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DISPERSAL OF DREDGED MATERIAL
Tees field study September 1986

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CONTRACT

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ABSTRACT

The fate of dredge material disposed of at open water sites by hopper dredgers has significant ecological and engineering importance. The suitability of a site for continued or proposed new disposal of dredged material can only be considered if the processes which occur in both the short-term and long-term with respect to the dispersal of the material are well understood.

To improve the knowledge of the physics involved in dredged material disposal, a field study was undertaken in September 1986 in co-operation with the Tees and Hartlepool Port Authority. The objectives were:

1. To characterise the dredged material within the hopper of the dredger prior to it being disposed of at the disposal site in respect of the density profile with depth, silt content and heavy metal concentrations.

2. To measure the extent of the near surface dispersion cloud released as the material plunged through the water column in the descent phase.

3. To determine the nature and velocity of the bed wave during the diffusive phase and to measure the effect on the propagation of this wave of the bed slope and current velocity.

4. To quantify the magnitude of bed level changes resulting from the repeated disposal of dredged material at the same location.

5. To examine the silt content and heavy metal concentrations on the bed material before and after the disposal exercise.

The general approach to the field study was to identify a relatively shallow and flat test area of sea bed within the disposal site in Tees Bay. At the centre of this test area all the material dredged by the two trailing suction hopper dredgers for a three day period was to be discharged. Samples of material were to be taken from the bed of the test area immediately before disposal commenced and again as soon as possible after disposal in the test area had ceased. Detailed soundings of the test area were to be taken before and after disposal.

The density of the dredged material in the hopper increased with depth, particularly within the bottom 1m. The mean densities of the nine hopper loads measured varied between 1.07 and 1.24T/m^3, with an average of 1.15T/m^3. Grab samples taken in the hopper had an average silt content of 50% and Cassella bottle samples taken in the upper part of the hopper contained 95% silt. The average concentration of metals in the grab samples were (in ppm) Cu-160, Zn-480, Pb-300, Fe-34000, Mn-420 and Co-11. The concentration of metals in the Cassella bottle samples were Cu-250, Zn-640, Pb-510, Fe-36000, Mn-310 and Co-13.

The concentrations of suspended solids in the upper 15m of the 30m water column were generally low and very limited in extent. Peak concentrations of 200ppm were recorded in a near surface plume approximately 80m in width. An estimate of the amount of material in the plume indicated that it comprised ½ to 2% of the dry weight of material in the hopper.

The velocity of the bed wave was measured to be approximately 0.9m/s over the first 50m from the disposal point reducing to 0.5m/s between 50 and 125m and to 0.1m/s between 125 and 155m. The bed slope of 1:700 did not have a significant influence on the propagation of the bed wave. The velocity of the current was found to influence dramatically the bed wave during its diffusion phase.

No significant change in the profile of the bed could be detected as a result of the disposal of the 25000m^3 (hopper volume) of dredged material.

The silt content of the bed in a 500m x 500m test area centred on the disposal point increased markedly due to the disposal operations. The samples at 50m from the disposal point had an increase in silt content from 8% to 49%, at 150m the increase was from 10% to 15% while at 250m there was no increase.

The average concentrations of heavy metals on the bed of the test area increased as a result of the disposal of the dredged material. The increase was significant at 50m from the disposal point (50 to 100%) but was less marked at a distance of 250m (15 to 50%).

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1 INTRODUCTION

1.1 Background

The fate of dredged material disposed of at open water sites by hopper dredgers has significant ecological and engineering importance. The suitability of a site for continued or proposed new disposal of dredged material can only be considered if the processes which occur in both the short-term and long-term with respect to the dispersal of the material are well understood.

The disposal process may be divided into three distinct transport phases according to the physical forces or processes that dominate during each period. These stages have been described by a number of investigators Clark et al (1971), Koh and Chang (1973), Gordon (1974), Brandsma and Divoky (1976), Johnson and Holliday (1978) and Bokuniewicz et al (1978). The most common terminology for these stages is convective descent, dynamic collapse and pressure diffusion (WES, 1986). A diagramatic representation of the transport processes during open-water disposal is shown in Figure 1.

Following release from the hopper, the dredged material descends though the water column as a well defined jet. During the descent large volumes of water are entrained in the jet and so the material becomes separated from the jet and remains in the upper portion of the water column. This material may be described as a near surface plume and would be advected by the current from the disposal point. The descending jet collapses as a result of impact on the bed and the material which is not deposited on impact will move out radially under its own momentum. When sufficient energy has been dissipated material will begin to settle rapidly on the bed. Diffusive processes will then dominate and any remaining material will be mixed with the lower water column. The concentration of suspended solids will be lower and settling will take place but at a much slower rate.

To improve the knowledge of the physics involved in dredged material disposal, a field study was undertaken in September 1986 in cooperation with the Tees and Hartlepool Port Authority. This study was the second major field exercise carried out on the Tees - the first being conducted in June 1985 (Delo and Burt 1987). The location of the Tees and the associated disposal site is shown in Figure 2.

1.2 Objectives

The field study concentrated on acquiring a more detailed knowledge of the short-term dispersal of dredged silty material dumped at the offshore spoil ground. There were five principal objectives of the exercise:

1. To characterise the dredged material within the hopper of the dredger prior to it being disposed of at the disposal site in respect of the density profile with depth, silt content and heavy metal concentrations.

2. To measure the extent of the near surface dispersion cloud released as the material plunged through the water column in the descent phase.

3. To determine the nature and velocity of the bed wave during the diffusive phase and to measure the effect on the propagation of this wave of the bed slope and current velocity.

4. To quantify the magnitude of bed level changes resulting from the repeated disposal of dredged material at the same location.

5. To examine the silt content and heavy metal concentrations on the bed material before and after the disposal exercise.

2 METHODOLOGY

2.1 Overall

The general approach to the field study was to identify a relatively shallow and flat test area of sea bed within the disposal site in Tees Bay. At the centre of this test area all the material dredged by the two trailing suction hopper dredgers for a three day period was to be discharged. Samples of material were to be taken from the bed of the test area immediately before disposal commenced and again as soon as possible after disposal in the test area had ceased. Detailed soundings of the test area were to be taken before and after disposal.

Measurements of the suspended solids concentration were to be made throughout the water column using a stack of four Partech monitors attached at various heights above the sea bed to a steel wire fixed to the survey craft. The position of the Partech monitors relative to the sea bed and the location of the survey craft relative to the location of the dredger when disposal were to be varied as necessary for each successive drop of dredged material.

In addition, samples of material were to be collected from within the hopper of one of the two dredgers by grab and by Cassella bottle samplers. Measurements were also to be taken of the in-situ density of the material with depth in the hopper using a Harwell radioactive transmission probe.

2.2 Test area location

An area of sea bed measuring 500m x 500m towards the western edge of the disposal site was selected as the test area (Fig 3). The sea bed in the test area was relatively flat and the water depth was approximately 27m LAT. The test area was divided up by a 100m x 100m grid and each node on the grid was identified by the numbers 1 to 36 (Fig 4). For the purposes of taking echo soundings the lines of the grid were assigned the numbers 1 to 6 in the north-south direction and A to F in the east-west direction.

The centre of the test area was marked by a small buoy which was placed at the start of each day by the survey craft and recovered again by the survey craft at the end of each day. The buoy was positioned daily to an accuracy of about 10m.

2.3 Dredgers and disposal procedure

During the field study the dredgers Heortnesse and Cleveland County, both trailing suction hopper dredgers, were directed to dredge a silty upper part of the Tees estuary (Fig 5). Each dredger had a hopper capacity of around 1500m^3 and maximum depth from the overflow weir to the bottom of the hopper of 7m. On arrival at the test area the material in the hopper was released as close as possible to the marker buoy with the dredger travelling as slowly as was practicable. In broad terms all the material from the discharges made during the three days of testing was released within 50m of the marker.

The round trip for a dredger to fill its hopper, reach the disposal site, dispose the material and return to the River Tees again ready to start dredging took in the region of three hours.

2.4 Echo soundings and position fixing

The survey craft used in the field exercise was the Tees Soundsman of the Tees and Hartlepool Port Authority. The sounding equipment was a dual frequency (210kHz/30kHz) Atlas Deso 20 running at 210kHz linked to the on board Hewlett Packard 9845B microcomputer. Position fixing was by a Motorala Mini Ranger III which was also linked to the microcomputer. A graphics terminal (HP 2648A) was mounted near the helm and was used to position the boat to an accuracy of $\pm$ 5m.

The procedure for sounding the test area involved first programming the microcomptuer with the coordinates of each line to be sounded (ie, the twelve 500m long lines within the test area). These lines were then displayed on the graphics terminal and the survey craft was steered along each line at a constant speed.

A copy of the display of the microcomputer on the Tees Soundsman could be printed out at any time as well as a single line of data giving the easting, northing, sounding, tide and time at any instant in time.

The readings from the echo sounder and position fixer were logged onto the microcomputer and then recorded onto a magnetic tape cartridge. The cartridge was taken ashore and a chart of the survey data plotted using another microcomputer system.

2.5 Suspended solids

A stack of four suspended solids monitors made by Partech Electronics Ltd was used to measure the solids concentrations in the water column. The four monitors were set up either in the upper 20m of the water column or within the bottom 2m. A number of monitors were available depending on the likely solids concentrations to be encountered, eg, 0-1000ppm or 0-50000ppm, and suspensions of silt and formasin were used to regularly calibrate each monitor.

The output from each of the four recorders was fed into a Tekman Servokass 600 four channel pen recorder which provided a hard copy of the variation in reading from each of the four Partech heads with time.

3 RESULTS

3.1 General

A total of seventeen discharges were made by the two dredgers, during the three days in which dredged material was disposed of within the test area. Details of the date, time, drop number, dredger, type of monitoring and weather are given in Table 1. The tide curve at River Tees Entrance for each of the three days of disposal in the test area are shown in Figures 6 to 8 respectively.

3.2 Current velocity and direction

A current meter had been installed earlier in April 1986 for a period of one month at a location approximately 600m to the north-east of the centre of the test area. The meter recorded data on the direction and strength of the current at a height of 1m above the bed for a total of 25 days. The processed data is given in Figures 9 to 13 as a time series of current velocity and current direction. The peak current velocity at 1m above the bed varied in the range 0.2 to 0.4m/s for neap to spring tides, respectively.

Progressive vector plot of the current velocities are shown in Figures 14, 15 and 16 for the periods 3.4.86 to 8.4.86, 11.4.86 to 16.4.86 and 19.4.86 to 2.5.86 (inclusive), respectively. For the first period of six days (Fig 14) the progressive vector plot orbital aligned SSE to NNW extending in both directions to a maximum distance of 1200m from the position of the current meter. During the second period of six days (Fig 15) the current follows mostly either an ESE or WNW direction. The furthest distance from the current meter position was 3000m to the ESE. The third period shown is fourteen days (Fig 16) in which the progressive vector plot is virtually unidirectional to the ESE of the current meter positions. After the fourteen days the distance travelled was 15000m. This period corresponded to a Neap-Spring-Neap cycle.

The current magnitude and direction were estimated for the time of each drop from the current meter data collected five months earlier. This was done by determining the current velocity as given by the current meter at exactly the same time in both the diurnal tidal cycle and the Spring-Neap cycle. The results of this analysis are given in Table 2 with the current direction as recorded in the dredgers' log and observed by the lie of nearby anchored ships. The current vectors at the time of each drop are also shown in Figure 17.

3.3 Characteristics of the dredged material

The density structure, percentage silt content and concentration of heavy metals were determined for nine of the seventeen loads of dredged material which were disposed of in the test area.

3.3.1 Density structure

The variation with depth of the density of the dredged material within the hopper was recorded by a Harwell transmission probe. The density profile of the hoppers with the minimum and maximum densities are presented in Figure 18 together with the average profile of all readings. The depth integrated mean density of each load measured is given in Table 3. These mean densities varied in the range 1.07 to $1.24 T/m^3$ with an overall average of $1.15 T/m^3$.

3.3.2 Silt content

The percentage silt content (ie, the amount of material $< 63 \mu m$) of the ninety-six grab and Cassella bottle samples are given in Table 4. It is likely that the grab sampling equipment would have taken a sample when the density of material into which the grab was dropped reached about $1.3 T/m^3$.

The silt content of the grab samples varied from 26% to 91% and had an average of 50%. On the other hand the Cassella bottle samples contained predominantly fine material with an average silt content of 95%.

Taking the variation in silt content with depth into account it is likely that overall the dredged material comprised about 70% silt.

3.3.3 Heavy metal concentrations

The concentrations of six selected heavy metals, copper (Cu), zinc (Zn), lead (Pb), iron (Fe), manganese (Mn) and cobalt (Co), were measured for a number of the grab samples and cassella bottle samples taken inside the hopper of the dredger. The analysis was performed on the total fraction of material in the case of the grab samples and on the silt fraction (ie, ~ 95% by weight of total) for the bottle samples. The results of the analyses are given for the grab samples in Table 5 and for the bottle samples in Table 6.

3.4 Surface plume

For the first nine of the seventeen drops of dredged material made by the two dredgers an attempt was made to quantify the extent of, and concentration of solids in, the surface plume. This plume is thought to occur as a result of material being entrained in the upper part of the water column during the descending phase of disposal (see Fig 1). Four Partech suspended solids concentration monitors were deployed from the survey craft held at various depths below the water surface on a steel wire. Although the exact depths varied a little between one drop and the next the approximate depths were 1.5, 9, 16 and 22m below the surface respectively.

The upper two monitors had a nominal range of 0-1000ppm while the lower two had a range 0-5000ppm in all the drops. Readings from the four monitors were also made as the survey craft moved slowly ahead at a couple of knots around the test area. In this mode the steel wire and monitors dragged behind the survey craft somewhat with the result that the depth below the water surface of each monitor was less at around 1, 6, 11 and 16m respectively.

Examples of the log of the navigation of the survey craft during the monitoring of the drops are shown for drop numbers 3 and 5 in Figures 19 and 20 respectively. Each log gives a record of the movement of the survey craft as a time series of eastings and northings and as a continuous trace on a chart of the test area and surrounding waters.

In broad terms, it was found that the suspended solids concentrations resulting from the disposal of dredged material were generally low in the upper 15m of the water column which had a typical total depth of 30m. However, in some of the drops the lowest monitor, which was positioned at about 16m below the water surface, recorded a concentration which very briefly exceeded 5000ppm. This was well before the surface plume was considered to have reached the monitoring position. A summary of the maxima of suspended solids concentrations recorded during each drop and the time and distance relative to the dredger's discharge are given in Table 7. These maxima tended to occur for periods of between 10 and 40 seconds thus indicating the passage of a plume of suspended material past the monitoring position. There were two exceptions - drop number 4 when concentrations in the range of 3000ppm were recorded for 120 seconds as the survey craft drifted with the current and in drop number 9 when concentrations in the range of 1000ppm were measured for 150 seconds as the survey craft drifted.

In drop numbers 5 and 8 the suspended solids concentrations in the upper 15m of the water column were negligible indicating that either the survey craft was not in the most favourable position for identifying the surface plume or that the surface plume was indeed very limited.

Evidence of the width of the surface plume was obtained during the monitoring of drop numbers 2 and 3 in which the survey craft was initially positioned about 140m down current from the disposal position.

In both instances the survey craft followed a line perpendicular to the direction of the current. The suspended solids monitors registered the existence of a well-defined plume in terms of its cross-section concentrations. Only the upper two monitors in each drop recorded any more than background suspended solids and the peak concentrations were approximately 200ppm at 1m below the surface and 80ppm at 6m below the surface for both drop numbers 2 and 3. The record of concentration with time is given for drop numbers 2 and 3 in Figures 21 and 22 respectively.

With respect to the width of the plume it may be seen from Figures 21 and 22 that the higher concentrations near the surface of the water extend for a shorter distance than the lower concentrations further down in the water column. Nevertheless, as noted above, there existed a high degree of correlation in both plumes between the suspended solids concentrations at the two depths. In drop number 2 the width of the plume was 40m and 85m respectively at 1m and 6m below the surface and 90m and 160m respectively in drop number 3.

One explanation for the greater width of the surface plume in drop number 3 was the fact that the dredger discharged its material while moving at a speed which was considerably higher than that for drop number 2. In fact, drop number 3 was unusual in this respect as all other drops were made at a very slow speed.

Further information regarding the width of the surface plume was obtained during drop number 7 when the survey craft again crossed the plume along a line perpendicular to the direction of the current. The concentration of suspended solids with time is shown in Figure 23. A peak concentration of 100ppm at 2m below the water surface was recorded. The width of plume was approximately 50m.

Unfortunately, no readings were recorded which could be related to the survey craft moving along the longtitudinal axis of the plume. Therefore, it is difficult to assess the probable length of the surface plume as it formed and was subsequently advected by the currents. However, for the purpose of calculating the amount of material in the surface plume an estimate of its length will be made.

From the suspended solids concentrations given in Figure 21 for drop number 2 an approximate value of the dry weight of solids per metre length of plume was calculated. This was achieved by simplifying the cross-section profile of the plume to that of a rectangle of depth 8m, width 80m and concentration 80ppm. The dry weight of solids of such a plume is about 50kg per m length of plume. If the length of plume is assumed to be 50m then the total dry weight of solids would be 2500kg or 2.5T. The mean bulk density of the material in drop number 2 (Table 3) was 1.13T/m^3 which is equivalent to a dry density of 0.21T/m^3. The volume of the hopper was 1550m^3, and hence, the total dry weight of solids discharged from the hopper was 330T. The ratio of material in the plume to material in the hopper was therefore approximately 2.5:330, ie, a little under 1%. Clearly, this is only an estimate, but in general terms, it is probably reasonable to conclude that the proportion of material which forms a surface or near surface plume is in the region of ½ to 2%.

3.5 Propagation of bed wave

3.5.1 General

The overwhelming majority of material (99%) discharged by the dredger descends to the bed and is dispersed in the lower part of the water column. The propagation of a lower depth wave with the resulting surge in concentrations of suspended solids as it radiates from the impact zone is probably what was recorded by the lowest monitor during some of the first nine drops. This monitor was between 10 to 15m above the bed and typically recorded concentrations over 5000ppm for periods of between 10 to 40 seconds.

To further study the behaviour of the bed wave, the suspended solids concentrations were monitored in the bottom two metres of the water column during drop numbers 10 to 16. The survey craft was initially held stationary at the start of each drop at a distance of between 50 and 150m from the disposal point until the head of the bed wave, characterised by a surge in suspended solids concentration, had passed beneath. Details of the position of the survey craft relative to the dredger, the direction and magnitude of the current, the time after disposal when the bed wave passed, the slope of the bed and the depth and maximum value of suspended solids concentration of each monitor are presented in Table 8. To determine the influence of current direction and bed slope on the characteristics of the mud wave the survey craft was positioned in each drop at a different point relative to the dredger with respect to these two parameters.

The typical time variation of suspended solids near the bed during the first 10 minutes after disposal is shown in Figures 24 and 25 for drop numbers 14 and 16 respectively. In drop number 14 the survey craft was about 110m from the dredger in a direction normal to the current while in drop number 16 the survey craft was very close to the dredger at the time of disposal (approximately 50m upstream).

The concentration of suspended solids increased very sharply in both drop numbers 14 and 16 when the bed wave reached the monitoring position (Figs 24 and 25). The lowest Partech instrument was approximately 0.2m above the bed and registered a peak concentration of 14000 and 17000ppm respectively for drop numbers 14 and 16. Similar concentrations were also recorded for the Partech instruments which were 0.7m and 1.2m above the bed in both drops. At 3.2m above the bed the maximum suspended solids concentration was considerably less than for the three lower monitors. In drop number 14 (Fig 24) the maximum solids concentration at 3.2m above the bed was only 2000ppm and occurred approximately one minute after the maxima of the three lower monitors. For drop number 16 the maximum solids concentration at 3.2m above the bed was 8000ppm which occurred 40 seconds after the maxima of the monitors at 0.2, 1.2 and 7m above the bed.

A comparison of the times taken for the bed wave to reach the survey craft in drop numbers 10, 15 and 11 indicates the changing characteristics of the bed wave as it radiated away from the impact point. In these three drops the survey craft was normal to the respective current direction and was down slope of the impact point. The distance of the survey craft from the dredger was 50, 125 and 155m respectively. The average speed of the bed wave on reaching these distances was 0.9, 0.5 and 0.3m/s thus indicating a steady reduction in the speed of the bed wave. In fact, by combining the values of the three drops it may be shown that the average velocity of the bed wave as it progresses from 50 to 125m is around 0.4m/s while from 125m to 155m it is only 0.1m/s.

However, the lowest monitor was still 0.2m above the bed and it would be reasonable to assume that the bed wave would continue to spread further than the distance indicated by the bottom monitor reading. The dynamic variation in suspended solids concentration with depth and distance from the drop point is rather difficult to assess from single position measurements. Nevertheless, some estimate of the depth of the bed wave (or more correctly the depth of the head of the bed wave) may be made by reference to the results of drop numbers 10, 15 and 11 (see Table 8). In drop number 10 in which the survey craft was 50m from the dredger, the uppermost monitor was 8m above the bed and did not record an increase in suspended solids. The other three monitors situated at 0.2, 2.2 and 4.2m above the bed did record concentrations in the range 3000 to 5000ppm. For drop number 15 (125m from the dredger) all four monitors recorded concentrations of suspended solids although the uppermost monitor at 3.2m above the bed gave a concentration of only 1000ppm compared to 3000 to 5000ppm between 0.2 and 1.2m above the bed. Considering finally the results of drop number 11 at 155m from the disposal point it is seen from Table 8 that only the lowest monitor at a height of 0.2m above the bed recorded a significant level of suspended solids. The other three monitors at a height above the bed of between 2.2 and 8.2m showing no evidence of any increase in solids concentration.

3.5.2 Influence of bed slope

The bed profile in the test area was relatively level compared to the overall bed profile of the disposal site (see Fig 3). Nevertheless, the bed of the test area sloped downwards by approximately half a metre in 250 metres towards the southern and western boundaries from the centre while remaining level to the north-east corner. The bed slope was therefore about 0.0011 downwards from the centre to the south-east corner, 0.0014 downwards to the south-west corner, and 0.0017 downwards to the north-west corner.

Some indication of the influence of the bed slope may be gained by comparing the results (Table 8) of drop numbers 14 and 15. The distance of the survey craft from the disposal point was similar in these drops at around 120m. The bed was level between the disposal point and the survey craft in drop number 14, but had a downwards slope of 0.0014 to the survey craft from the disposal point in drop number 15. In both drops the current direction was perpendicular to a line between the disposal point and the survey craft.

In broad terms, it is reasonable to conclude, from a comparison of the results of drop numbers 14 and 15, that the effect of a downwards bed slope of 0.0014 (ie, 1 in 700) on the propagation of the bed wave is not significant. The average velocity of the wave up to the survey craft was a little higher at 0.5m/s in drop number 15 with the down slope compared to 0.4m/s in drop number 14 with a level bed. The peak concentrations of each of the four monitors were similar in both drops.

3.5.3 Influence of current

Some indication of the possible effect of the current on the nature of propagation of the bed wave may be ascertained by comparing the results given in Table 8 for drop numbers 13 and 15. The distance of the survey craft from the dump point was similar in both drops at around 125m. In drop number 13 the survey craft was upstream of the dredger while in drop number 15 it was perpendicular to current direction. Unfortunately, the bed slopes for the two drops were not exactly the same but this has been shown not to have had a significant effect (see Section 3.5.2).

Clearly, judging from the results of drop numbers 13 and 15, the effect of the current was to restrict the propagation of the bed wave. None of the monitors recorded any increase in suspended solids concentration in drop number 13 when the survey craft was upstream of the dredger. This would indicate that the current direction had a significant influence on the propagation of the bed wave.

The results from drop numbers 16 and 12 may also be used to assess the effect of the current. However, as can readily be seen from the relevant results given in Table 8 the suspended solids concentrations recorded upstream of the disposal point in drop number 16 were higher and occurred earlier than those measured at a similar distance downstream from the disposal point in drop number 12. It may be concluded that the influence of the current on the propagation of the bed wave was more pronounced the further away from the disposal point the measurements of suspended solids concentration were made. This concurs with the view that at a distance of 50m from the disposal point it was the collapse phase (see Fig 1) of the dispersal process which was monitored. Whereas, further away at 125m from the disposal point, the diffusive phase was monitored and this phase was found to be influenced by the current velocity.

3.6 Bathymetry of test area

Two detailed hydrographic surveys of the 500m by 500m test area were conducted during the field exercise.

Twelve 500m lines identified as A to F and 1 to 6 in Figure 4, were surveyed before and after the disposal operations. The first survey was conducted in the afternoon of the day before disposal in the test area commenced. The follow up survey was undertaken on the morning after disposal in the test area had ceased. Accordingly, there was a little less than four days between the two surveys during which time 25000m^3 (hopper volume) of dredged material with a mean density of 1.15T/m^3 was disposed of at the centre of the test area.

A comparison of the results of the two hydrographic surveys for the east-west line D is shown in Figure 26 and for the north-south line 4 in Figure 27. The centre 100m x 100m of the test area was bounded by the four lines C,D,3 and 4 (Fig 4) and therefore any changes in the bed level due to disposal should be more prominent in these lines.

With reference to the bed profiles shown in Figures 26 and 27 it is seen that within the limits of the technique used there is no significant difference in the level of bed before and after the disposal operations. The error in estimating the tidal depth at the time of survey was probably in the region of 0.1m and the effects of swell at the times of the surveys could easily give a variation in the water level of ± 0.2m. Furthermore, it may have been unlikely that thin layers of stationary mud overlying the initially fairly sandy bed of the test area would have been detected by the echo sounder working at the high frequency of 210kHz. More favourable results may be obtained using the lower frequency of 30kHz which would tend to reflect from a low density mud layer.

3.7 Bed samples in test area

Thirty-six bed samples were taken by grab across the test area on a 100m grid both before and after the disposal of the seventeen loads of dredged material. The samples were analysed to determine the silt content and the concentrations of the six heavy metals; Cu, Zn, Pb, Fe, Mn and Co. The metal analysis was made on the total fraction of sediment.

3.7.1 Silt content

The results of the analysis of the bed samples for silt content are given in Table 9. Generally, the silt content of the bed was increased by the disposal of the dredged material in the test area over the three day period.

A clearer insight of the changes in silt content in the test area is given by the histogram in Figure 28 which depicts the average silt content for three groups of the thirty-six samples (Table 12). The samples were grouped by distance from the disposal point. The distances of the three groups are 50, 150 and 250m and comprise 4, 12 and 20 samples respectively. It may be seen from Figure 28 that the effect of the dumped material was most pronounced nearest to the centre of the test area where the silt content was increased from 8% to 49%. At 150m from the centre of the test area the increase in silt content was less marked but still significant with a change from 10% to 15% due to the disposal. Further away from the centre of the test area at a distance of 250m there was little change in the silt content of the bed material which was about 12% both before and after disposal.

3.7.2 Heavy metals

The results of the analysis of heavy metals concentration of the thirty-six bed samples taken in the test area before disposal are given in Table 10 and after disposal in Table 11. The average concentrations of heavy metals for the samples divided into the three groups by distance from the centre of the test area are presented in Table 12. Also given in Table 12 are the average concentrations of heavy metals on the dredged material in the hopper.

The results given in Table 12 are shown graphically for each metal as histograms in Figures 29 to 34. It is clear that the extent of spreading of the disposed dredged material may be determined approximately by the increase in the concentration of heavy metals on the bed of the test area.

4 CONCLUSIONS

1. A field study was undertaken in September 1986 in collaboration with the Tees and Hartlepool Port Authority. The objectives were to characterise the dredged material in the hopper of the trailing suction hopper dredger; to measure the suspended solids concentrations of the near surface plume and the velocity and suspended solids concentrations of the bed wave formed during disposal; to determine the change in bed levels as a result of repeated disposal at the same point; and, to analyse the bed material before and after the disposal operation for silt content and concentration of six heavy metals.

2. The density of the dredged material in the hopper increased with depth, particularly within the bottom 1m. The mean densities of the nine hopper

loads measured varied between 1.07 and $1.24T/m^3$, with an average of $1.15T/m^3$.

3. Grab samples taken in the hopper had an average silt content of 50% and Cassella bottle samples taken in the upper part of the hopper contained 95% silt. The average concentration of metals on the grab samples were (in ppm) Cu-160, Zn-480, Pb-300, Fe-34000, Mn-420, Co-11, and on the bottle samples they were Cu-250, Zn-640, Pb-510, Fe-36000, Mn-310 and Co-13.

4. The concentrations of suspended solids in the upper 15m of the 30m water column were generally low and very limited in extent. Peak concentrations of 200ppm were recorded in a near surface plume approximately 80m in width. An estimate of the amount of material in the plume indicated that it comprised ½ to 2% of the dry weight of material in the hopper.

5. Solids concentrations up to approximately 20000ppm were recorded in the bottom 2m of the water column. The passage of the bed wave was characterised by a very rapid increase in solids concentration following by a gradual decrease over the subsequent one minute period. The average velocity of the bed in the first 50m from the disposal point was 0.9m/s. From 50 to 125m the velocity was 0.4m/s and from 125 to 155m it was 0.1m/s.

6. The effect of the bed slope on the average velocity of the bed wave was not significant for a downwards bed slope of 1 in 700. The velocity of the current was found to influence the propagation of the bed wave dramatically at a distance of 125m from the disposal point but had

no effect at a distance of 50m. This was attributed to the fact that at 50m from the disposal point the collapse phase and momentum effects were evident while at a distance of 125m the bed wave would be in the diffusion phase and susceptible to advection.

7. No significant change in the profile of the bed could be detected as a result of the disposal of the 25000m^3 (hopper volume) of dredged material.

8. The silt content of the bed in a 500m x 500m test area centred on the disposal point increased markedly due to the disposal operations. The samples at 50m from the disposal point had an increase in silt content from 8% to 49%, while at 150m the increase was from 10% to 15% and at 250m there was no increase with the silt content remaining constant at 12%.

9. The average concentrations of heavy metals on the bed of the test area increased as a result of the disposal of the dredged material. The increase was significant at 50m from the disposal point (50 to 100%) but was less marked at a distance of 250m (15 to 50%).

5 REFERENCES

1. Bokuniewicz, H J, et al, 1978. "Field Study of the Mechanics of the Placement of Dredged Material at Open-Water Sites", Technical Report D-78-7, prepared by Yale University for the US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

2. Brandsma, M G, and Divoky, D J, 1976. "Development of Models for Prediction of Short-term Fate of Dredged Material Discharged in the Estuarine Environment", Contract Report D-76-5, prepared by Tetra Tech, Inc, for US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

3. Clark, B D, et al, 1971. "The Barged Disposal of Wastes, A Review of Current Practice and Methods of Evaluation", Pacific Northwest Water Quality Laboratory, Northwest Region, US Environmental Protection Agency, Corvallis, Oreg.

4. Delo, E A, and Burt T N. "Disposal of Dredged Material: Tees field study June 1985", Hydraulics Research Report No SR 110 March 1987.

5. Gordon, R B, 1974. "Dispersion of Dredge Spoil Dumped in Near-shore Waters", Estuarine and Coastal Marine Science, Vol 2, pp 349-358.

6. Koh, R C Y, and Chang, Y C, 1973. "Mathematical Model for Barged Ocean Disposal of Wastes", Environmental Protection Technology Series EPA-660/2-73-029, US Environmental Protection Agency, Washington, DC.

7. Johnson, B H, and Holliday, B W, 1978. "Evaluation and Calibration of the Tetra Tech Dredged Material Disposal Models Based on Field Data", Technical Report D-78-47, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

8. Waterways Experiment Station (WES). "Environmental Effects of Dredging", Technical Notes EEDP-01-2, September 1986.

TABLES.

ble 1 Drop number, date, time, dredger, type of monitoring and weather

Drop No.	Date	Time	Dredger	Hopper Density & Samples	Dispersal Monitoring	Weather
1	23-Sep	09-55	CC	YES	Surface	Overcast, sea calm
2	23-Sep	13-35	CC	YES	Surface	Cloudy, sea calm
3	23-Sep	14-03	H	NO	Surface	Cloudy
4	23-Sep	16-30	H	NO	Surface	Cloudy
5	23-Sep	17-32	CC	YES	Surface	Cloudy, slight wind
6	24-Sep	08-50	H	YES	None	Cloudy
7	24-Sep	09-56	CC	NO	Surface	Cloudy
8	24-Sep	12-15	H	YES	Surface	Cloudy
9	24-Sep	13-30	CC	NO	Surface	Clear, sea calm
10	24-Sep	16-03	H	YES	Bed	Clear, sea calm
11	24-Sep	17-17	CC	NO	Bed	Cloudy
12	25-Sep	09-27	H	YES	Bed	Fine, sunny
13	25-Sep	10-21	CC	NO	Bed	Fine, sunny
14	25-Sep	12-53	H	YES	Bed	Fine, sunny
15	25-Sep	13-52	CC	NO	Bed	Fine, sunny
16	25-Sep	16-26	H	YES	Bed	Fine, sunny
17	25-Sep	17-35	CC	NO	None	Fine, sunny

Note: CC Cleveland County
H Heortnesse

Table 2 Current direction and magnitude during each drop

Drop No.	Current Direction: Dredger records	Current Direction: Current meter	Current Direction: Visual observation	Current Magnitude: Current meter 1m above bed m/s
	Bearing (degrees)			
1	60		–	
2	325	319	–	0.25
3	300	318	–	0.22
4	110	126	–	0.08
5	160	177	–	0.05
6	104		–	
7	80	35	–	0.08
8	307	310	–	0.19
9	310	325	–	0.24
10	284	300	–	0.15
11	110	315	–	0.08
12	106	120	–	0.09
13	90	110	120	0.07
14	305	326	270	0.14
15	310	286	270	0.13
16	285	277	300	0.08
17	Slack water			

Note: The current meter was deployed between 3-4-86 and 2-5-86 and the values given for current velocities were determined by reference to equivalent times in the tidal cycle.

Table 3 Mean specific densities of dredged material in hoppers

Drop No.		Time	Mean Specific Density
1	A	Predisposal	1.07
2	A	Postdredge	1.14
	B	Predisposal	1.12
	A	Predisposal	1.15
5	A	Postdredge	1.14
	B	Predisposal	1.09
	A	Predisposal	1.10
6	B	Predisposal	1.10
	A	Predisposal	1.10
8	A	Postdredge	1.17
	B	Predisposal	1.18
	A	Predisposal	1.18
10	A	Postdredge	1.15
	B	Predisposal	1.20
	A	Predisposal	1.17
12	A	Postdredge	1.14
14	A	Postdredge	1.12
	B	Predisposal	1.12
	A	Predisposal	1.15
16	A	Postdredge	1.20
	B	Predisposal	1.24
	A	Predisposal	1.24
		Average	1.15

Table 4 Silt content of dredged material

Drop No	Location in hopper	%Silt Content Grab	%Silt Content Bottle
1	A	44.3	93.1
	B	44.3	88.1
	C	30.6	84.2
2	A	31.5	98.8
	B	41.9	98.5
	C	40.8	98.2
	A	52.0	93.5
	B	54.2	90.5
	C	40.2	96.5
5	A	31.4	98.5
	B	50.1	98.6
	C	58.4	97.0
	A	52.6	93.8
	B	55.8	96.2
	C	50.7	96.6
6	A	66.8	72.4
	B	76.3	84.2
	C	69.6	88.2
	C	61.8	97.7
8	A	36.8	98.7
	B	35.4	99.3
	C	62.9	99.4
	A	26.2	91.7
	B	35.4	95.9
	C	49.3	97.5
10	A	38.7	99.3
	B	38.1	98.6
	C	33.1	98.5
	A	52.0	98.0
	B	52.9	98.7
12	A	29.8	98.9
	B	47.3	99.2
	C	41.4	98.9
	A	91.3	93.8
	B	89.6	91.5
	C	91.5	75.0
14	A	41.7	96.4
	B	70.8	95.8
	C	75.3	95.3
	A	62.8	96.3
	B	36.4	96.1
	C		93.4
16	A	54.4	99.6
	B	34.3	99.4
	C	41.9	98.2
	A	38.9	99.4
	B	44.2	99.2
	C	31.5	99.5
	Mean	50	95

Table 5 Concentrations of six heavy metals in grab samples taken in hopper

Drop No.	Cu	Zn	Pb	Fe	Mn	Co	% silt
1	87	346	333	25300	358	11	44.3
1	95	361	338	26500	380	10	44.3
2	117	345	237	28700	323	10	52.0
2	128	370	260	28800	334	9	54.2
5	90	302	185	29200	403	10	52.6
5	134	415	256	34400	423	10	55.8
6	242	651	284	48900	616	16	66.8
6	217	634	281	46100	606	15	76.3
8	105	352	199	26800	343	8	26.2
8	105	367	211	26400	340	9	35.4
10	154	461	300	31200	344	9	52.0
10	266	805	449	42000	452	14	52.9
12	183	544	353	34900	416	12	91.3
12	290	880	520	45000	537	16	89.6
14	192	659	450	37600	451	13	62.8
14	151	313	201	29500	405	11	36.4
16	137	429	253	32700	468	9	38.9
16	162	469	300	35300	381	9	44.2
Mean	159	484	301	33850	421	11	54.2

No. of samples 18

ble 6 Concentrations of six heavy metals in bottle samples taken in hopper

Drop No.	Cu	Zn	Pb	Fe	Mn	Co	% silt
1	358	769	832	41400	246	15	93.1
1	346	725	776	39200	249	16	88.1
2	347	868	688	44200	319	18	93.5
2	259	655	570	35100	247	14	90.5
5	297	693	520	41100	345	18	93.8
5	253	602	474	42100	311	14	96.2
6	141	268	182	23800	342	6	72.4
6	95	230	115	14400	213	3	84.2
8	258	484	388	33200	240	10	91.7
8	307	649	483	34900	220	13	95.9
10	294	865	610	46200	453	16	98.0
10	325	942	707	48600	478	18	98.7
12	68	175	80	12600	129	3	93.8
12	25	49	30	4160	54	1	91.5
14	298	895	715	45100	493	17	96.3
14	281	871	723	44900	487	16	96.1
16	312	949	689	45500	433	16	99.4
16	288	916	664	44200	405	15	99.2
Mean	253	645	514	35592	315	13	92.9
No. of samples		18					
Mean (excluding 6&12)	302	777	631	41836	352	15	95.0
No. of samples		14					

Table 7 Results summary for surface plume monitoring

Drop No.	Survey Craft Distance from drop (m)	Survey Craft Bearing Relative to drop	Survey Craft Time after drop (s)	Current Bearing	Current Magnitude (m/s)	Depths Below Surface (m) Concentration (ppm) Depth	Conc.	Depth	Conc.	Depth	Conc.	Depth	Conc.
2	132	343	360	319	0.25	1	200	6.5	80	11.6	0	16.2	0
3	154	345	463	318	0.22	1	180	6.5	90	11.6	0	16.2	0
4	54	200	-	126	0.08	1	0	6.5	0	11.6	0	16.2	0
5	80	150	-	177	0.05	2.5	0	6.4	0	11.5	0	16.1	0
6	NOT MONITORED												
7	42	148	173	35	0.08	2.3	130	6.8	0	11.8	0	17	0
8	100	305	121	310	0.19	2	20	5.9	0	11.1	0	15.7	0
9	70	310	-	325	0.24	2	0	5.9	0	11.1	0	15.7	0

N.B. Time after drop refers to the time at which the surface plume was identified at the monitoring position.
N.B. On most drops the monitor at 16m had went offscale (>5000ppm) within 4 minutes of drop

e 8 Results summary for near bed monitoring

	Survey Craft					Current		Height above bed (m) Concentration (ppm)							
Drop No.	Distance from drop (m)	Bearing Relative to drop (deg)	Bed slope	Time after drop (s)	Average speed of Bed wave (m/s)	Bearing (deg)	Magnitude (m/s)	Height	Conc.	Height	Conc.	Height	Conc.	Height	Conc.
10	51	270	DOWN (1:400)	60	0.9	300	0.15	8.2	0	6.2	6000	4.2	9000	0.2	10000
11	153	190	DOWN ([illegible])	524	0.3	315	0.08	8.2	0	6.2	0	4.2	0	0.2	4000
12	60	125	LEVEL	60	1	120	0.09	8.2	4000	6.2	7000	4.2	7000	0.2	7000
13	120	320	LEVEL	-	-	110	0.07	8.2	0	6.2	0	4.2	0	0.2	0
14	112	45	LEVEL	260	0.4	326	0.14	3.2	4000	1.2	7500	0.7	7500	0.2	10000
15	128	245	DOWN (1:700)	278	0.5	286	0.13	3.2	2000	1.2	7000	0.7	7000	0.2	10000
16	48	90	LEVEL	32	1.5	277	0.08	3.2	8000	1.2	20000	0.7	22000	0.2	30000
17	NOT MONITORED														

Time after drop refers to the time for the bed wave to reach the instruments ble 9 Silt content of samples in the test area

Sample No	% silt before	% silt after
1	7.0	4.5
2	3.7	4.9
3	3.3	4.0
4	9.8	8.0
5	10.6	19.4
6	3.9	4.1
7	6.6	9.5
8	4.8	26.6
9	26.4	13.1
10	2.5	7.3
11	5.8	5.1
12	6.7	15.5
13	6.4	20.5
14	3.6	7.7
15	9.1	36.9
16	3.9	67.8
17	12.0	18.5
18	58.0	9.8
19	6.4	7.6
20	16.8	11.4
21	13.0	53.9
22	5.8	25.6
23	14.2	11.3
24	6.7	9.2
25	38.4	89.2
26	7.4	19.2
27	4.5	15.4
28	8.1	31.5
29	10.1	14.9
30	6.8	18.2
31	19.0	12.2
32	7.8	20.9
33	5.3	12.3
34	6.0	11.9
35	8.0	11.3
36	14.4	18.1

able 10 Concentrations of six heavy metals on bed of test area before disposal

Sample No	Cu	Zn	Pb	Fe	Mn	Co
1	54	111	74	15400	228	4
2	27	95	60	13600	243	5
3	19	78	47	12500	205	4
4	30	113	61	13300	186	5
5	57	164	85	17400	245	6
6	35	109	63	17800	254	8
7	30	112	62	16000	236	6
8	37	180	67	17400	267	7
9	38	105	94	17100	266	6
10	24	93	54	14700	255	6
11	23	106	44	18500	276	6
12	26	100	51	17100	278	7
13	21	93	44	16700	277	7
14	22	87	46	15300	271	6
15	26	91	53	17300	278	7
16	25	140	42	14000	249	6
17	52	149	66	25800	444	8
18	38	114	47	34600	600	13
19	27	85	47	14900	231	7
20	27	82	43	19500	289	9
21	24	89	39	17500	266	7
22	18	89	41	15400	257	6
23	53	117	68	19000	254	10
24	28	102	52	18900	278	7
25	144	363	178	38300	520	15
26	22	87	40	14900	224	4
27	17	80	43	14500	263	3
28	22	80	43	15400	249	5
29	29	100	46	23900	293	5
30	22	76	38	14600	215	5
31	42	117	52	19000	291	5
32	25	80	46	21700	258	5
33	18	78	37	13600	242	4
34	22	85	38	14400	239	5
35	24	99	47	15300	255	5
36	36	107	56	18300	273	6

able 11 Concentrations of six heavy metals on bed of test area after disposal

Sample No	Cu	Zn	Pb	Fe	Mn	Co
1	18	94	37	16100	268	5
2	24	95	45	30200	274	5
3	23	94	168	15500	270	6
4	28	104	52	15400	260	5
5	34	168	87	17800	269	5
6	28	82	41	14000	261	4
7	34	102	57	18600	268	7
8	784	415	141	33000	698	30
9	64	194	120	25400	311	7
10	33	109	53	23800	344	6
11	19	81	35	18100	220	4
12	34	134	63	19100	263	7
13	41	149	50	40000	367	13
14	31	125	60	18700	276	6
15	47	149	74	27800	366	10
16	58	185	78	34000	516	11
17	37	113	62	17000	241	8
18	36	120	48	33600	358	13
19	30	125	60	16300	239	5
20	44	151	87	17400	274	6
21	47	175	66	36000	391	14
22	38	161	76	52900	337	8
23	32	112	58	16300	257	5
24	30	106	44	17000	279	12
25	348	649	234	46000	689	20
26	32	107	49	17700	265	6
27	44	123	59	17900	257	4
28	29	116	45	33700	369	9
29	40	133	60	18300	269	4
30	35	122	52	19300	274	4
31	34	109	60	17000	243	5
32	50	121	57	19900	276	7
33	30	96	42	15600	250	5
34	31	112	58	16500	256	3
35	30	99	45	15600	233	3
36	37	132	66	21400	272	7

N.B. Sample No.'s 8 and 25 were considered to be unrepresentative able 12 Mean concentrations of six heavy metals on bed of test area with distance from centre of disposal point

BEFORE

Area	Approx. Distance from drop point (m)	No. of samples	Cu	Zn	Pb	Fe	Mn	Co	%silt
1	50	4	23	102	44	16050	263	7	8.0
2	150	12	31	106	55	18000	279	6	9.7
3	250	20	36	114	59	18170	278	6	11.7

AFTER

Area	Approx. Distance from drop point (m)	No. of samples	Cu	Zn	Pb	Fe	Mn	Co	%silt
1	50	4	48	168	74	37675	403	11	49.1
2	150	11	37	124	63	20391	280	6	14.7
3	250	19	32	110	60	19942	273	6	11.5

FIGURES.

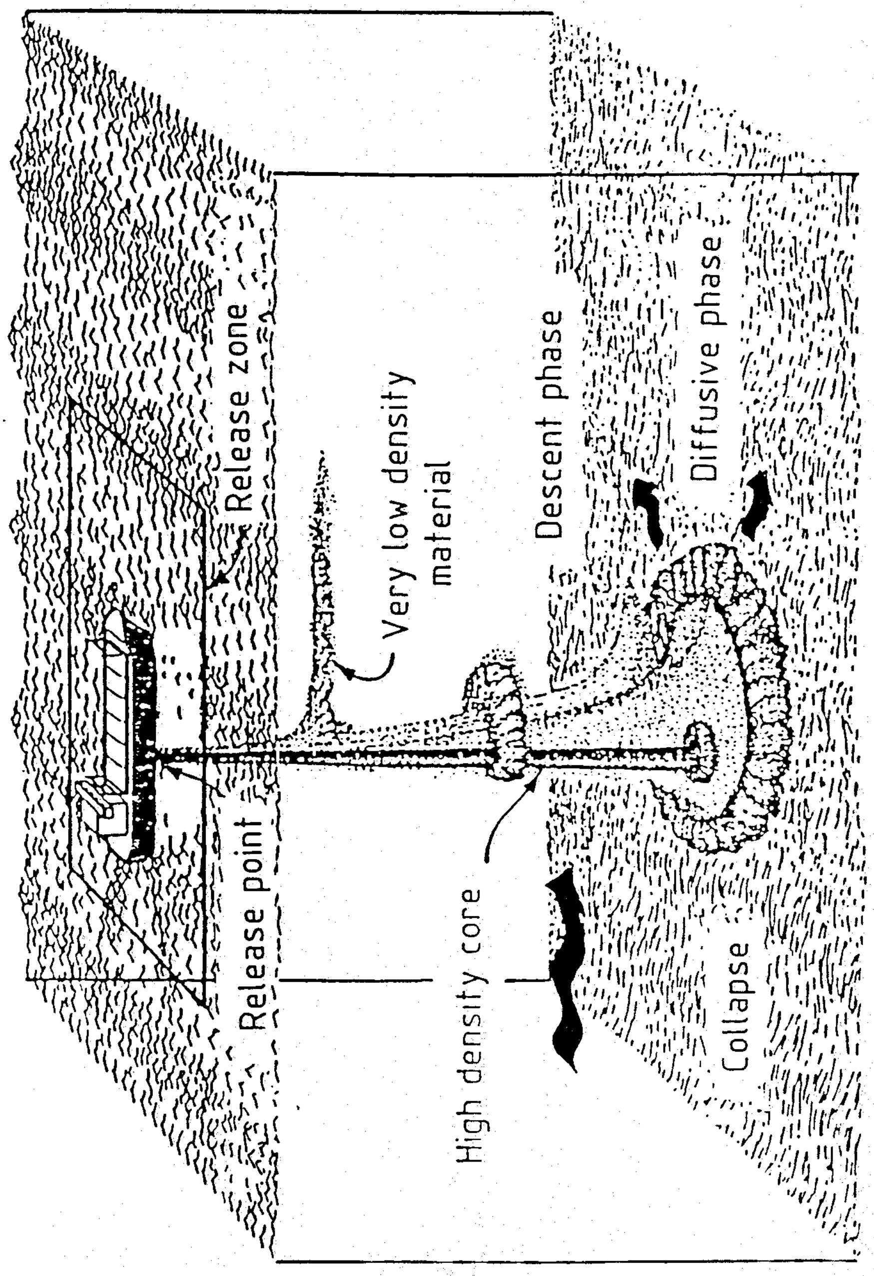


Fig 1 Transport processess during open-water disposal (after WES)

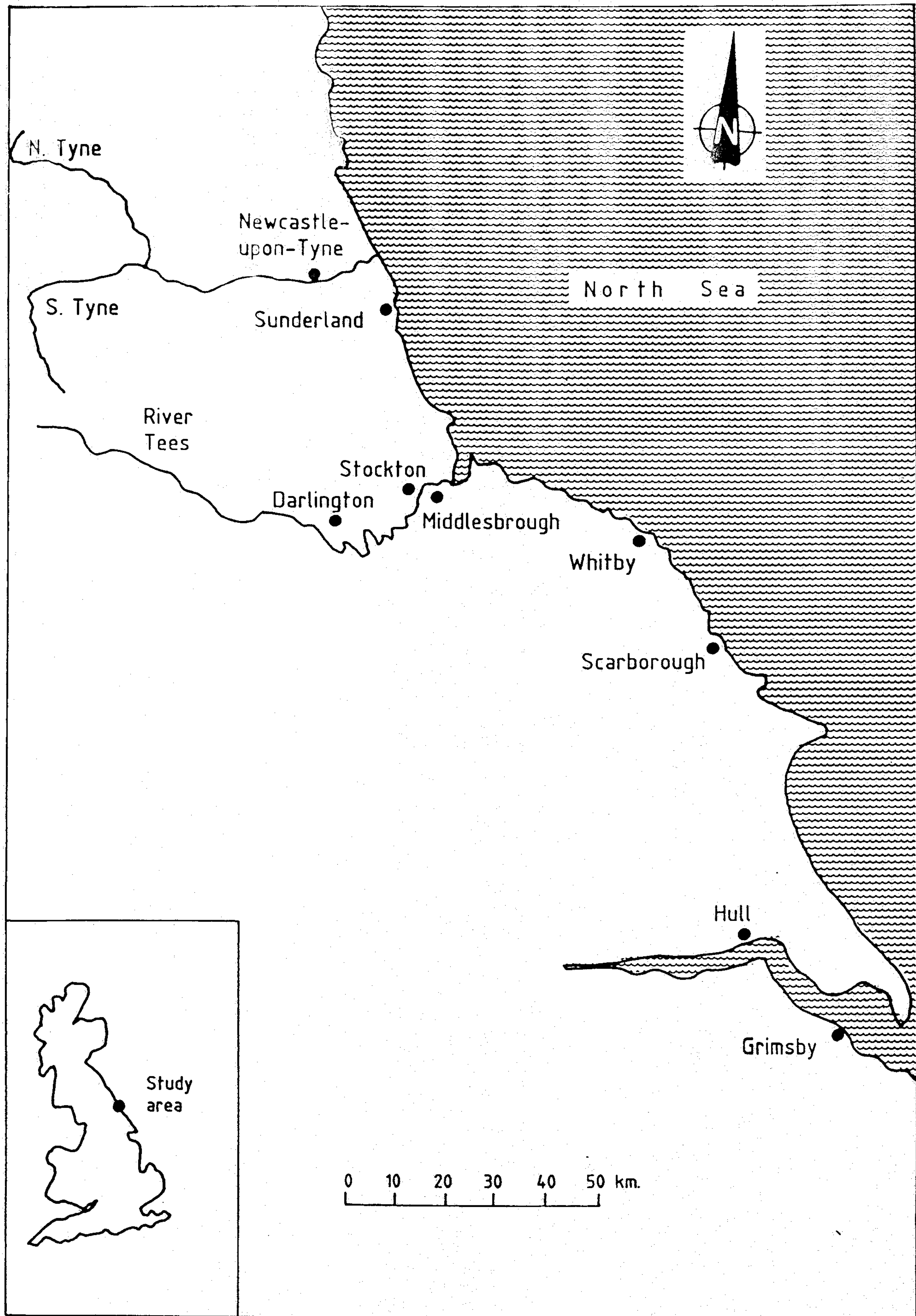


Fig 2 Location map of River Tees

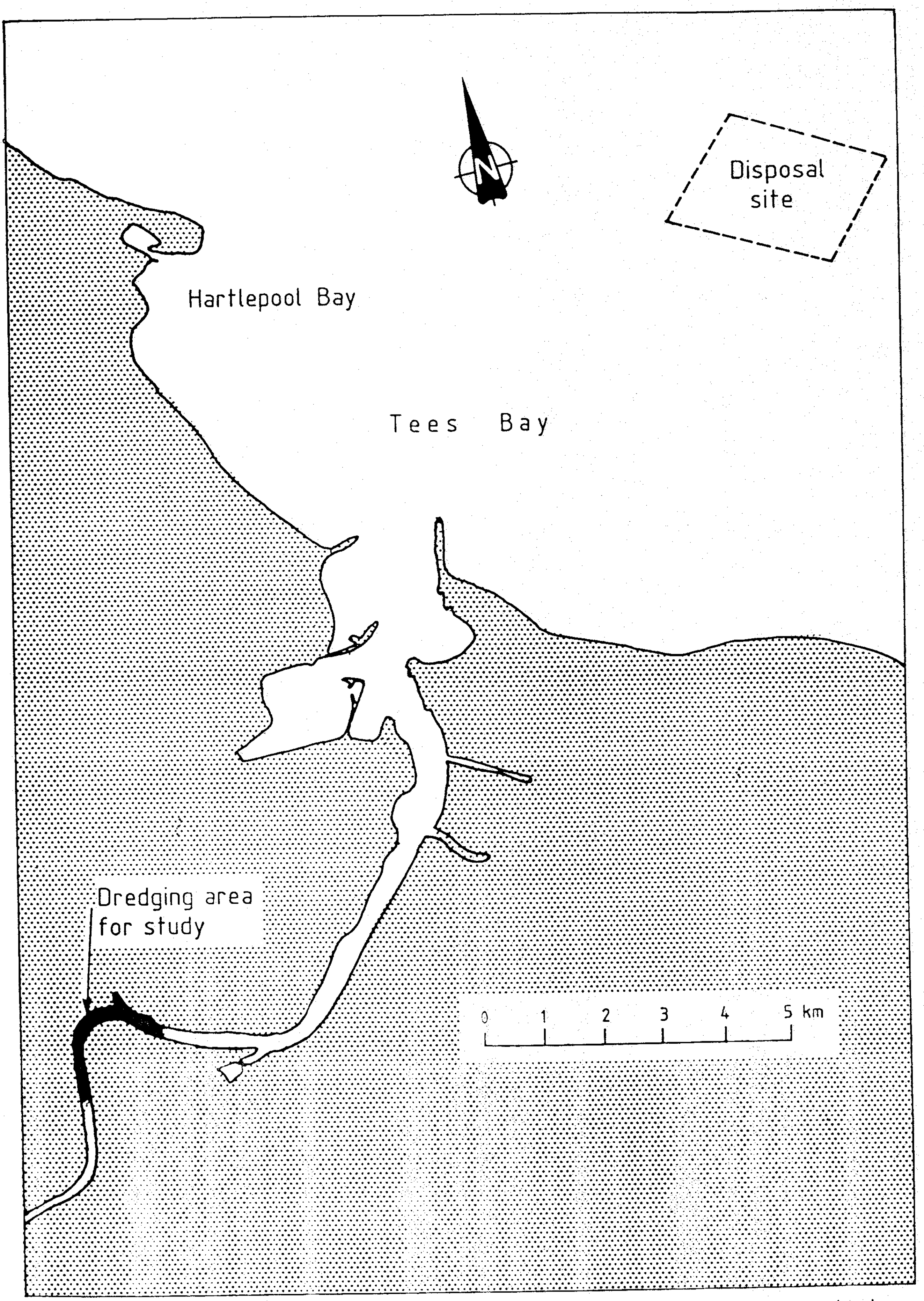


Fig 3 Location map of disposal site and dredging area for study

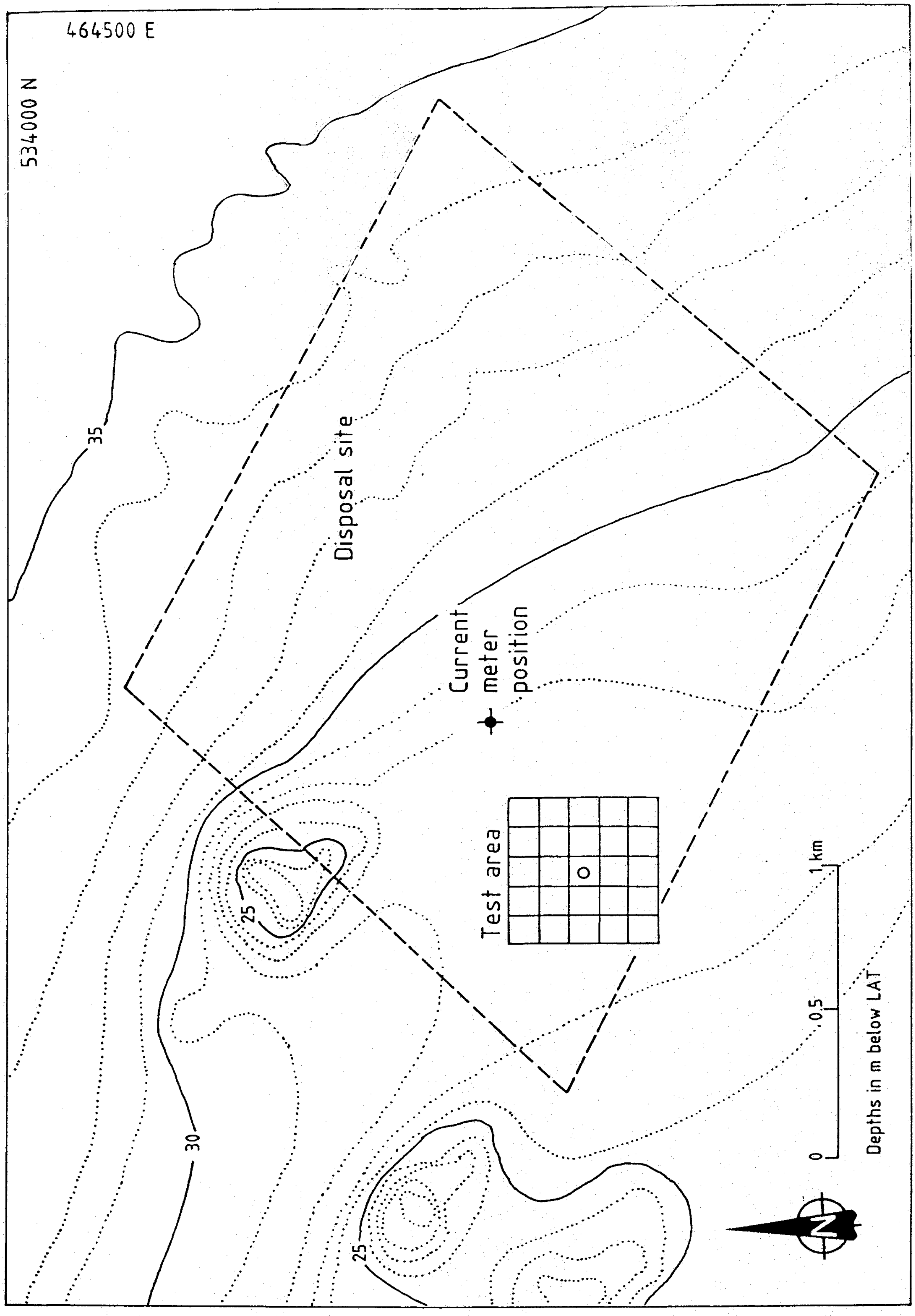


Fig 4 Location of test area within disposal site

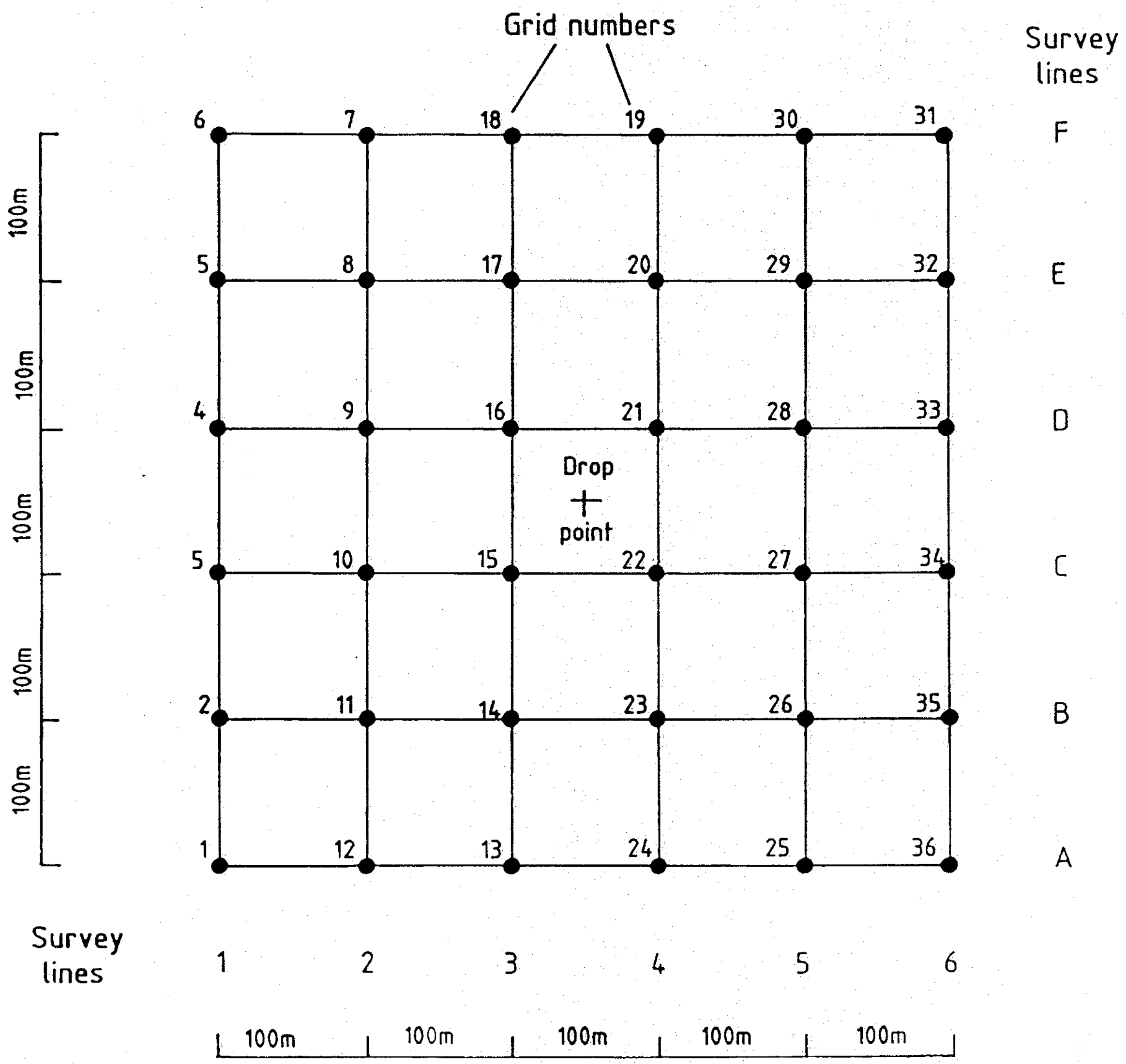


Fig 5 Sample positions and hydrographic survey lines in test area

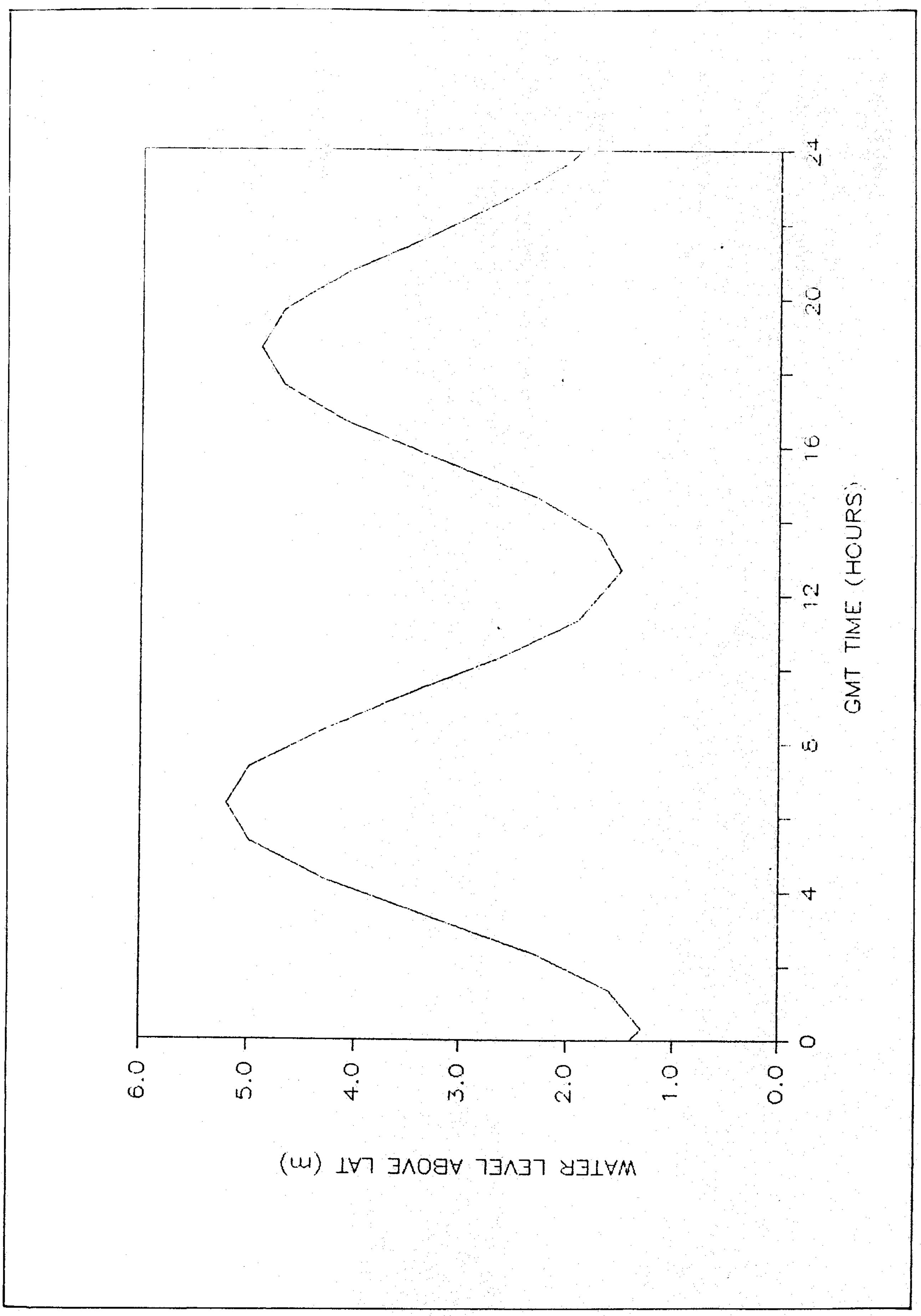


Fig 6 Tide curves at Tees entrance on 23.9.86

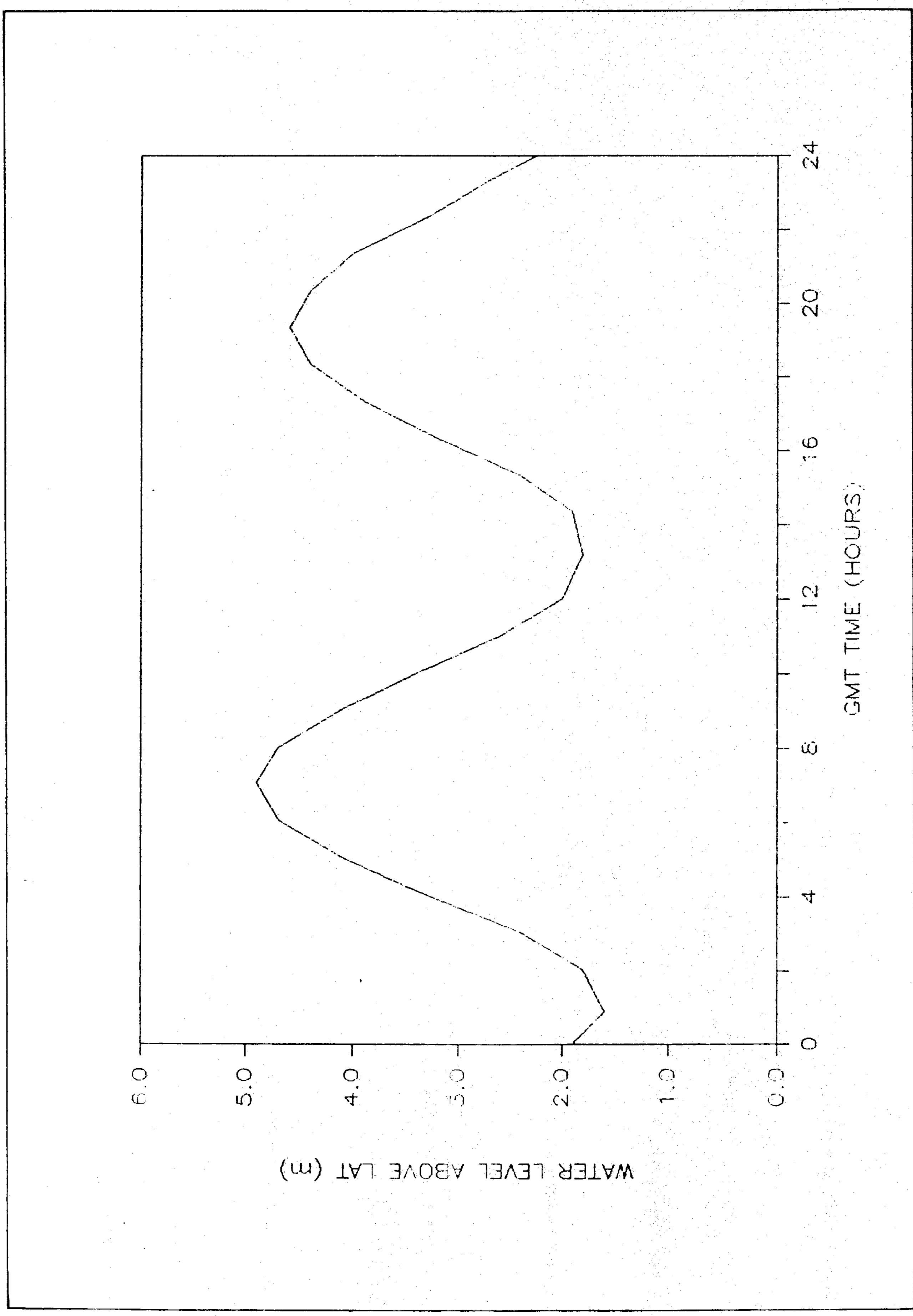


Fig 7 Tide curves at Tees entrance on 24.9.86

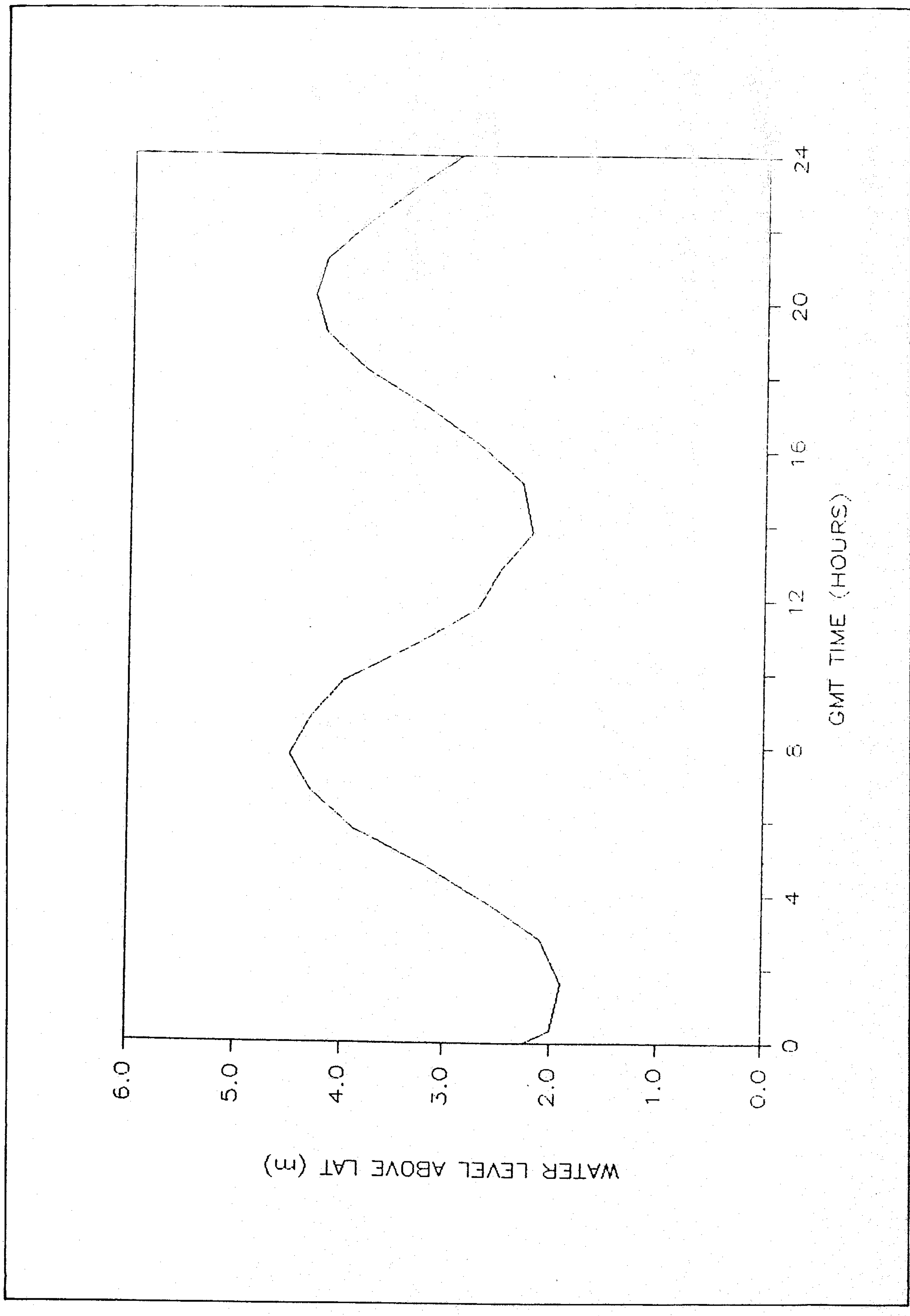


Fig 8 Tide curves at Tees entrance on 15.9.86

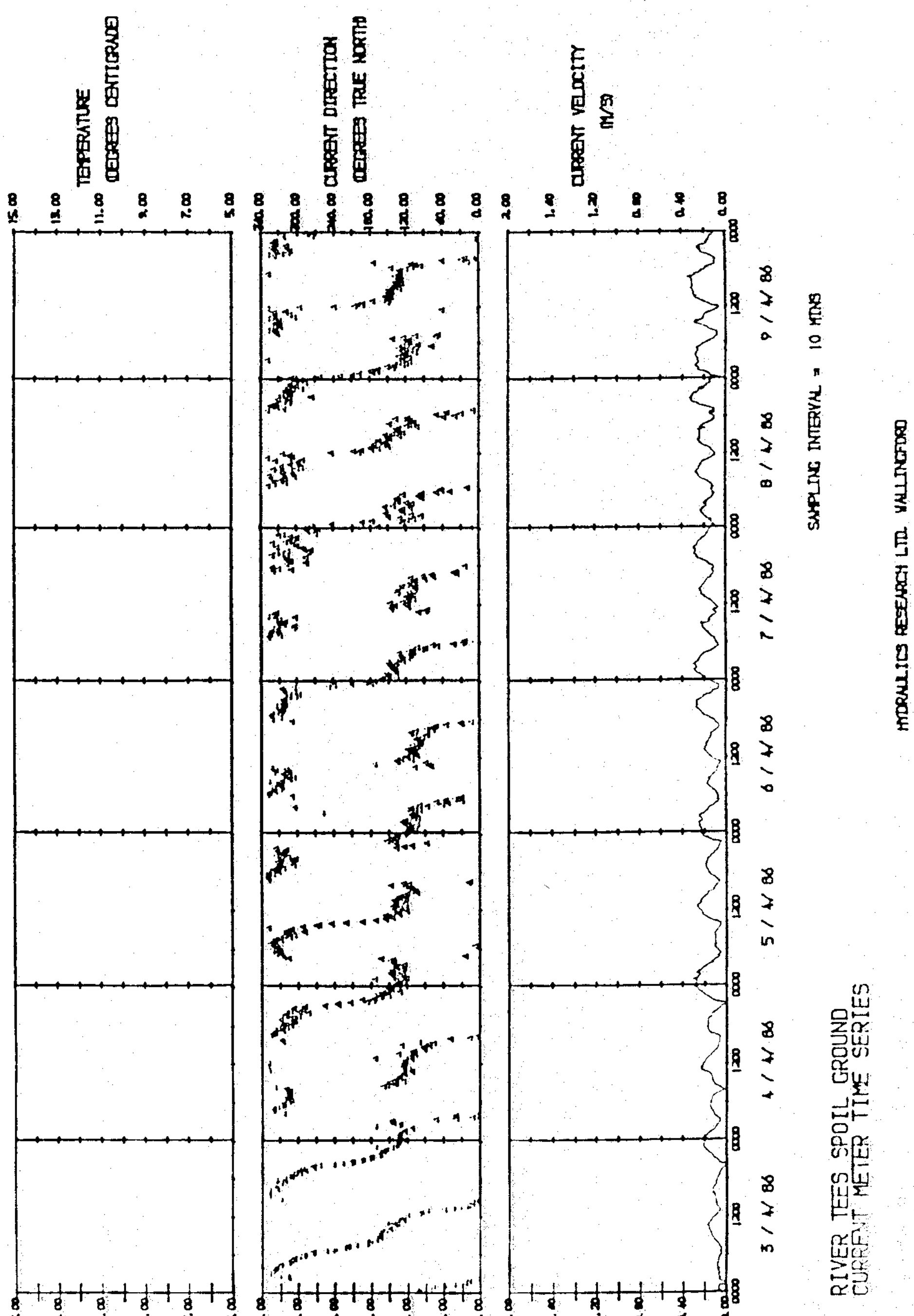


Fig 9 Current meter time series: 3.4.86 to 9.4.86

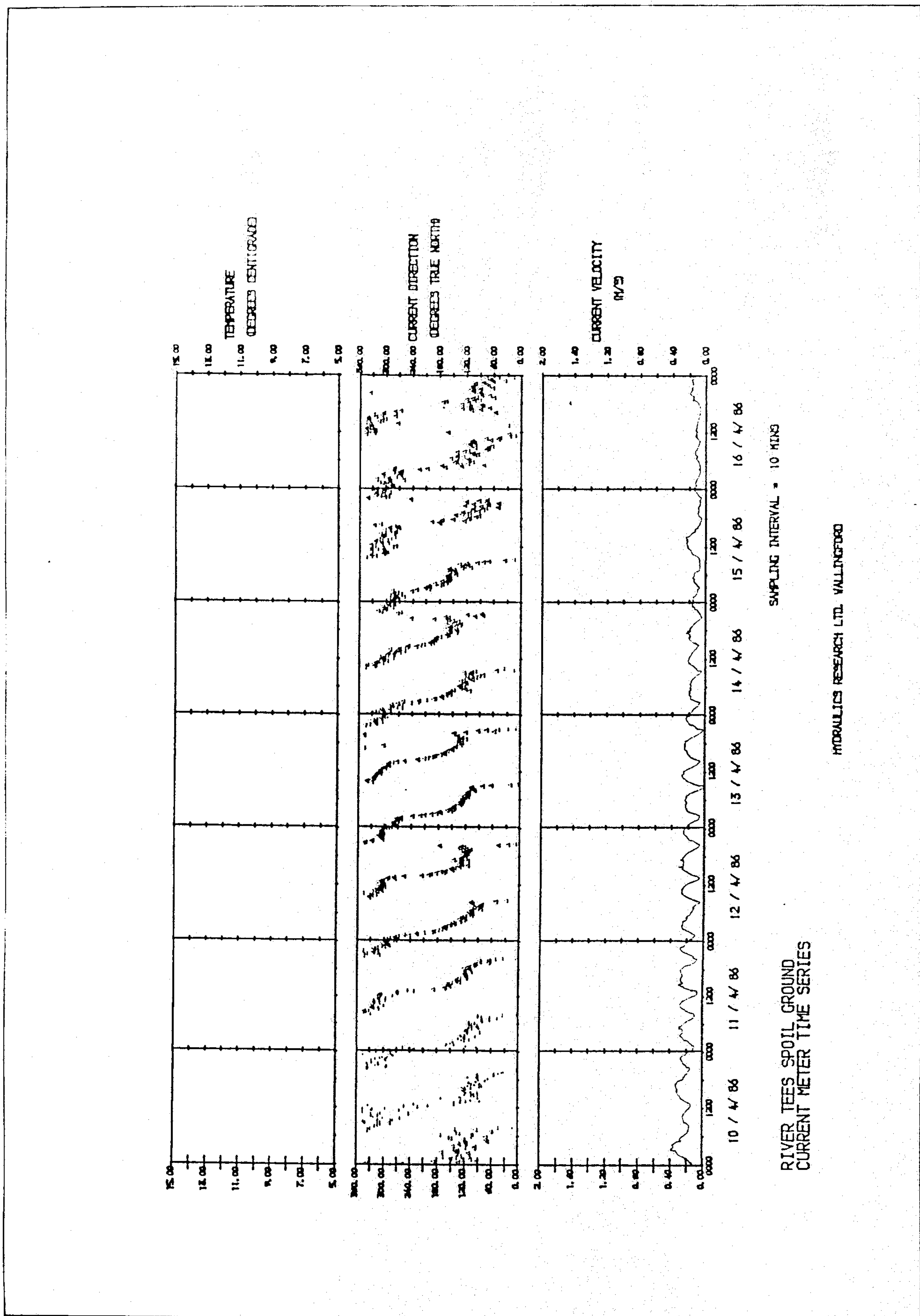


Fig 10 Current meter time series: 10.4.86 to 16.4.86

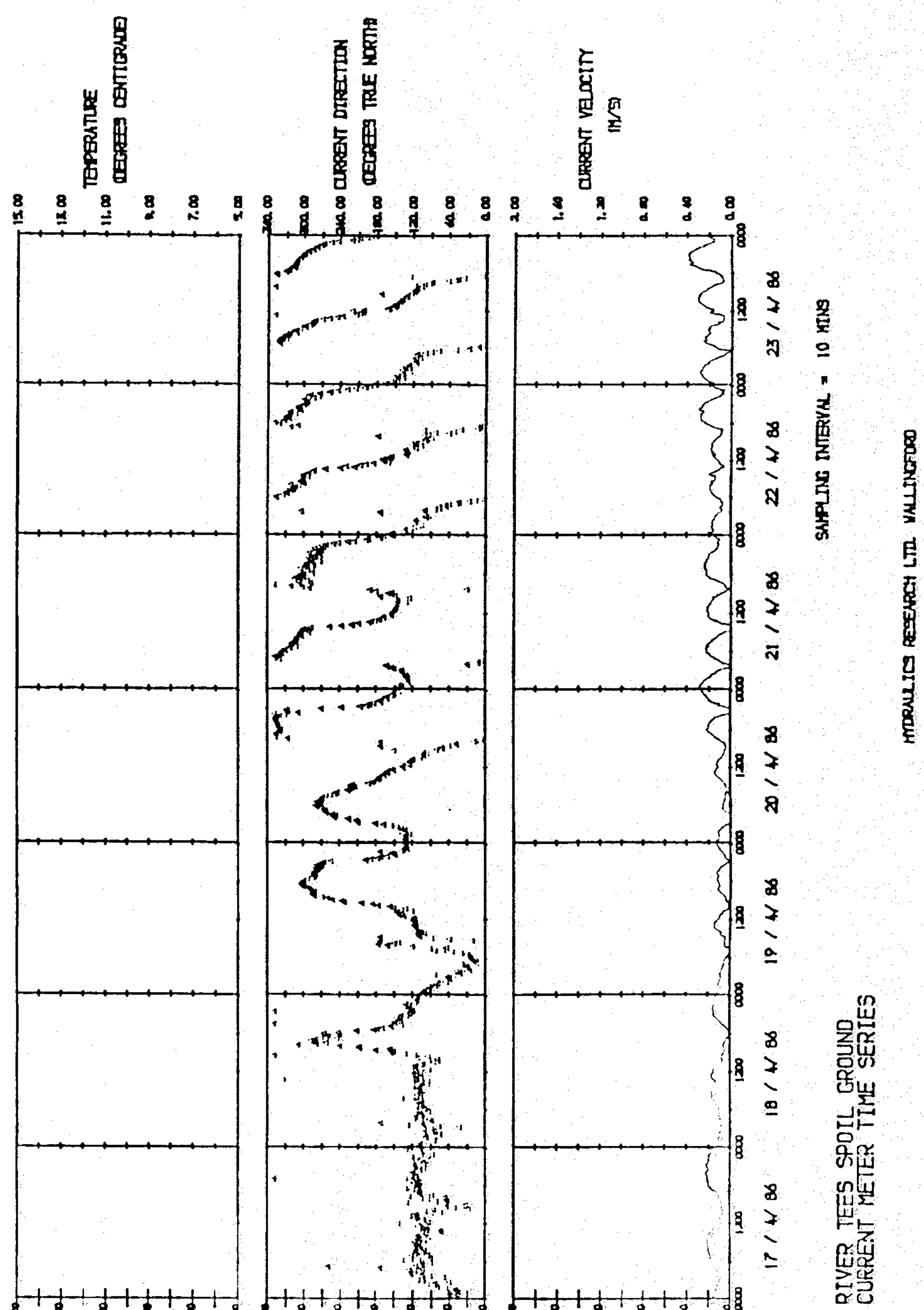


Fig 11 Current meter time series : 17.4.86 to 23.4.86

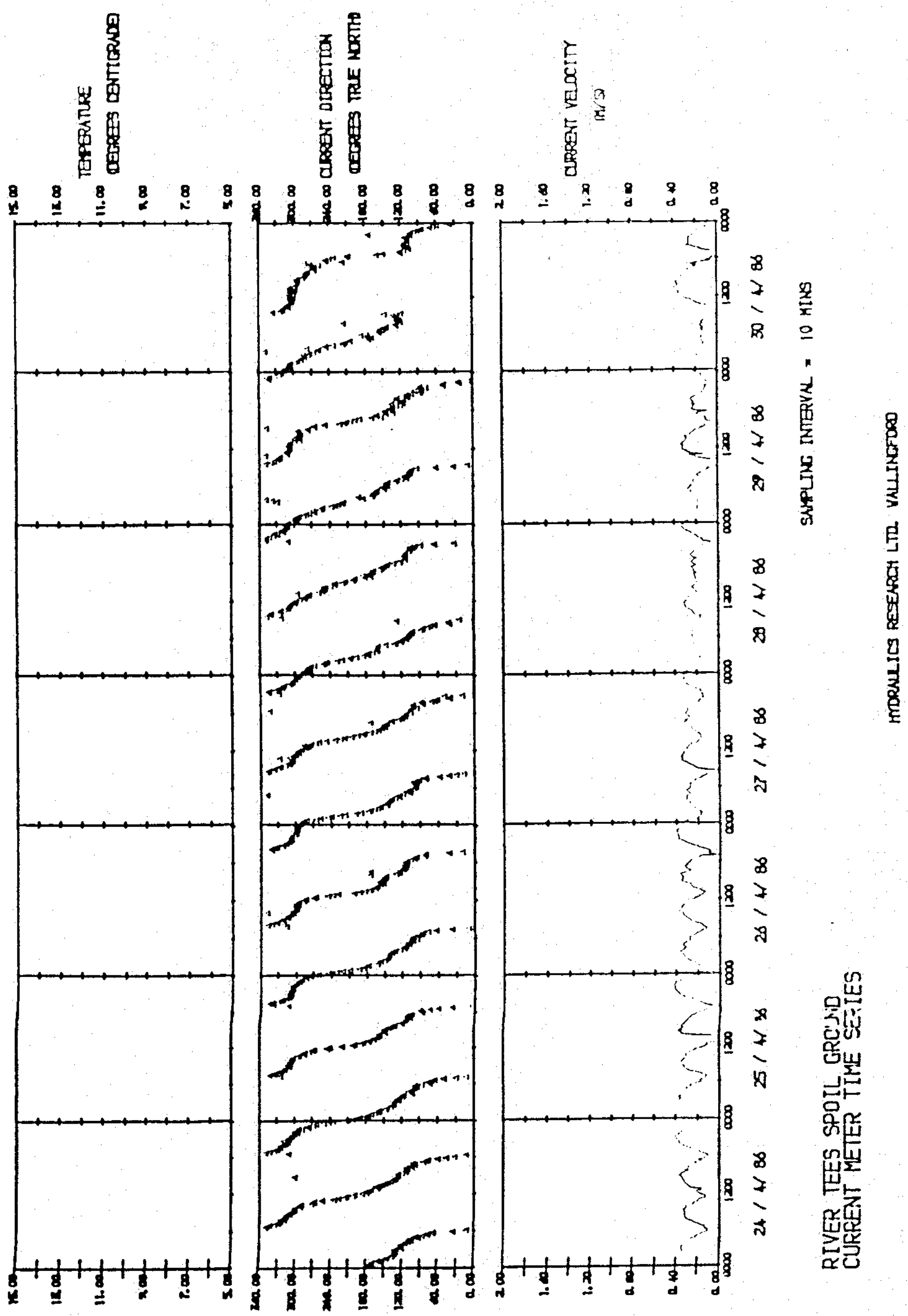


Fig 12 Current meter time series : 24.4.86 to 30.4.86

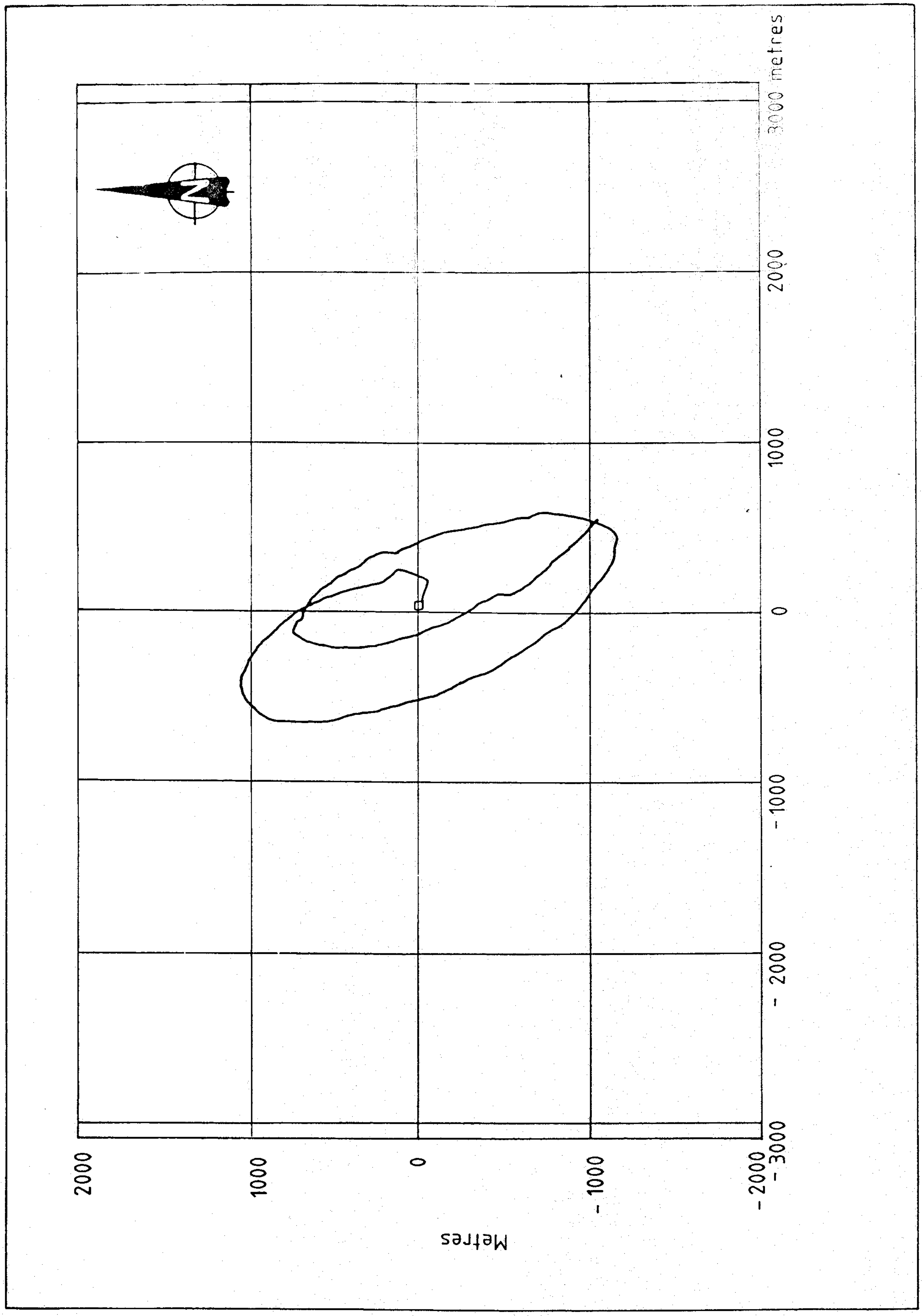


Fig 14 Progressive vector plot of current meter time series : 3.4.86 to 8.4.86

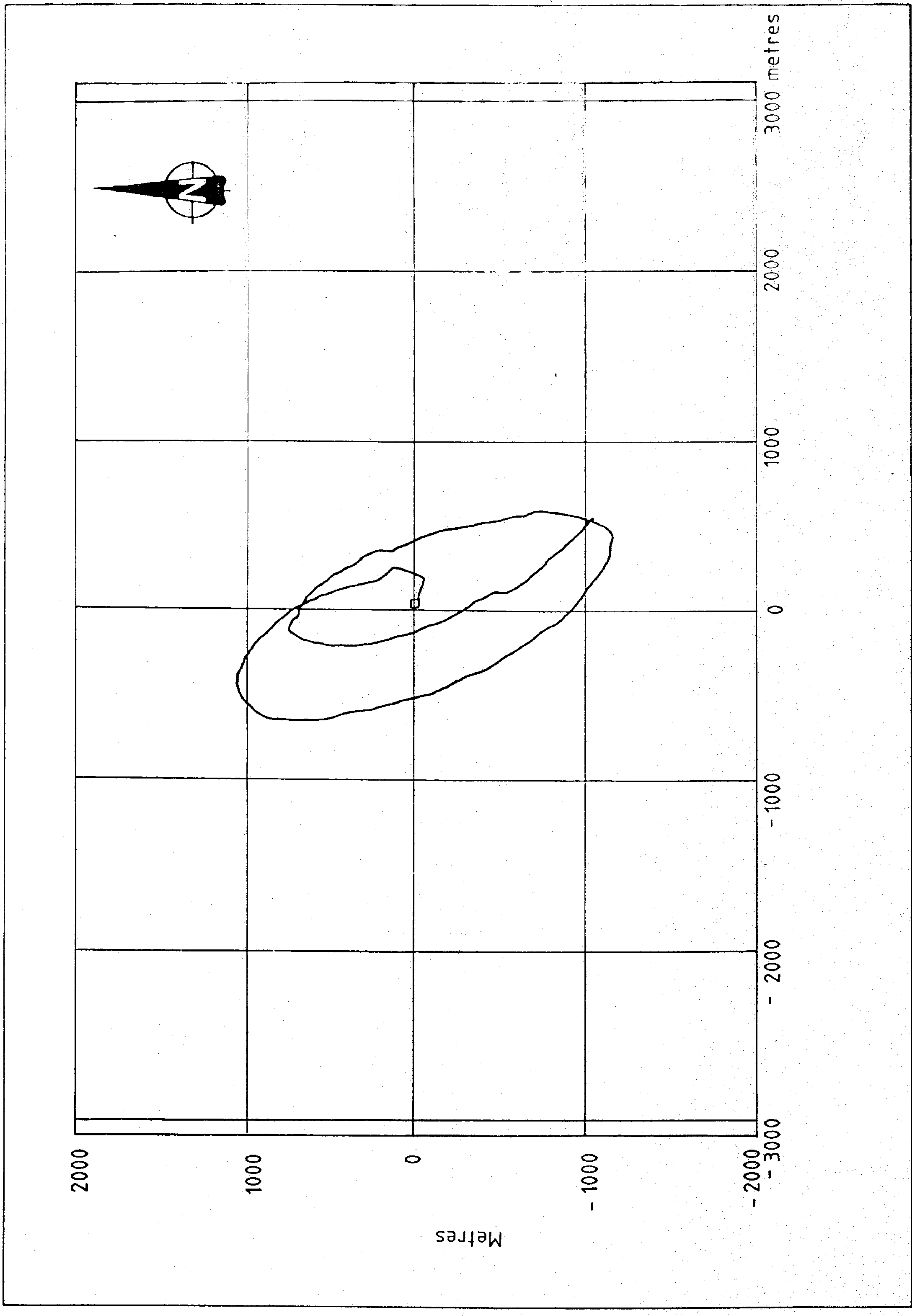


Fig 14 Progressive vector plot of current meter time series : 3.4.86 to 8.4.86

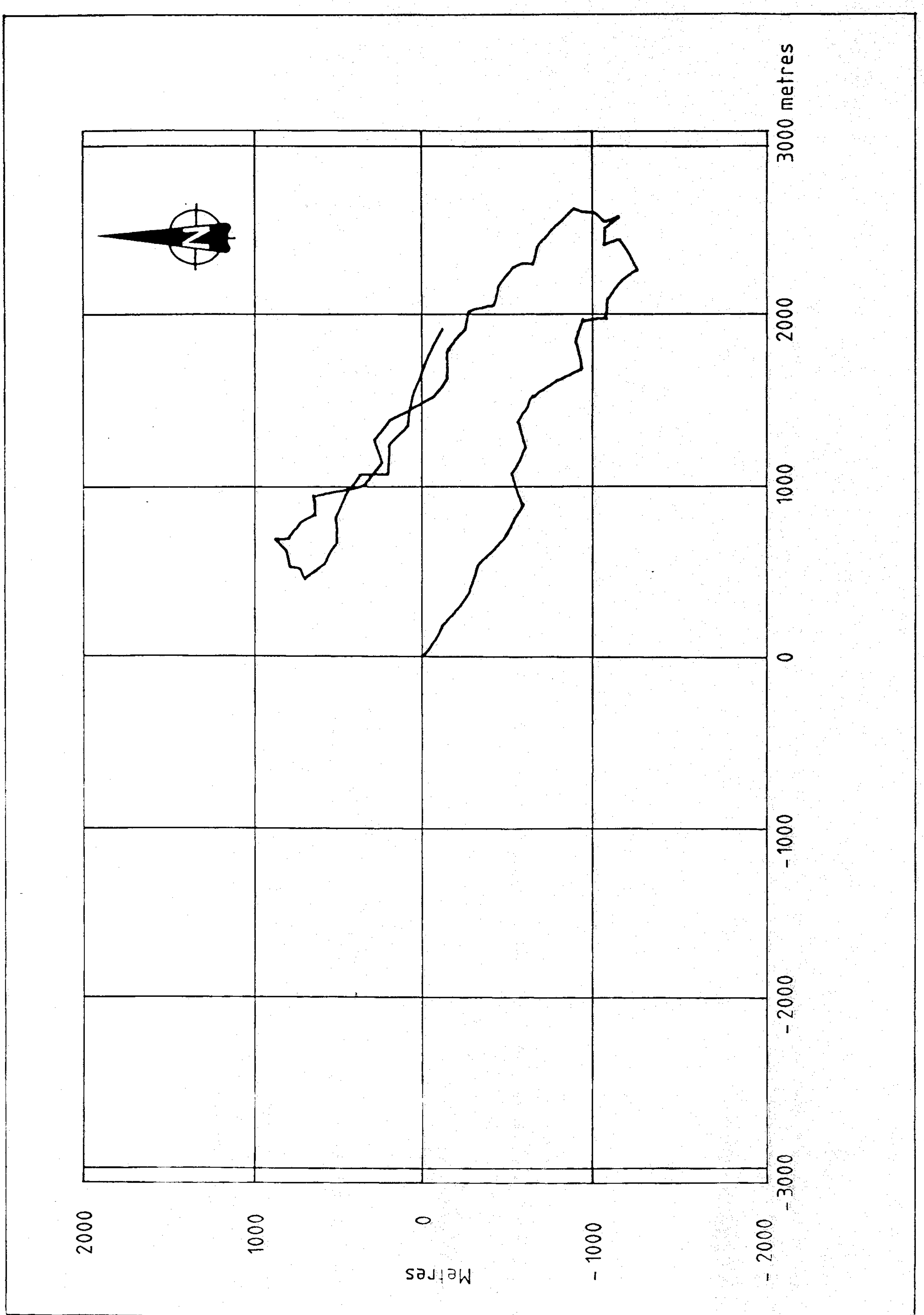


Fig 15 Progressive vector plot of current meter time series: 11.4.86 to 16.4.86

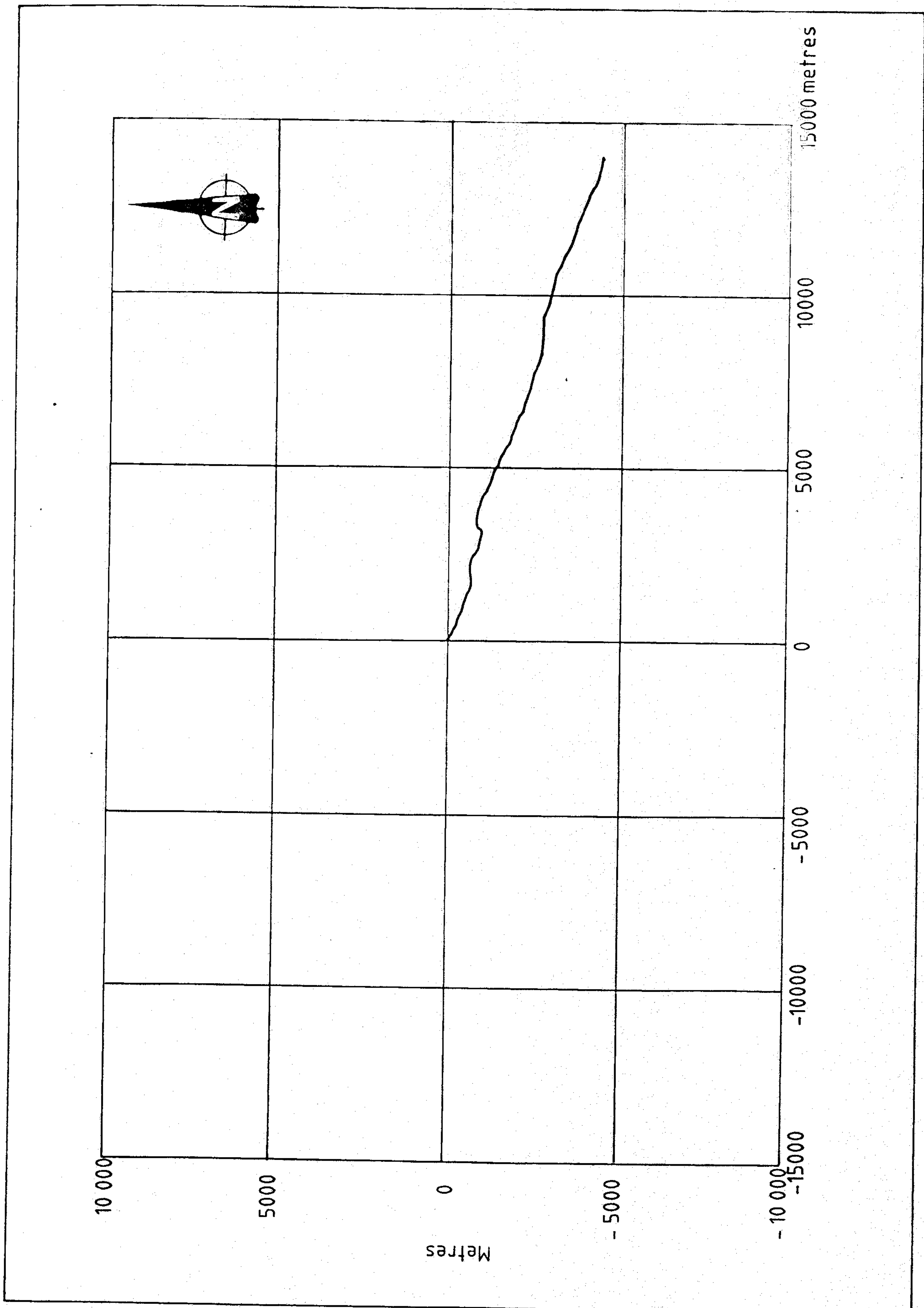


Fig 16 Progressive vector plot of current meter time series: 19.4.86 to 2.5.86

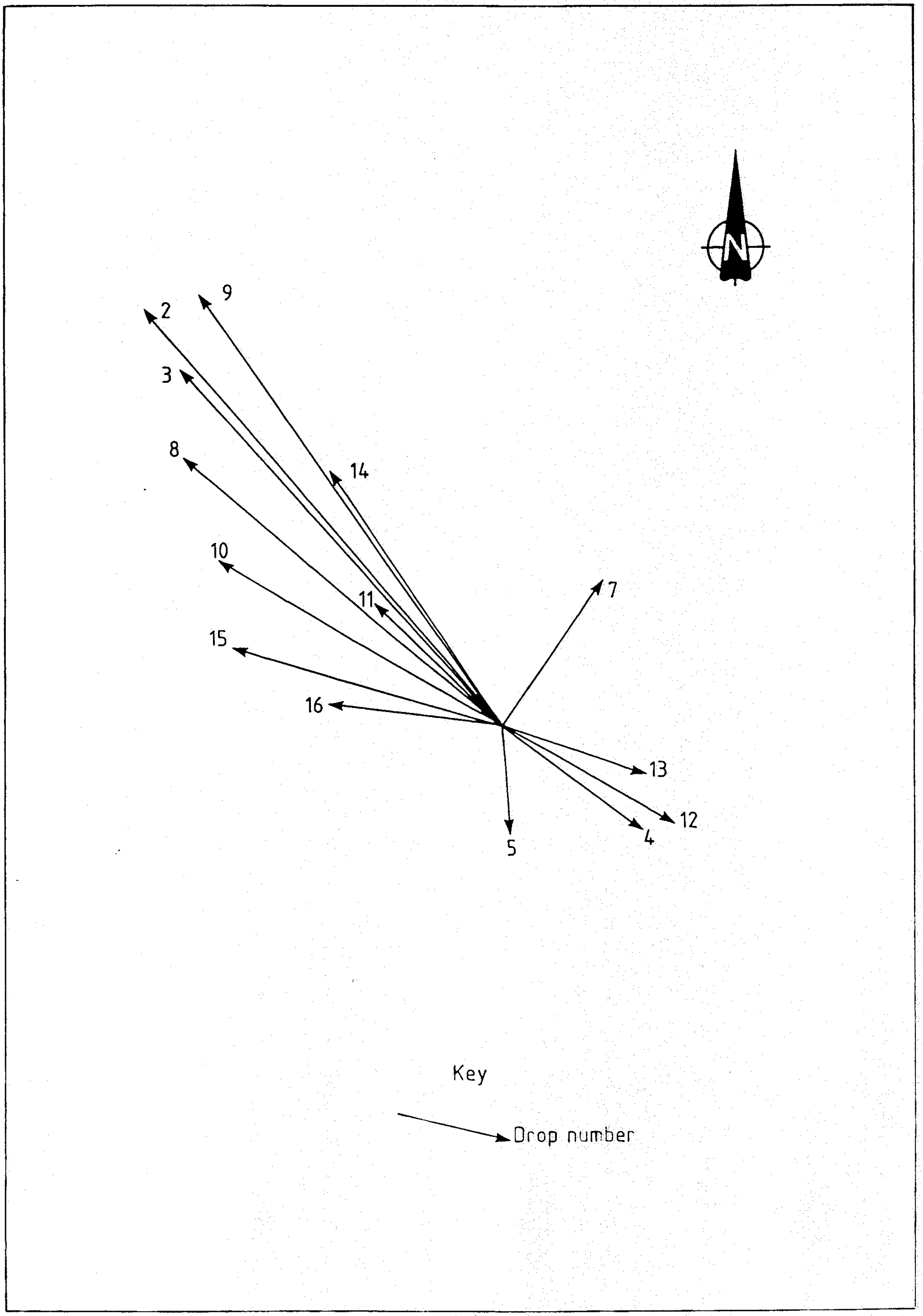


Fig 17 Current vector at the time of each drop

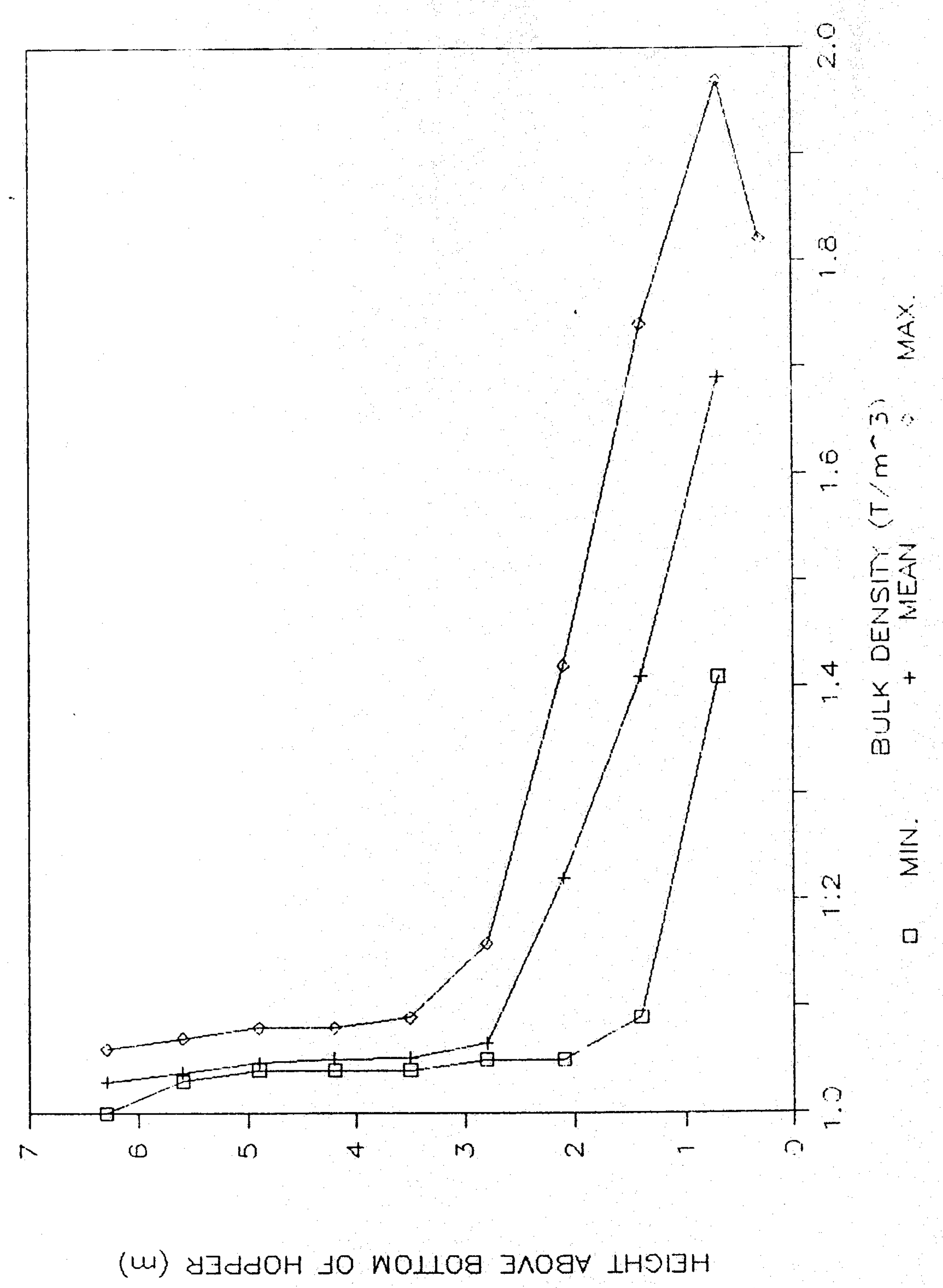


Fig 18 Typical pre-disposal density profiles of dredged.

LOG OF DATA OUTPUT

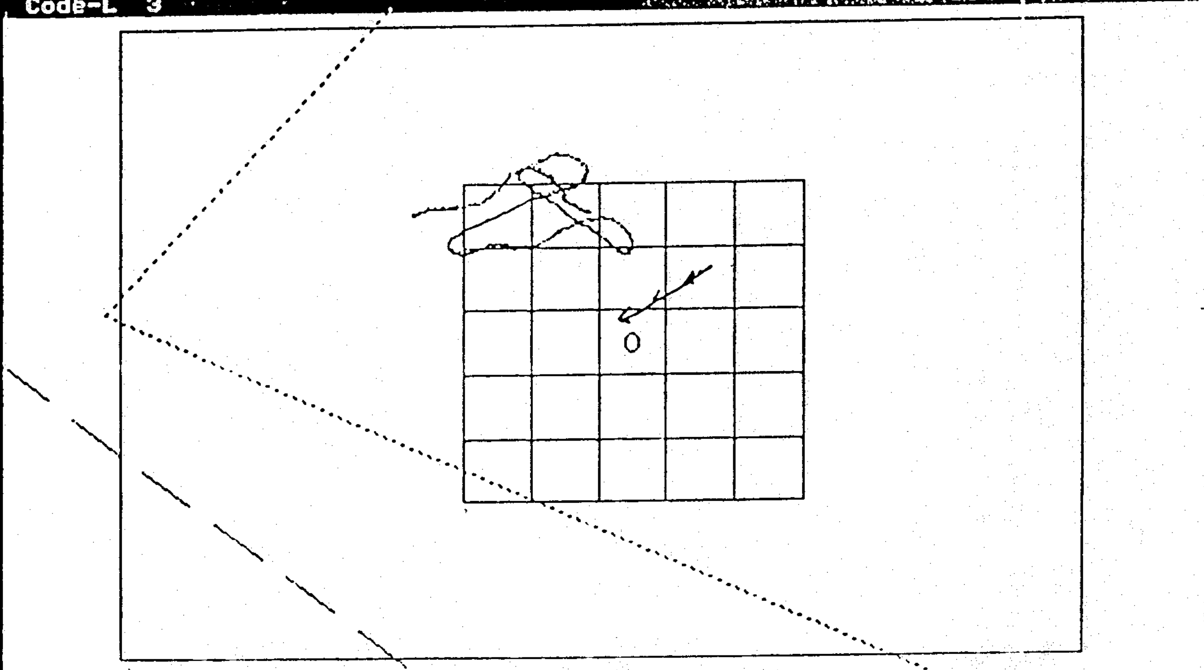
DATE 23:09:86
SURVEY S.Ground
SURVEYOR M J W

Set No	Eastings	Northings	Sounding	Tide	Time
0	461380.722	532259.071	28.650	1.500	14:03:56
0	461375.609	532263.341	28.510	1.500	14:04:37
0	461364.503	532267.954	28.330	1.500	14:06:01
0	461351.981	532273.534	28.500	1.500	14:07:49
0	461336.474	532253.295	28.430	1.500	14:08:55
0	461442.532	532174.334	0.000	1.500	14:10:53
0	461495.569	532138.903	28.210	1.500	14:12:32
0	461462.711	532194.537	28.290	1.500	14:14:33
0	461357.571	532155.191	28.300	1.500	14:16:00
0	461324.236	532149.102	28.510	1.500	14:16:42
0	461270.199	532146.892	28.850	1.500	14:17:54
0	461246.621	532175.288	28.610	1.500	14:19:11
0	461381.943	532235.571	28.520	1.500	14:21:18
0	461428.598	532255.666	28.540	1.500	14:22:51
0	461432.155	532266.600	28.600	1.500	14:24:02
0	461376.892	532292.854	28.490	1.500	14:24:57
0	481.963	212.877	28.930	1.500	14:27:18
0	461230.503	532213.332	28.950	1.500	14:27:19

NAVIGATIONAL MODE Station co-ords

Date	23:09:86	R.Range	9461.99	Eastings	461172.98	E-left	456903.7
Time	14:28:24	L.Range	14499.17	Northings	532201.34	N-left	518344.9
Update	.95	Int/angle	78.85	Sets Left	4000	E-right	451762.4
						N-right	533186.6

Code-L 3 Code-R 2



Survey-S.Ground Surveyor- M J W Present survey

Tide(auto)	0.00	SOUNDINGS	28.69	Eastings-start	460750.00
				Northings-start	532000.00
Tide(manual)	1.50	Scale	Normal	Eastings-end	462160.63
				Northings-end	532000.00

Fig 19 Survey craft navigation log : drop number 3

LOG OF DATA OUTPUT

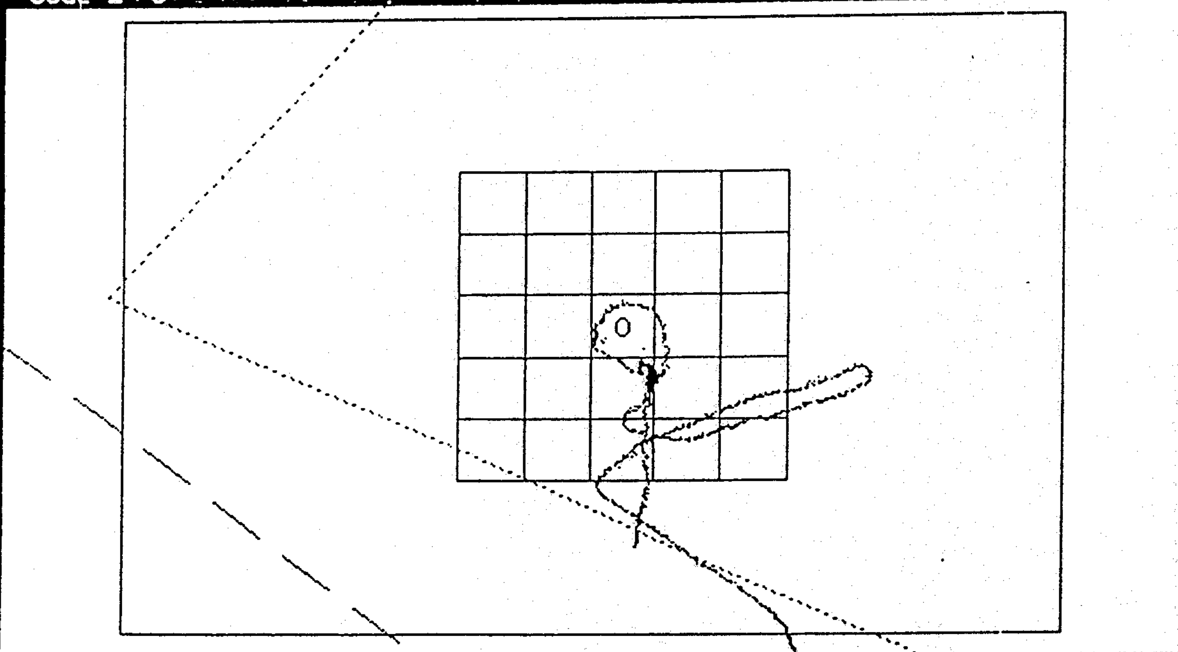
DATE 23:09:86
SURVEY S.Ground
SURVEYOR M J W

Set No	Eastings	Northings	Sounding	Tide	Time
0	461545.001	531933.417	30.890	3.900	17:32:17
0	461544.169	531934.758	30.330	3.900	17:32:49
0	461539.958	531937.252	30.540	3.900	17:33:22
0	461526.577	531942.864	30.490	3.900	17:34:27
0	461527.286	531925.198	30.600	3.900	17:36:28
0	461515.177	532035.380	33.460	3.900	17:39:33
0	461546.504	531902.790	30.890	3.900	17:41:30
0	461530.576	531826.342	30.970	3.900	17:43:03
0	461633.674	531823.896	31.020	3.900	17:44:21
0	461682.930	531840.985	30.790	3.900	17:45:15
0	461782.596	531873.317	30.920	4.000	17:46:48
0	461869.293	531907.764	30.790	4.000	17:48:06
0	461848.379	531929.235	30.360	4.000	17:49:05
0	461484.960	531771.156	31.040	4.000	17:54:53
0	461614.755	531623.309	31.350	4.000	17:57:30
0	461720.833	531546.889	31.370	4.000	17:58:53
0	461755.154	531501.287	31.470	4.000	18:00:33
0	461779.428	531444.317	31.610	4.000	18:03:01
0	461854.251	531427.982	31.670	4.000	18:04:37
0	461990.879	531427.504	32.390	4.000	18:07:04
0	462151.450	531390.332	1.710	4.000	18:11:41

NAVIGATIONAL MODE

Date	23:09:86	R.Range	15253.10	Eastings	462154.78	E-left	456903.7
Time	18:11:42	L.Range	14061.31	Northings	531388.99	N-left	518344.9
Update	.94	Int/angle	77.26	Sets Left	4000	E-richt	447097.5
						N-richt	533825.3

Code-L 3 Code-R 4



Survey-S.Ground Surveyor- M J W Present survey

Tide(auto)	.07	SOUNDINGS	32.41	Eastings-start	460750.00
Tide(manual)	4.00	Scale	Normal	Northings-start	532000.00
				Eastings-end	462160.63
				Northings-end	532000.00

Fig 20 Survey craft navigation log : drop number 5

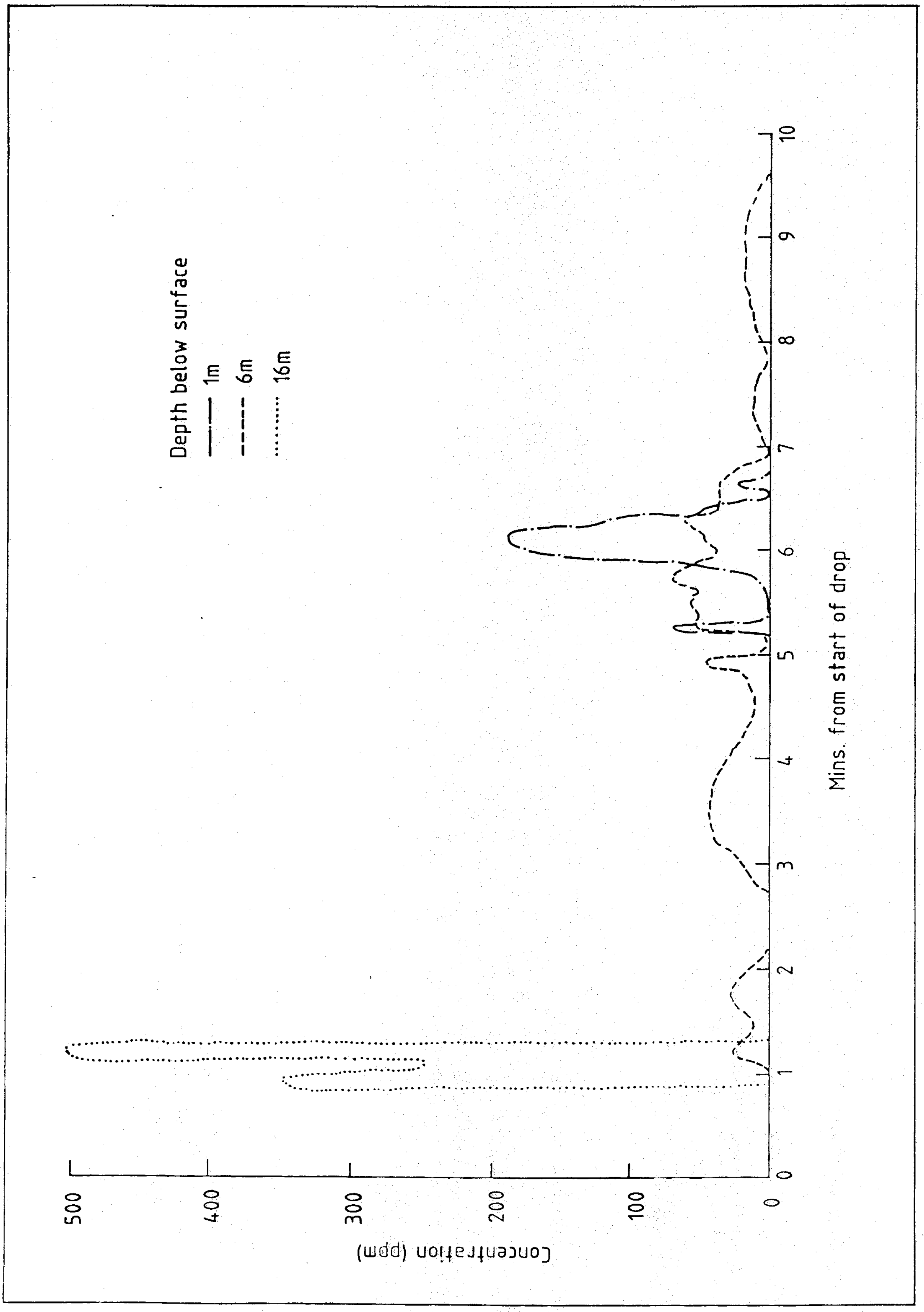


Fig 21 Suspended solids concentrations in upper part of water column for drop number 2

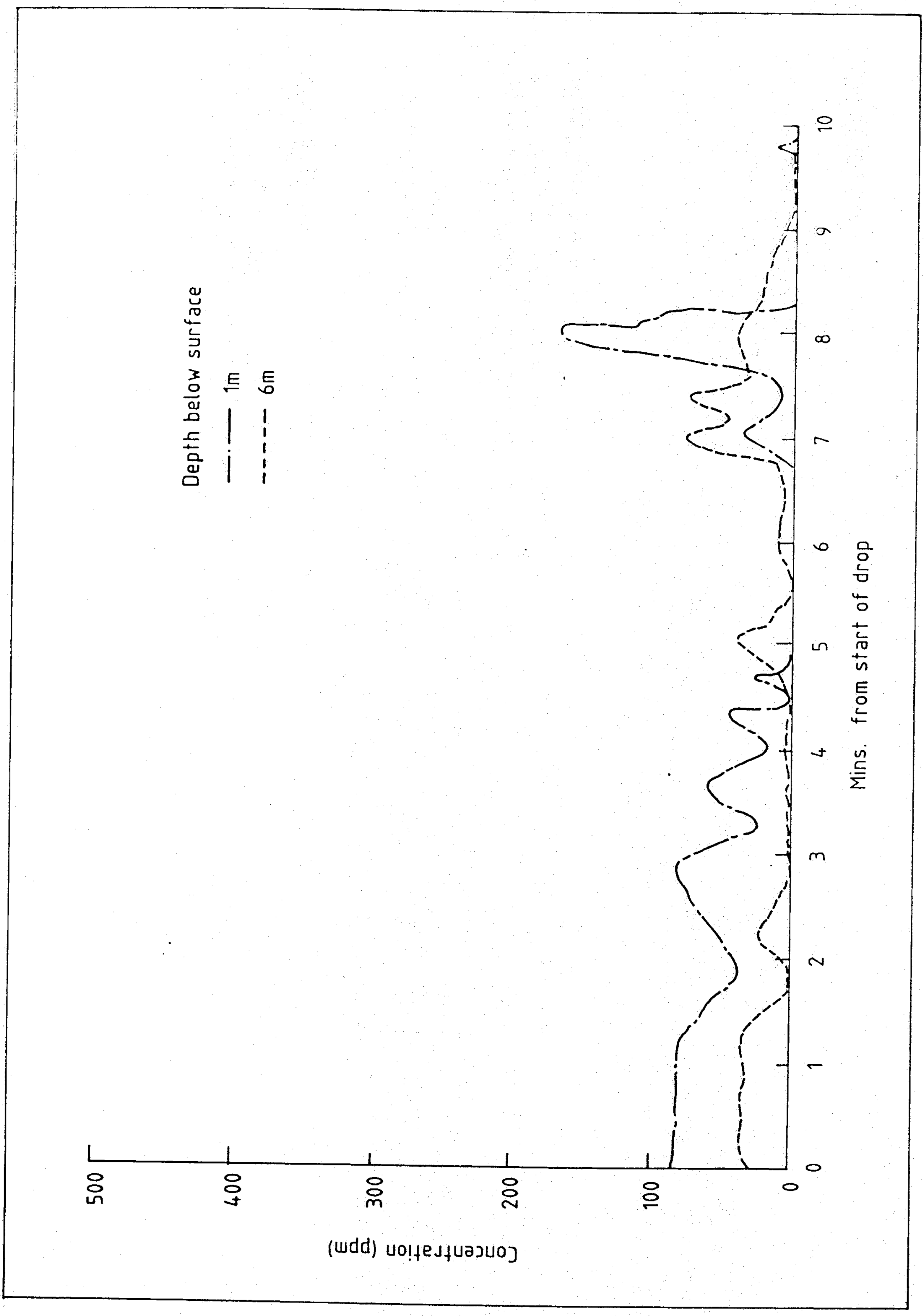


Fig 22 Suspended solids concentrations in upper.part of water column for drop number 3

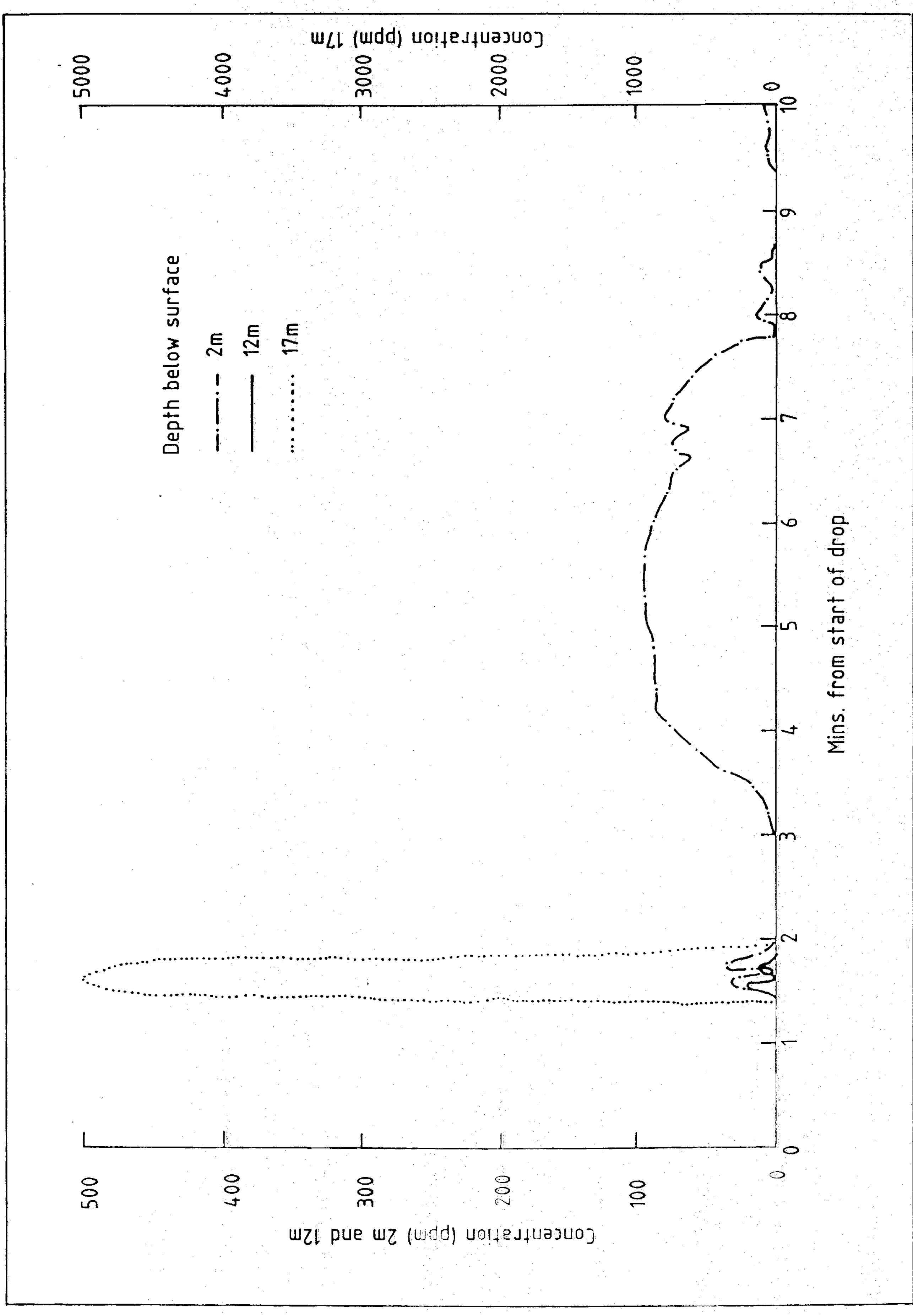


Fig 23 Suspended solids concentrations in upper part of water column for drop number 7

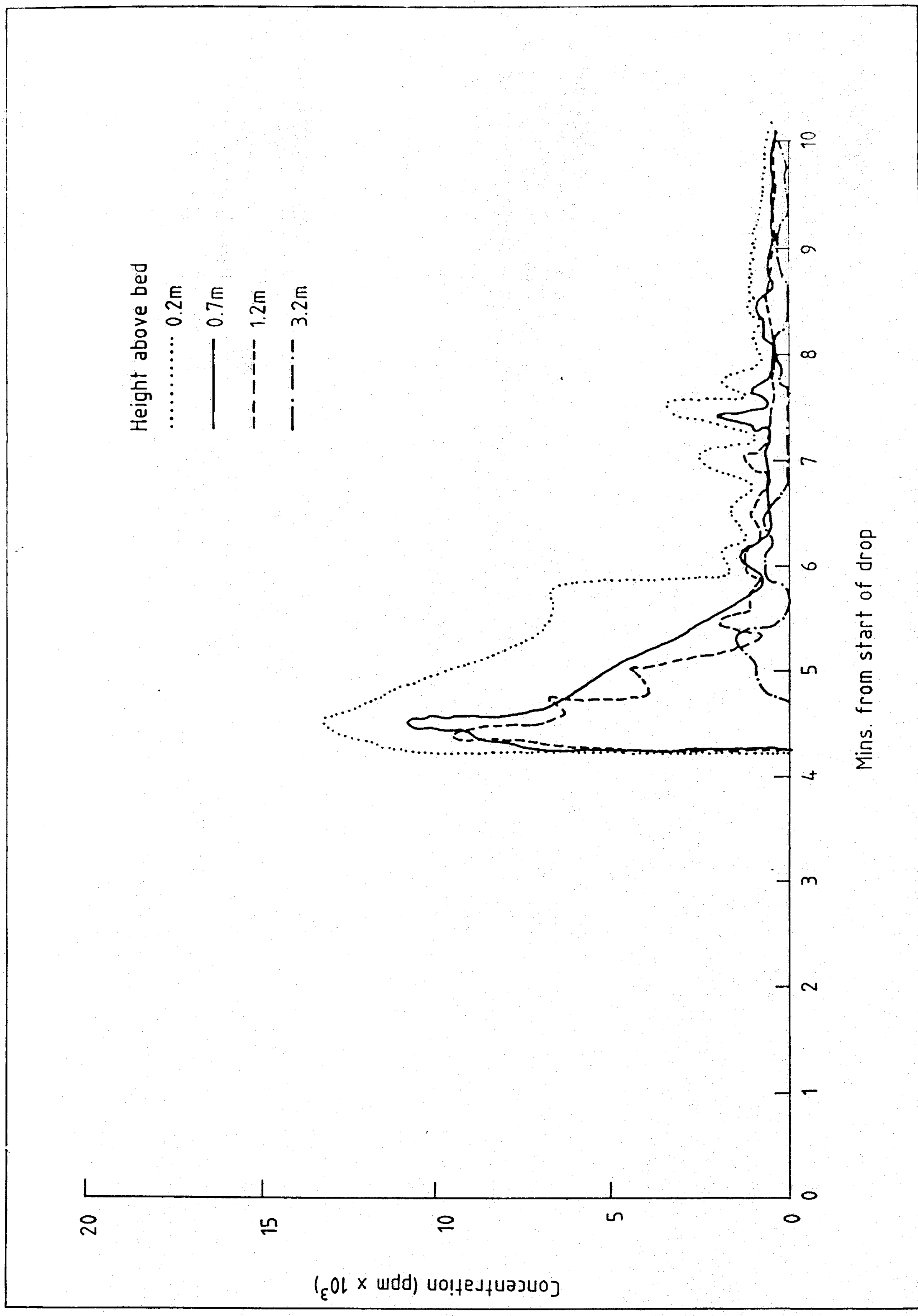


Fig 24 Suspended solids concentrations near the bed
for drop number 14

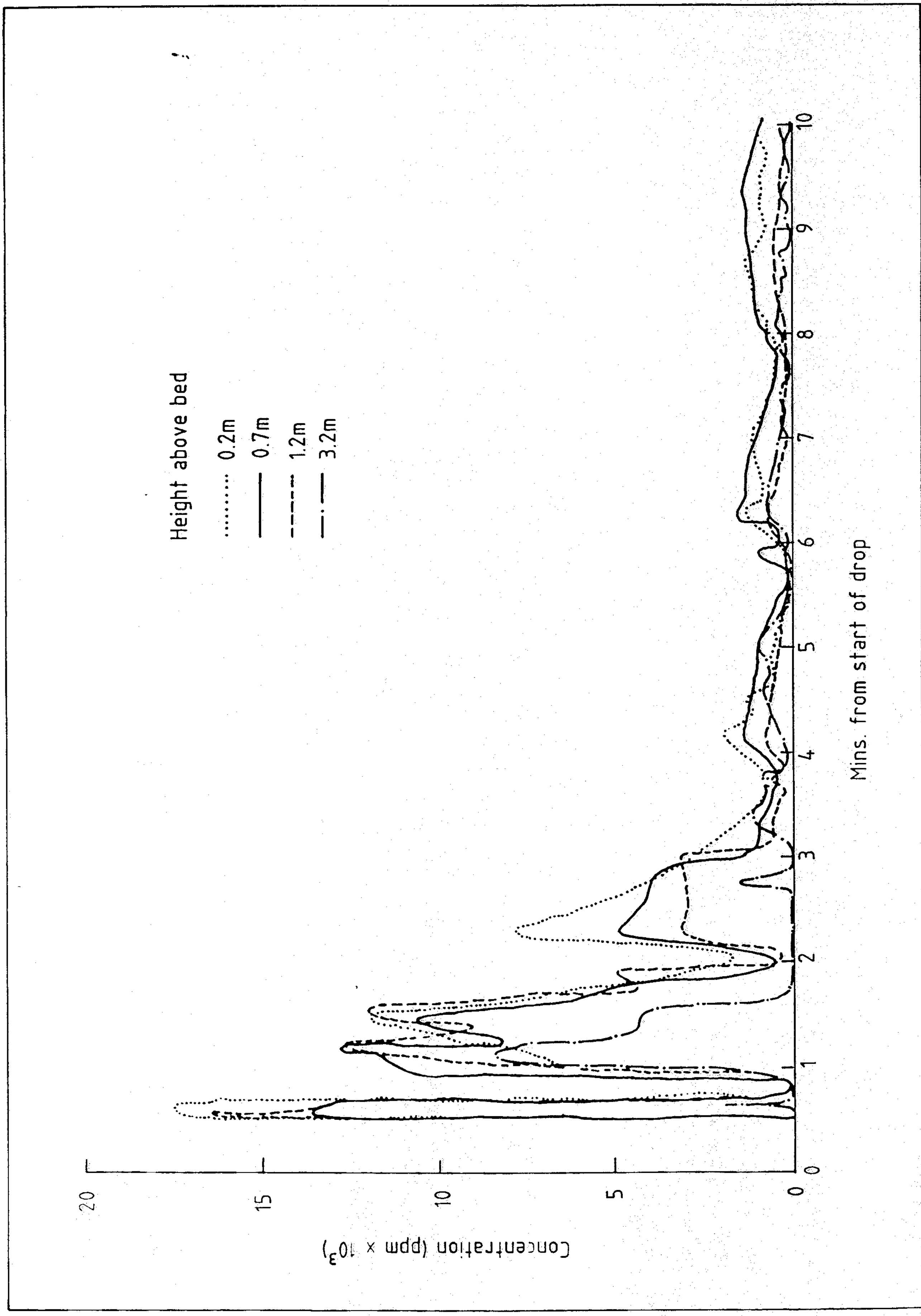


Fig 25 Suspended solids concentrations near the bed for drop number 16

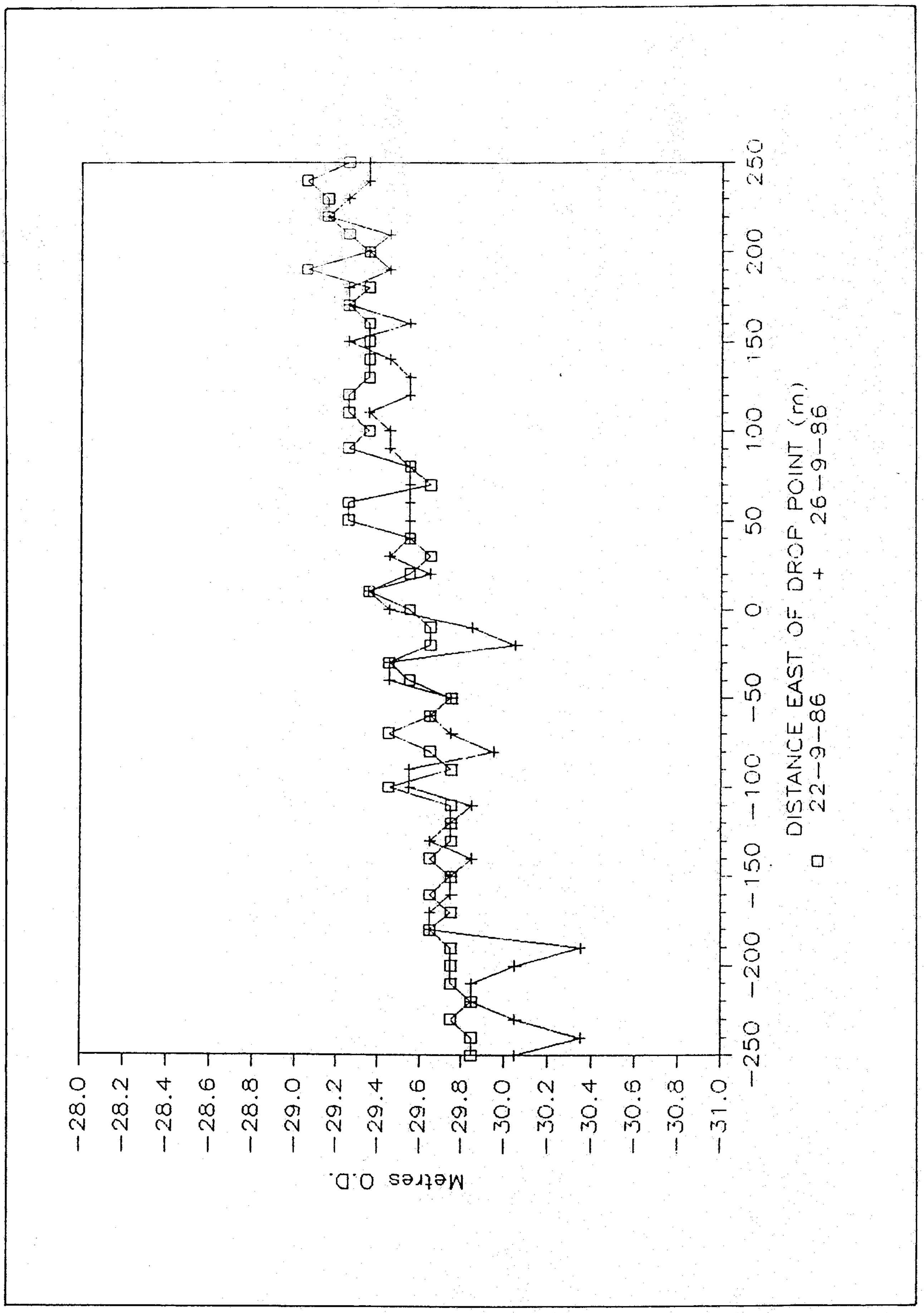


Fig 26 Pre and post disposal hydrographic survey of Line D

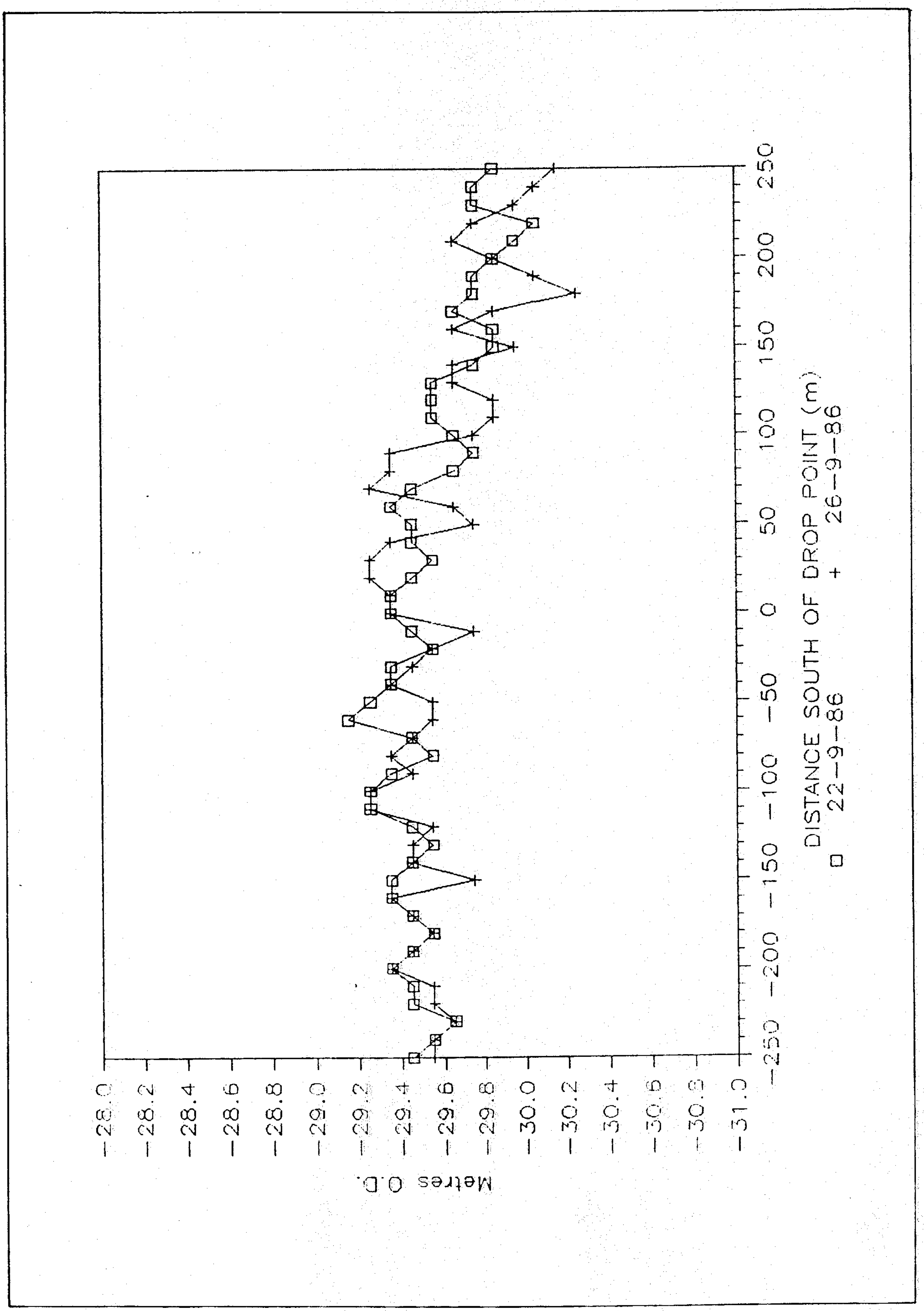


Fig 27 Pre and post disposal hydrographic survey of Line 4

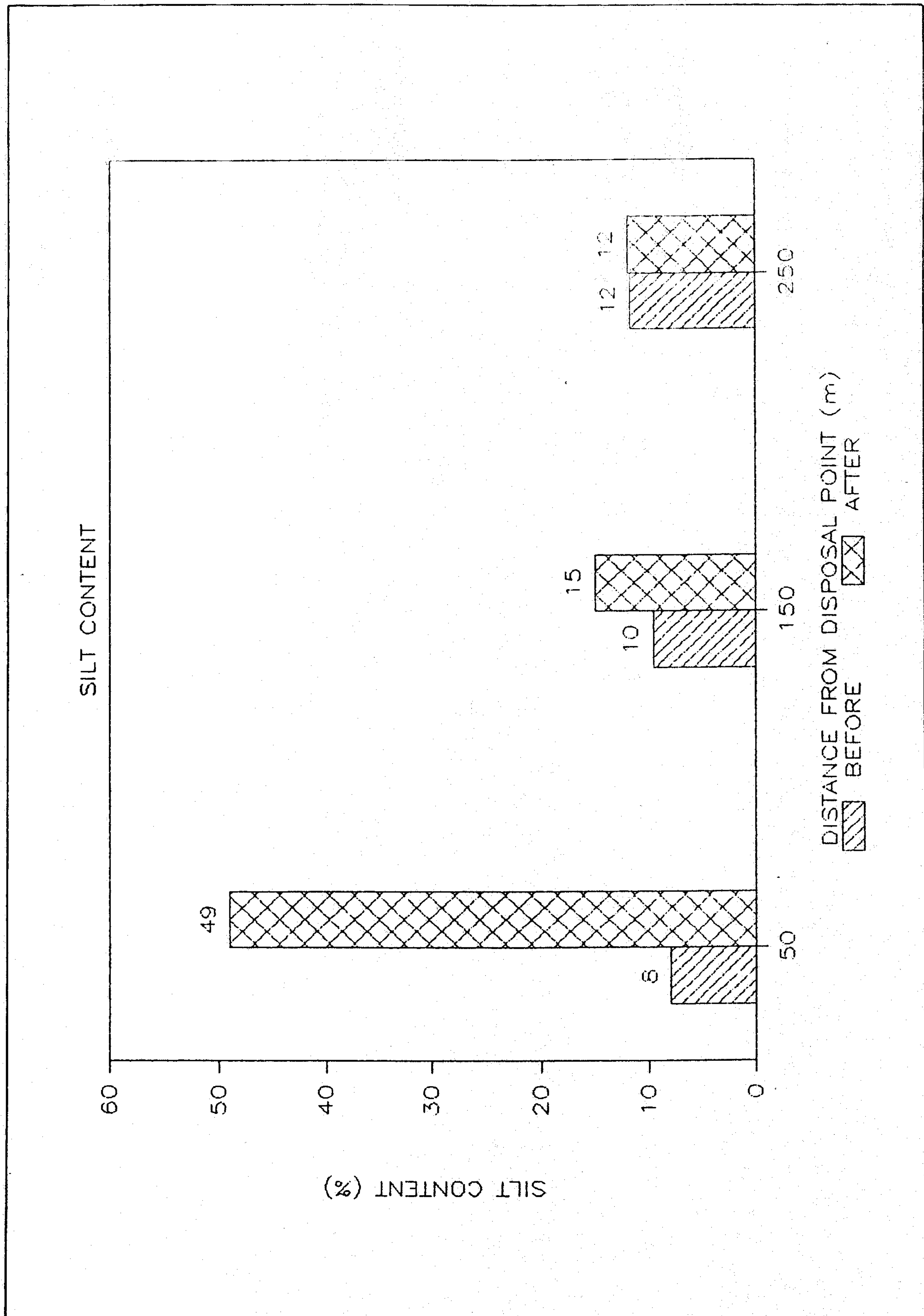


Fig 28 Silt content of bed samples taken in test area before and after disposal

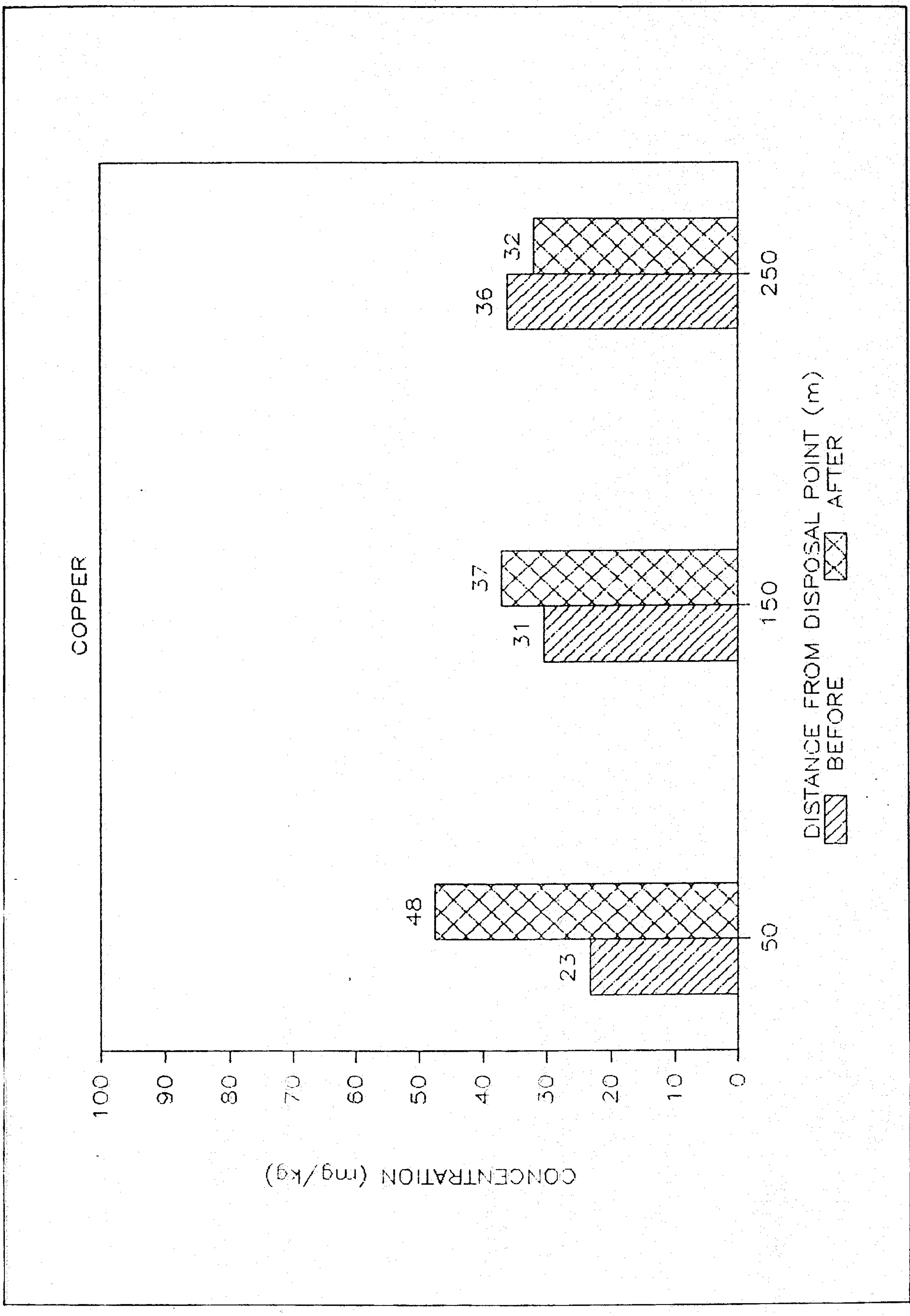


Fig 29 Copper concentrations on bed samples taken in test area before and after disposal

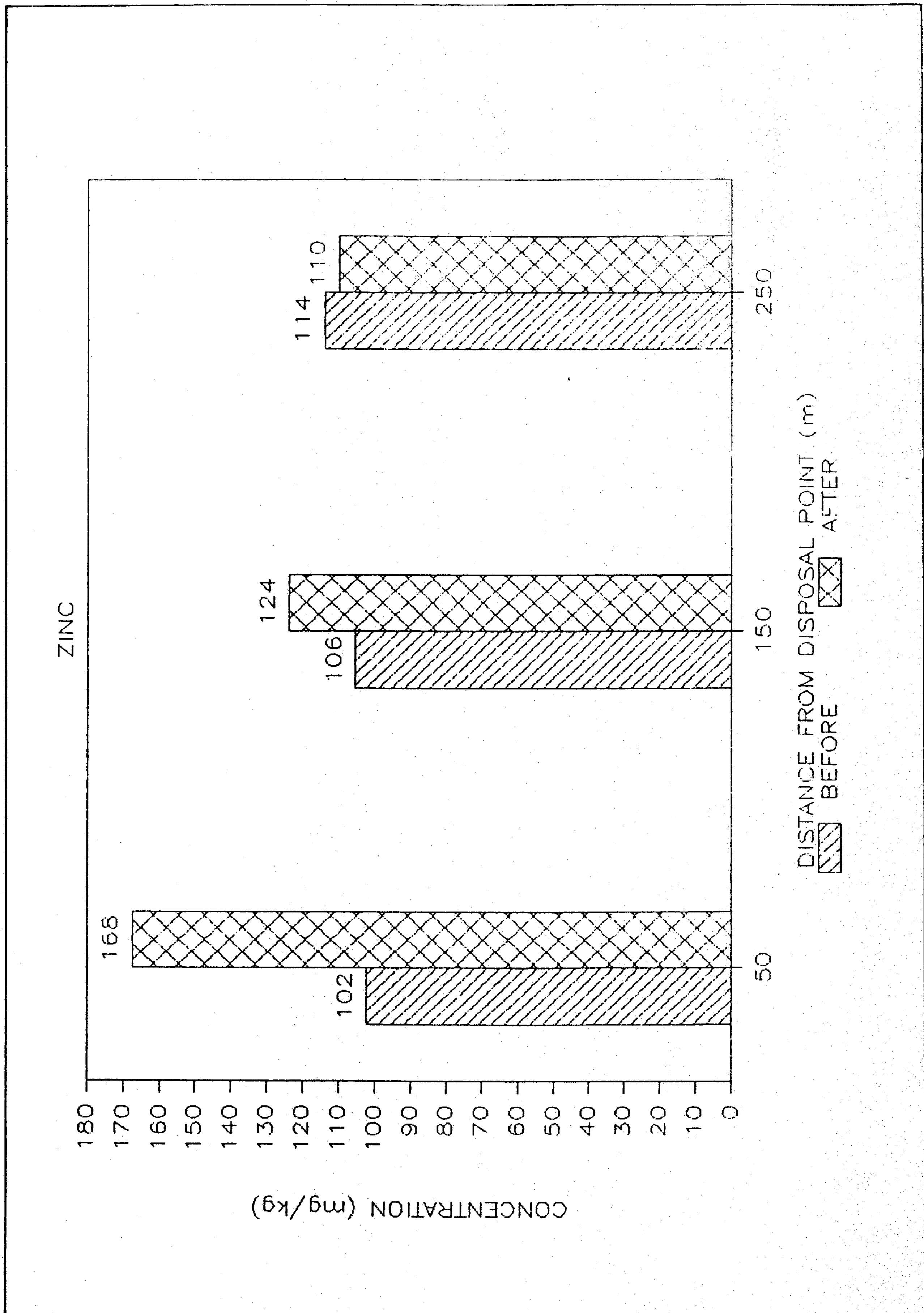


Fig 30 Zinc concentrations on bed samples taken in test area before and after disposal

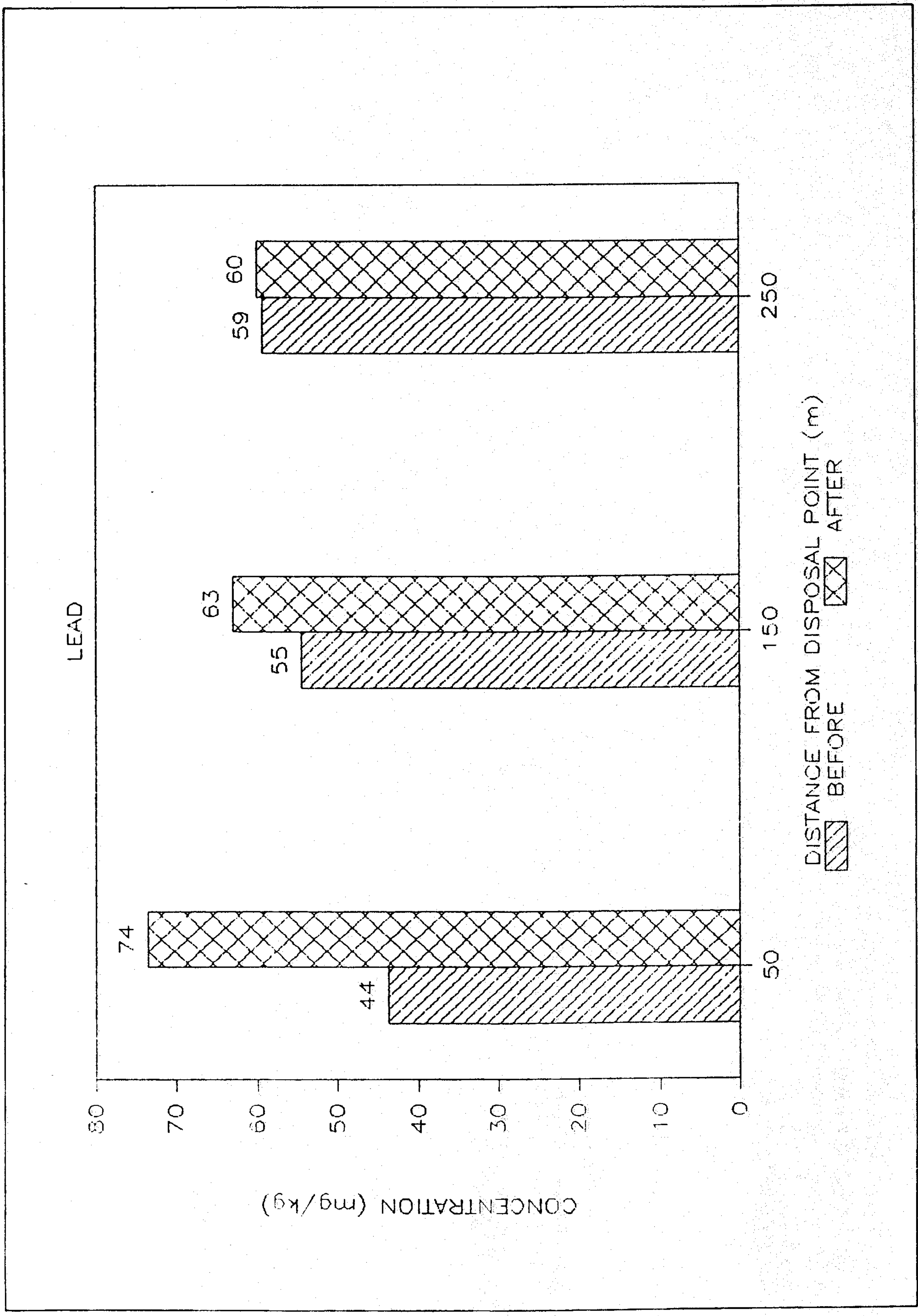


Fig 31 Lead concentrations on bed samples taken in test area before and after disposal

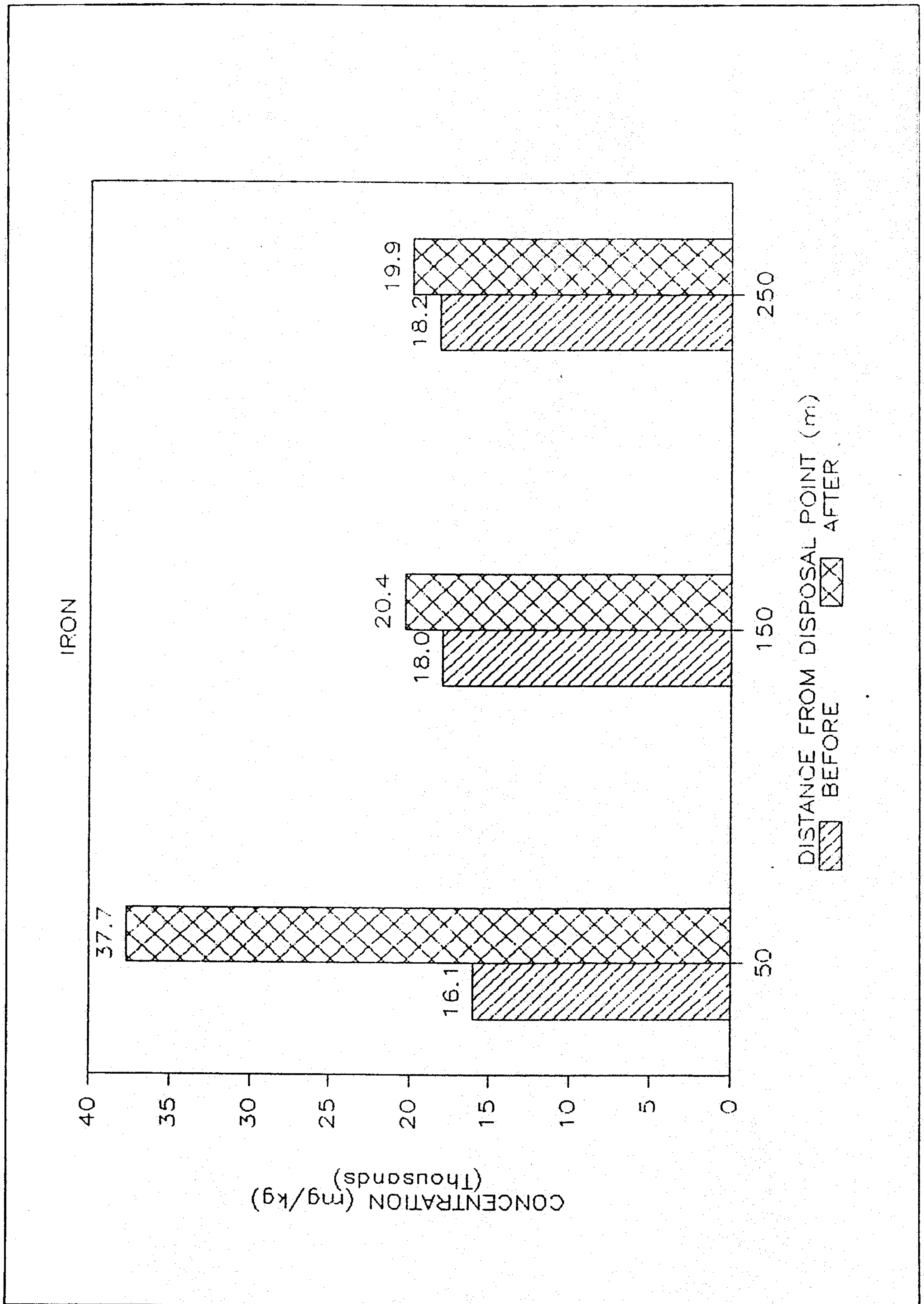


Fig 32 Iron concentrations on bed samples taken in test area before and after disposal

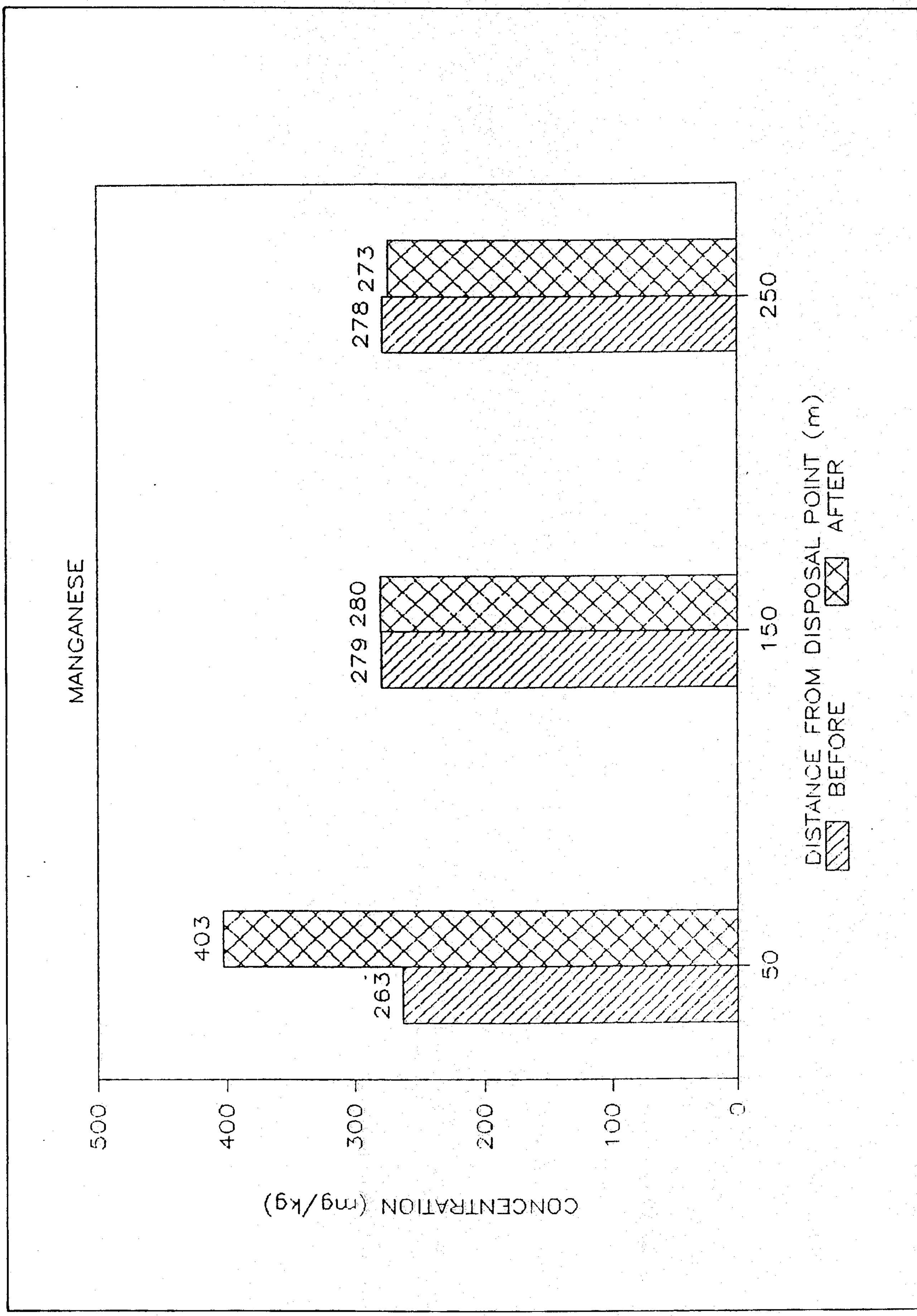


Fig 33 Manganese concentrations on bed samples taken in test area before and after disposal

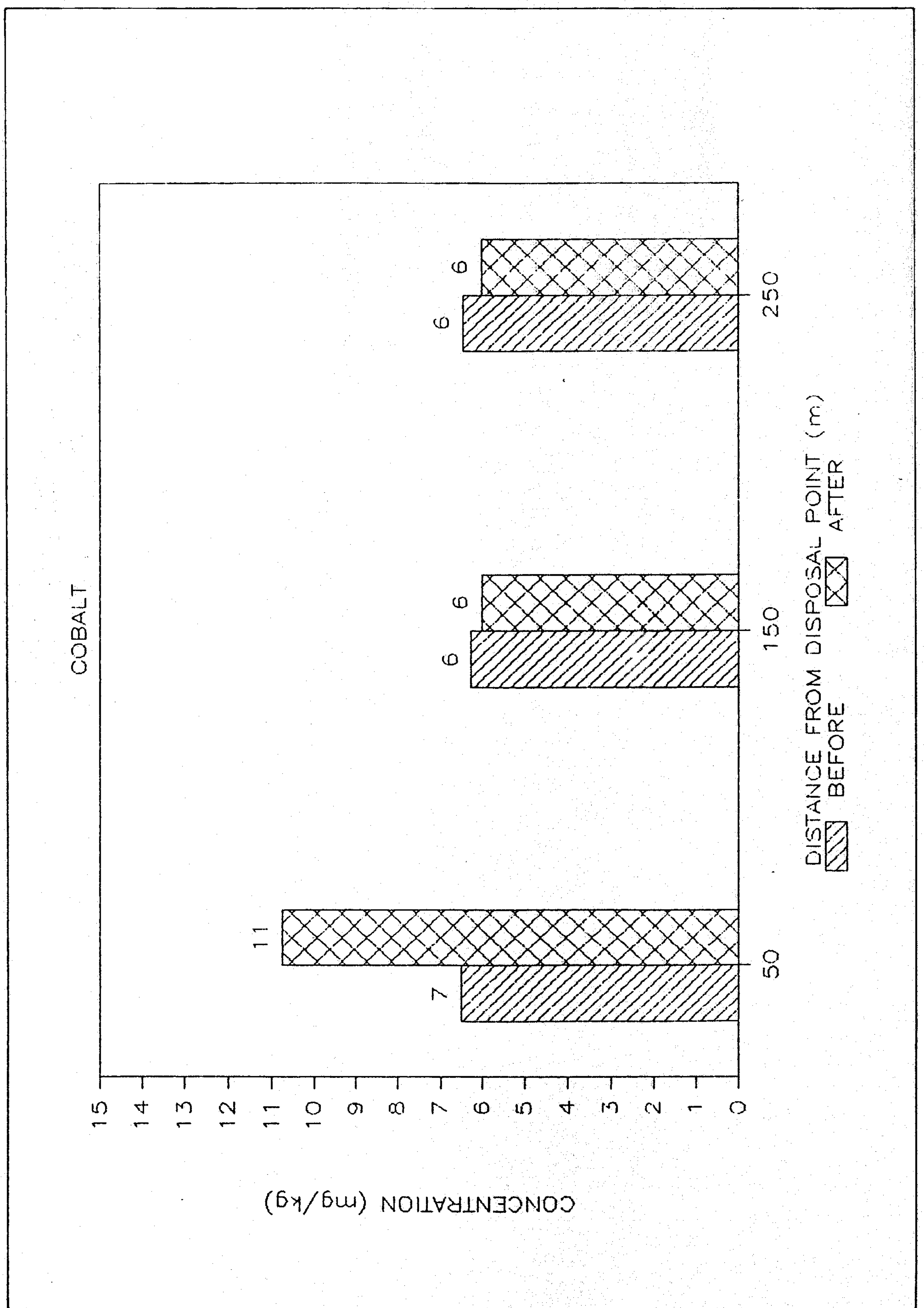


Fig 34 Cobalt concentrations on bed samples taken in test area before and after disposal