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Geometry and Stability of Contaminated Sediments at Randle Reef, Hamilton Harbour

BY:
N. Rukavina

NWRI Contribution No. 03-156

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GEOMETRY AND STABILITY OF CONTAMINATED SEDIMENTS AT RANDLE REEF, HAMILTON HARBOUR

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ABSTRACT

Data on sediment properties are needed to plan and carry out remediation of contaminated sediments at the Randle Reef site on the south shore of Hamilton Harbour. A number of procedures has been used to measure the areal and vertical distribution of the geotechnical properties of the sediments. Data are now available on the bathymetry of the site and its stability, the distribution of sediment type, and the sediment thickness and volume. They are compiled in this report as a series of maps and profiles showing the properties of the designated site in plan view and cross section.

Sediment stratigraphy at the site consists in general of 1-2 m of soft silty clay over a base of cohesive sands or clays. Because there is considerable variation in sediment thickness, the focus of this study has been on preparing an estimate of the total volume of soft sediments which could be removed by dredging. Volume estimates depend upon the procedures used for thickness measurements and range from about 12,000 m^3 from Benthos coring to 32,000 m^3 from penetrometer measurements.

Measurements of the stability of bottom sediment by repeated sounding and multibeam-sonar surveys show that most of the changes observed seasonally and over a two-year time span fall within the survey error of about +/_20 cm.

RÉSUMÉ

Nous avons besoin de données sur les propriétés des sédiments pour procéder à la restauration des sédiments contaminés du récif Randle sur la rive sud du port de Hamilton. Bon nombre de méthodes ont été utilisées pour mesurer la distribution verticale et spatiale des propriétés géotechniques des sédiments. Nous disposons maintenant de données sur la stabilité et la bathymétrie du site, sur la distribution des types de sédiments ainsi que sur leur volume et leur épaisseur. Ces données sont rassemblées dans ce rapport sous forme de cartes et de profils illustrant, au moyen de vues en plans et de coupes transversales, les propriétés du site en question.

Dans l'ensemble, la stratigraphie des sédiments du site consiste en un mètre ou deux d'argile silteuse molle sur une base d'argile ou de sable cohésif. Comme l'épaisseur des sédiments varie beaucoup, la présente étude a surtout porté sur l'évaluation du volume total de sédiments meubles qui pouvaient être enlevés par dragage. Les volumes déterminés dépendent des méthodes utilisées pour mesurer l'épaisseur et ils varient de 12 000 m^3 environ lorsqu'on utilise un système de carottage Benthos, à 32 000 m^3 lorsqu'on utilise un pénétromètre.

Les mesures relatives à la stabilité des sédiments de fond obtenues au moyen de levés bathymétriques répétés et de relevés de sonars multi-faisceaux montrent que la plupart des variations saisonnières observées au cours d'une période de deux ans se situent à l'intérieur de la marge d'erreur de ±20 cm.

NWRI RESEARCH SUMMARY

Plain language title

This is a report on surveys conducted by NWRI in Hamilton Harbour to determine the geometry and stability of contaminated sediments at Randle Reef.

What is the problem and what do scientists already know about it?

Only limited information is available about the volume, physical properties, and stability of contaminated sediments at the Randle Reef dredge site in Hamilton Harbour. Detailed and current information is required for estimates of remediation costs and for the use of contractors in planning extraction or capping.

Why did NWRI do this study?

NWRI undertook the study to determine the bathymetry, thickness and volume, and stability of the Randle deposit.

What were the results?

A very detailed bathymetry of the site was obtained with multibeam-sonar surveys which provided complete coverage of the depth distribution in the area. Sediment thickness and volume were measured by coring and with two penetrometers, devices which are lowered into the bottom and record the base of soft modern sediment. Volume estimates ranged from about 12,000-30,000 cubic metres. Repeated surveys of bathymetry seasonally and over a two-year time span showed that most bottom changes were less than the survey error and suggested that the effects of either shipping or storm activity on the bottom sediments should be minor.

How will these results be used?

The results will be used for planning of the remediation of the contaminated sediments at the site.

Who were our main partners in the study?

The Canadian Hydrographic Service, Central Region, was responsible for the multibeam-sonar surveys and the study was funded by Environment Canada's Great Lakes 2000 Sustainability Fund.

Sommaire des recherches de l'INRE

Titre en langage clair
Il s'agit d'un rapport sur les études menées par l'INRE dans le port de Hamilton pour déterminer la géométrie et la stabilité des sédiments contaminés du récif Randle.

Quel est le problème et que savent les chercheurs à ce sujet?
Nous ne disposons que de peu d'informations sur le volume, les propriétés physiques et la stabilité des sédiments contaminés au site de dragage du récif Randle dans le port de Hamilton. Or, nous avons besoin de données détaillées et à jour pour pouvoir évaluer les coûts de restauration et le recours à des entrepreneurs pour planifier l'extraction ou le recouvrement en milieu aquatique.

Pourquoi l'INRE a-t-il effectué cette étude?
L'INRE a entrepris cette étude pour déterminer la bathymétrie, l'épaisseur, le volume et la stabilité du dépôt de Randle.

Quels sont les résultats?
L'utilisation de sonars multi-faisceaux a permis d'obtenir des données bathymétriques très détaillées sur la distribution en profondeur de toute cette région. L'épaisseur et le volume des sédiments ont été mesurés par carottage ainsi qu'à l'aide de deux pénétromètres, des appareils que l'on descend jusqu'au fond pour déterminer la base du sédiment meuble moderne. Les évaluations de volume s'échelonnaient de 12 000 à 30 000 mètres cubes environ. Des études bathymétriques répétées sur une période de deux ans ont permis de constater que la plupart des variations étaient moins importantes que la marge d'erreur et elles suggèrent que la navigation ou les orages n'auraient que des effets mineurs sur les sédiments de fond.

Comment ces résultats seront-ils utilisés?
Les résultats de cette étude serviront à planifier la restauration des sédiments contaminés du site.

Quels étaient nos principaux partenaires dans cette étude?
Le Service hydrographique du Canada, Région du Centre, était responsable des relevés faits au moyen des sonars multi-faisceaux, et l'étude a été financée par le Fonds de durabilité des Grands Lacs, 2000, un programme d'Environnement Canada.

1. Introduction

Removal of highly-contaminated sediments in Hamilton Harbour just east of Randle Reef has been recommended by the Hamilton Harbour RAP stage 2 report (1992). Information about the properties of the sediments at the site is required to plan and estimate the cost of its remediation. This report is a compilation of data collected by or for NWRI on the geometry, bathymetry and stability of the contaminated sediments. It incorporates and expands upon two earlier reports on the sediment thickness at the site and the stability of its bathymetry (Rukavina 1999a, 1999b). The report is based on surveys conducted between 1996 and 2000 with field procedures including Benthos coring, borehole coring, penetrometer measurements of sediment thickness, and acoustic surveys of bathymetry and bottom type. Data collection was concentrated in an area identified from earlier studies (Murphy *et al* 1990) as being the most heavily contaminated (Figure 1).

Cores were used to estimate the minimal thickness of unconsolidated sediments. The geometry of the deposit was also mapped with penetrometer measurements of depth to refusal, and the results were used to estimate sediment volume. Repeated echo-sounder surveys of bathymetry provided the bottom morphology of the site and information on its susceptibility to bed disturbance by shipping or storms.

Site data have been compiled as maps showing the bathymetry and its stability, and the distribution of sediment types and deposit thickness. Although the results show considerable variation in sediment thickness both areally and vertically, it has been possible to provide some estimates of the volume of unconsolidated sediments within the target site which could be removed by dredging.

Although the study's primary objective was to characterize the physical properties of the Randle site, it was also used to develop and test new procedures for thickness and stability measurements. The combination of penetrometer measurements for sediment geometry and acoustic surveys for bathymetric and stability data applied here should be applicable to similar work in other Areas of Concern.

2. Field Procedures

2.1 General

Positioning for all surveys was by differential GPS with corrections from the CCIW rooftop antenna or the Youngstown New York beacon. Earlier data were collected in the NAD27 geodetic datum but then converted to NAD83 for consistency with the later data sets. Static checks of position accuracy at local benchmarks indicated that it was sub-metre and dynamic accuracy was assumed to be in the range of 2-4 m. Because the site is known to be prone to reflections from harbour buildings and ships, larger errors may occur. This was dealt with in the penetrometer and acoustic surveys by logging continuous data on position which showed up reflection errors. Because no logging software was available for the coring surveys, their positional accuracy is unknown.

2.2 Benthos Coring

NWRI's Technical Operations Section undertook the coring surveys under the direction of Mr. Roger Santiago of the Environmental Protection Branch. Cores were collected with a 3-inch diameter Benthos corer (Mawhinney and Bisutti, 1987) in May and December 1996 and December 1999. The same type of corer was used in each survey but corer weight varied within and between surveys. Weight was 100 kg for the May 1996 survey, 80 kg for the December 1996 survey and 60 or 80 kg for the December 1999 survey. The objective of the coring was to collect the longest core possible and the free-fall distance and weight were varied to try to accomplish this. The use of varying weights and procedures, although well-intentioned, resulted in different degrees of compression of the sediment and inconsistencies in core length and stratigraphy

Cores were described upon recovery in terms of colour, texture and the depth of a hard-clay substrate which was designated the clay plug. All cores were then capped and sealed and held in cold storage prior to analysis.

May 1996 cores were collected at 41 sites on a 50-m grid within the area known to be elevated in PAHs from an earlier survey of the site (Murphy *et al* 1990). Because of errors in the georeferencing of the Murphy survey, coring was repeated in December 1996 and 75 cores were collected on a 25-m grid. December 1999 cores were taken at 27 sites, most of which corresponded to the 1996 sites in the area just west of the Stelco dock. Where sites were resampled, their coordinates were generally within 5 m of the original 1996 core positions. Figure 2 shows the core sites. Data on core position, length and depth of the "clay plug" are listed in Appendix 1.

2.3 Borehole coring

In April 1999, Trow Consulting Engineers Ltd. was contracted to collect 9 borehole cores just west of the Stelco Dock at locations that had previously been sampled with Benthos cores. The cores were taken with a drill rig mounted on the front of a spud barge and adapted for sediment sampling (Trow Consulting Engineers Ltd. 1999). A split-spoon sampler was used to subsample the cores, and the undrained shear strength of the sediment was measured with a field vane and pocket penetrometer. Where recovery was poor, other sampling equipment including Shelby tubes, piston samplers and side samplers was used to supplement the standard samples. Figure 2 shows the Trow core sites and data on core position and length are listed in Appendix 1.

2.4 Acoustic Tripod Measurements

Measurements of sediment thickness to refusal were carried out at a subset of the core sites with NWRI's acoustic-video tripod in 1998 (Rukavina 1999b) and supplemental data were collected in 1999. 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 the legs. The total submerged weight of the tripod used for this survey was 47.6 kg. Measurements of soft-sediment thickness were made 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. There were two tripod surveys. On July 28, 1998, tripod data were collected at 25 of the 1996 core sites, and on April 27, 1999, at the 9 borehole-core sites. Figure 3 is a map of tripod sites and Appendix 2 lists the tripod data.

2.5 STING™ Penetrometer Survey

Because of the concern that the tripod data might underestimate the thickness of soft sediments deposit, a second series of measurements was made with a STING free-fall penetrometer (Racca 1999). The STING is a stainless-steel rod 1-3 m long with a recording head containing a pressure transducer and accelerometer. It is dropped from the surface on a tether and allowed to freefall through the water column and into the sediment until it encounters enough resistance to bring it to refusal. The recording head logs its depth and its deceleration as it penetrates the sediment. The instrument is then quickly recovered and the drop is repeated as many times as possible within the 60-second period that is available for data collection. In general, three to four profiles can be collected. The device is then recovered and data are offloaded to the analysis software in a notebook computer. Figure 4 shows a typical result. The data are presented as a profile of bearing strength vs depth. A sharp increase in bearing strength marks the boundary between soft surface sediment and firmer substrate, and its depth has been used as the measure of unconsolidated sediment thickness.

The original STING survey was run in April and May of 1999. Data were collected at 8 sites within the target area. The 1999 experience indicated that the STING had problems with poor resolution of depth in shallow water and with detection of the sediment-water interface where sediments were very soft. This lead to a redesign by the manufacturer to correct both these problems. The 1999 data were also passed on to the STING manufacturer for inspection and a small contract was issued for reanalysis (Jasco Research Ltd. 2002). The modified STING was then used in a much more detailed second survey in March and April of 2000. Data were collected at 46 sites. Figure 5 shows the STING sites for both years and STING data on the thickness of soft sediments are listed in Appendix 3.

2.6 Sub-bottom Profiling

A contracted acoustic survey of soft-sediment thickness at the Randle site was run by McQuest Marine Sciences Limited in December 1998 (McQuest 1999). Data were collected with a Klein 3.5 kHz sub-bottom profiler along 26 survey lines spaced at 25 m and parallel to the Stelco dock. No attempt was made to calibrate the system with sound-velocity profiles of the sediment or independent data on sediment stratigraphy. Soft-sediment thickness over a harder substrate was merely interpreted from the record characteristics, and data were made available by McQuest for comparison with the tripod and STING data.

2.7 Bathymetry and sediment stability- vertical sounding

Echo-sounder surveys in 1998 were used to map the bathymetry of the Randle site and its stability over part of the shipping season (Rukavina 1999). Because the site is adjacent to a major dock and could be disturbed by shipping, surveys along the same tracklines were run in the summer and fall and compared to determine whether any measureable changes occurred over that time interval.

Sounding work took place on July 30, July 31 and November 5, 1998 along the tracklines shown in Figure 6. The survey was repeated on subsequent days in July to establish the survey error. All traverses were run with a 5-m spacing along lines parallel to the Stelco Pier. Data on depth and GPS quality were logged at 1-second intervals to a laptop computer running the survey program, Microplot®. A boat speed of 2-3 m/s provided a data spacing along the lines of 2-3 m.

2.8 Bathymetry and sediment stability- multibeam-sonar surveys

The Canadian Hydrographic Service (CHS) mapped the bathymetry of the Randle site with multibeam-sonar surveys in 1998 and 2000 (personal communication, P. Travaglini, CHS). Unlike vertical sounding in which data are limited to a series of parallel lines, the multibeam sonar collects data as overlapping swaths and produces complete coverage of site bathymetry. The multibeam data permitted much greater detail in the bathymetric maps than was available in the vertical-sounding survey and the data needed to measure longer-term bottom changes.

2.9 Acoustic mapping of sediment types

A RoxAnn™ seabed-classification system (Rukavina and Caddell 1997, Rukavina 1998) was used to map the bottom-sediment types of the site during the bathymetric survey of November 1998. Bathymetric and RoxAnn data were collected simultaneously along the lines shown in Figure 6c. RoxAnn uses the acoustic hardness and roughness of the echo-sounder echoes to produce an acoustic classification of bottom sediments. Independent data like samples or underwater-television observations are then required to convert the acoustic types to a physical sediiment classification. In this case, calibration with sample data was not possible, and interpretation was based on past experience with the system and on sediment data collected during the 1999 coring survey.

3.0 Survey Analysis and Results

3.1 Sediment thickness

The depth of the clay plug in the Benthos and borehole cores was used as an estimate of the thickness of the soft-sediment layer. Consistency in the core data was tested by comparing the lengths recovered and the clay-plug depth in the three sets of 1996 and 1999 Benthos cores and the 1999 borehole cores. Figure 7 shows the results for the core pairs or triplets whose sites were within 5 m of each other. Core length within these sets ranged from less than half a metre to more than 2 metres, and lengths at the same site differed by as much as a metre. At most sites, the1996 Benthos cores were longer than those from 1999, and the borehole cores were longer than both. The stiff-clay horizon, which was assumed to be the base of contaminated sediments, varied widely in both colour and texture, and it was not certain that it represented a single layer. The high degree of variability in closely-spaced samples may be real because the site is a highly-disturbed industrial site, but it is also likely that some of the variation is the result of the inconsistency in coring procedures described above.

The highest values for sediment thickness were found in the borehole cores where clay-plug depth ranged from 0.8 to 3.4 m and averaged 2.2 m. The higher values were not unexpected because the cores were collected as shorter sequential samples and should have been less affected by compression. For this reason, borehole-core data would be expected to provide the most reliable estimates of soft-sediment thickness. Unfortunately, the number of core sites was too small to permit thickness mapping or an estimate of sediment volume.

Tripod thickness ranged from 0.68 - 1.88 m and averaged 1.19 m. Data for multiple drops at the same site were much more consistent than the core data.

STING thicknesses were higher than both the cores and the tripod data. Results from multiple drops at the same site were more consistent than the core data but more variable than the tripod data. Penetration ranged from 0.2 - 2.98 m and averaged 1.46 m.

Sediment thickness interpreted from the sub-bottom profiling records was lower than the tripod and STING values and showed a completely different pattern. Because the profiler data were not calibrated with sound-velocity measurements, and because they may have been affected by gas in the sediments, they were not considered to be useful for either thickness mapping or volume estimates and no further analysis was attempted.

Surfer 8© software was used to contour the thickness data and compute sediment volumes. Figure 8 shows Surfer contour maps of the thickness patterns of the Benthos-core, tripod and STING data within the dredging polygon. Borehole-core data were not mapped because of the small number of sites. For Benthos cores where no clay-plug depth was recorded, the core length was used as an estimate of minimum depth. All maps show the same basic pattern but differ in detail and in maximum thickness. In general, core values were lowest, tripod values intermediate, and STING values highest. The thickest sediments occurred along a swath extending from the west-central edge of the polygon to its southeastern corner with maximum values of up to 3 m at the western and eastern limits of this zone. The STING map shows the best definition of the geometry of the soft sediments because it has the largest dataset.

The low core values were expected because of sediment compression. Earlier experience with the collection of harbour cores from large box samples had shown length reductions of as much as 30 per cent. The difference between the tripod and STING values was likely related to the differences in the procedure used. The tripod was lowered slowly into the sediment and allowed to settle to the depth at which its weight was supported. The STING was permitted to freefall into the sediment from the surface, and its momentum and narrower cross-sectional area generally resulted in greater penetration. STING thicknesses agreed best with those from the borehole cores. Interpolated STING thicknesses at the 8 borehole-core sites within the dredging polygon ranged from 0.9 m higher than the core values to 2.8 m lower and averaged 0.6 m lower.

Surfer was also used to compute the sediment volumes within the dredge polygon for the three data sets (inset, Figure 8). Volume based on the Benthos-core data was lowest at 21,590 cubic metres; the jetting value was intermediate at 28,674 cubic metres; and the STING volume of 32,039 was the highest. For reasons discussed above, the STING value was considered to be the best estimate of unconsolidated sediment volume at the site.

3.2 RoxAnn bathymetry and sediment stability

Depths for both RoxAnn surveys were adjusted to the IGLD 1985 datum and corrected for the difference between the July and November water temperatures. The water-level gauge used was in Lake Ontario at the entrance to the harbour. According to the Canadian Hydrographic Service, this generally represents the harbour level to within a few cm unless there is a wind setup. Peak wind speeds for the survey periods were all too low to introduce a significant error in the level data.

The RoxAnn position data were checked for GPS errors and bad data were removed. For this report, position coordinates were converted from their original NAD27 datum to NAD83 so that they would be consistent with current data. All corrected depth data within the area selected for comparison (Figure 6) were then imported into Surfer for analysis. Bathymetric maps were prepared for all the surveys and the map of differences between the July 30 and 31 surveys was used as a measure of total survey error. In all cases, Surfer's contouring was done by interpolating to a 5-m grid using the default kriging procedure.

Figure 9 shows the contoured bathymetry for the July 31 survey and a contour map of differences between the July 31 and 30 data. The bottom morphology consists of a 6-7 m deep shelf m in the southern third of the area, a steep north-facing slope from 7 to 8 m, and then an irregular topography with depths between 8 and 9 m in the northern two-thirds of the area. In the map of differences, positive values indicate deepening in the later survey and negative values, shoaling. Because of the one-day interval between surveys, it was assumed that the differences recorded were a measure of survey error rather than real depth changes. Most of the area consists of the 2 classes 0 to 20 cm and 0 to -20 cm, and the average difference in depth of 0.76 cm indicates that the differences are symmetrical about 0. Accordingly, survey error was taken to be a maximum of ±20 cm. The larger changes occurring as a band across the south part of the area are not real but result from insufficient data in areas of high gradient.

Figure 10 is the map of the change in depth between the July 31 and November 5 surveys. Differences range from -10 cm to +20 cm. Most of the area is in the 0-10 cm range. Average depths are 8.07 m and 7.99 m respectively for July and November. The difference of 8 cm is within the error range of ±20 cm for each survey and is not considered to represent a significant change.

3.3 Multibeam-sonar bathymetry and sediment stability

Multibeam-depth data were edited and processed by the Canadian Hydrographic Service (Travaglini, personal communication), and made available as data files of positions and corrected depths. Surfer was again used to plot the bathymetric maps for the individual surveys and to plot the differences between the two surveys, this time using a 1-m grid because of the higher density of the data.

Figure 11 shows the contoured bathymetric maps for the 1998 and 2000 surveys. The basic pattern is similar to that in the earlier RoxAnn map but there is far more detail and better coverage of the southern part of the area. Figure 12 which displays the 2000 data as a wire-frame map gives a clearer picture of the bottom morphology discussed earlier and clearly shows the inshore shelf, steep slope, and irregular offshore bathymetry.

Differences between the 1998 and 2000 bathymetry were mapped in Figure 13. CHS made no attempt to measure survey error, but later data collected in replicate surveys in the Windermere Arm of the harbour yielded an error of about ±20 cm. Most of the differences fall within this error window, and this suggests that the seasonal stability determined by the RoxAnn mapping applies over a longer time span as well. Deepening of up to 0.8 m did occur in three small areas in the centre of the polygon and in the north end of the polygon next to the Stelco dock. Its source is unknown but likely related to bottom scouring by shipping.

3.4 Acoustic sediment types

Acoustic mapping of bottom-sediment types with RoxAnn was part of the November 1998 bathymetric survey. Figure 13 shows the results. Sediments within the dredge polygon were classified as muds or sandy muds on the basis of past experience with the system. No bottom samples were collected at the time of the survey, but qualitative size data were available from the 1999 sediment cores. These are the circles superimposed on the acoustic map. The core sizes are slightly finer than the acoustic labels, but both data sets indicate that the sediment type within the dredge polygon is a uniform mud or sandy mud.

4. Conclusions and Recommendations

Sediment cores collected at the proposed dredge site at Randle Reef showed a resistant clay or sand at some sites which was inferred to be the base of soft contaminated sediments. Because of inconsistencies in the coring method with the Benthos corer, the data on the soft-sediment thickness were too variable to be used to define the soft-sediment base. Better data were obtained from borehole cores, but the number of sites was too small to permit thickness mapping.

Surveys based on STING and acoustic-tripod penetrometers were successful in recording depth to refusal at 89 sites within the proposed Randle dredge site. Recorded thickness for the tripod ranged from 0.68 - 1.62 m and averaged 1.19 m. STING values were higher, ranging from 0.2 - 2.98 m and averaging 1.46 m. Computed sediment volumes were lowest for the core data, intermediate for the tripod, and highest for the STING. The STING value of 32,039 cubic metres was considered to be the best estimate of soft-sediment volume because the STING depth to refusal agreed best with that of the borehole cores.

Acoustic sub-bottom profiling was not successful in detecting the base of unconsolidated sediments, and the poor results were attributed to the lack of calibration and the high gas content of the harbour sediments.

The bathymetry of the site was measured with both vertical sounding surveys (RoxAnn) and multibeam sonar. The multibeam surveys with their complete coverage provided the greatest detail. The morphology of the site consists of an inshore shelf with a steep northern slope and then an deeper irregular offshore topography.

Some idea of the stability of the site sediments in response to shipping and storms was determined by replicate seasonal surveys with vertical sounding and multibeam surveys in 1998 and 2000. Comparison of the datasets indicated that most of the changes observed were within the survey error for both the seasonal and two-year data.

Acoustic mapping of bottom sediments with the RoxAnn seabed-classification system and data from sediment cores both showed a uniform bottom of muds or sandy muds within the dredge polygon.

5. Acknowledgements

NWRI's Technical Operations Section provided the launch and staff support for the tripod and STING measurements, and B. Trapp of NWRI's Aquatic Ecosystem Restoration Branch (AEMRB) assisted in the surveys. Technical Operations also collected the sediment cores under the direction of R. Santiago of EC. T. Patterson of AEMRB analysed the core data and produced the graphs of core thickness and plug depth. The Canadian Hydrographic Service collected and processed the multibeam-sonar data. D. Gilroy of Technical Operations helped with the reduction of the data and the graphics. The sub-bottom profiler data were made available by McQuest Marine Services. The Randle Reef study and the development of the acoustic tripod and the STING penetrometer as survey tools were funded by Environment Canada's Great Lakes 2000 Sustainability Fund.

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Figures

Appendices

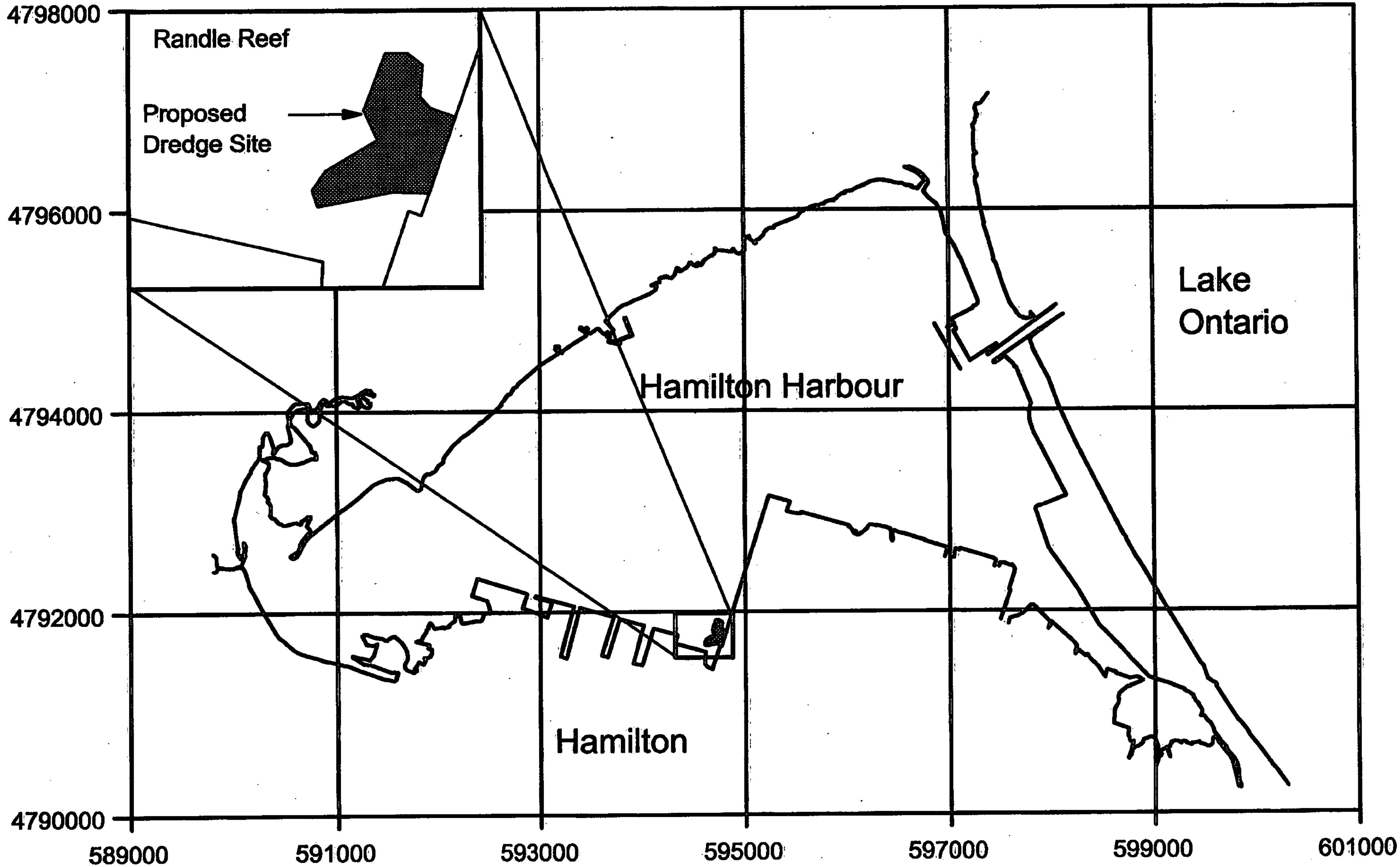


Figure 1: Randle Reef Site Map

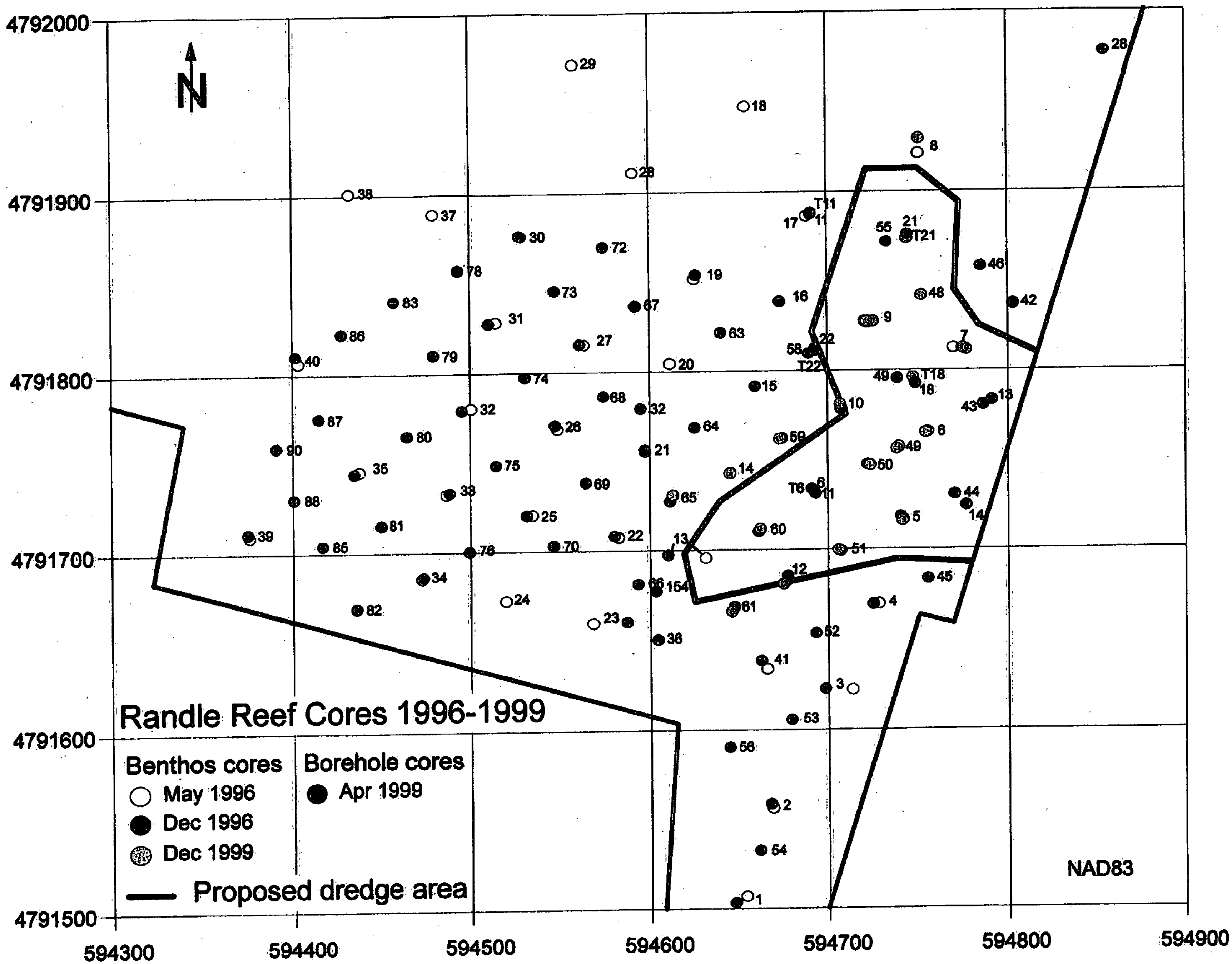


Figure 2. Core sites

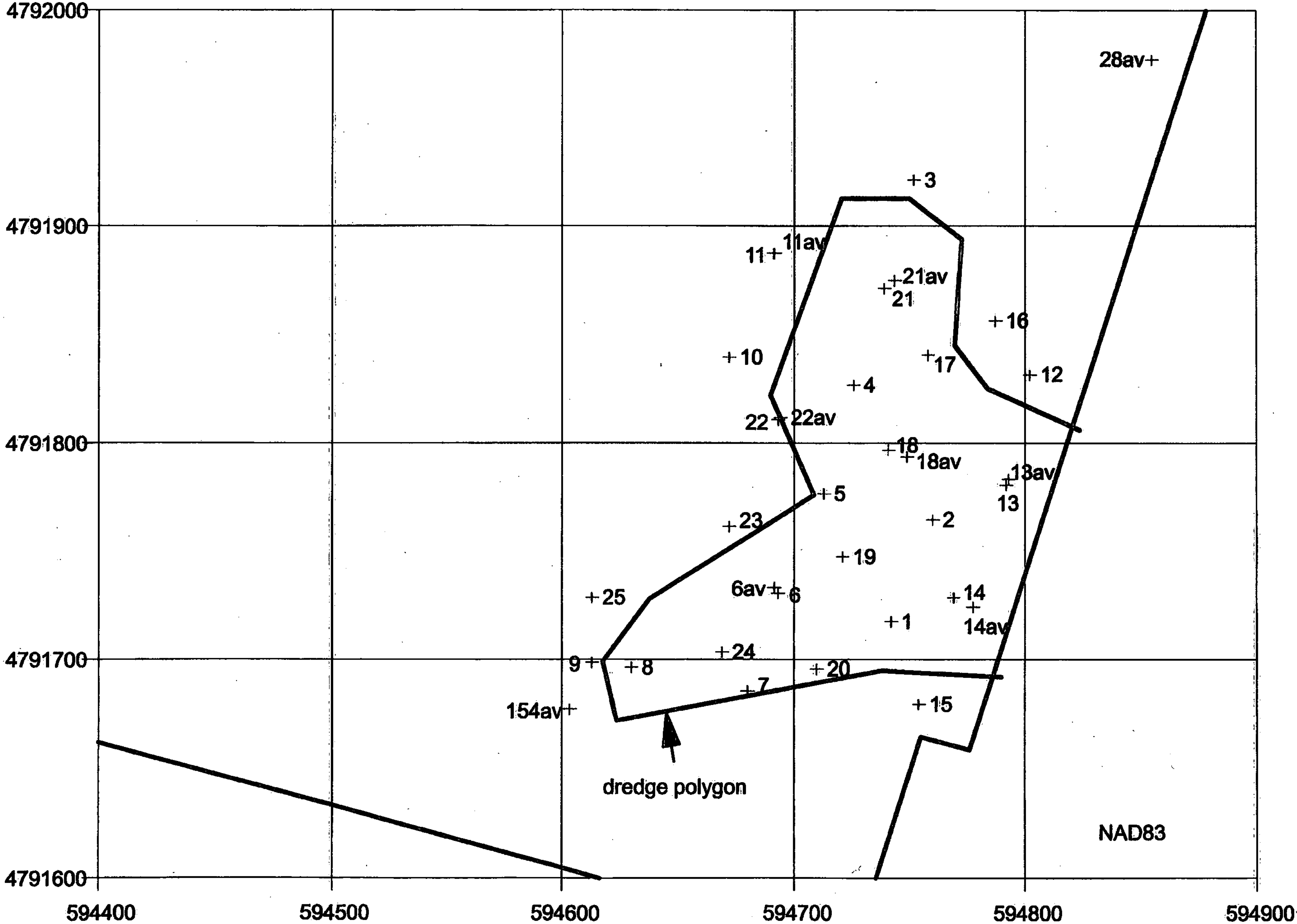


Figure 3. Tripod sites

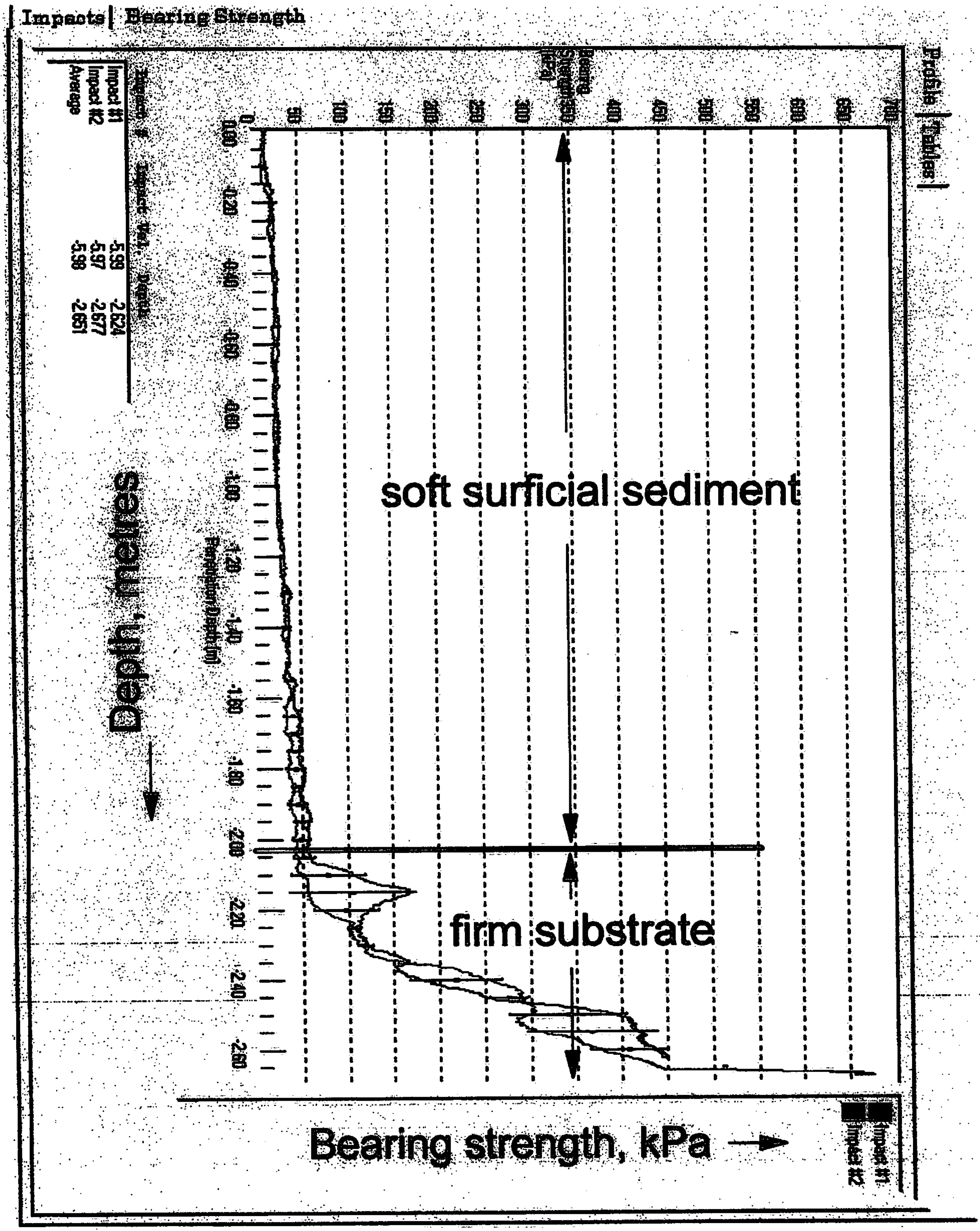


Figure 4. STING profile

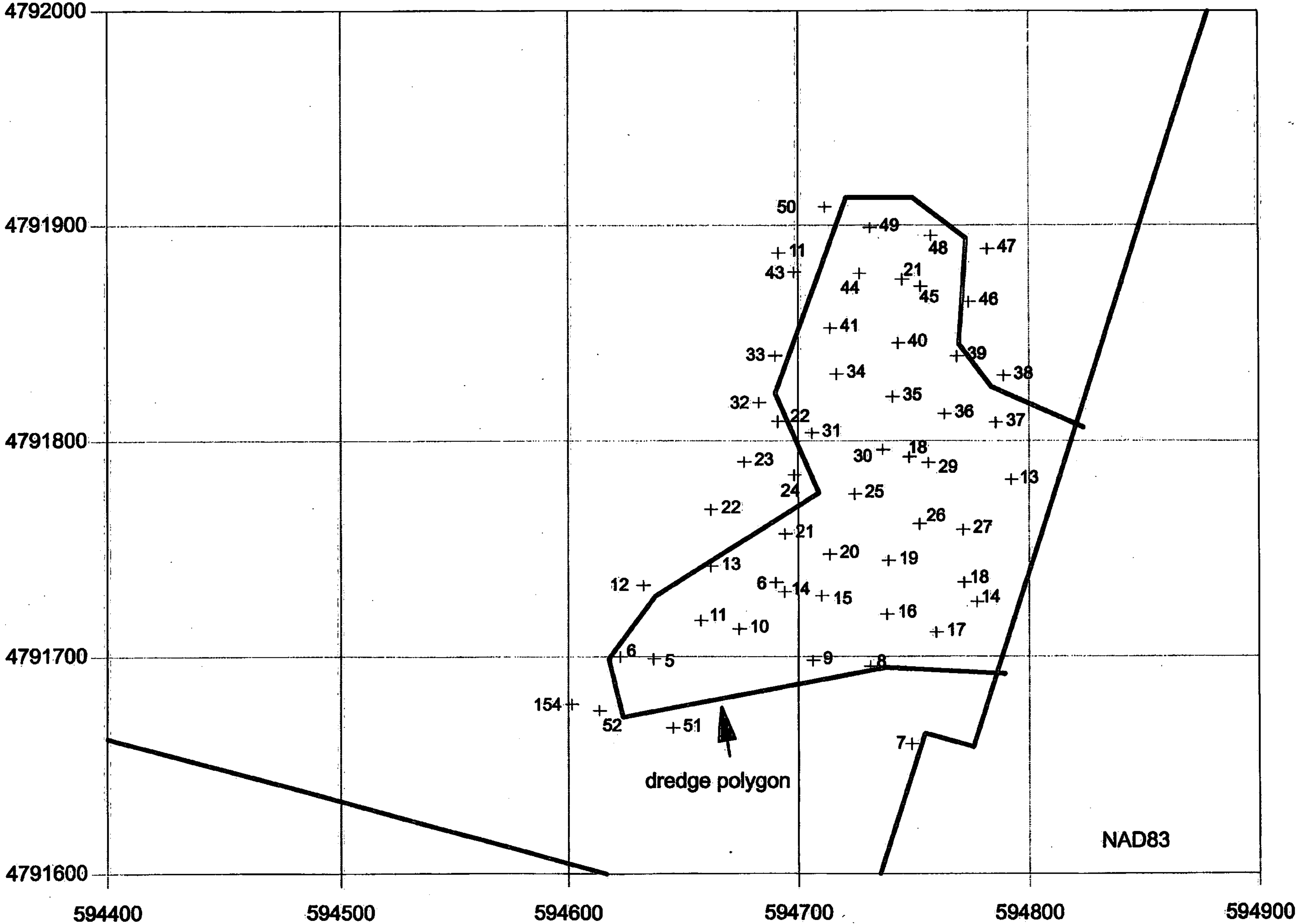


Figure 5. STING sites

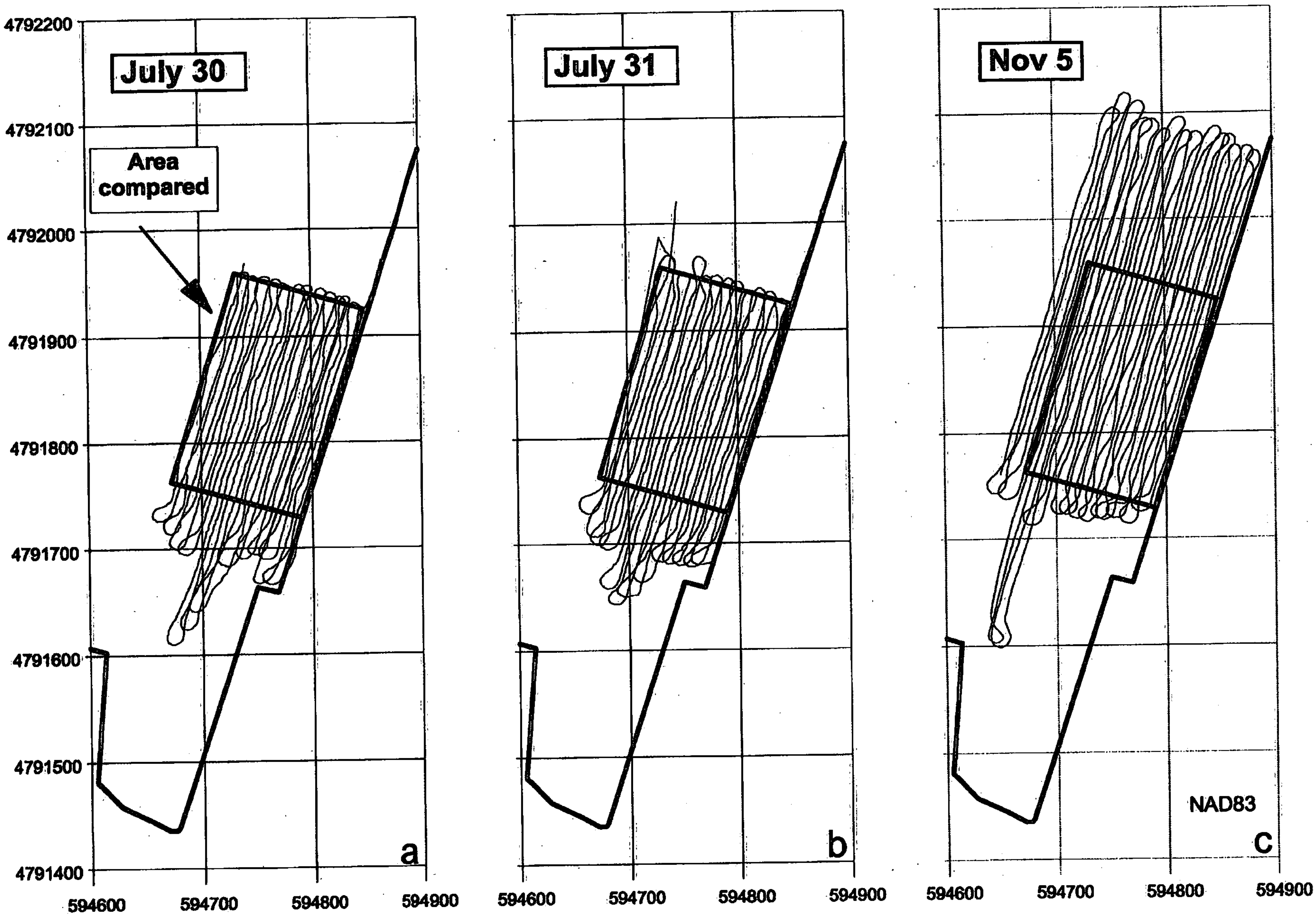


Figure 6. RoxAnn sounding tracks

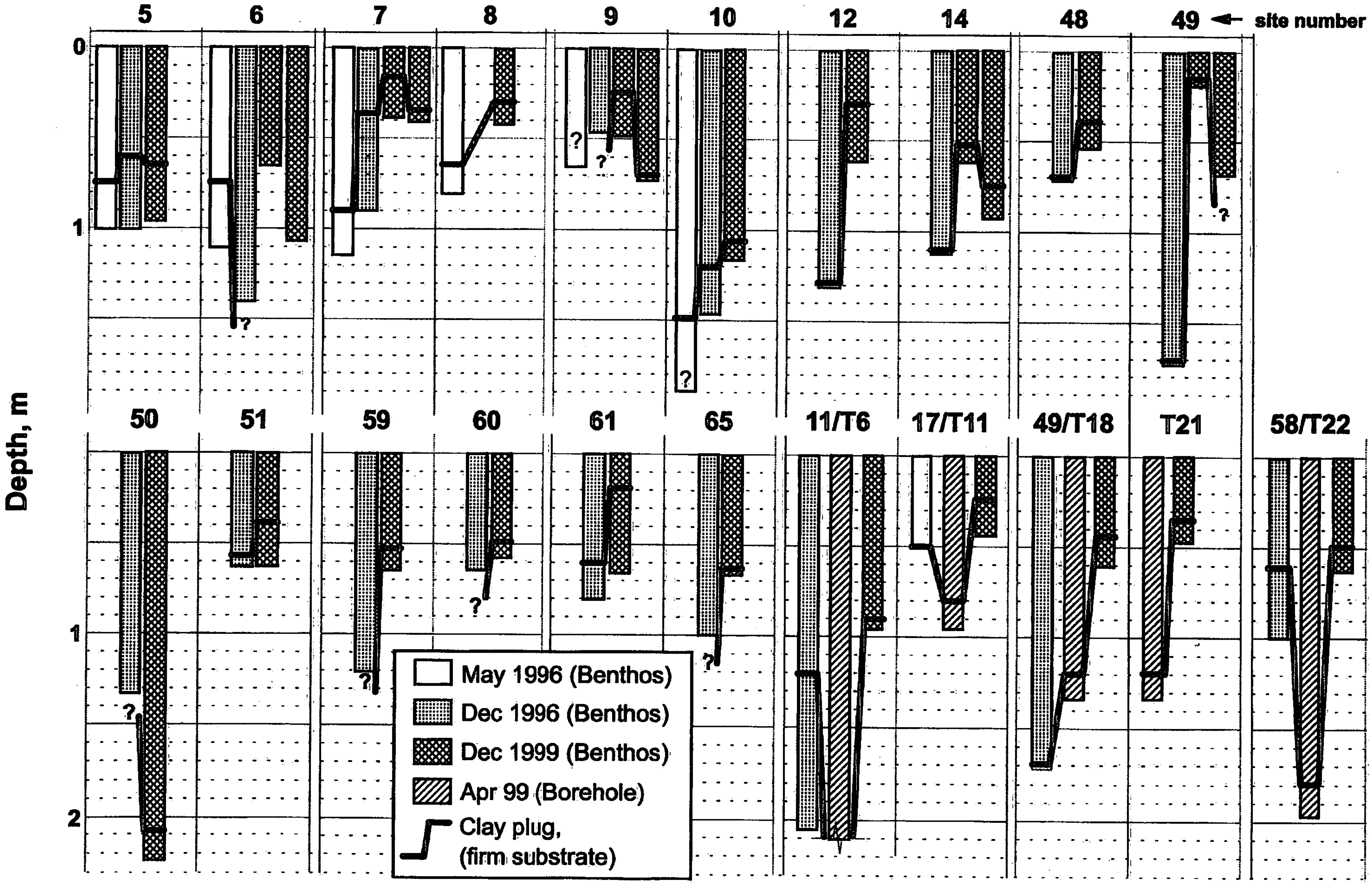
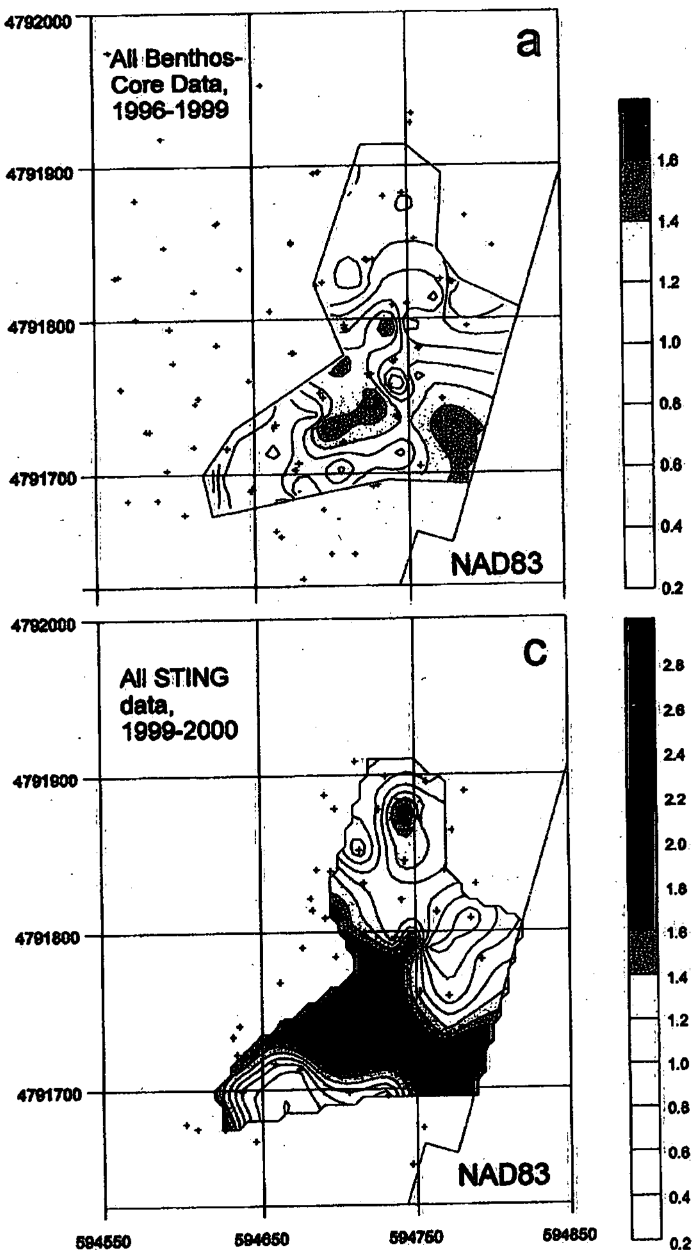
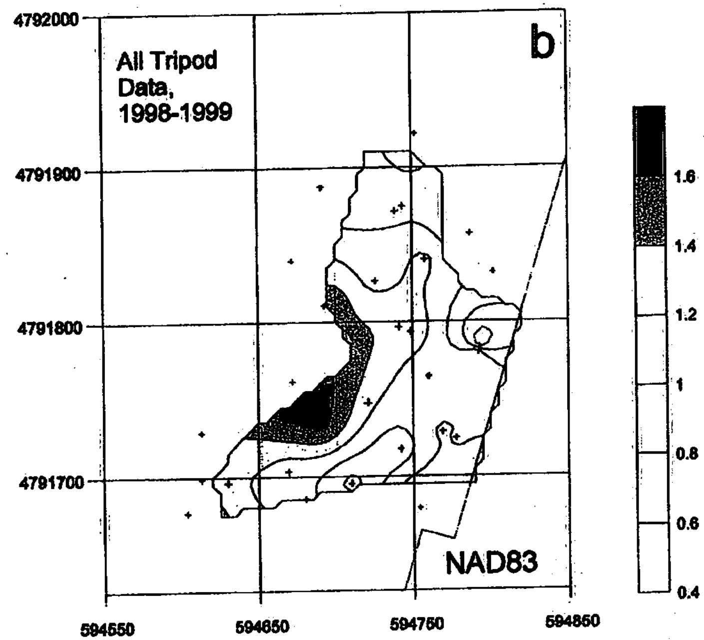


Figure 7. Core length and base of contaminated sediment





Volumes, cubic metres*:

Core data:	21590
Tripod data:	28674
STING data:	32039

*Surfer kriging, default settings, trapezoidal rule, 5-m grid

+ : sites

Figure 8. Randle Polygon soft-sediment thickness, metres

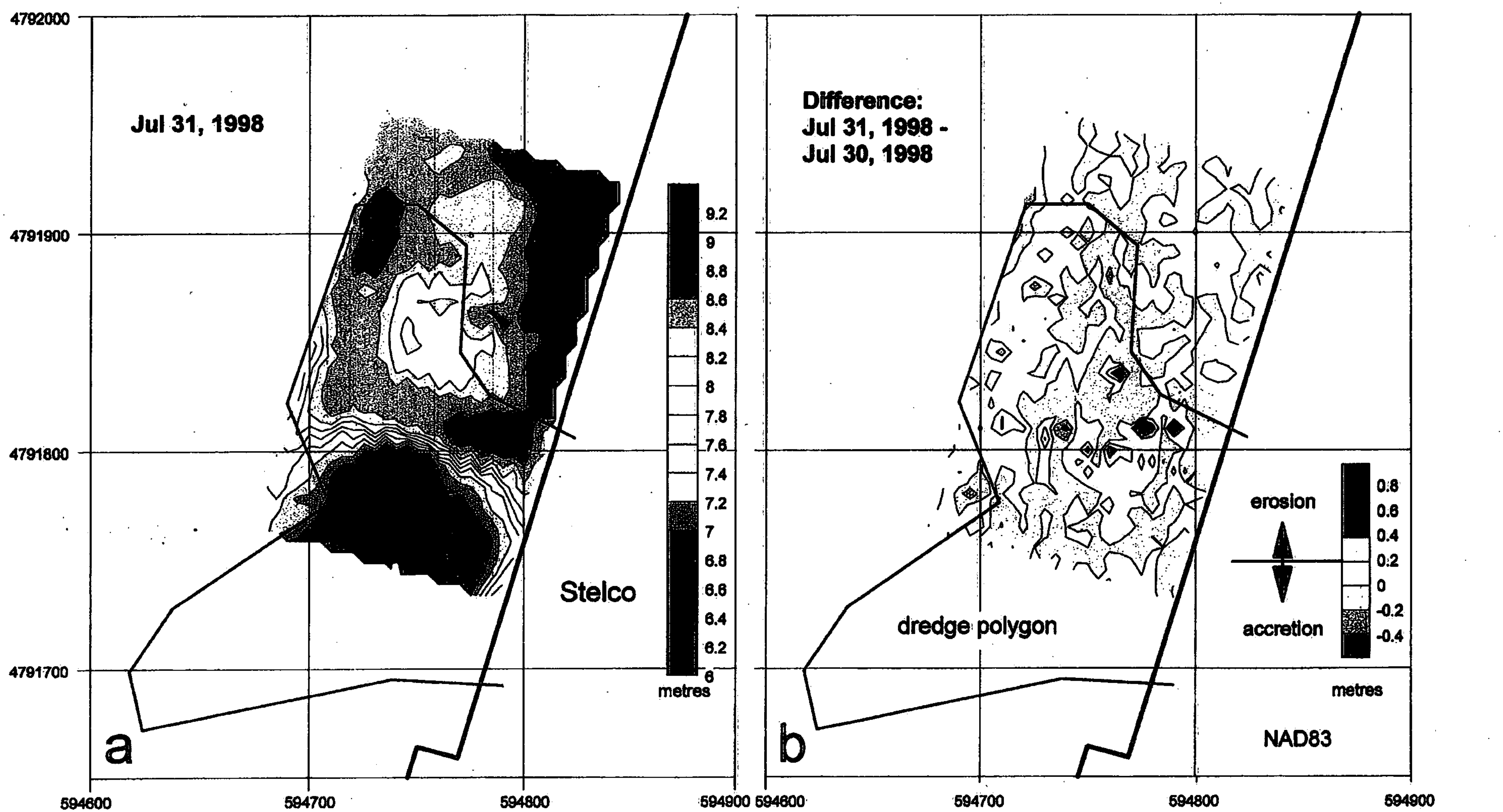


Figure 9. a) July 31,1998 bathymetry and b) difference from July 30

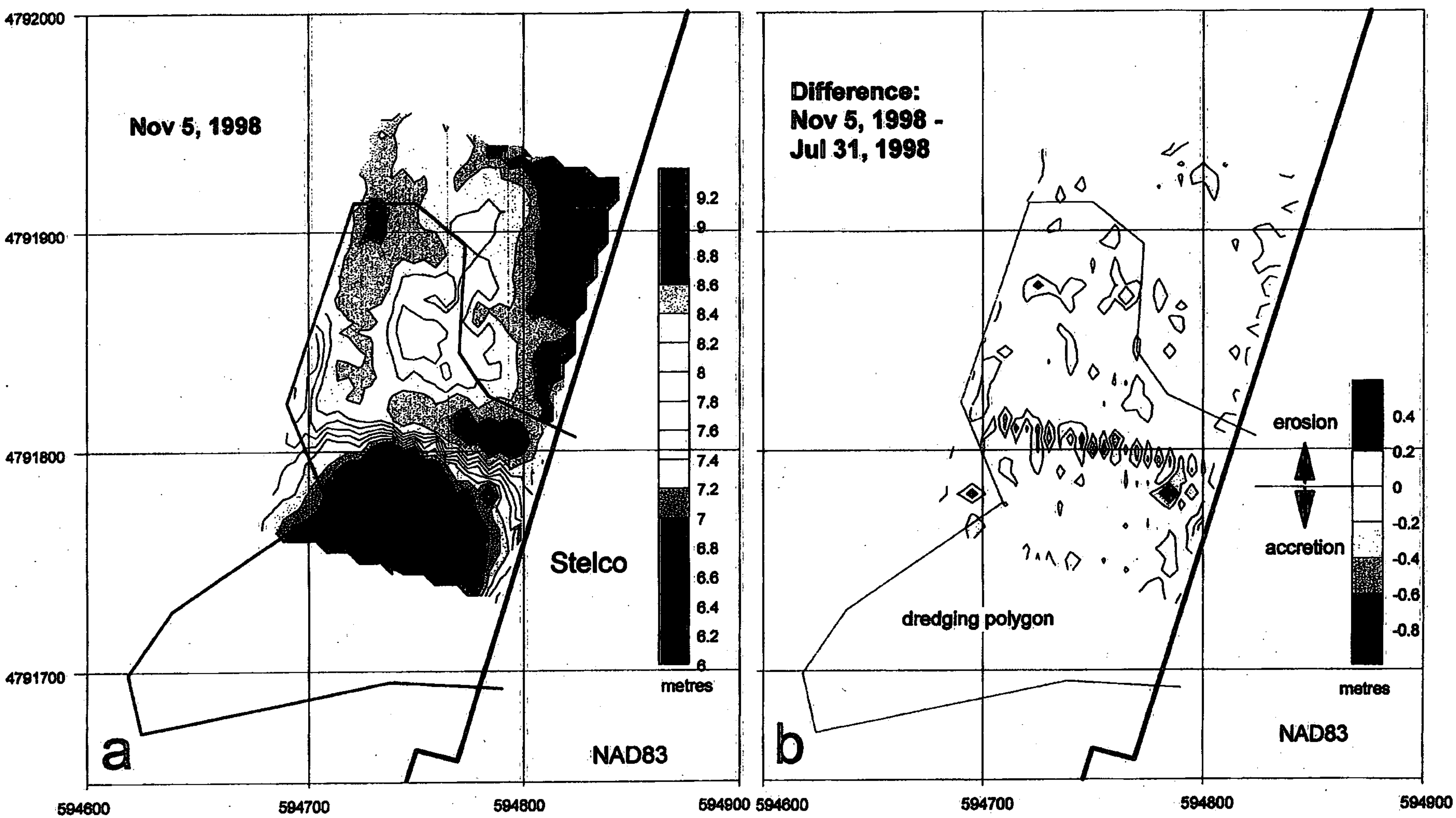


Figure 10. a) Nov 5,1998 bathymetry and b) difference from July 31

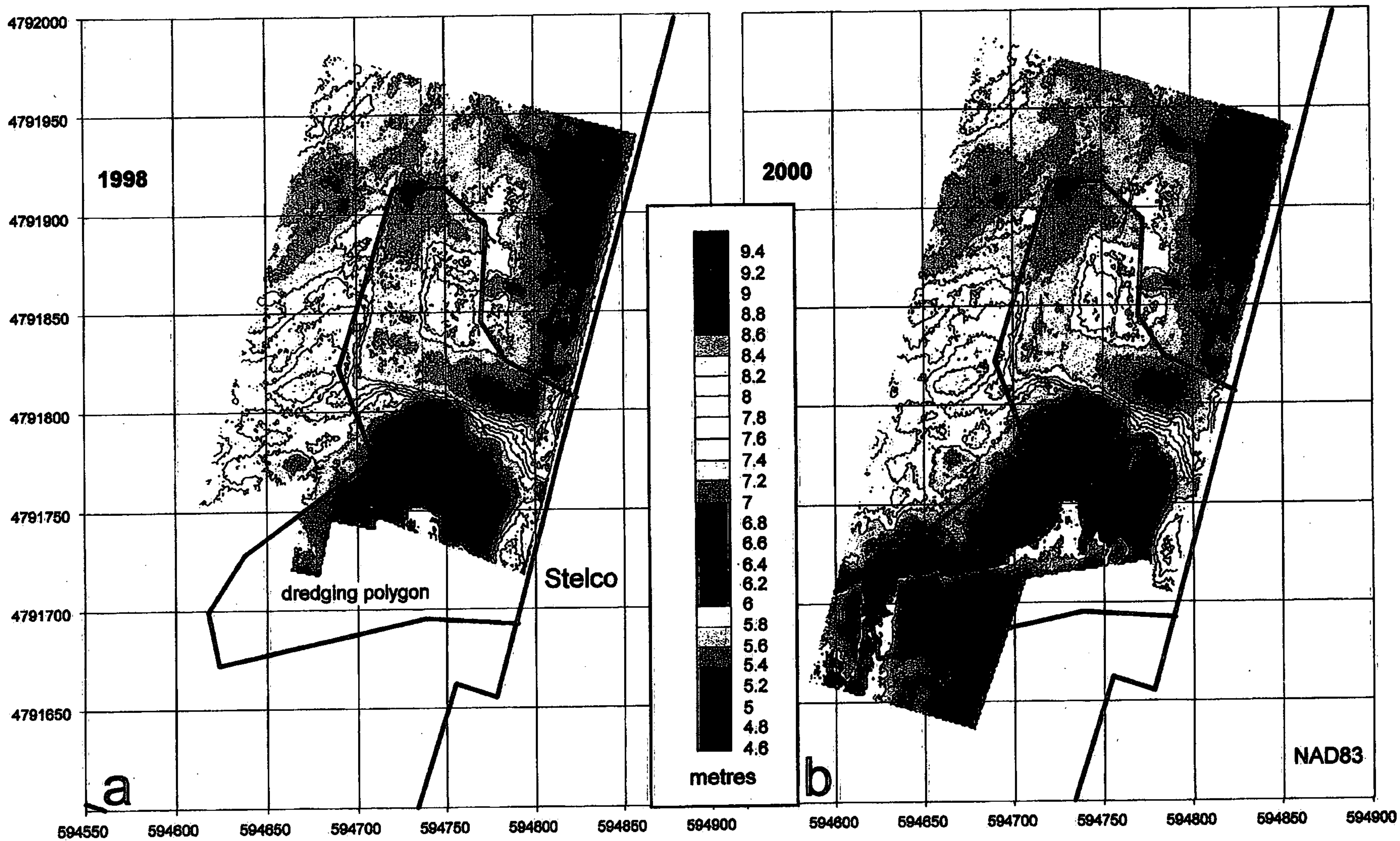


Figure 11. Multibeam-sonar bathymetry, a) 1998 and b) 2000

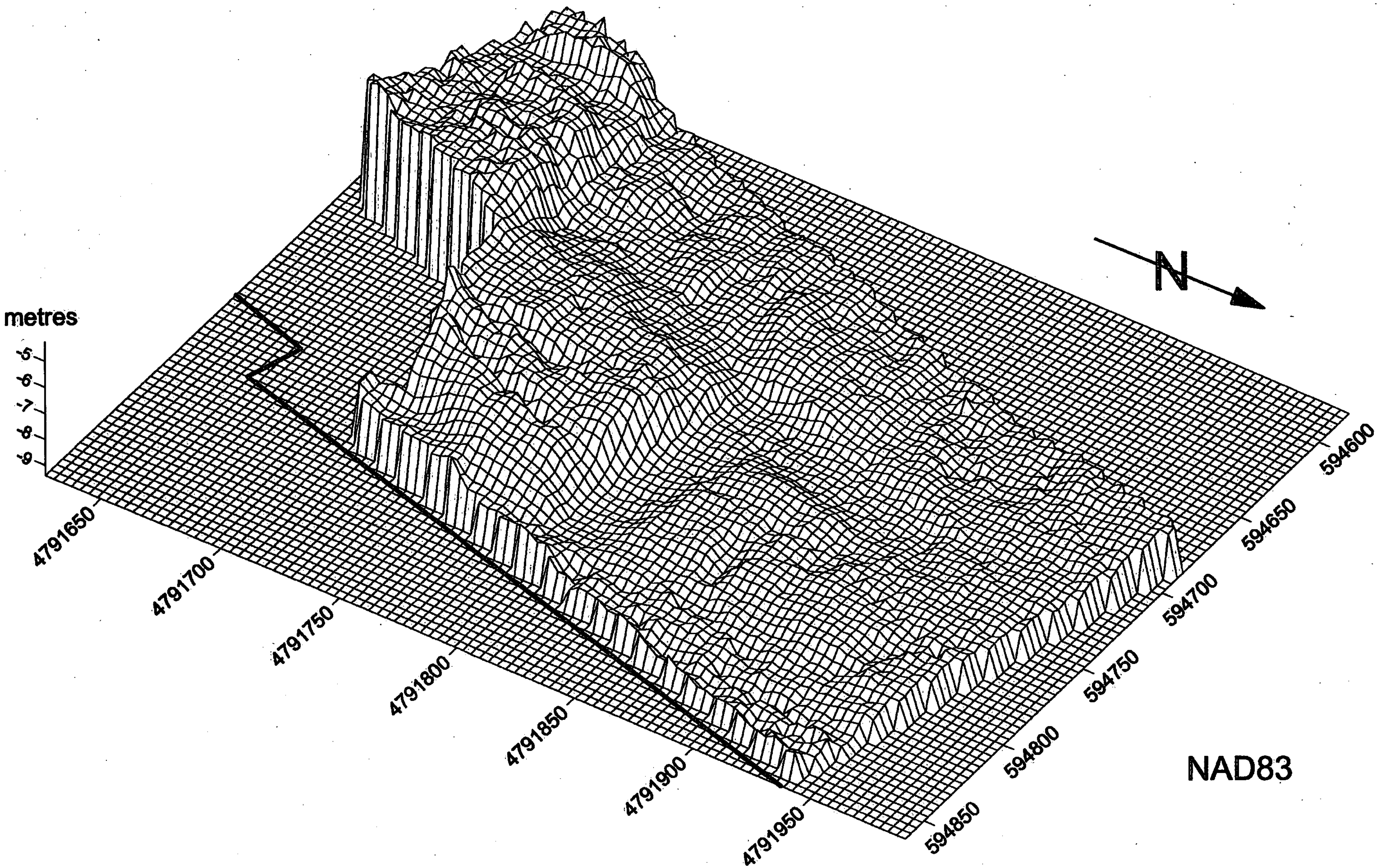


Figure 12. 2000 Multibeam bathymetry, wireframe 3D

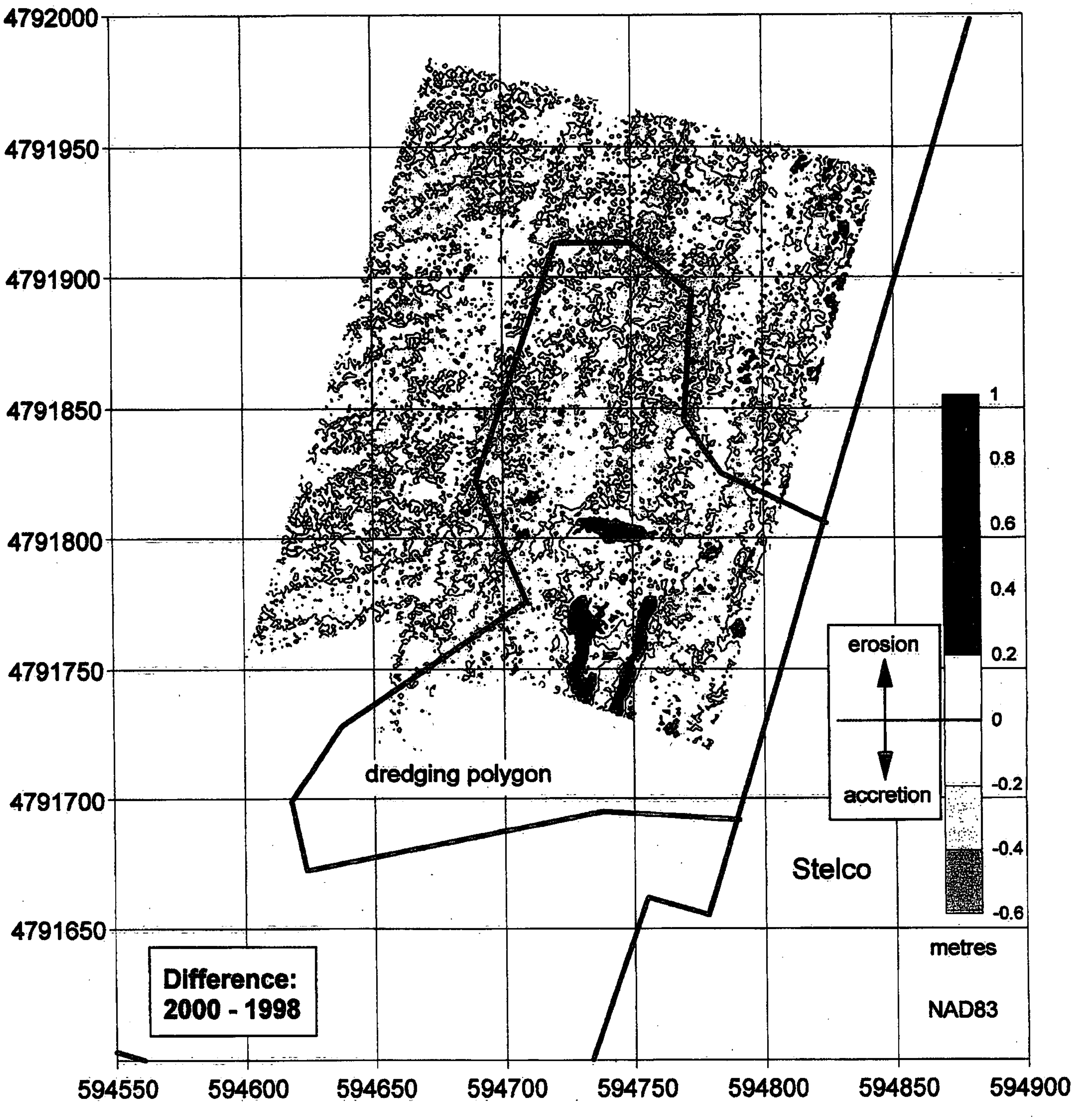


Figure 13. Difference between 2000 and 1998 multibeam bathymetry

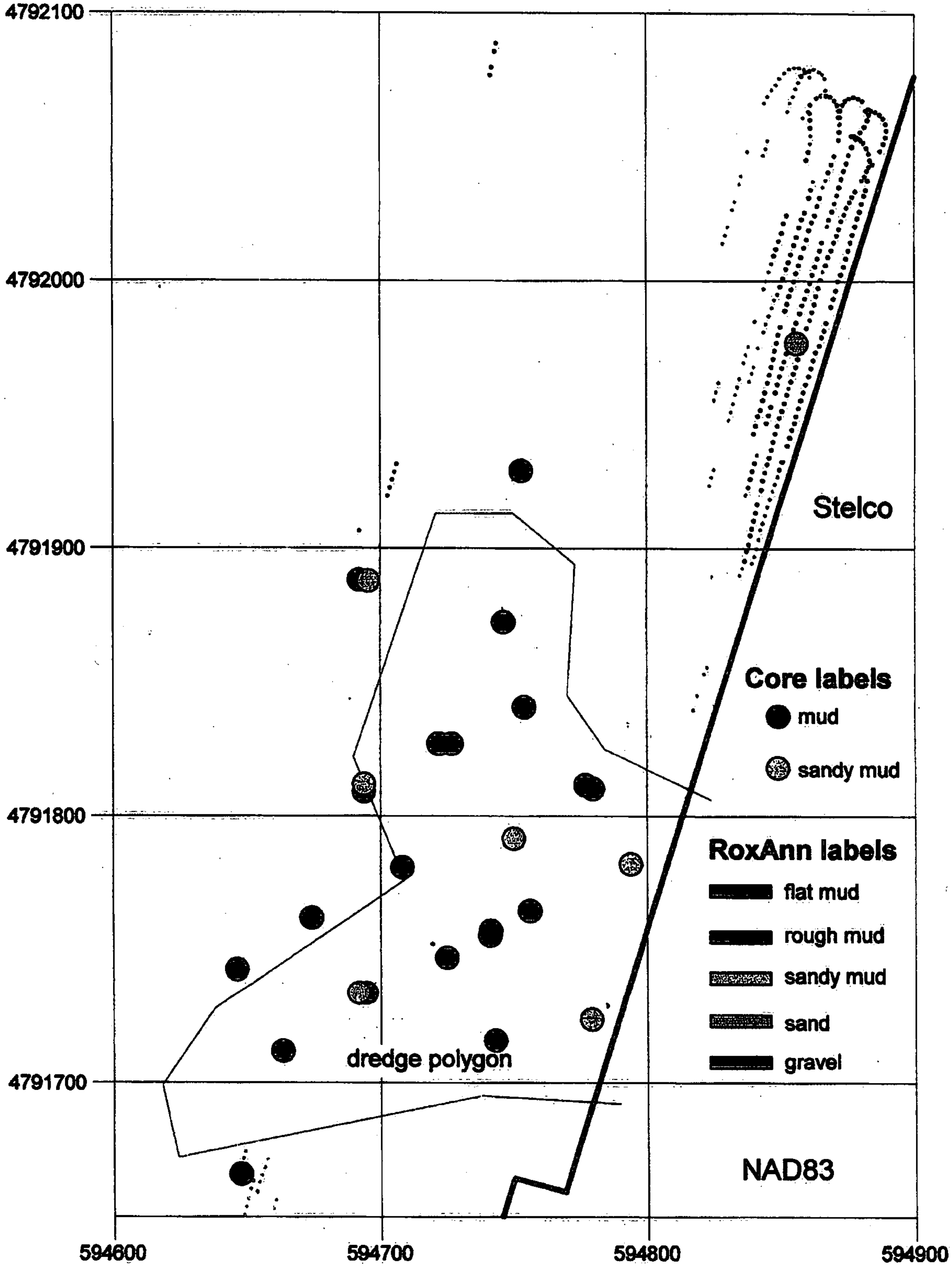


Figure 14. RoxAnn bottom types, November 5, 1998 survey

Appendix 1: Core-thickness Data

Benthos Cores: May, 1996, 100-kg corer				
Core	Easting	Northing	Length	"clay plug"
Site	UTM NAD83, m		metres	depth, m
1	594654	4791507	0.90	
2	594669	4791556	0.66	0.66
3	594714	4791622	1.73	
4	594729	4791670	2.05	
5	594743	4791717	1.00	0.77
6	594757	4791766	1.10	
7	594771	4791813	1.13	
8	594752	4791922	0.80	0.64
9	594723	4791827	0.64	
10	594708	4791779	1.88	1.88
13	594632	4791696	0.86	0.63
16	594674	4791839	0.99	0.87
17	594689	4791887	0.50	
18	594655	4791949	0.69	0.50
19	594626	4791852	0.52	0.34
20	594612	4791805	0.35	0.26
21	594598	4791756	1.10	0.98
22	594583	4791708	0.58	
23	594569	4791660	1.37	1.30
24	594520	4791673	1.35	1.20
25	594535	4791721	1.13	0.94
26	594549	4791769	1.37	1.28
27	594564	4791816	0.77	0.60
28	594592	4791912	0.70	0.59
29	594559	4791973	0.43	0.31
30	594529	4791877	0.54	0.47
31	594515	4791829	0.80	0.70
32	594501	4791781	0.69	0.52
33	594487	4791733	0.84	0.72
34	594473	4791686	1.10	0.98
35	594438	4791746	0.79	0.63
37	594480	4791890	0.84	0.60
34	594474	4791686	0.60	
35	594435	4791744	0.96	
36	594605	4791650	1.50	1.32
39	594375	4791711	0.90	
40	594402	4791810	0.50	
41	594663	4791638	1.37	1.37

Benthos Cores: Dec, 1996, 80-kg corer				
Core	Easting	Northing	Length	"clay plug"
Site	UTM NAD83, m		metres	depth, m
1	594648	4791503	1.20	
2	594668	4791558	1.20	0.70
3	594699	4791622	1.48	
4	594726	4791669	2.20	
5	594742	4791718	1.00	
6	594756	4791765	1.40	
7	594778	4791811	0.90	0.35
9	594723	4791826	0.45	0.45
10	594709	4791778	1.45	
11	594694	4791731	2.05	1.90
12	594678	4791685	1.29	1.30
13	594611	4791697	2.15	2.15
14	594646	4791743	1.10	
15	594660	4791791	1.00	
16	594674	4791838	0.75	0.75
19	594627	4791853	0.40	0.32
21	594598	4791756	1.06	0.40
22	594581	4791708	1.20	
23	594588	4791660	1.40	
25	594532	4791720	0.90	
26	594548	4791770	0.75	0.75
27	594562	4791815	0.60	
30	594528	4791876	0.60	
31	594511	4791827	0.87	
32	594596	4791779	0.90	
32A	594496	4791779	0.89	
33	594489	4791733	0.70	0.70
42	594805	4791836	0.80	0.30
43	594788	4791780	0.80	
44	594772	4791730	1.60	
45	594757	4791683	1.40	
46	594787	4791857	0.74	0.50
48	594754	4791841	0.70	0.70
49	594740	4791795	1.70	1.70
50	594723	4791747	1.32	1.32
51	594708	4791699	0.72	
52	594694	4791653	1.75	1.00
53	594680	4791605	1.40	
54	594662	4791532	0.32	
55	594734	4791871	0.55	0.55
56	594645	4791590	0.80	
58	594690	4791809	1.20	
59	594675	4791762	1.20	
60	594662	4791710	0.65	0.65

Benthos Cores: Dec, 1996, 80-kg corer				
Core	Easting	Northing	Length	"clay plug"
Site	UTM NAD83, m		metres	depth, m
61	594648	4791668	0.80	
63	594641	4791821	0.95	
64	594626	4791768	1.10	
65	594612	4791727	1.00	1.00
66	594594	4791681	1.40	1.40
67	594593	4791836	0.59	
68	594575	4791786	0.60	
69	594565	4791738	1.20	1.00
70	594547	4791703	0.90	
72	594575	4791869	0.20	
73	594548	4791845	0.58	0.40
74	594531	4791797	0.55	0.55
75	594515	4791748	0.90	0.80
76	594500	4791700	0.95	0.95
78	594494	4791857	0.59	
79	594480	4791810	0.60	
80	594465	4791765	0.77	
81	594450	4791715	0.90	0.45
82	594436	4791669	0.42	
83	594458	4791840	0.67	
85	594417	4791704	1.07	0.50
86	594428	4791822	0.42	
87	594415	4791775	0.89	
88	594401	4791730	0.40	0.20
90	594391	4791759	0.50	0.70

Borehole Cores: Apr, 1999, Trow Consulting				
Core	Easting	Northing	Length, m	"clay plug"
Site	UTM NAD83, m			depth, m
6	594692	4791734	4.60	3.20
11	594692	4791887	2.40	0.80
13	594793	4791783	3.70	Complex
14	594779	4791724	4.00	2.50
18	594750	4791792	5.00	3.40
21	594746	4791875	2.40	1.20
22	594694	4791812	3.10	1.80
28	594856	4791977	2.50	None
154	594604	4791678	3.70	2.20

Benthos Cores: Dec, 1999, 80-kg corer				
December 17				
T22B	594694	4791811	0.62	0.49
10	594708	4791781	1.17	1.06
49A	594741	4791757	0.19	0.12
49B	594740	4791756	0.70	0.59
9A	594722	4791827	0.49	0.23
9B	594727	4791827	0.72	0.72

Benthos Cores: Dec, 1999, 80-kg corer				
Core	Easting	Northing	Length	"clay plug"
Site	UTM NAD83, m		metres	depth, m
December 17				
7A	594779	4791811	0.38	0.17
7B	594777	4791812	0.41	0.34
60	594663	4791712	0.58	0.49
12	594676	4791681	0.61	0.30
51	594707	4791700	0.62	0.39
5	594743	4791716	0.97	0.65
61	594647	4791666	0.66	0.19
14-1	594646	4791743	0.61	0.52
14-2	594646	4791743	0.92	0.75
T 21	594746	4791873	0.49	0.35
48	594754	4791841	0.53	0.39
8	594753	4791929	0.41	0.29
T 11	594692	4791888	0.43	0.24
59	594674	4791762	0.64	0.52
December 20				
6A	594756	4791765	0.61	None
6B	594756	4791765	1.07	1.04
50	594725	4791747	2.23	2.08
T6	594692	4791734	0.97	0.70
T18	594749	4791796	0.60	0.44
65	594614	4791731	0.67	0.59

Appendix 2: Tripod-thickness Data

Site No.	Date	Easting	Northing	Tripod
		metres, NAD83		Thickness
				metres
1	1998-07-28	594742	4791718	0.86
2		594760	4791765	0.98
3		594752	4791922	1.16
4		594726	4791827	1.10
5		594713	4791777	1.46
6		594693	4791731	1.62
7		594680	4791686	1.06
8		594630	4791697	1.24
9		594613	4791699	1.38
10		594672	4791840	1.30
11		594691	4791888	0.78
12		594802	4791832	1.04
13		594792	4791781	1.22
14		594769	4791729	1.26
15		594754	4791680	1.66
16		594787	4791857	0.68
17		594758	4791841	1.26
18		594741	4791797	1.38
19		594721	4791748	1.26
20		594710	4791696	0.71
21		594739	4791872	0.93
22		594693	4791811	1.24
23		594672	4791762	1.88
24		594669	4791704	1.06
25		594613	4791729	1.43
6av	1999-04-27	594692	4791733	1.7
11av		594692	4791888	0.7
13av		594793	4791783	0.4
14av		594778	4791724	1.2
18av		594749	4791794	1.4
21av		594744	4791875	1.0
22av		594694	4791812	1.6
28av		594855	4791977	0.3
154av		594604	4791677	1.8

Appendix 3: STING thickness data

STING site	Date	Easting	Northing	STING thickness, metres*		STING site	Date	Easting	Northing	STING thickness, metres*
		metres, NAD83						metres, NAD83		
6	Apr/May,	594690	4791735	2.88		41	Mar/Apr,	594714	4791852	0.20
11	1999	594691	4791887	1.40		43	2000	594698	4791879	0.74
13		594793	4791782	0.91		44		594727	4791878	0.82
14		594778	4791725	2.50		45		594753	4791872	1.12
18		594748	4791793	2.21		46		594774	4791865	1.06
21		594745	4791875	2.13		47		594782	4791889	1.00
22		594691	4791809	2.33		48		594758	4791895	0.77
154		594602	4791678	2.84		49		594731	4791899	0.70
5	Mar/Apr,	594637	4791699	0.70		50		594712	4791909	0.56
6	2000	594623	4791700	1.49		51		594646	4791667	0.60
7a		594754	4791675	1.68		52a		594626	4791675	1.93
7b		594747	4791652	1.72		52b		594609	4791675	2.31
8		594731	4791696	0.65						
9		594706	4791698	0.97			* average of multiple drops			
10		594674	4791713	0.58						
11		594658	4791717	0.84						
12a		594636	4791741	2.10						
12b		594634	4791723	2.00						
12_7		594632	4791734	2.26						
13		594662	4791742	1.94						
14		594694	4791730	2.98						
15		594710	4791728	2.48						
16		594739	4791720	1.60						
17		594760	4791711	2.40						
18		594772	4791734	1.23						
19a		594745	4791740	1.95						
19b		594736	4791747	1.98						
20		594714	4791748	2.50						
21		594694	4791757	1.73						
22		594662	4791768	2.13						
23		594677	4791790	2.02						
24		594698	4791784	2.35						
25		594725	4791776	2.40						
26		594753	4791762	1.07						
27		594772	4791759	0.63						
29		594757	4791790	0.37						
30		594737	4791796	0.79						
31		594706	4791804	1.43						
32		594683	4791814	1.27						
32r		594682	4791822	1.38						
33r		594695	4791839	1.25						
33		594686	4791840	1.10						
34		594717	4791831	0.97						
35		594741	4791821	0.81						
36		594764	4791813	0.71						
37		594786	4791808	0.24						
38		594789	4791830	0.79						
39		594769	4791840	1.00						
40		594743	4791845	1.36						

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