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Executive Summary

The site previously selected for a trial of contaminant dredging at Cornwall (Rukavina 1994a, 1994b) has been relocated within an area designated by OMEE on the basis of new contaminant data. This report describes the rationale used to select the new site and the GIS analysis of its sediment distribution and properties. The analysis has been based on Roxann mapping of bottom-sediment type, sediment-thickness data from cores and diver and underwater-television observations, and OMEE data on contaminant distribution (Richman 1996). The new data will be used to support RAP decisions on dredging technology and cost.

Introduction

The Cornwall RAP committee has designated an area in east Cornwall opposite the Courtauld's plant to be considered for a contaminated-sediment removal project. This is an area of highly variable surface sediments (Rukavina 1993) in which levels of heavy metals are known to exceed the severe-effect-level criteria (Beak 1993; Richman 1996). In 1994, a site was selected and field surveys (Rukavina 1994a) and GIS analysis of the resulting data (Rukavina 1994b) were used to provide the information on sediment distribution and volume needed to choose the appropriate dredging technology and to estimate its cost. New contaminant data now available from OMEE samples collected in late 1994 (Richman 1996) require that the boundaries of the dredge site be reassessed and a new site selected.

This report has used the new contaminant data and earlier data on sediment type and thickness as the basis for the selection of a new site within the area designated by OMEE for remediation. GIS analysis of the data set for the new site was then used to develop maps of its bathymetry, sediment types, sediment thickness, and contaminant distribution, and to estimate its contaminated-sediment volume. The new site is a 2-ha area of mainly mud and muddy sand bottom with an average sediment thickness of 0.33 m and with low-effect or severe-effect levels for the contaminants mercury, zinc, lead and copper. Total sediment volume is 7 642 m^3 ninety percent of which consists of the finer-grained sediments in which contaminants should be concentrated.

Site Selection

New and more complete data on contaminants for the entire reach between Windmill Point and Pilon Island are now available from an OMEE report by Richman (1996). The report indicates that sediment contamination is highest at nearshore sites adjacent to shore-based outfalls opposite the Courtaulds' site and suggests that a zone of elevated concentrations of mercury, lead, zinc and copper in that area be considered for remediation. This target zone overlaps the eastern portion of the original dredge site (Rukavina 1994a, 1994b) but extends about 200 m further east along the shoreline (Figure 1). Only a portion of the zone has sufficient data on bottom-sediment type and geometry to support the volume calculations required for specification of a dredging contract.

Data on bottom-sediment type in the target area include the 1994 diver survey of the original dredge site, 1994 OMEE cores and 1994 and 1995 NWRI cores, underwater-television observations and Roxann acoustic bottom-classification surveys in 1994 and 1995 (Figure 2). Diver observations were made at 23 sites, UWTV observations at 49 sites and cores or samples were collected at 26 sites. The Roxann data were collected continuously during sounding surveys along a series of shore-parallel lines with a 5-m spacing. Each survey generated more than 3000 records of bottom type within the target area in eight sediment classes: mud, muddy sand, sand, coarse sand, gravel, hard bottom or boulders, weeds on soft sediment, and weeds on hard sediment. A differential global positioning system (DGPS) was used to locate samples and cores and to navigate the Roxann survey lines. Static checks on the accuracy of the system indicate that it is in the range of 0.5-2 m.

The Roxann data provide the only practical basis for mapping the boundaries of sediment types because of their continuity and high density in comparison with the other types of data available. Because of this, it is important to understand how Roxann classifies bottom types and the limitations of its approach. Roxann is an appendage to a conventional echo sounder which extracts information on the acoustic hardness and roughness of bottom sediment as its basis for classification (Murphy et al. 1995). When calibrated with sample data, it can discriminate broad classes of sediment texture consistently but the size limits of the classes are poorly defined and cannot be easily converted to grain-size fractions. It has other limitations. Because the current Roxann surveys have been run with a high-frequency echo sounder with limited penetration, the classification applies only to the top 3-10 cm of the surficial sediment and is insensitive to sediment type below that depth. Roxann's resolution of the bottom depends upon the beam characteristics of its echo sounder and the water depth. In this case its footprint diameter is somewhere between the water depth and twice the water depth. Variations in bottom type at a smaller scale than the footprint cannot be detected and could lead to a misleading classification. The averaging that occurs over the footprint could result, for example, in an equal mix of boulders and mud being identified as uniform gravel. Invalid classications can also occur in fine-grained gassy sediments which are good reflectors and produce returns similar to coarser sediments. Many of the limitations can be overcome or reduced by calibration of the system with data from bottom samples or observations and this was done during the initial trials of the system at Cornwall in 1993 and by comparison of Roxann labels with the other data for the site acquired since then.

Data on sediment thickness were available from diver measurements at the original dredge site in 1994, scattered underwater-television observations collected during surveys from 1993 to 1995, and the 1994 OMEE cores (Figure 3). The data set consists of about 100 measurements most of which are concentrated in the western end of the target area where the earlier site was located. Diver and UWTV measurements were made by probing to refusal and should be accurate to within 2-5 cm. The sediment-core lengths are considered to be minimal estimates of sediment thickness because not all of the unconsolidated sediment was recovered and because of compression of core sediment by the coring process.

New dredge-site boundaries were chosen by superimposing the Roxann and thickness data on the target zone of contaminants (Figure 4) and selecting the portion of that area with adequate data for GIS computation of sediment volume.

The general guideline used for selection was a spacing of data points of less than 50 m. The western and offshore boundaries of the new site correspond with the limits of the contaminant data and the eastern and inshore boundaries with the limits of Roxann coverage. The new site is a polygon about 100 m wide and 250 m long oriented parallel to the shoreline and located just east of the Courtaulds' pumphouse. The site area is 0.0208 km^2 or about 2 ha. Table 1 gives its bounding coordinates.

GIS Analysis

Mapping

Maps of bottom-sediment type, sediment thickness, and metal concentrations were produced within the SPANS geographic-information system (GIS) by voronoi analysis. This is a procedure which generates a map from point data by subdividing the map area into a series of polygons centred on the data sites, and then grouping polygons with the same attribute to produce a chloropleth map (Rukavina and Delorme 1992).

Figure 5 is GIS map of sediment type based on the Roxann labels. Bottom sediment is mainly mud, a mix of silt- and clay-sized sediment. Muddy sand is present inshore and along the diffuser line and there are also small inshore areas of weeds on hard and soft bottom and coarser deposits ranging from sand to boulders. Size data from the 19 cores in the area were used as a check on the accuracy of the Roxann size classification. Twelve of the 19 sites with mud content greater than 50% were correctly labelled as mud by Roxann. Three sites with sand content greater than 76% were mislabelled mud and 4 sites with mud content ranging from 70-84% were mislabelled muddy sand. Sediment variability in the area as observed in underwater-television and diver observations is large enough to account for most of the differences. High gas content may be responsible for the mislabelling of the finer muds as muddy sands since they are all located in an area of weed beds and decomposing organic debris.

Figure 6 is the GIS map of sediment thickness based on 97 values from diver, core, and UWTV thickness data. Thickness ranges from 0 to 80 cm and is highly variable, particularly in the western quarter of the area. There is a trend towards increasing thickness from west to east and the thickest deposits occur in the central and northeastern parts of the area.

The OMEE data on contaminant concentrations were obtained from analyses of grab samples and the top 10 cm and bottom 10 cm portions of cores. Richman (1996) provides a thorough discussion of methodology and contaminant distribution. For the purposes of this report, only the core data for mercury, zinc, lead and copper have been used. Each core site has been represented by the average of the metal concentrations for the core top and core bottom or the average of averages at sites where replicate cores were collected. Figures 7-10 show the distribution of the average values subdivided into no-effect, low-effect-level and severe-effect-level classes. Concentrations for all four metals exceed the no-effect level but differ in the proportions and locations of the low-effect levels (LEL) and severe-effect levels (SEL). Mercury has the largest area of SEL followed by zinc, lead, and copper.

Figure 11 is a contour map of site bathymetry generated within Spans by contouring data on water depths recorded by Roxann. The contour interval is 2 m. Depths are relative to the water level at the time of collection and have not been adjusted to the local IGLD. The new site falls within the depth range of 2 to 10 m. Depth contours are sub-parallel to shore and there is a break in slope at 6 m with steeper smooth slopes inshore and shallower more irregular slopes offshore.

Sediment Statistics

GIS analysis was also used to compute the statistics on sediment thickness, areas and volumes of bottom types, and contaminant distribution. For each set of data, the dredge site was subdivided into a number of voronoi polygons each of which was associated with a data point and represented the area of influence of that data point. The areal distributions of bottom type, thickness and contaminant levels were then computed by summing the areas of polygons of the same class. By superimposing the thickness polygons on those for bottom type, Spans generated a third set with the attributes of area, bottom type, and sediment thickness. These polygons were used to compute the volumes of individual bottom types and the total sediment volume for the site. The raw data and the results are summarized in Table 2.

The area of the dredge site is 20 756 m^2 or 2.1 ha. Mud and muddy sand are the dominant bottom types with areas of 15 675 m^2 (75.5%) and 2 966 m^2 (14.3%) respectively, and the coarser and weedy sediments account for less than 10% of the total area. Sediment thickness for the site as a whole averages 0.33 m and has a modal value of 0.5-0.6 m (Table 3). Average thicknesses for individual bottom types range from 0.28-0.50 m (Table 2) but not all the values are equally reliable. The data for types with small areas like boulders or weeds on hard are spurious byproducts of the GIS voronoi analysis which occur because of the different densities of the thickness and bottom-type data.

Total sediment volume for the site is 7 642 m^3 of which mud and muddy sand are the principal components at 5 967 m^3 (78%) and 958 m^3 (13%) respectively. The remaining sediment types collectively account for less than 10% of the deposit volume. The volume calculations are based on surface-sediment data and assume that grain size at the surface is representative of the entire sediment column. This appears to be a valid assumption since only minor changes with depth (<1-2 %)

were observed in the size data from the tops and bottoms of the OMEE cores (Table 4).

The GIS statistics for the major contaminants are listed in Table 5. The areas and percentage areas at the severe-effect level range from a maximum of 1.9 ha (91%) for mercury to 0.3 ha (16%) for copper. The area for which all contaminants are above the SEL corresponds to SEL area for copper (Figure 10).

Table 6 is the result of an analysis of the areas between the depth contours of Figure 11. About 1.7 ha or 80% percent of the site is equally divided between the 6-8 m and 8-10 m contours, 0.3 ha (15%) is in the interval 4-6 m, and the remaining 0.6 ha (3%) is at depths of 2-4 m.

Reliability of the Statistics

It would be desirable to be able to assign confidence levels to the areas, thicknesses and volumes computed by the GIS but the nature of the data does not permit that to be done quantitatively. It is still useful to reiterate some of the limitations of the data types used and to suggest the effect they may have on the statistics which make use of them.

All positioning of samples, cores and Roxann records was done with a stable differential GPS. The accuracy of location data should be better than 2 m.

The Roxann classification of bottom types is a quantitative one based on limiting values for the parameters which represent bottom hardness and roughness. The problem is that the same parameters can result from a wide range of sediment properties including differences in composition, water content, gas content and grain size. The small data set currently available for comparing the Roxann size grades with size data from samples agrees with Roxann for between 50 and 75% of the analyses depending on the variability of the bottom and complicating factors like the presence of gas, organic matter, fibres, etc. Underwater-television surveys along Roxann survey tracks indicate that Roxann's identification of mud is reliable but that its coarser size grades may in fact be muds with varying gas content. This would suggest that GIS estimates of the areal coverage for mud and muddy sand are conservative and that they should be considered to be minimal values.

Roxann maps are maps of the properties of the surficial 3 to 10 cm of bottom sediments and do not reflect changes at depth. This should not be a serious problem since the OMEE data on grain size show only minor differences between samples from the tops and bases of cores.

Another factor which must be taken into account is the possibility of seasonal or annual changes in the sediment pattern. The Roxann data used were collected at the same time as the OMEE cores in October 1994 and describe the sediment pattern at that time. New data for the same area collected in October 1995 show the same basic pattern of fine and coarse-grained sediments but a change to more muddy sand and less mud. Whether this is a real textural change or one resulting from changing gas content has not been determined. There have been no spring or summer Roxann surveys so no data exist on the scale of seasonal changes. Some data on bottom-sediment stability just east of the site are available from acoustic monitoring with a bottom-mounted fixed-transducer system. They indicate that erosion or sedimentation during the summer-fall period is on a scale of a few cm. If this applies to the balance of the year as well, then it is likely that area and volume estimates based on the 1994 pattern will still be valid in 1996.

The sediment-thickness data used were a mix of direct measurements made by divers or underwater television and core lengths. The direct measurements have a precision of ±2-5 cm. Core lengths are known to underestimate sediment thickness but there are no data on the size of the error. The report on GIS analysis of sediment properties of the earlier site (Rukavina 1994b) assigned a confidence level for thickness of ±5 cm based on the variability of the 4 thickness measurements collected at each survey site. Because the thickness map (Figure 6) shows this to be an area of greater variability than the site as a whole, we can use its confidence level as an estimate of maximum error for the direct measurements.

The sediment volume is the volume of wet sediment and should not be confused with the volume of solids. If the volume or weight of solids is needed to determine the quantity of dredged sediment which will require treatment, then additional data on sediment bulk-density or water content from sediment cores will be necessary.

The bathymetric map was produced from depth data collected by Roxann. Depth resolution was 1 cm but the assumed precision is ±30 cm which is the hydrographic standard.

Better estimates of sediment distribution, grain size and volume would require detailed sampling on a grid with replication, and statistical analysis to determine the confidence intervals of the results. It would also be desirable to extend the GIS analysis to estimates of contaminant weight and distribution once data on sediment bulk density and contaminant-size-composition relationships were available. The current data should be adequate as a basis for selection of dredging technology and priorities and for estimating dredging costs.

Conclusions

A new site has been selected for remedial dredging at Cornwall by reviewing the new data available on contaminant levels, bottom-sediment types and sediment thickness. The site is a 2-ha polygon located just east of the Courtaulds' site in the depth range 2-10 m.

GIS analysis of site data indicates that muds and muddy sands are the dominant bottom types and that coarser or weedy sediments the minor ones. Average sediment thickness is 0.33 m and total sediment volume is 7 642 m^3. Mud and muddy sand account for about 90% of the sediment volume, 5967 m^3 and 958 m^3 respectively. These are considered to be conservative estimates because the methods used tend to underestimate area and thickness. No attempt has been made to estimate error levels for the sediment statistics because the data are not appropriate for this type of analysis.

The contaminants mercury, zinc, lead, and copper are all above low-effect levels and much of the area has mercury and zinc at severe-effect levels. The area for which all contaminants are above the severe-effect level corresponds to the area of copper severe-effect level (Figure 10, Table 5). Further GIS analysis to determine the weight of contaminants at the site and the areal and vertical distribution of contaminant weight would be desirable but must await further data on the bulk density of the sediments and the relationship of contaminants to sediment size and mineral composition.

In spite of their limitations, the new data represent a considerable improvement in the characterization of sediment properties and geometry of the proposed dredge site and should provide the RAP team with a better basis for decisions on dredging technology, priorities and costs.

Acknowledgements

H. Biberhofer of Environment Canada, Ontario Region, identified the need for selection of a new site and outlined the specifications required on behalf of the Cornwall RAP and their dredging committee. L. Richman of OMEE, Toronto, provided the data on contaminants. R. Delorme of Geomatics International was responsible for the SPANS GIS analysis. The study was funded by Environment Canada's Great Lakes 2000 Cleanup Fund.

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Figures

Tables

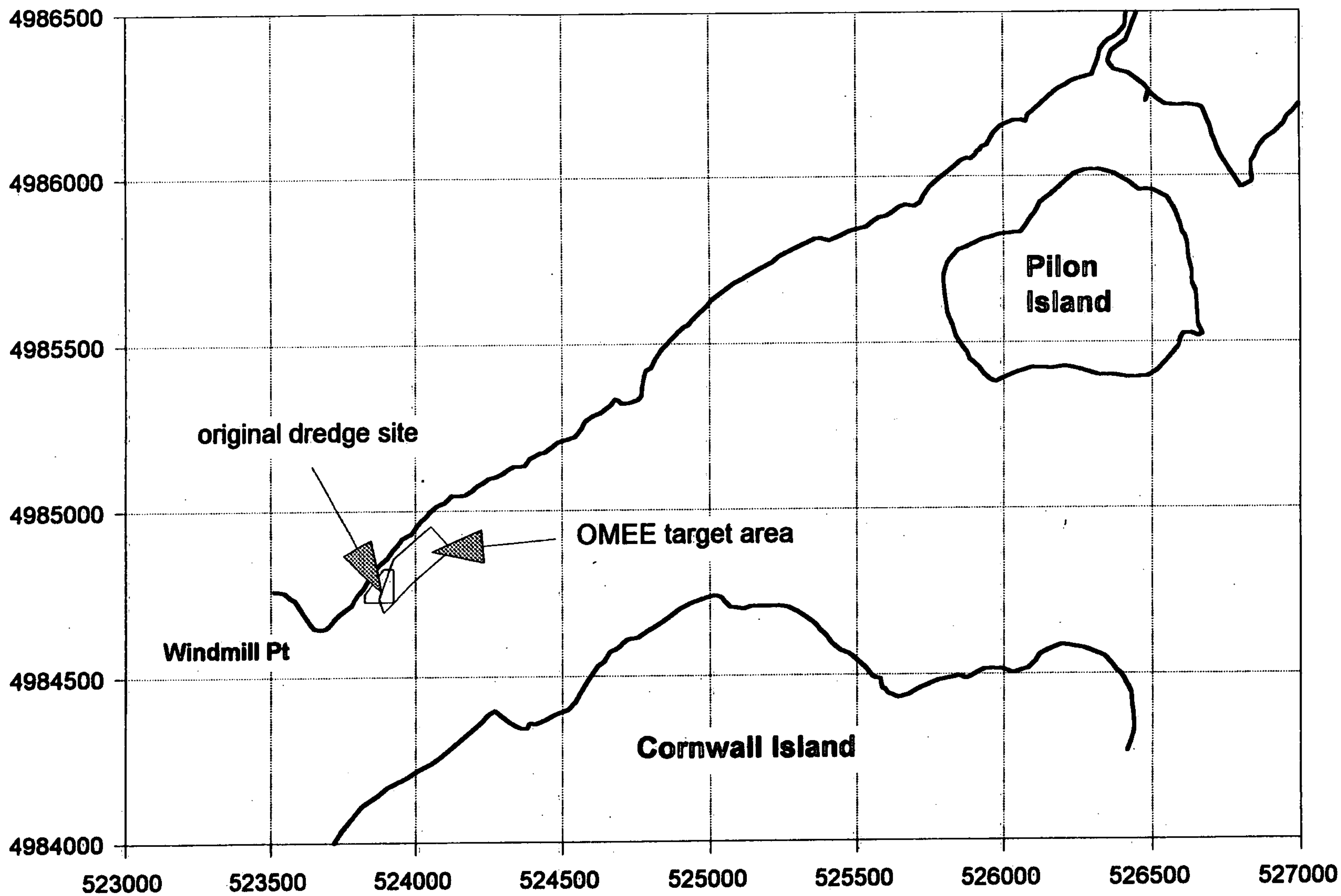

Fig. 1 Site map

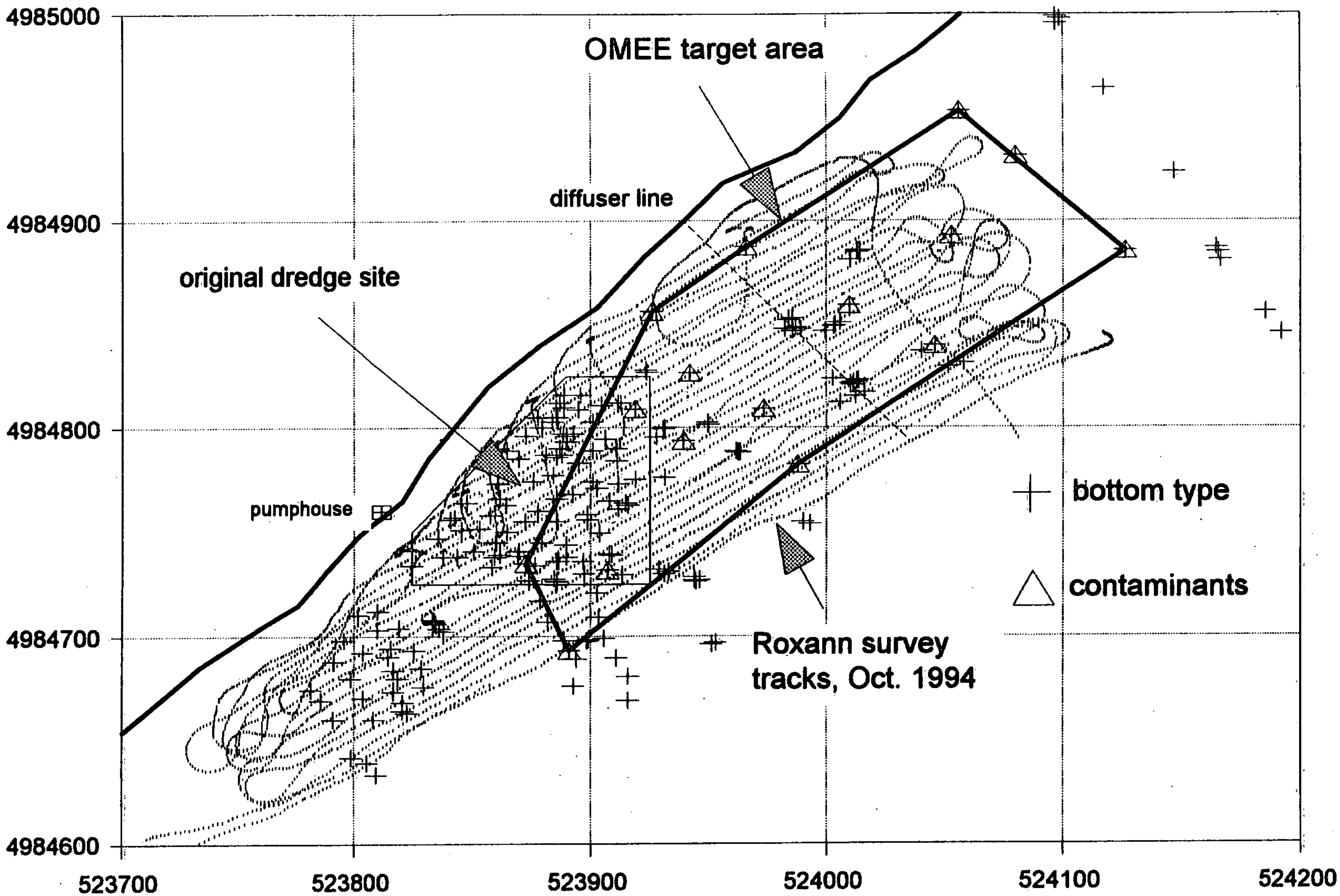

Fig. 2 Bottom-sediment data

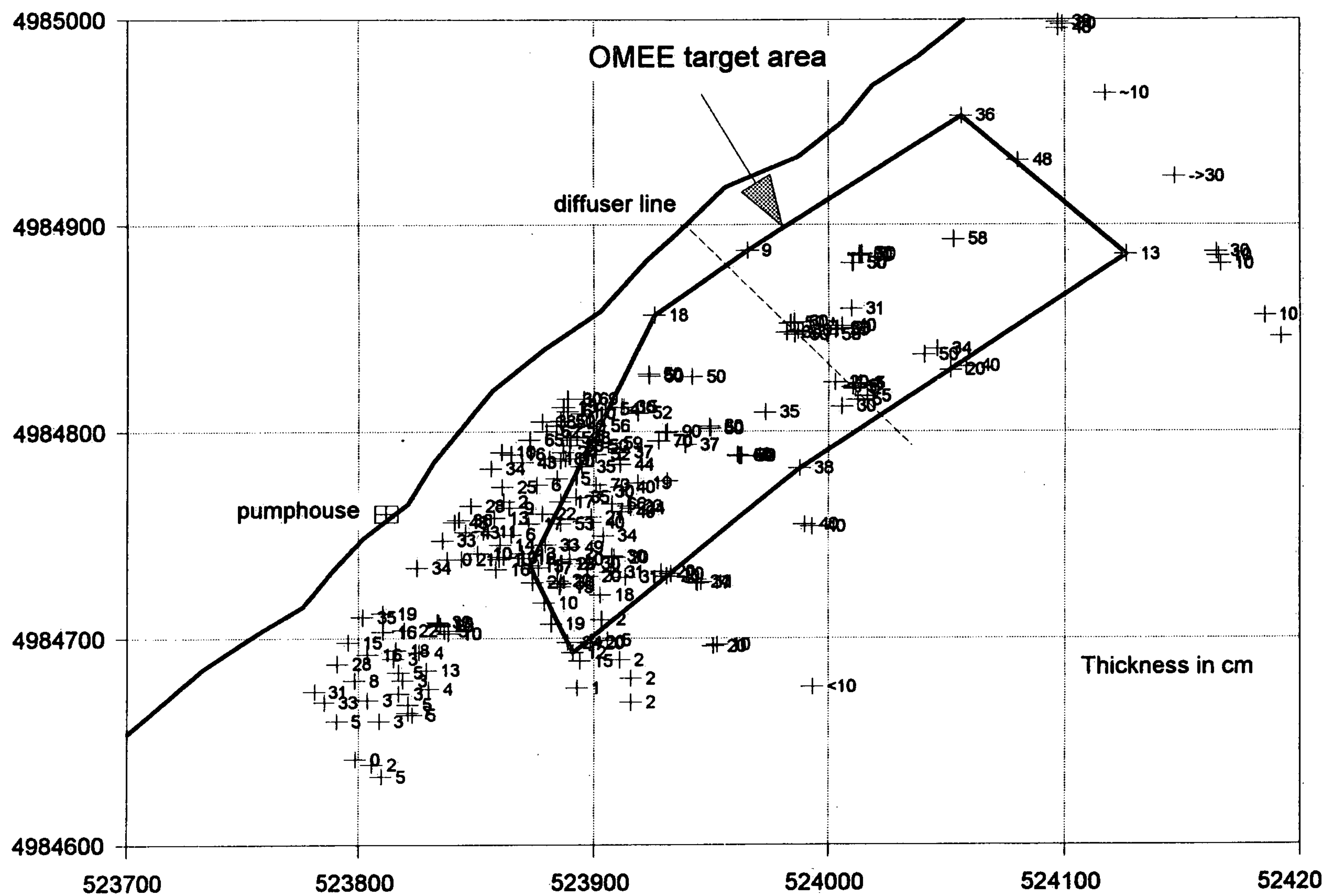

Fig. 3 Sediment-thickness data

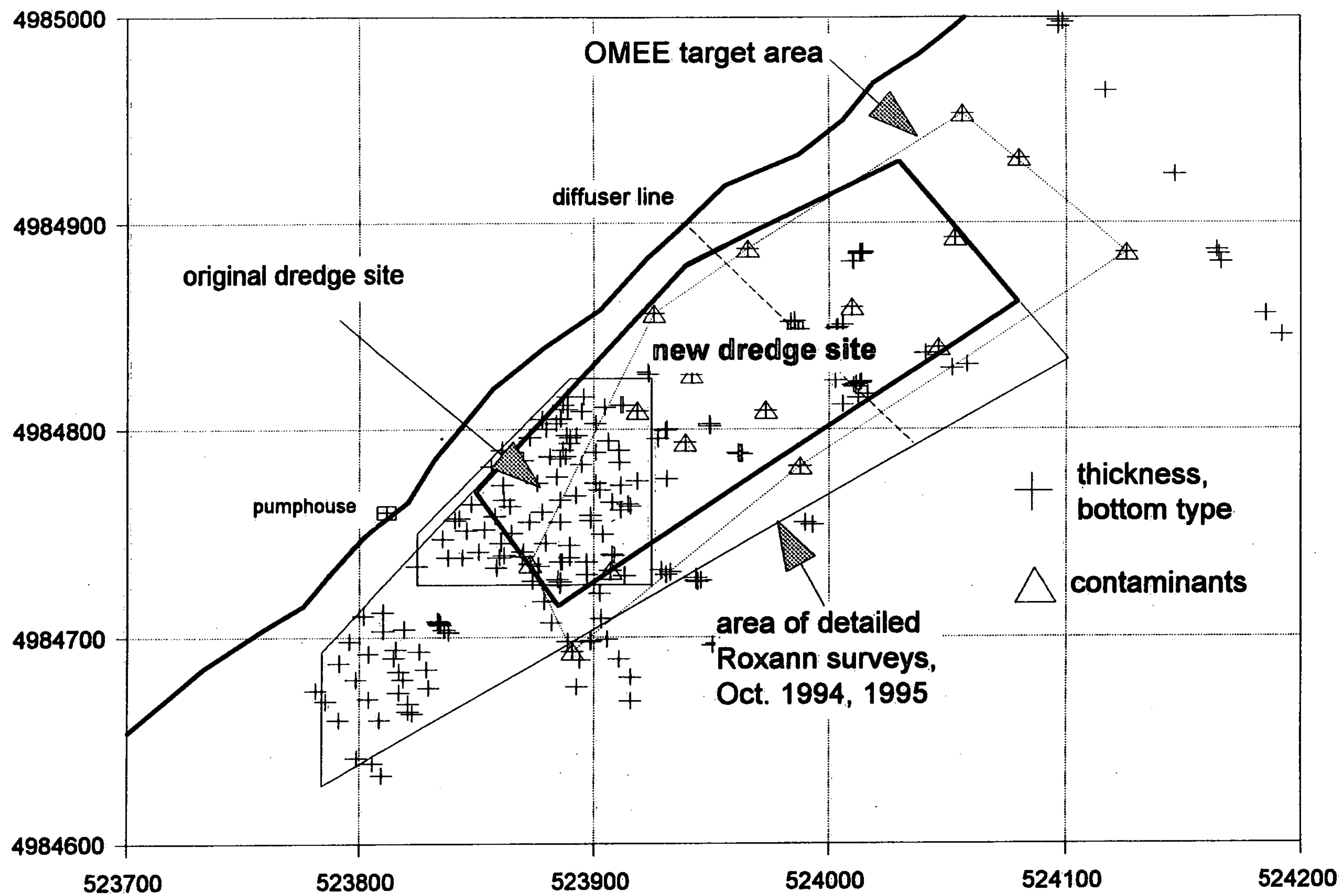

Fig. 4 New site

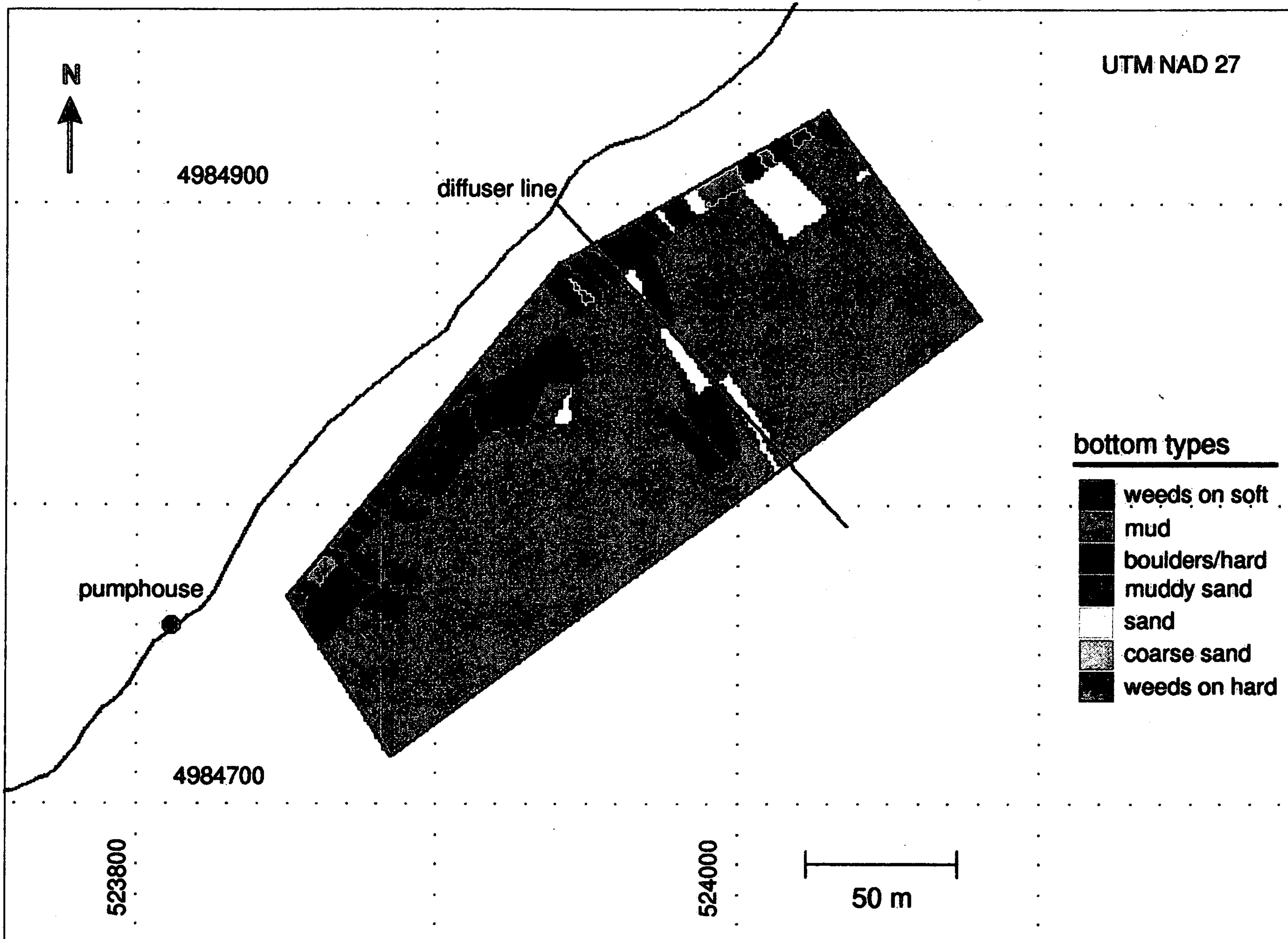

Fig. 5 GIS map of bottom-sediment types

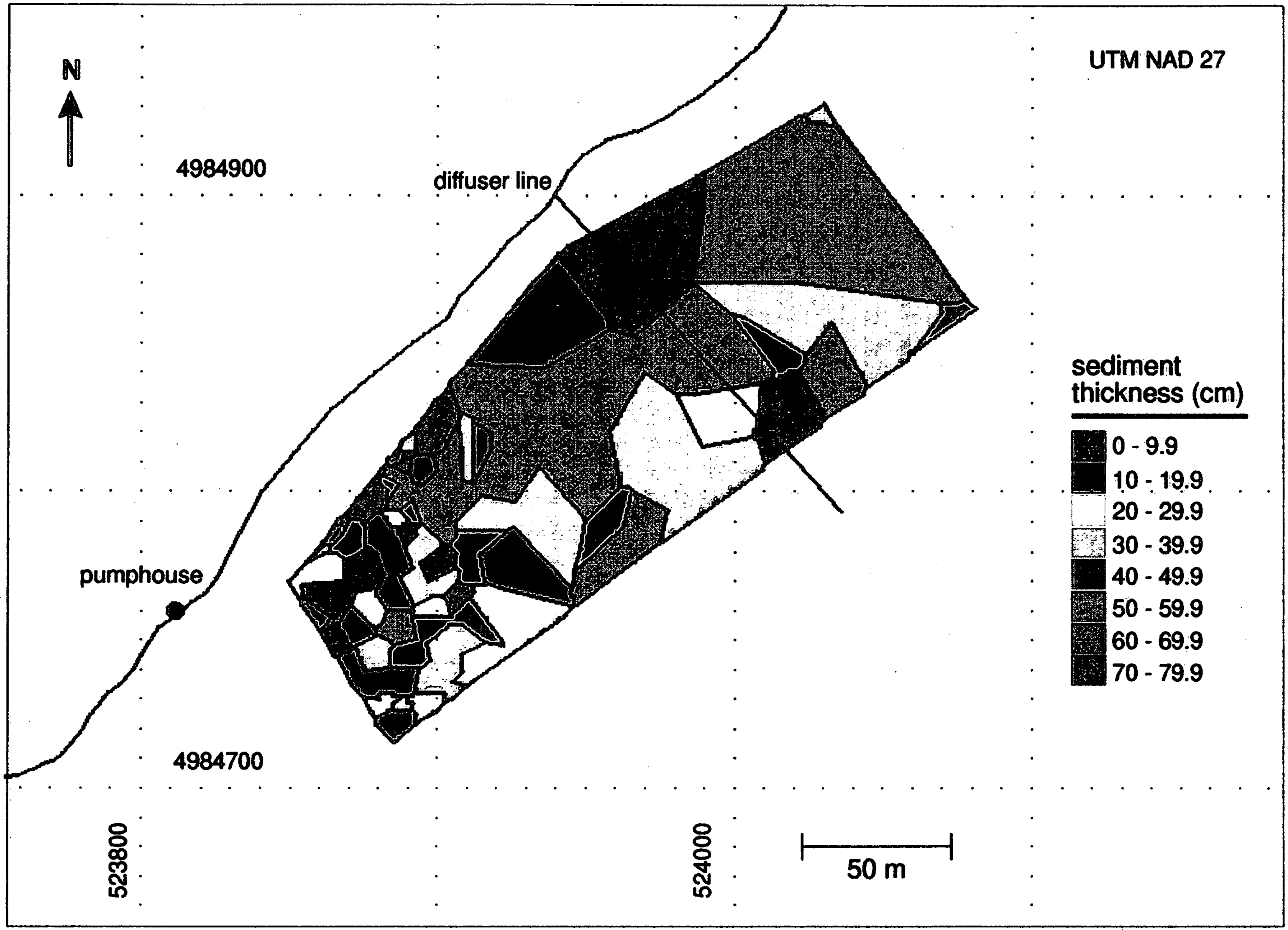

Fig. 6 GIS map of sediment thickness

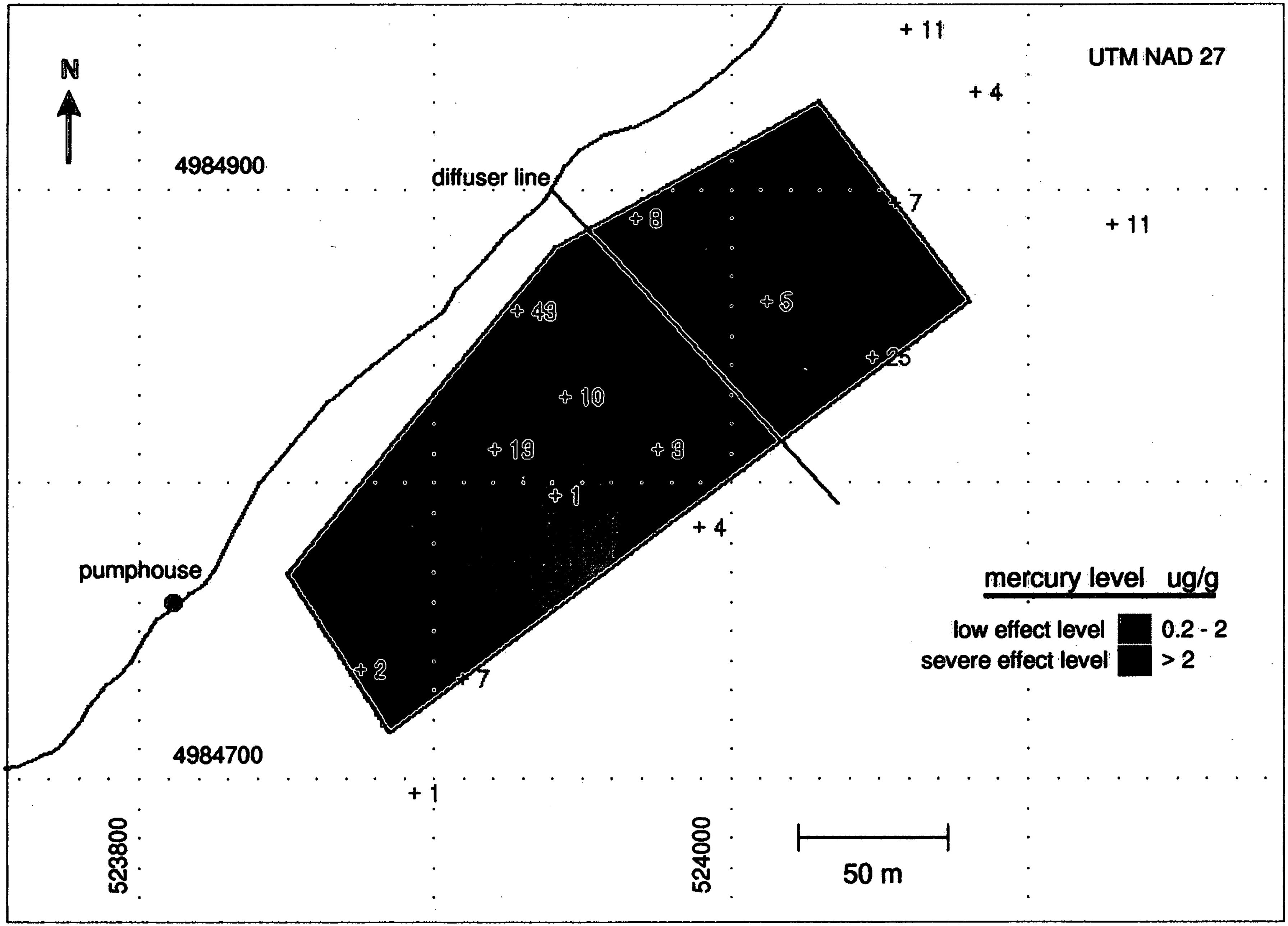

Fig. 7 GIS map of mercury levels

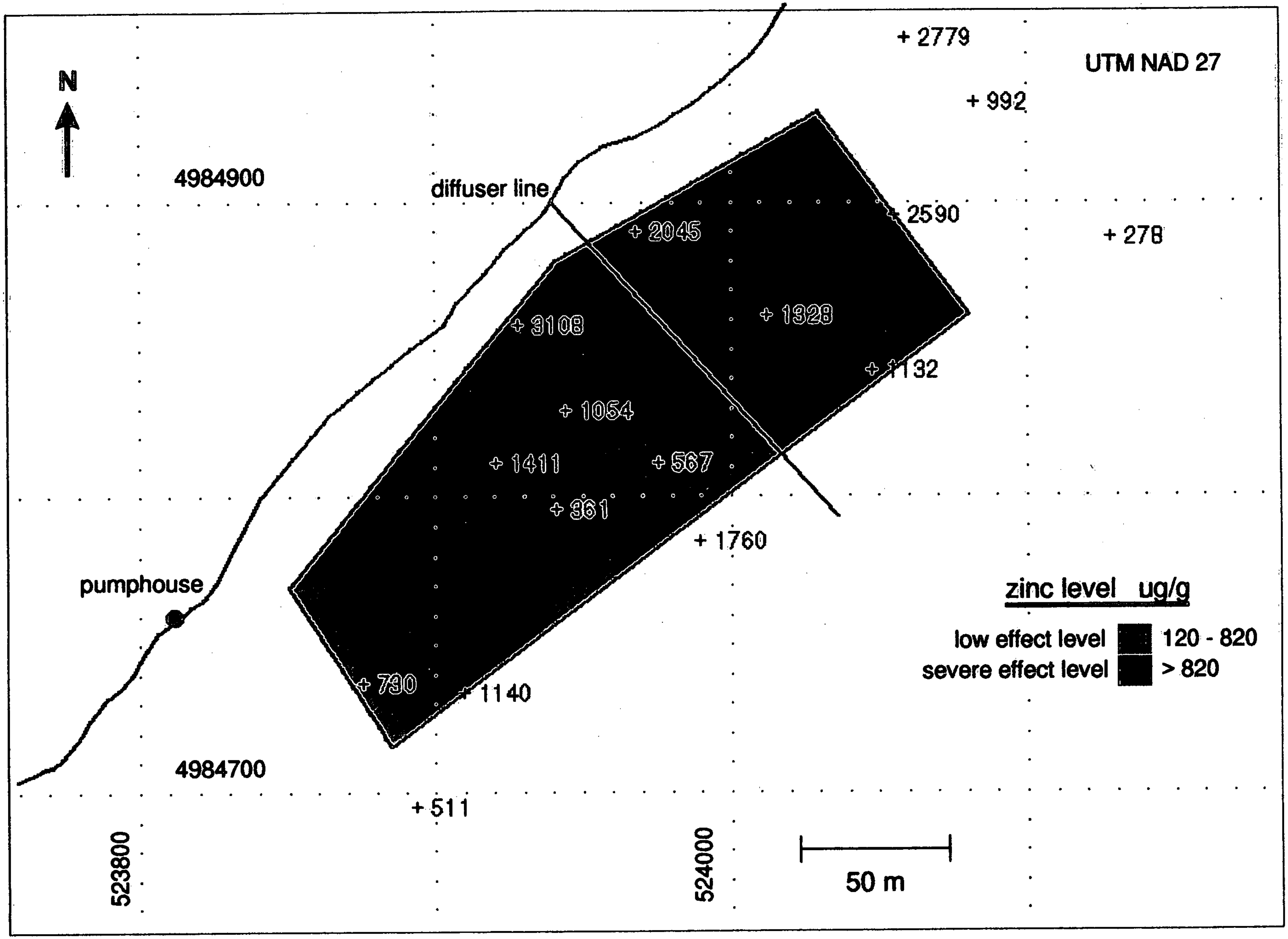

Fig. 8 GIS map of zinc levels

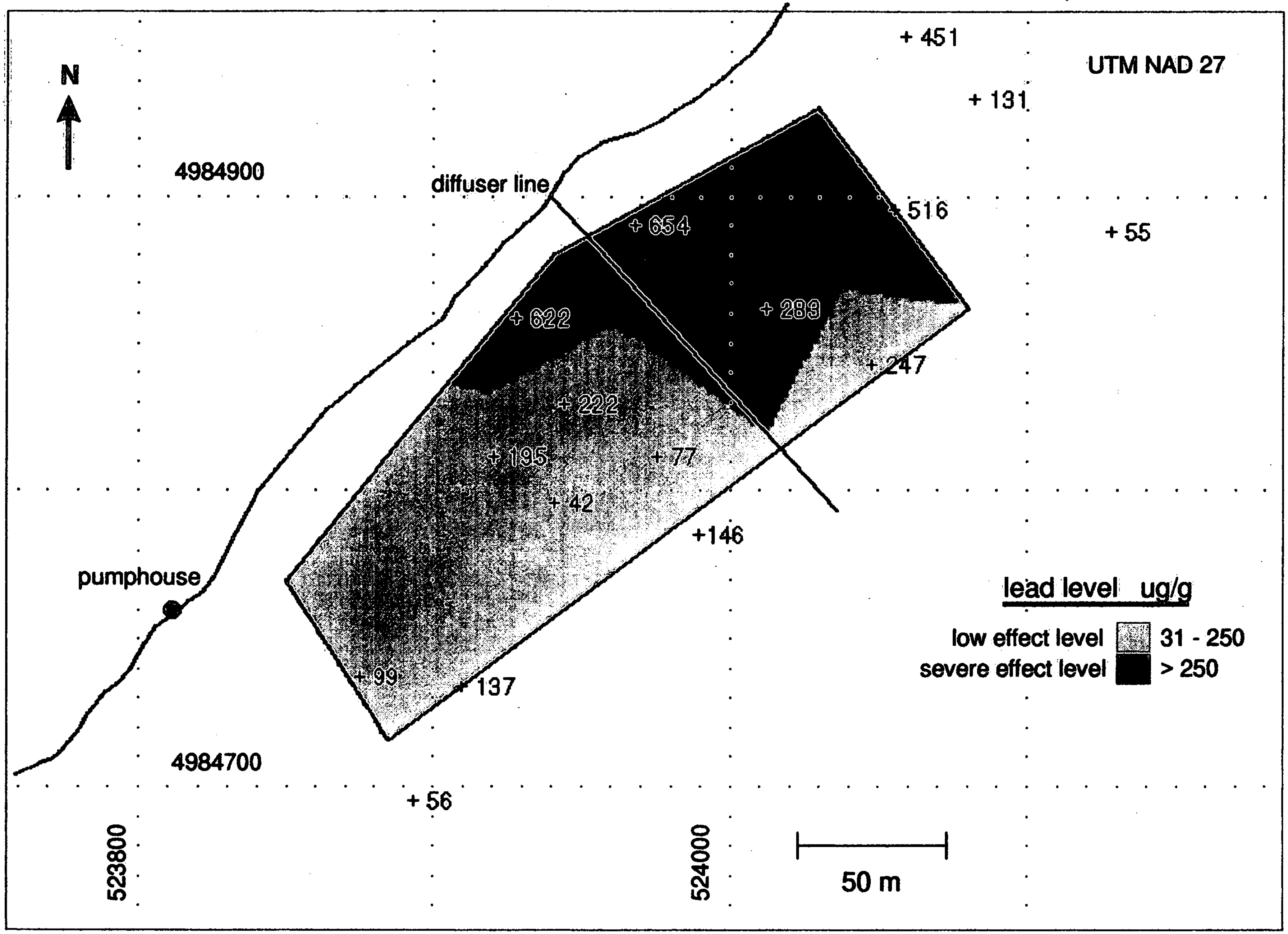

Fig. 9 GIS map of lead levels

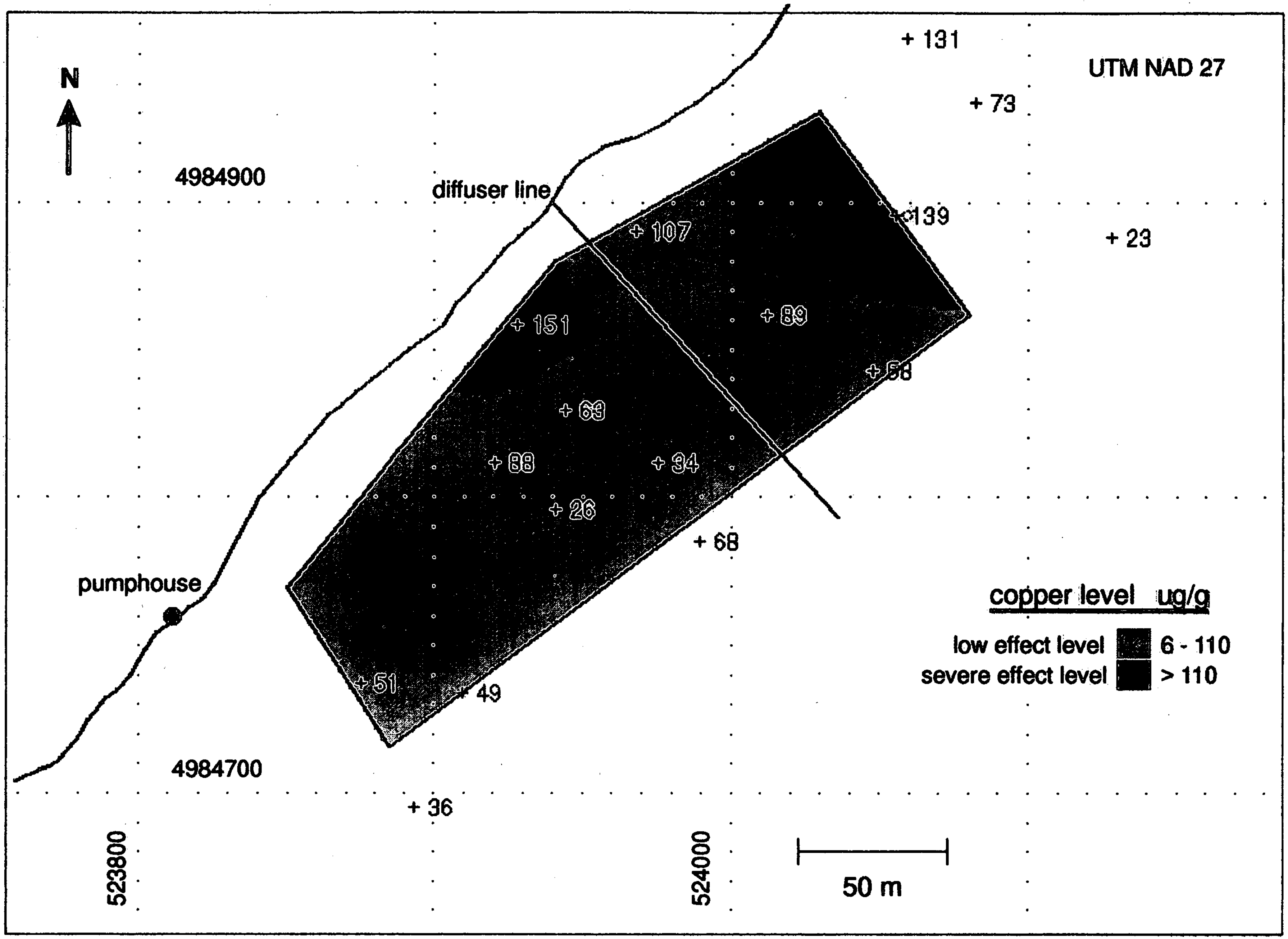

Fig. 10 GIS map of copper levels

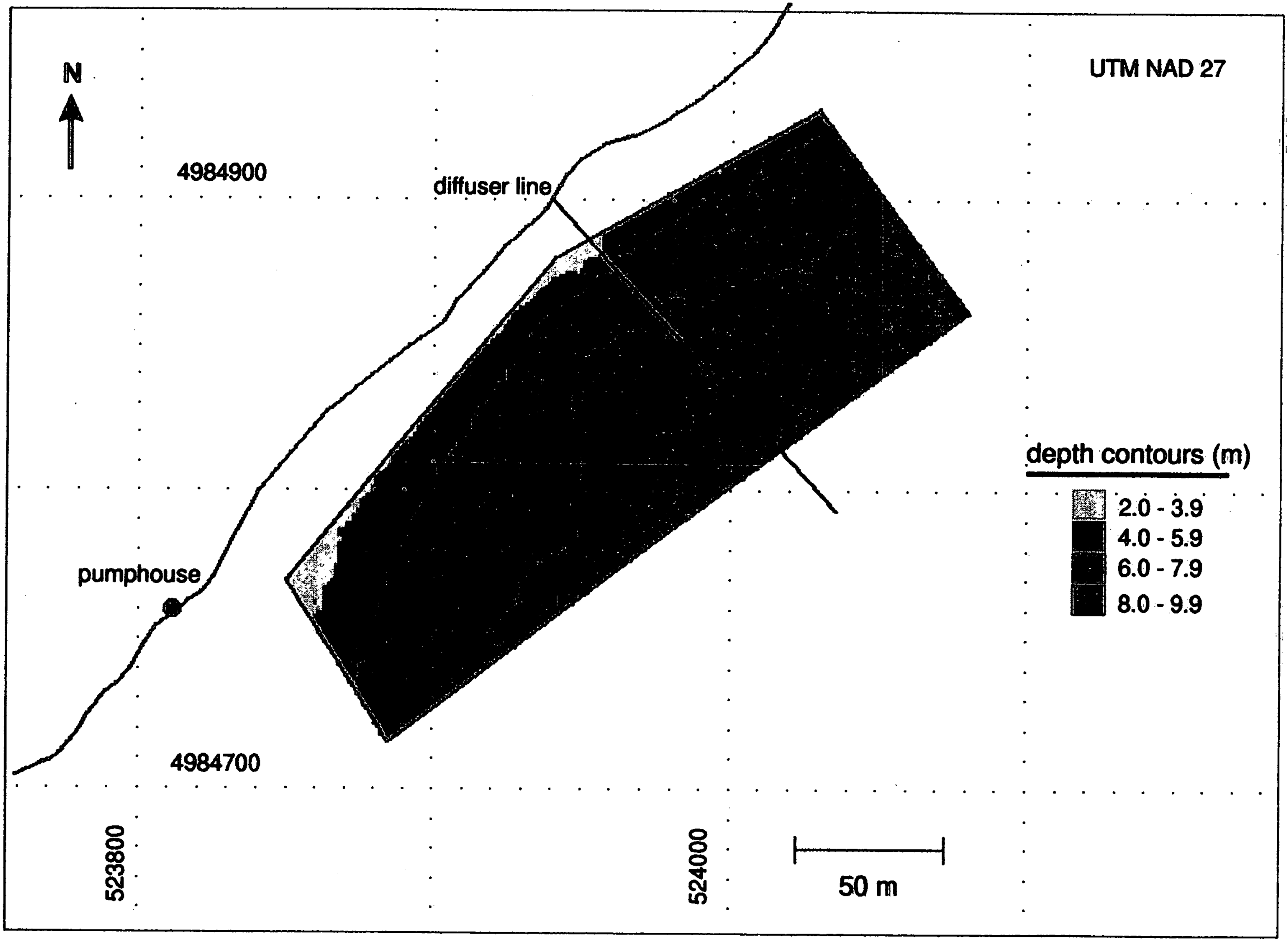

Fig. 11 GIS contour map of site bathymetry

Table 1: Bounding coordinates of the new site*

Northing	Easting	Feature
4984770	523850	northwest corner
4984715	523885	southwest corner
4984862	524080	southeast corner
4984930	524030	northeast corner
4984880	523940	northcentral corner

* Coordinates are Universal Transverse Mercator grid coordinates in metres in the datum NAD27.

Table 2: Sediment area, thickness, and volume statistics

Sediment type	Area m^2	Area %	Average Thickness, m	Volume m^3	Volume %
mud	15675	75.5	0.38	5967	78.1
muddy sand	2966	14.3	0.32	958	12.5
sand	781	3.8	0.41	318	4.2
weeds on soft	1024	4.9	0.28	282	3.7
coarse sand	200	1.0	0.38	76	1.0
weeds on hard	72	0.3	0.30?	22	0.3
boulders	38	0.2	0.50?	19	0.2
Total	20756	100	0.33	7642	100

Table 3: GIS sediment-thickness distribution

Thickness, cm	Area %	Cum. Area %	Area, m^2
0 - 10	11.17	11.17	2 318
10 - 20	11.02	22.18	2 287
20 - 30	7.15	29.34	1 485
30 - 40	21.32	50.66	4 427
40 - 50	5.86	56.52	1 217
50 - 60	41.15	97.67	8 542
60 - 70	1.93	99.60	400
70 - 80	0.40	100.00	84
Total	100.00		20 761

Table 4: OMEE grain-size data from cores

Core Site	% Sand	% Silt	% Mud
3T	40.5	53.1	59.5
3B	47.4	47.5	52.6
4T	25.1	67.8	74.9
4B	34.1	59.3	65.9
5T	35.8	57.9	64.2
5B	21.1	70.9	78.9
6T	43.8	50.8	56.2
6B	37.3	56.5	62.8
7T	45.1	49.0	54.9
7B	50.3	43.5	49.7
10T	76.5	20.6	23.5
10B	70.8	26.0	29.2
12T	47.1	47.5	52.9
12B	53.3	42.1	46.7
13T	29.0	62.2	71.0
13B	68.5	28.4	31.5
14T	52.7	43.5	47.3
14B	33.6	59.0	66.4
Average tops:	43.9	50.2	56.1
Average bottoms:	46.3	48.1	53.7
Average overall:	45.1	49.2	54.9

Table 5: GIS contaminant statistics

Metal	LEL	SEL	Area LEL, m^2	Area SEL, m^2	Area% LEL	Area% SEL
Mercury	0.2 - 2.0	> =2.0	1 927	18 835	9.28	90.72
Zinc	120 - 820	> =820	5 619	15 142	27.07	72.93
Lead	31 - 250	> =250	12 646	8 116	60.91	39.09
Copper	16 - 110	> =110	1 752	3 241	84.39	15.61

Table 6: GIS depth distribution

Depth, m	Area %	Cum. Area %	Area, m^{2z}
2 - 4	2.92	2.92	606
4 - 6	15.28	18.2	3 172
6 - 8	41.89	60.09	8 697
8 - 10	39.91	100.00	8 286
Total	100.00		20 761