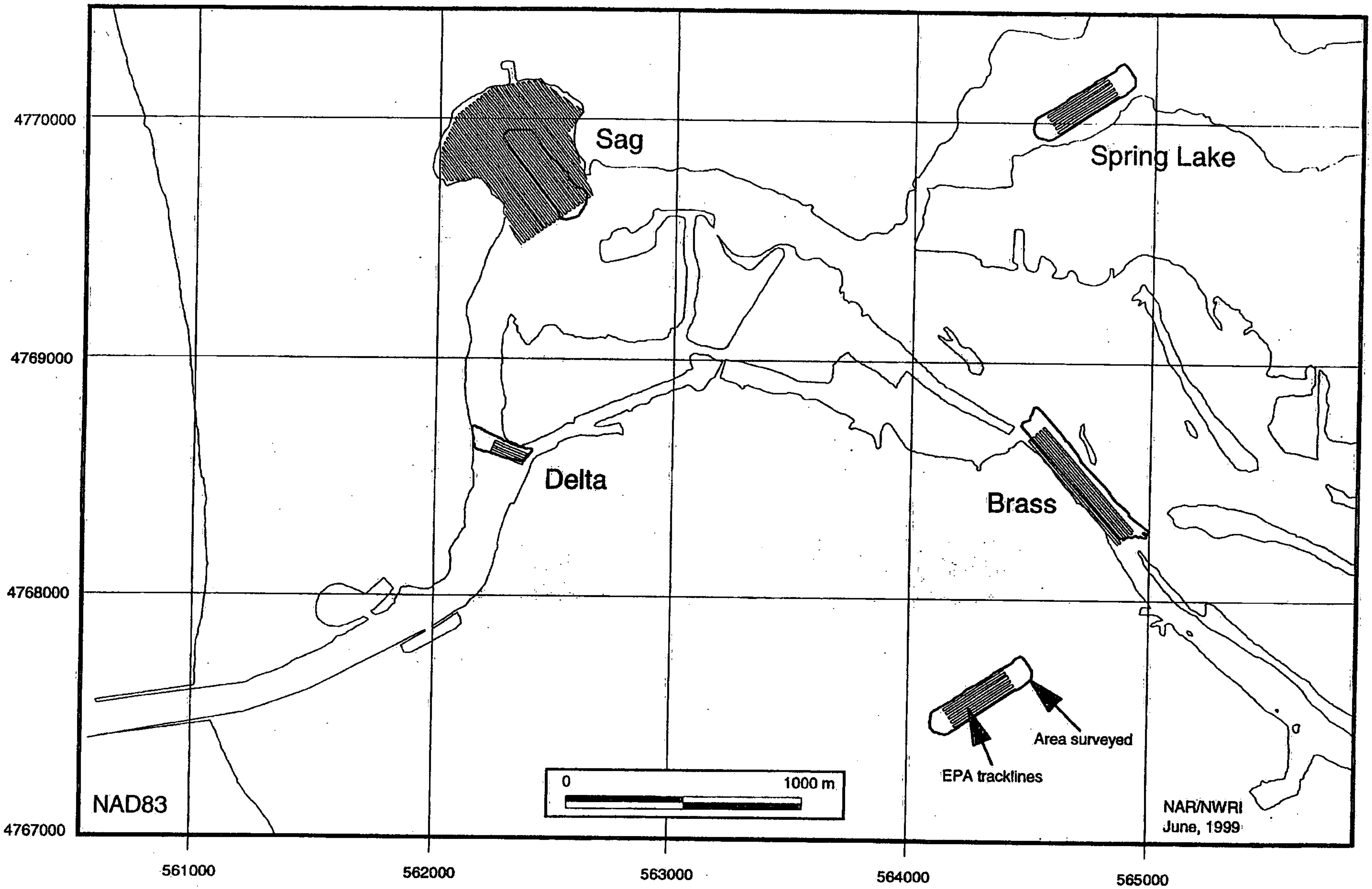

Figure 1. Study site

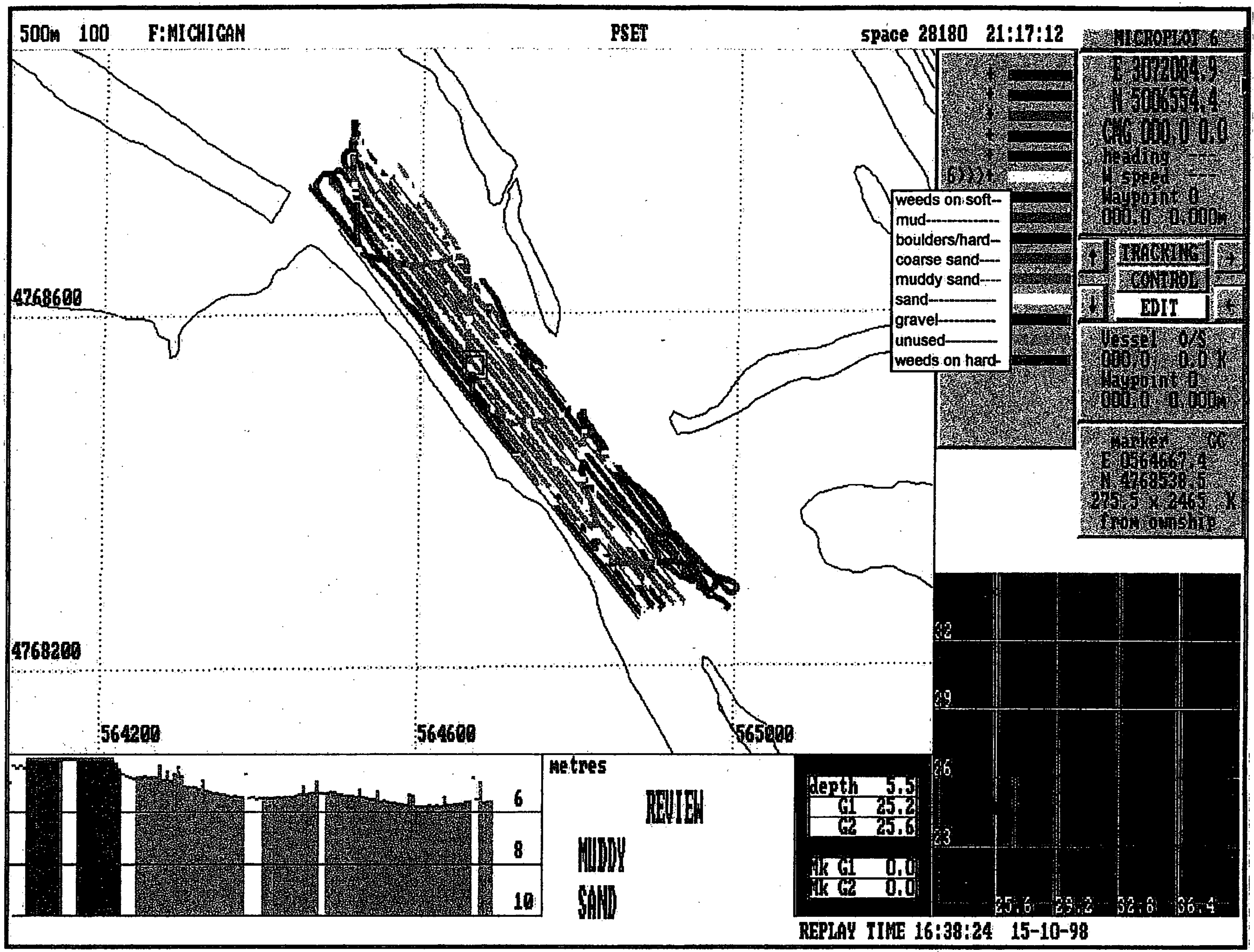

Figure 2. RoxAnn/Microplot sample, site Brass

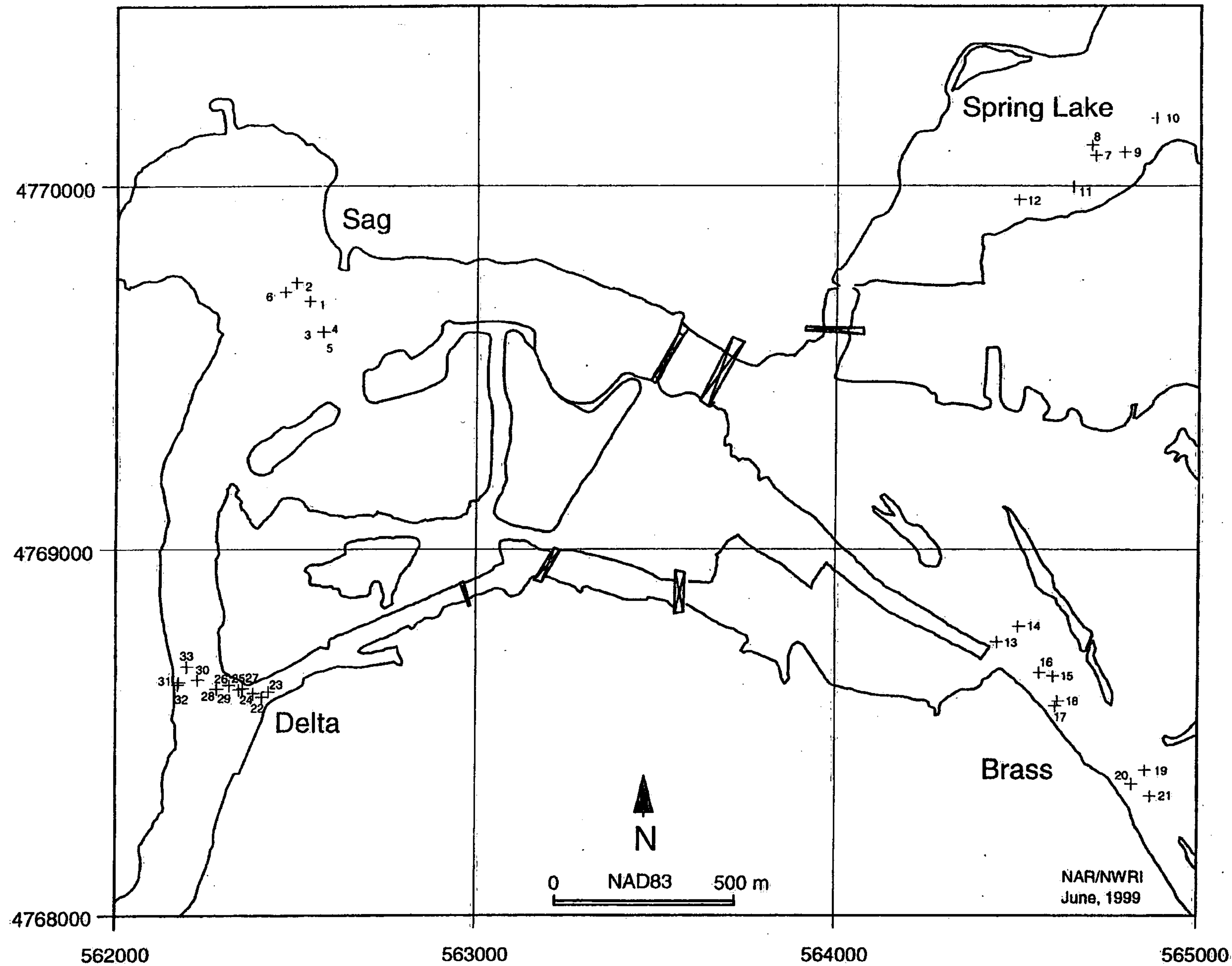

Figure 3. Shipek-sample sites

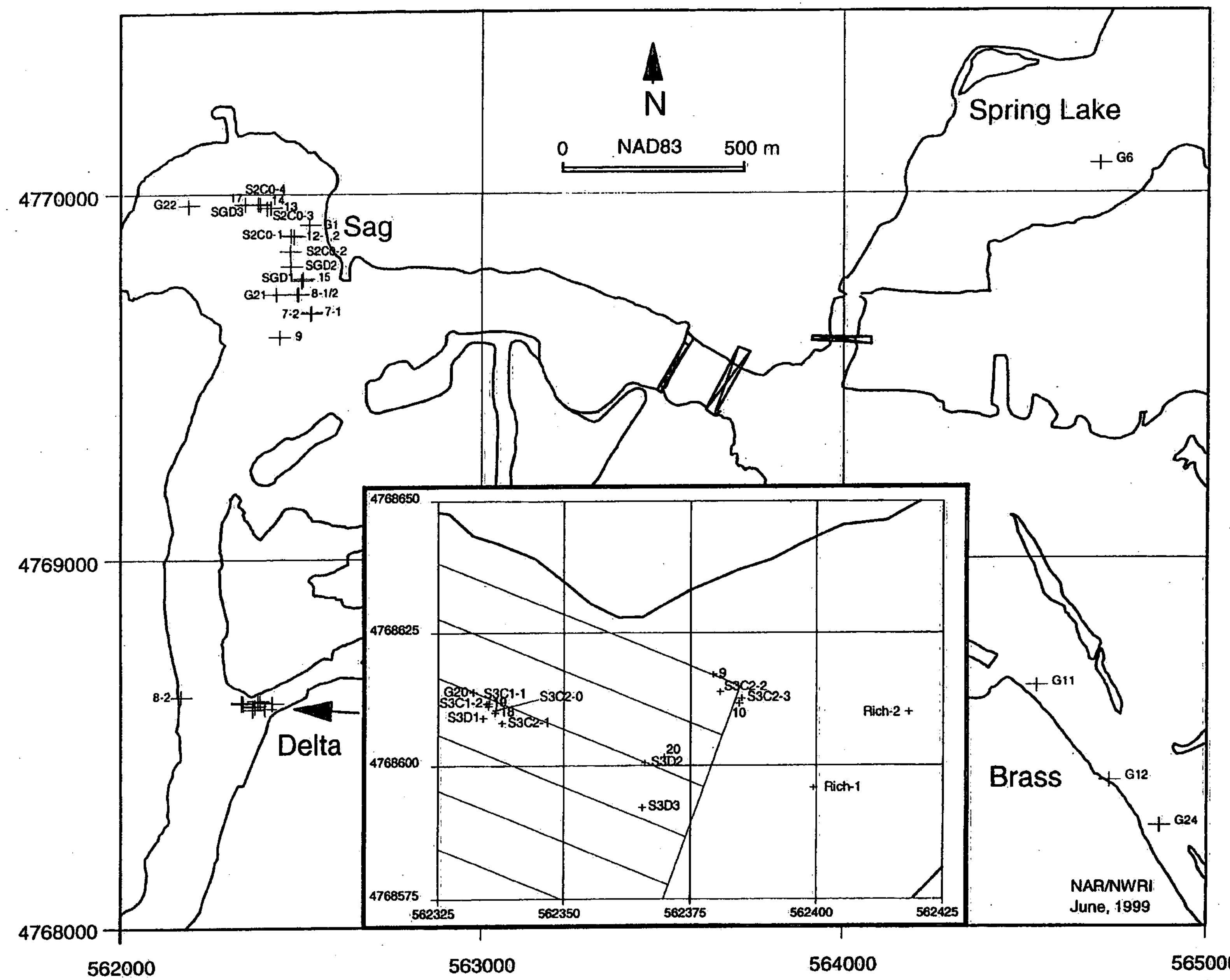

Figure 4. Core, tripod sites

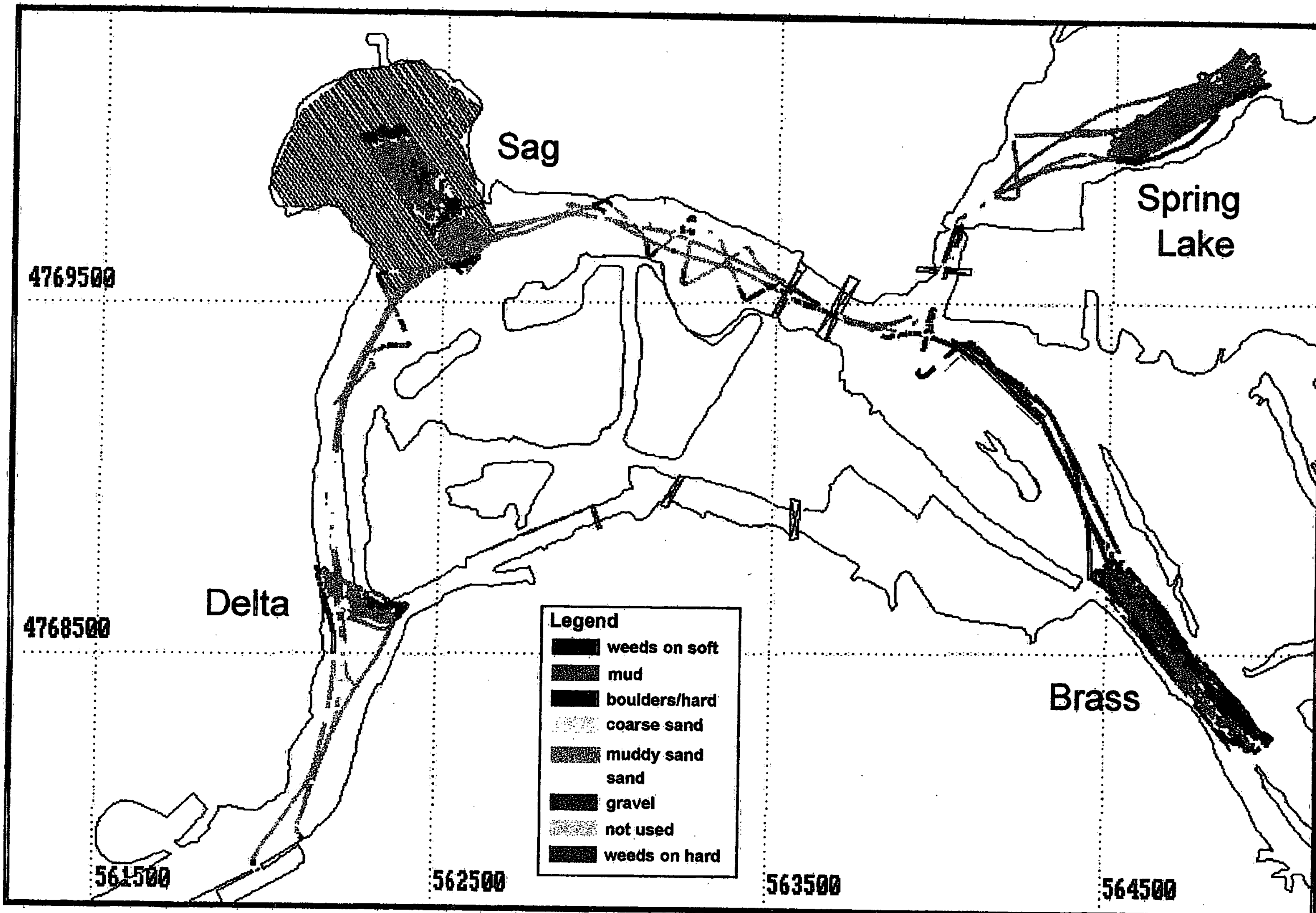

Figure 5. Survey coverage

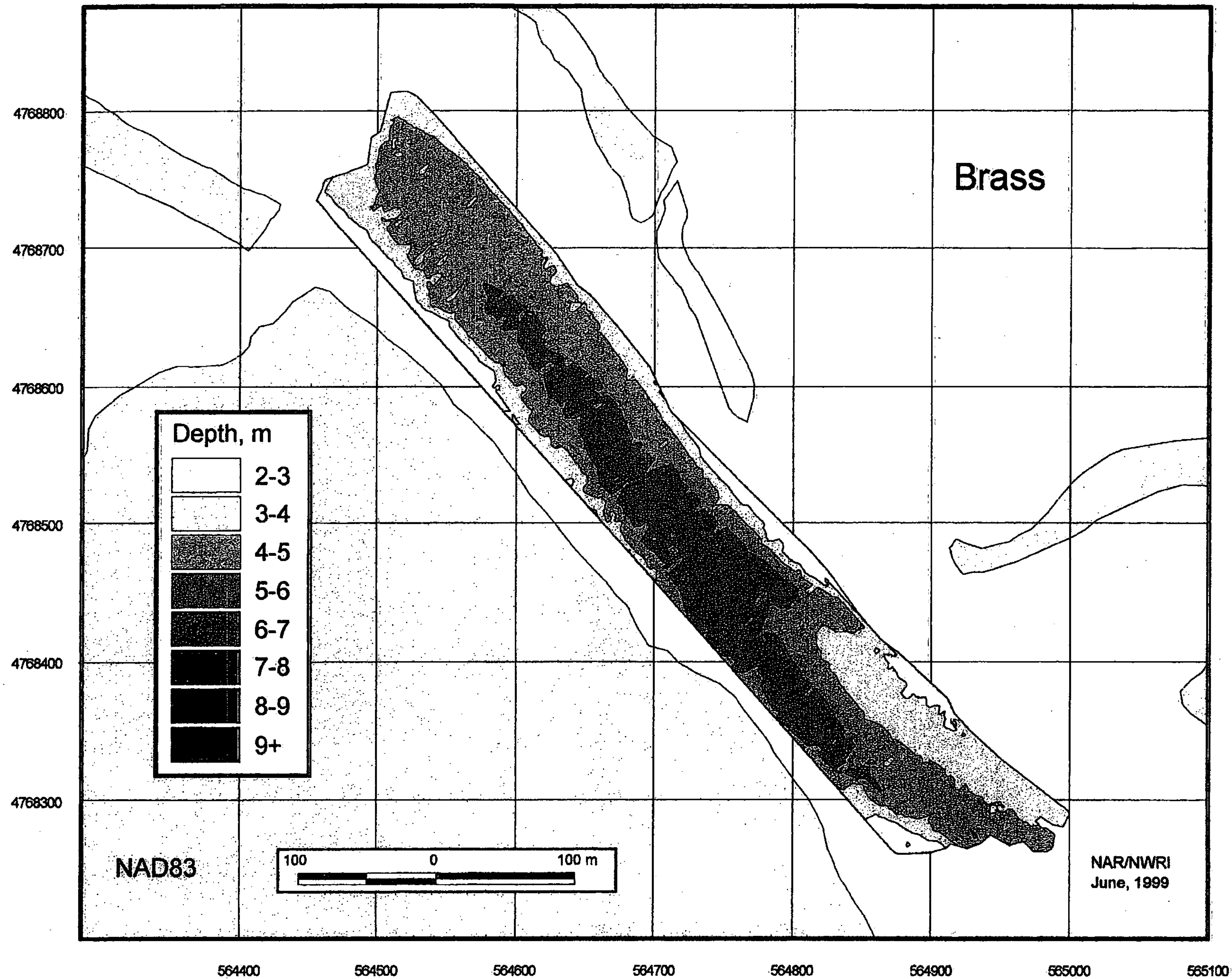

Figure 6. Bathymetry, site Brass

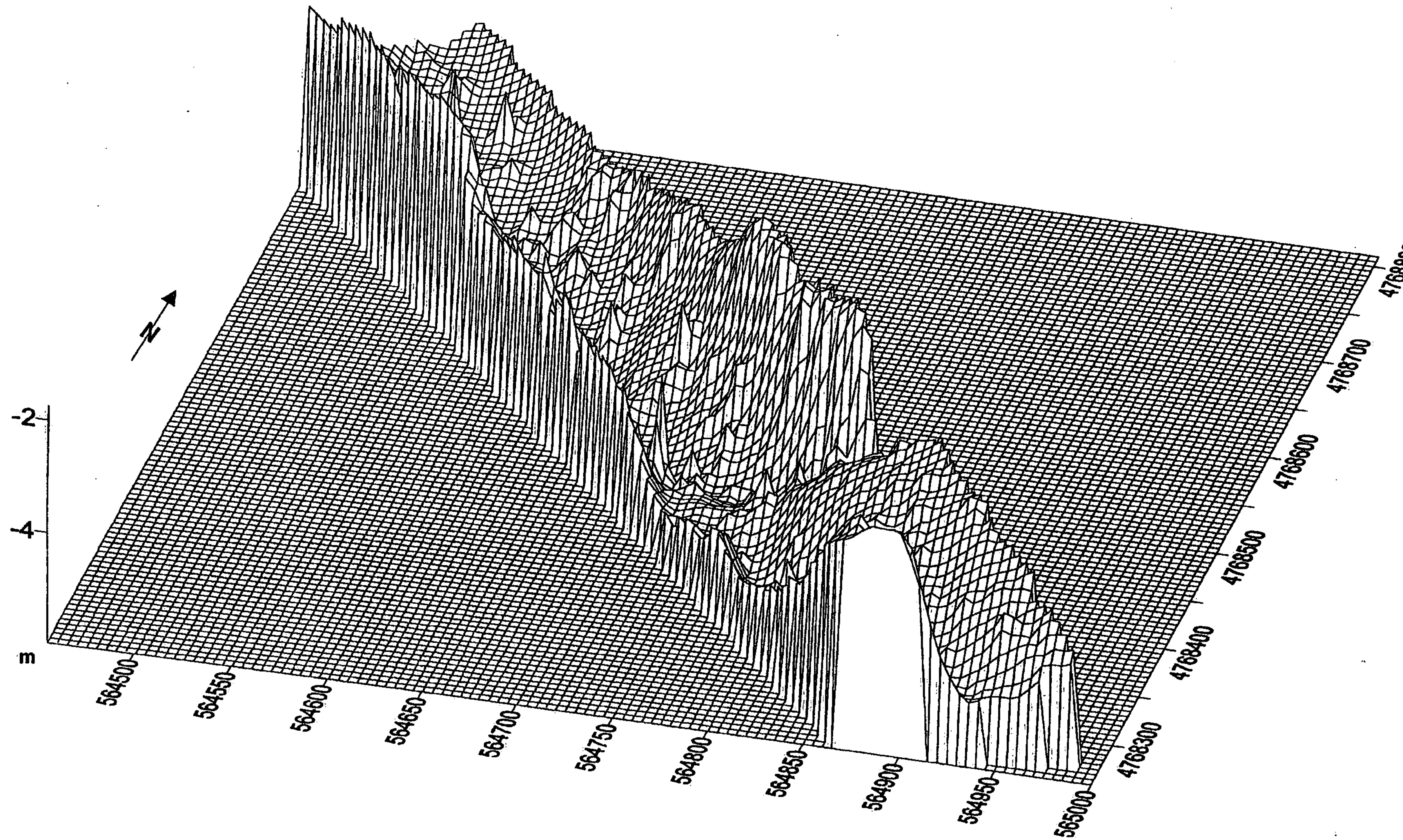

Figure 7. Bed morphology, site Brass

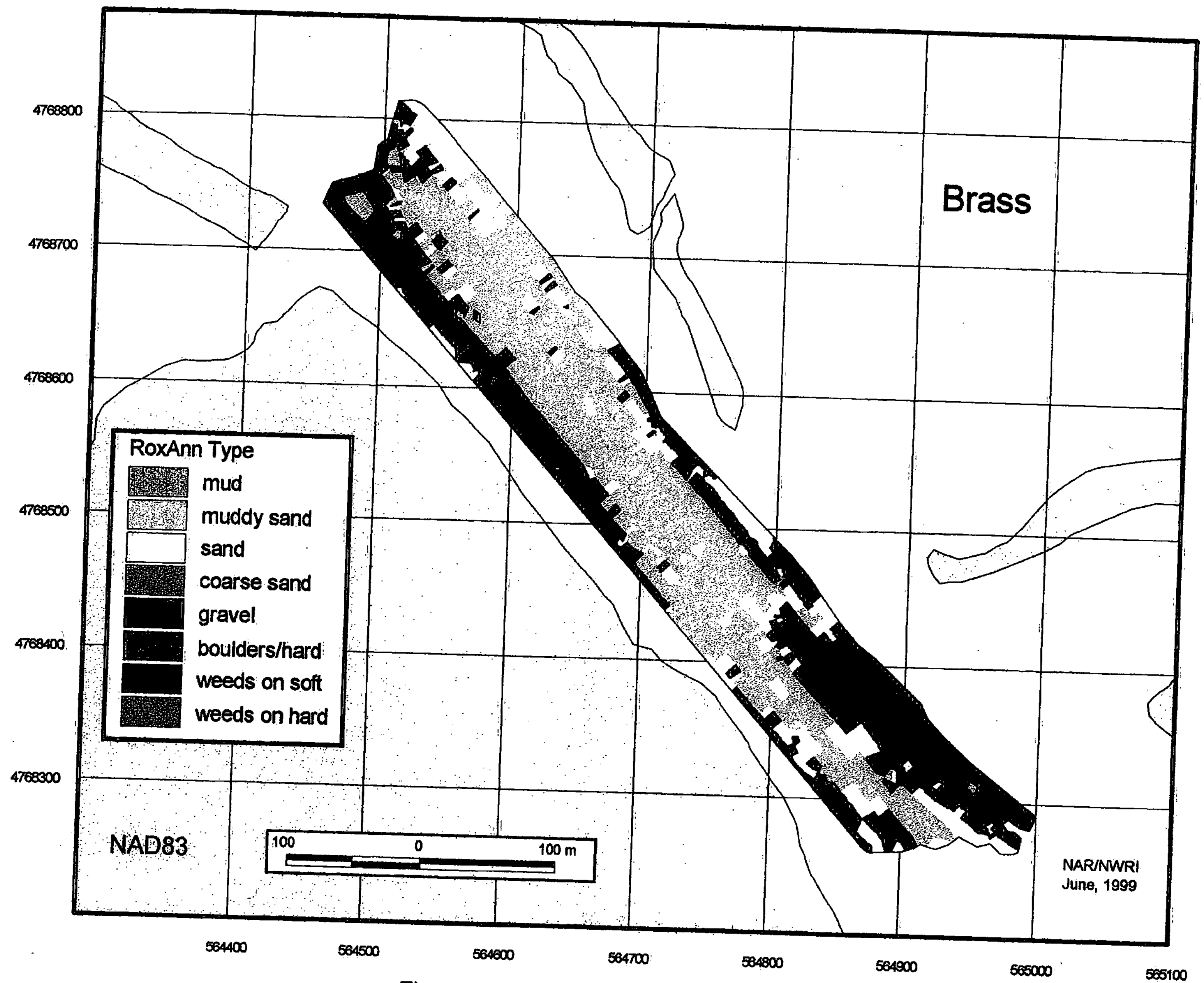

Figure 8. RoxAnn bottom types, site Brass

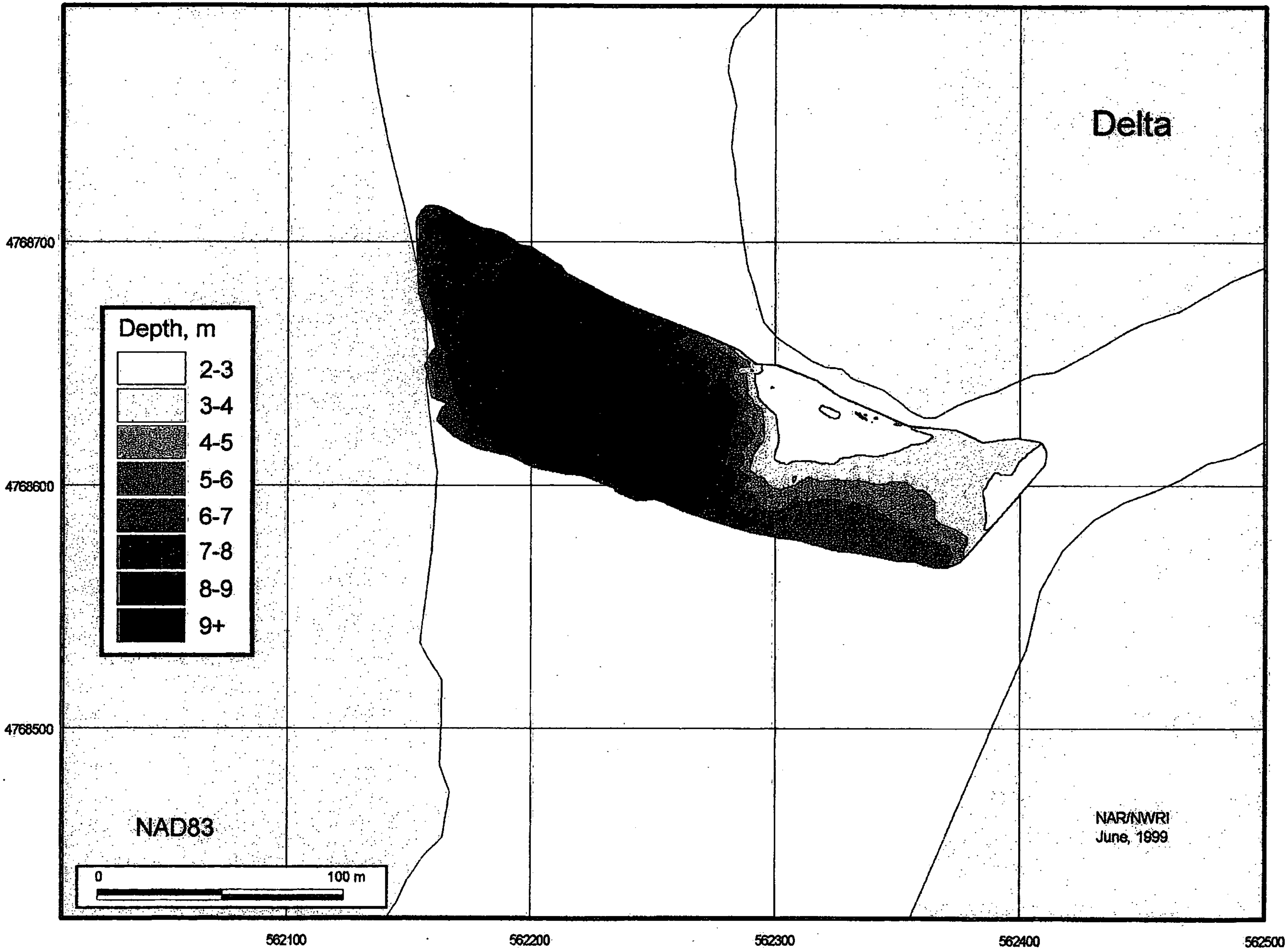

Figure 9. Bathymetry, site Delta

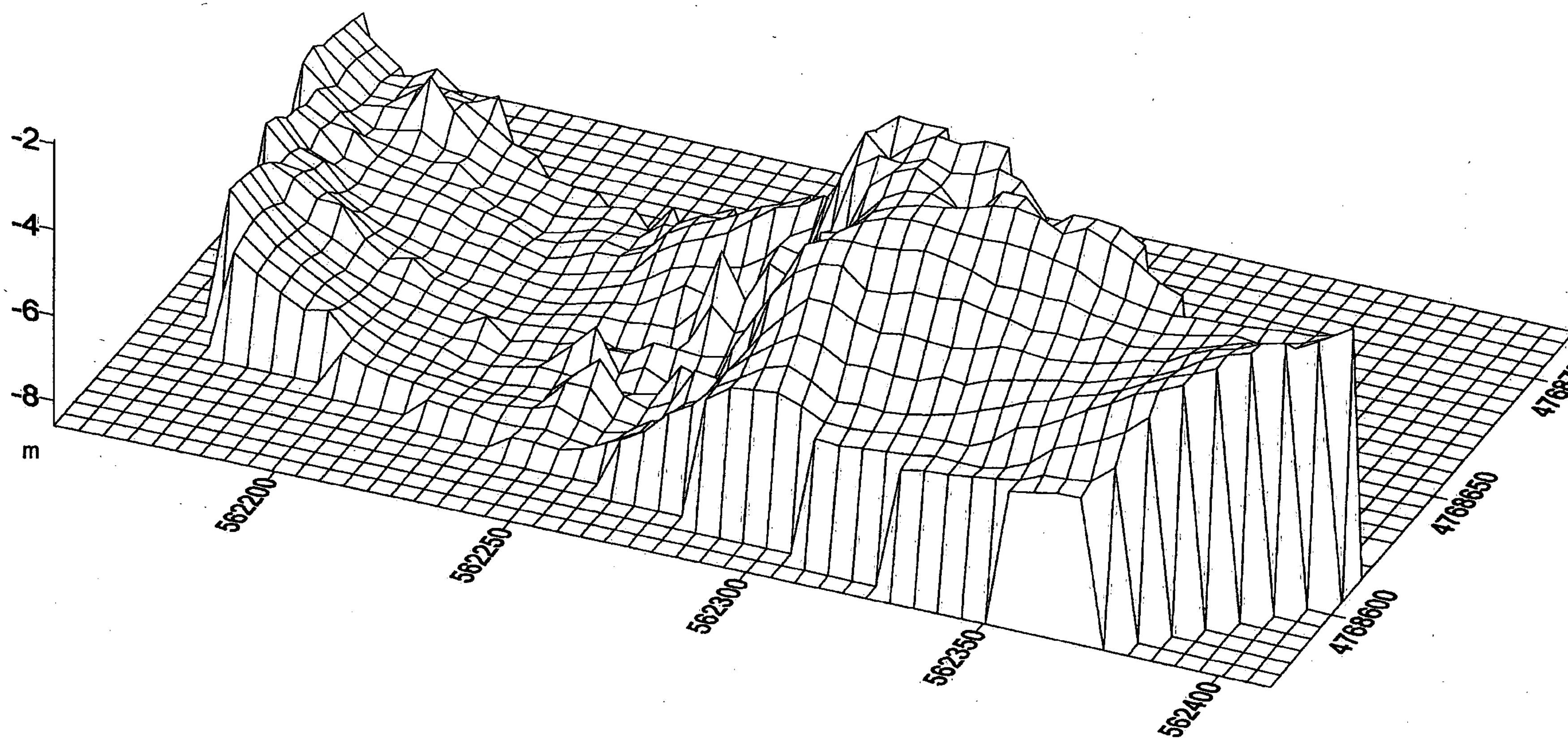

Figure 10. Bed morphology, site Delta

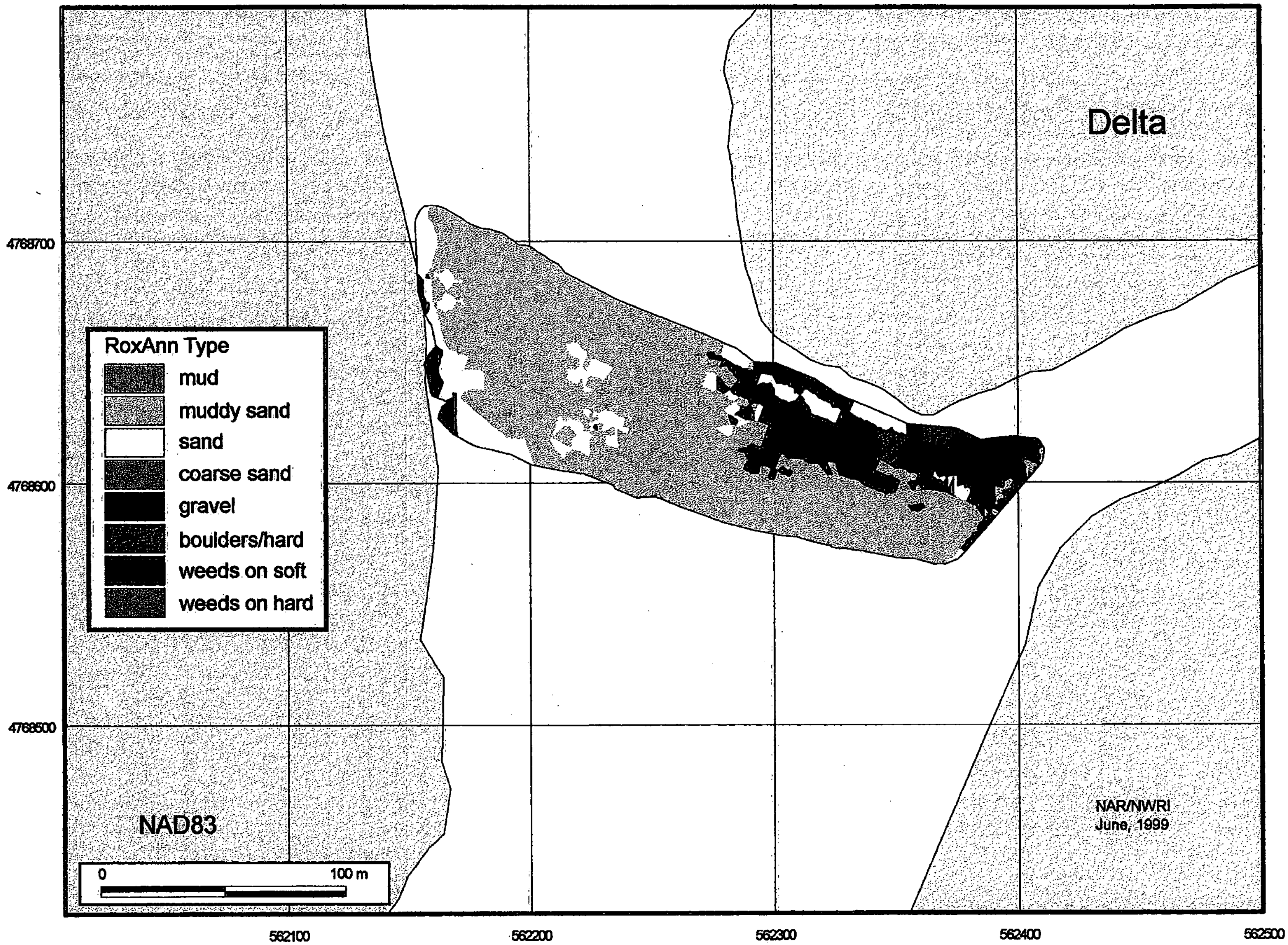

Figure 11. RoxAnn bottom types, site Delta

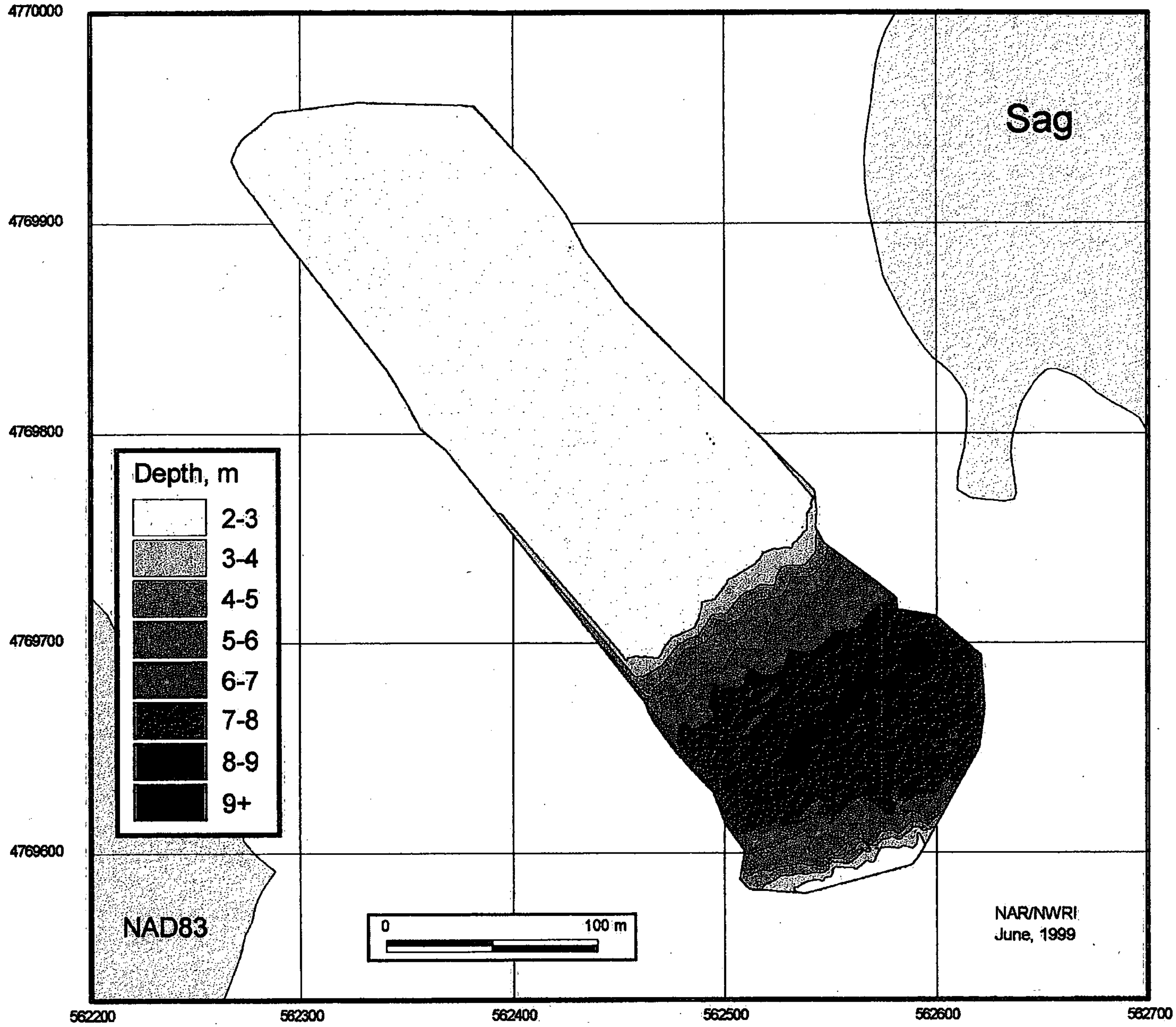

Figure 12. Bathymetry, site Sag

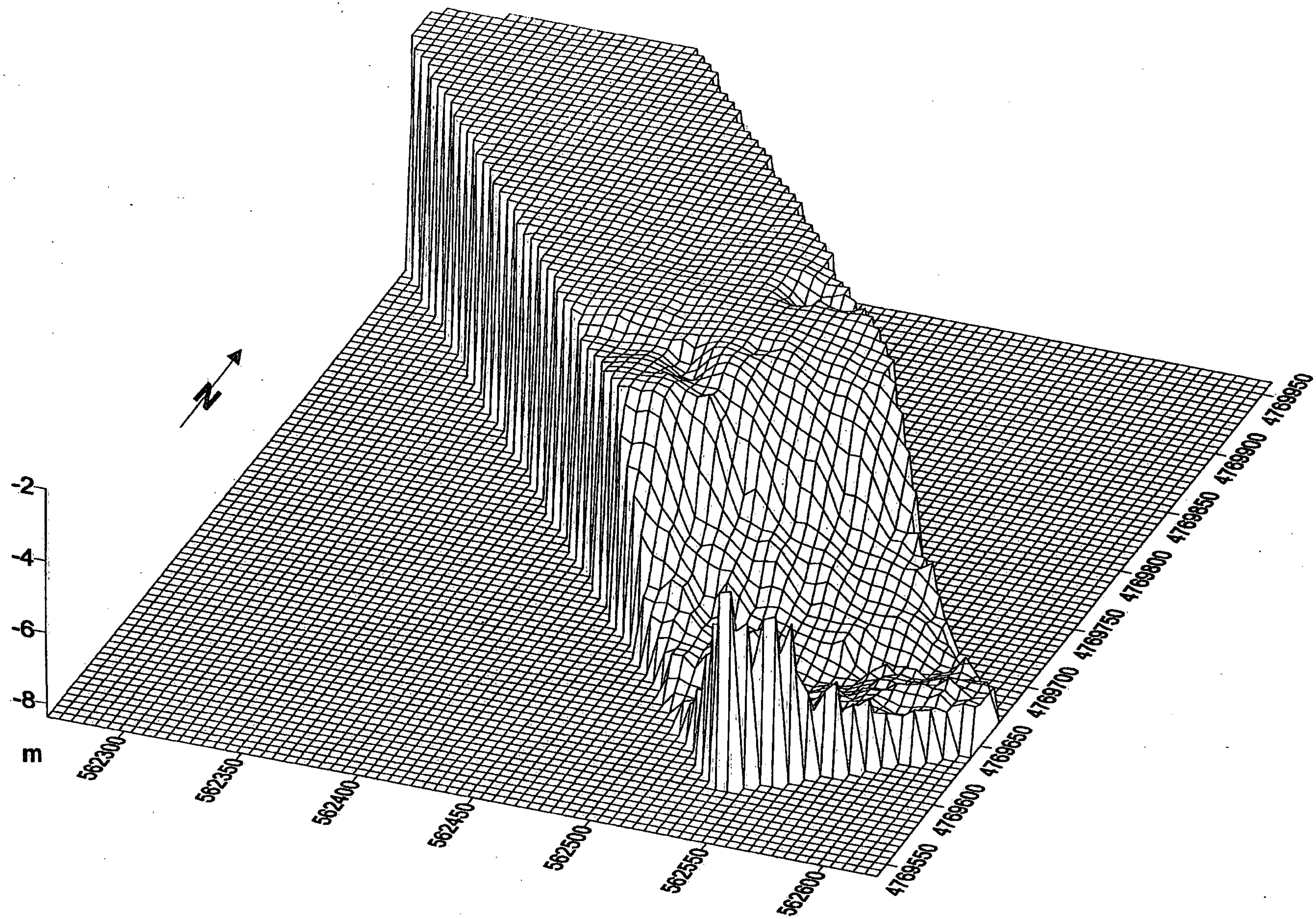

Figure 13. Bed morphology, site Sag

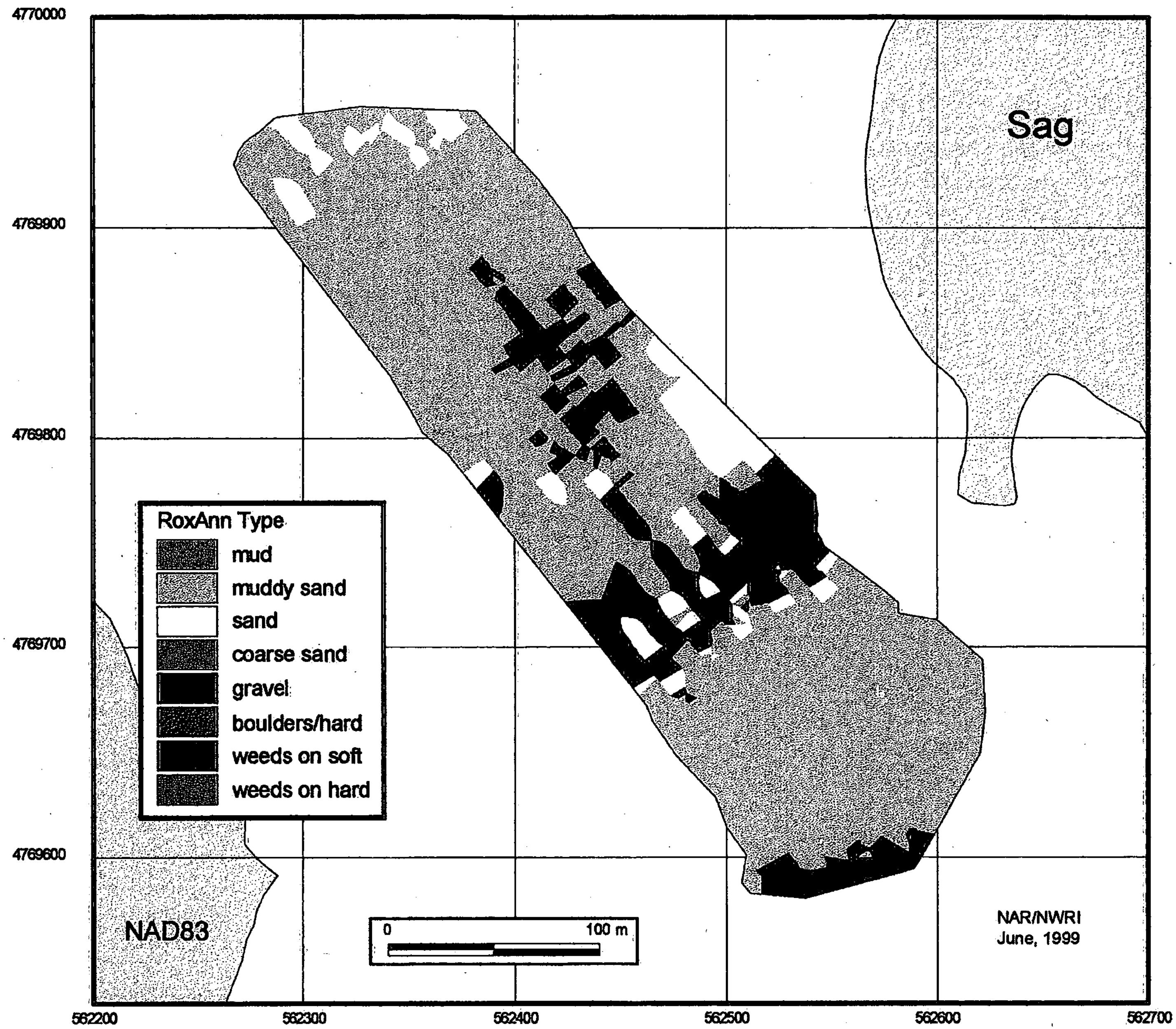

Figure 14. RoxAnn bottom types, site Sag

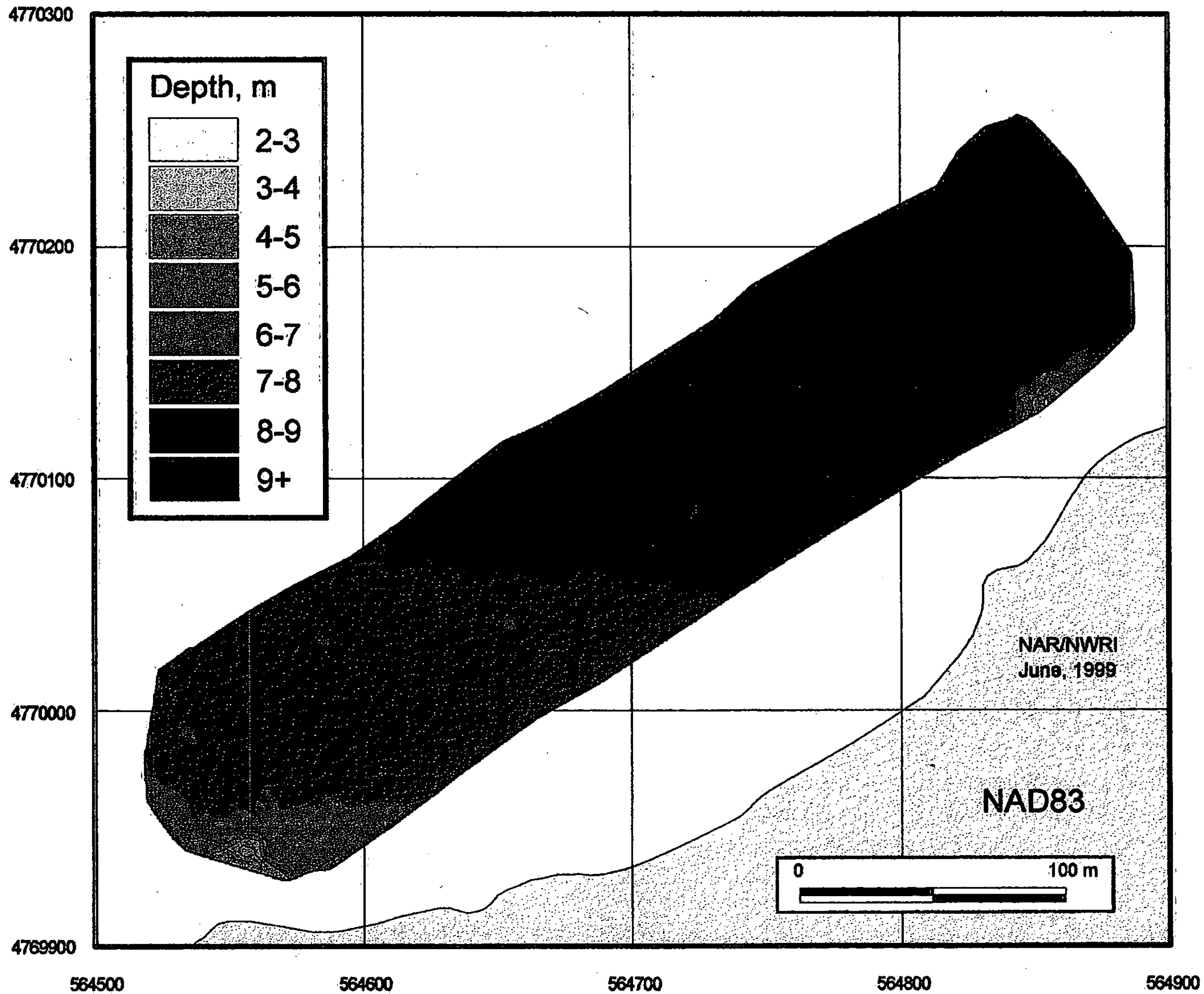

Figure 15. Bathymetry, site Spring Lake

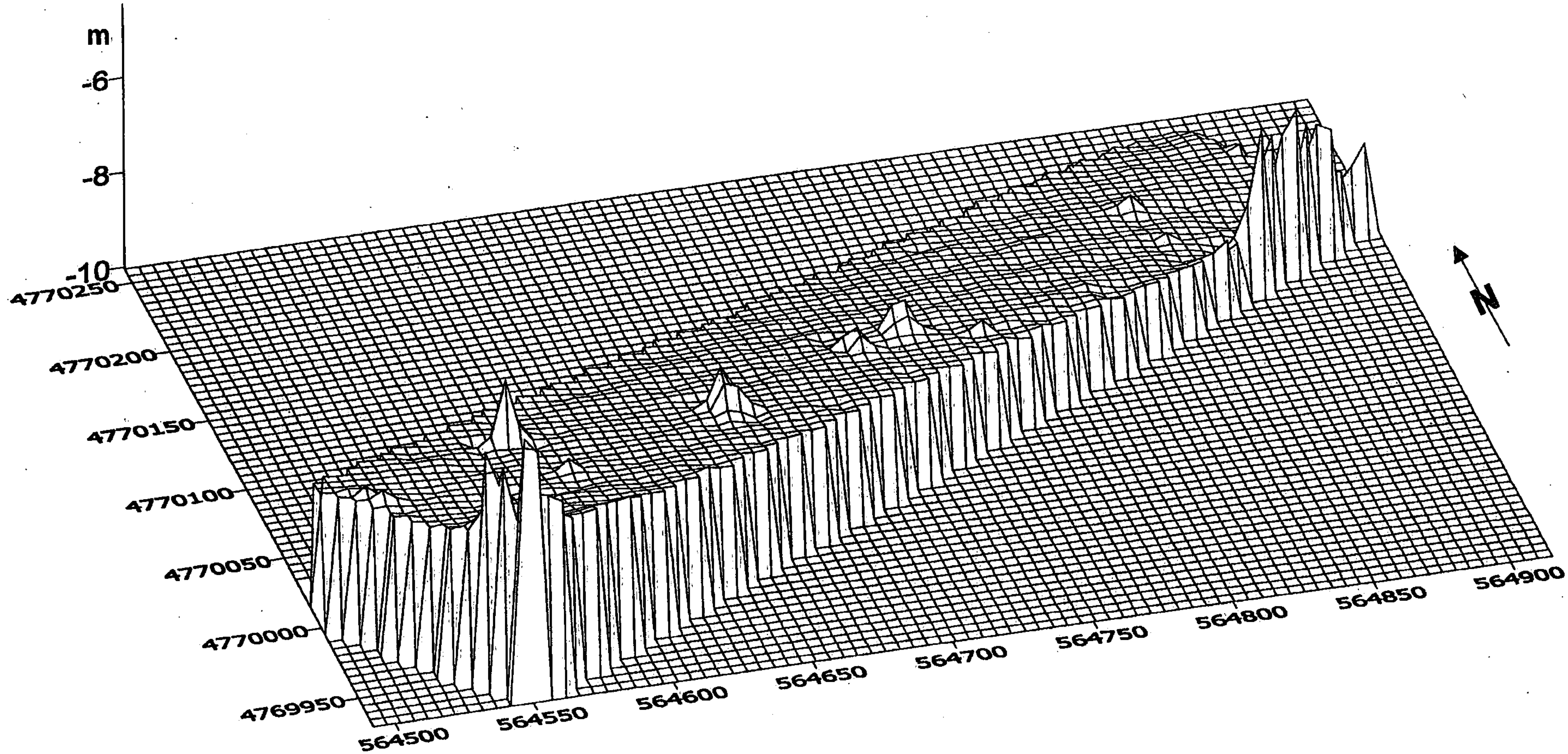

Figure16. Bed morphology, site Spring Lake

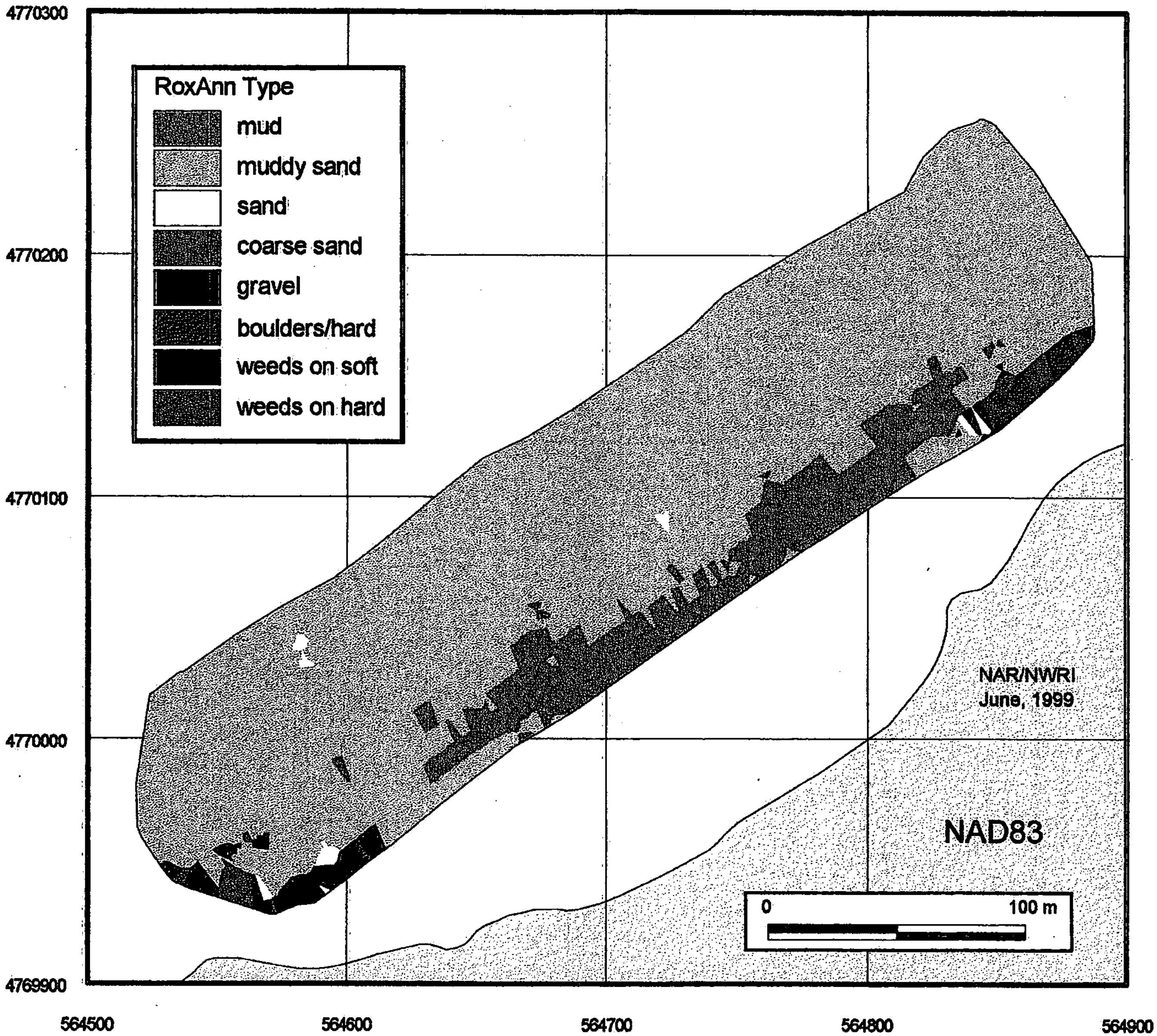

Figure 17. RoxAnn bottom types, site Spring Lake

Appendix 1

Survey log

Tuesday, October 13, 1998

- left NWRI for Grand Haven at 910 for Grand Haven with crew of Norm Rukavina (project leader), Dave Gilroy (coxswain), Brian Trapp (RoxAnn/GPS operator) and Jerry Ford (acoustics engineer).
- arrived Grand Haven at 1700 and checked into the Days Inn.
- met John Filkins and Bob Gregory at the Grand River Resort marina.
- suggested by Filkins that we use our beacon receiver rather than their GPS radio because of its poor stability.
- Gregory showed us the launch site, STAND the GPS checksite and the dock at the Coast Guard station and Corps offices.
- met Dr. Willy Lick and the UCSB crew (Jesse, Rich and Shannon) at the motel.
- locked on to the Milwaukee GPS beacon at the hotel and confirmed reasonable data.
- Brian sorted out the settings for our Sercel GPS and the Mplot survey program.

Wednesday, October 14, 1998

- cold and rainy, winds light, clearing later in the day.
- met Filkins and Dave Caulfield at breakfast and arranged Jerry's time on the Mudpuppy.
- launched the NWRI survey launch, Puffin, at Harbour Island and moved to the Coast Guard dock.
- setup the Puffin, confirmed that the Milwaukee beacon OK, and calibrated both RoxAnns by 835.
- GPS checks at benchmarks STAND and YARD showed readings 8m high in Northing and 20m low in Easting because Mplot was not converting properly from WGS84 to state plane. Adjusted for the offset.
- started the Delta survey at 1100 and then reran because of problems with slow update of the left-run indicator in the initial setup. Completed at 1230.
- away again at 1430 to survey Spring Lake, Brass and Sag sites. Difficult survey at the Sag because shallow depths required a slow running speed and limited lines to the central part of the area.

- Puffin struck unmarked submerged concrete? shoal while leaving the Sag. Minor damage to the keel.rox
- docked at CG station at 1830. End-of-day RoxAnn calibration completed by 1915. Back to motel at 1930.
- picked 14 sites for tripod-thickness readings at Delta and the Sag.

Thursday, October 15, 1998
- cool, sunny, winds light from south
- Jerry on Mud Puppy today as an observer.
- setup Puffin for tripod work. GPS check at STAND completed at 950.
- started tripod work at the Sag at 1020 with Rich as a helper.
- tripod drops at 3 sites at Sag but sediments too thick for the standard legs. Switched to grab sampling with the Mini-Shipek sampler at 4 sites. Recovered sediment described but not retained.
- returned to CG dock at noon because unable to work at Delta till Mud Puppy finished her lines. Calibrated RoxAnn and used yesterday's data to select sample sites at Spring Lake and Brass. Found that yesterday's survey had been run with Mplot toggled to record ship rather than RoxAnn data. RoxAnn tracks could be displayed but not track data had been logged. Confirmed with RoxAnn headquarters that the data could not be recovered.
- left at 1430 to redo the entire survey. Completed by 1805 including a number of zigzag lines across each site.
- GPS check at STAND and returned to CG dock for RoxAnn calibration at 1830. Complete at 1915.
- Jerry picked up by NWRI Tech Ops crew and returned to Burlington.

Friday, October 16, 1998
- clear sunny day, light winds from the south in the morning, stronger from the west in early afternoon and then dropping off in late afternoon.
- worked in the Corps office during boat set up on selection of new tripod/shipek sites

based on yesterday's survey.

- demonstration of RoxAnn for the Corps' Brian Mallory during the run to the GPS check.
- problems with the RoxAnn echosounder required that it be replaced with a second unit.
- started Shipek sampling at Spring Lake at 1130. Milwaukee GPS beacon off the air so forced to use raw GPS for sampling of both Spring Lake and Brass sites. Collected 15 samples and ran RoxAnn to ensure that we were sampling the required bottom type. Survey complete at 1400 and returned to CG dock.
- to Delta site at 1515 with Rich and Shannon to collect 2 UCSB cores. Completed at 1600.
- started Shipek sampling at the Delta at 1700 and collected 10 samples by 1750
- tripod work at Sag started at 1800. Tripod-thickness measurements of 5 Sag sites and 5 Delta sites completed by 1850.
- final GPS check at STAND complete by 1900. Left CG dock at 1940.

Saturday, October 17, 1998

- packed Puffin, loaded on trailer and left for Burlington at 1030.
- arrived NWRI at 1830.

Appendix 2

Grab-sample descriptions

Site	Site #	Date	Time	UTM NAD83		Depth,	GPS	Estimated	Notes
				Easting	Northing	m	Qual	Grainsize	
Sag	1	1998-10-15	11:02:29	562528	4769680	7.2	8D9	m	full bucket, dark-brown sticky mud, minor sand, fibrous, gassy
	2		11:12:00	562492	4769731	2.4	9D9	x or s	2/3 bucket, packed muddy fine-medium sand, many conical snail shells, wood fragments
	3		11:22:19	562566	4769597	2.0	ND	m	time/position approximate, 3/4 bucket, brown-black organic mud, fibres, black leaves and wood fragments
	4		11:37:55	562568	4769597	3.2	9D9	s/h?	small amount of fibrous material and fine sand
	5		11:40:13	562567	4769596	3.0	9D9	s/h?	small amount of fibrous material and fine sand, hard bottom
	6		11:45:43	562461	4769706	1.3	9D9	s	full bucket, fine-medium sand, a few snail shells, one blackened leaf
Spring Lake	7	1998-10-16	11:59:00	564721	4770082	8.2	ND	s	time/position approximate, minor organic debris and fine sand
	8		12:03:00	564710	4770110	8.3	ND	m	time/position approximate, full bucket soft black gassy mud, brown surface
	9		12:13:00	564800	4770092	8.1	ND	m	time/position approximate, full bucket soft black mud, less gas than 17-2, veneer of brown sediment, surface plants and organic matter
	10		12:20:00	564888	4770185	9.2	ND	m	time/position approximate, 2/3 bucket soft black mud, mottled with brown from surface because disturbed during recovery, surface weeds
	11		12:30:00	564658	4769997	7.2	ND	m	time/position approximate, full bucket soupy black mud, brown surface
	12		12:36:00	564508	4769960	7.0	ND	m	time/position approximate, full bucket soupy black mud, disturbed surface
Brass	13		12:54:00	564452	4768745	3.4	ND	x & g	time/position approximate, 1/3 bucket muddy sand with pebbles and shells
	14		12:58:00	564513	4768788	3.6	ND	m/s/h	time/position approximate, full bucket mud on coarse sand, a few pebbles and shells, sounder shows hard bottom
	15		13:09:00	564609	4768652	4.4	ND	s/h?	time/position approximate, smear of sand, hard bottom?
	16		13:16:00	564570	4768661	4.1	ND	x & g/h?	time/position approximate, 1/2 bucket black muddy sand with pebbles, hard substrate?, strong current
	17		13:25:00	564616	4768571	3.2	ND	s/h?	time/position approximate, minor sand only, hard substrate?
	18		13:27:00	564623	4768586	1.6	ND	s/h?	time/position approximate, bucket jammed, minor sand only, hard bottom suggested by multiple echoes on sounder record
	19		13:36:00	564864	4768396	1.8	ND	s/h?	time/position approximate, small amount of coarse sand, clear water, strong current, hard bottom?

Site	Site #	Date	Time	UTM NAD83		Depth,	GPS	Estimated	Notes
				Easting	Northing	m	Qual*	Grainsize**	
Brass	20		13:39:00	564828	4768359	2.6	ND	x & g/h	time/position approximate, very flat hard bottom (concrete slab), 1/3 bucket muddy, pebbly coarse sand, conical snail shells
	21	1998-10-16	13:46:35	564878	4768326	4.1	8D9	s	1 cm muddy medium-coarse sand
Delta	22		15:21:15	562399	4768596	2.4	8D9	m	full bucket soft black-brown mud with minor sand
	23		15:55:07	562418	4768610	2.3	7D9	m	full bucket soft black mud, some fibres, gas bubbles
	24		16:58:44	562376	4768605	3.6	9D9	m	full bucket soft black mud with a few slag? fragments, fibres
	25		17:05:06	562335	4768615	2.4	9D9	x	1/3 bucket muddy fine-medium sand , wood fragments, a few granules
	26		17:09:02	562308	4768627	2.4	9D9	s/h?	small amount of clean sand, hard bottom?
	27		17:12:26	562346	4768619	1.9	8D9	s/h?	small amount of clean sand, hard bottom?
	28		17:16:06	562272	4768618	7.5	8D9	m	small amount of mud, opposite outfall
	29		17:18:22	562273	4768616	7.3	8D9	m	full bucket soft grey-black mud with twigs, fibres, a chironomid
	30		17:26:02	562221	4768642	8.1	8D9	m/x	full bucket brown surface mud and mud "pebbles" over muddy medium-coarse sand
	31		17:31:52	562171	4768636	5.7	8D9	s	small amount clean sand
	32		17:37:02	562166	4768628	5.3	7D9	x	sandy mud over muddy sand
	33		17:47:08	562192	4768679	7.2	7D9	x	full bucket soft brown sandy mud, twigs

*
GPS Quality: xDy
x- no. of satellites (max. 10)
D- differential
y- data quality (max 10)
ND - non-differential

**
m - mud
x - muddy sand
s - sand
g - gravel
h - hard

Appendix 3

Sediment-thickness data

Site #	Date	UTM NAD83		Tripod	Core
		Easting	Northing	depth, m	length, m
Brass					
G11	1997	564537	4768653		0.6
G12	1997	564739	4768397		0.3
G24	1997	564875	4768274		1.4
Delta					
8-2	1998	562166	4768628	0.2	
9	1998	562380	4768617	0.75	
10	1998	562385	4768612	0.8	
18	1998	562336	4768610	0.65	
19	1998	562335	4768611	0.5	
20	1998	562370	4768602	0.9	
S3C1-1	1998	562335	4768612		0.25
S3C1-2	1998	562335	4768612		0.33
S3C2-0	1998	562336	4768610		sand
S3C2-1	1998	562338	4768608		sand
S3C2-2	1998	562381	4768614		0.3
S3C2-3	1998	562385	4768613		0.5
S3D3	1998	562366	4768592		2.56
Rich-1	1998	562399	4768596		0.27
Rich-2	1998	562418	4768610		0.31
Rich-1	1998	562399	4768596	0.9	
Rich-2	1998	562418	4768610	0.85	
S3D1	1998	562334	4768609		0.56
S3D2	1998	562366	4768600		0.72
G20	1997	562332	4768614		1.5

Site #	Date	UTM NAD83		Tripod	Core
		Easting	Northing	depth, m	length, m
Sag					
7-1	1998	562526	4769677	0.9	
7-2	1998	562527	4769680	0.9	
8-1	1998	562492	4769730	0.3	
8-2	1998	562487	4769728	0.25	
9	1998	562438	4769612	0.1	
12-1	1998	562477	4769884	0.75	
36495	1998	562477	4769884	0.75	0.66
13	1998	562415	4769962	0.75	0.46
14	1998	562385	4769972	0.85	0.3
15	1998	562501	4769764	0.65	0.3
17	1998	562342	4769973	0.8	1.02
S2C0-1	1998	562472	4769885		0.52
S2C0-2	1998	562468	4769843		0.83
S2C0-3	1998	562405	4769961		1.4
S2C0-4	1998	562381	4769973		1.7
SGD1	1998	562505	4769769		2.8
SGD2	1998	562470	4769804		
SGD3	1998	562343	4769971		1.9
G1	1997	562522	4769915		
G2	1997	562430	4769728		
G22	1997	562186	4769967		
Spring Lk					
G6	1997	564709	4770078		

Appendix 4

RoxAnn Groundtruth

Site	Grain size		RoxAnn label		Fit	GPS Qual
	%St+Cy	Sztype	Oct 14	Oct 15		
NWRI grab samples (size estimated)						
1		x	msand	msand	g	8D9
2		x or s	gravel	sand	f	9D9
3		m or x	w/soft	w/soft	f	ND
4		s/h?	w/soft	w/soft	p	9D9
5		s/h?	w/soft	w/soft	p	9D9
6		s	sand	sand	g	9D9
7		s	msand		f	ND
8		m or x	msand	msand	g	ND
9		m or x	mud	mud	g	ND
10		m or x	msand	msand	g	ND
11		m or x	msand	msand	g	ND
12		m or x	msand	msand	g	ND
13		x or g		gravel	g	ND
14		m/s/h		w/soft	g	ND
15		s	w/soft	msand	f	ND
16		x or g	msand	msand	g	ND
17		s or h		gravel	g	ND
18		s or h		msand	g	ND
19		s or h		hard	g	ND
20		x/g/h	msand	msand	g	ND
21		x	w/soft	w/soft	f	8D9
24		m or x	sand	w/soft	f	9D9
25		x	hard	gravel	p	9D9
26		s or h	gravel	gravel	g	9D9
27		s or h	gravel	hard	g	8D9
28		m or x	msand	msand	g	8D9
29		m or x	msand	msand	g	8D9
30		m or x	sand/msand	sand	f	8D9
31		s		sand/gravel	g	8D9
32		x	gravel	gravel	p	7D9
33		x	msand	msand	g	7D9

Site	Grain size		RoxAnn label		Fit	GPS Qual
	%St+Cy	Sztype	Oct 14	Oct 15		
EPA/UCSB cores						
S3C1-1	58	x	hard	w/soft/gravel	p	
S3C1-2	63	x		w/soft/gravel	p	
S3C2-2	60	x	w/soft	w/soft	f	
S3C2-3	56	x	w/soft	w/soft	f	
Rich-1	54	x	msand	w/soft	g	8D9
S3D2	64	x	sand		f	
S3D3	66	x	msand		g	
S2C0-2	55	x	msand	msand	g	
SGD1	48	x		w/soft	f	
SGD2	58	x	msand	msand	g	
1997 EPA surface subsamples from cores						
G2	14	s	sand	gravel	g	
G6	88	m	msand	msand	f	
G11	47	x	w/soft		f	
G12	37	x		sand	f	
G20	53	x	grav/wsoft	grav/wsoft	f	
G24	2	s		gravel	f	

Summary of Fit:

Fit	Number	%
good	25	53
fair	16	34
poor	6	13
total	47	100

m - mud
x - muddy sand
s - sand
g - gravel
h - hard

Appendix 5

GIS areas, bottom type and depth

RoxAnn type	Brass		Delta		Sag		Spring Lake	
	Area, sq m	Percent	Area, sq m	Percent	Area, sq m	Percent	Area, sq m	Percent
mud							6061	12.2
muddy sand	30138	44.5	11785	67.9	38675	74.4	41276	83.3
sand	11333	16.7	1978	11.4	4273	8.2	277	0.6
coarse sand	196	0.3						
gravel	16771	24.7	1446	8.3	3523	6.8	362	0.7
boulders	3770	5.6	245	1.4			360	0.7
weeds on soft (gassy mud?)	5497	8.1	1915	11.0	5531	10.6	616	1.2
weeds on hard	58	0.1					615	1.2
All types	67763	100	17370	100	52001	100	49567	100
Fine sediment (mud, muddy sand, weeds on soft)								
	35635	53	13700	79	44205	85	47953	97
Depth interval	Area, sq m	Percent	Area, sq m	Percent	Area, sq m	Percent	Area, sq m	Percent
2-3	5413	8.0	1895	10.9	33439	64.3		
3-4	17633	26.0	2209	12.7	1586	3.0	39	0.1
4-5	29419	43.4	1320	7.6	1227	2.4	281	0.6
5-6	15336	22.6	2179	12.5	2071	4.0	439	0.9
6-7			2397	13.8	3548	6.8	2254	4.5
7-8			4923	28.3	9389	18.1	17770	35.9
8-9			2465	14.2	756	1.5	17497	35.3
9+							11286	22.8
All depths	67801	100	17388	100	52016	100	49566	100

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