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Hydraulics Research
Wallingford

DISPERSAL OF DREDGED MATERIAL

Application of short term model for cohesive sediments

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Report SR 210
May 1989

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CONTRACT

This report describes work funded by the Department of the Environment under Research contract PECD 7/7/164 for which the nominated officer was Mr C E Wright. It is published on behalf of the Department of the Environment, but any opinions expressed in the report are not necessarily those of the Funding Department. The work was carried out by Mr A P Diserens in Dr E A Delo's Section in the Tidal Engineering Department of Hydraulics Research, Wallingford under the management of Mr M F C Thorn.

ABSTRACT

There are two main factors governing the suitability of a site for the disposal of dredged material. Firstly, short-term recycling of material back into the dredged area must be low enough for this method of disposal to be cost effective. Secondly, the environmental impact must be within an acceptable level.

To quantify the degree of short term re-cycling it is necessary to know the fate of the disposed material. In the past this has been done using tracer studies to look at the suitability of specific sites. However tracer studies involve considerable organization which limits the number of positions that can be investigated. Clearly a mathematical model which will predict the fate of material disposed of at any given time and position will enable more effective selection and evaluation of disposal sites with respect to term re-cycling.

This report details the application of a mathematical model for predicting the short term dispersal of muddy dredged material. The aim was to calibrate the model by simulating the distribution of deposited sediment on the bed after one particular disposal experiment and then verify the model by using the same parameters to simulate the deposited mass on the bed after another disposal experiment.

The short term dispersal model is applicable to predicting the fate of cohesive sediments either out-washed during aggregate dredging or discharged by side-casting of dredged material. It is therefore a useful tool in assessing the appropriateness of proposed disposal sites in UK tidal waters in connection with licence applications for the disposal of dredged material.

Existing field data were used from a study associated with the proposed enlargement of a dredged channel. This has involved monitoring the dispersal of muddy dredged material, labelled with a radioactive tracer, from a floating pipe. The distribution of the sediment on the bed after disposal was determined by monitoring the radio-activity on the bed. Flow conditions and water depth were measured over the experimental period. Experiments had been carried out on both the flood and ebb tides.

Using the hydrodynamic data measured at the time of the study, the local bathymetry and the rate and duration of sediment input, the distribution of the disposed material on the bed was predicted using the model.

The model was calibrated by optimising the settling velocity and the diffusion coefficients to simulate as closely as possible the distribution of deposited sediment on the bed produced by the flood tide experiment. The settling velocity and the diffusion coefficients in the x and y directions for the sediment were unknown parameters. Accordingly, estimated values were chosen for initial model runs, these values were modified to produce a distribution similar to that found in the field survey.

In the course of the calibration runs it was found to be necessary to modify the equation for the rate of deposition to take into account the decrease in settling caused by horizontal flow. The model was also found to give more

satisfactory results with a constant floc settling velocity rather than as a function of suspended sediment concentration. The median floc settling velocity was varied as part of the model optimising process.

The model was then verified by using the optimised values of settling velocity and diffusion coefficients to simulate the ebb tide deposition plume.

The distribution of deposited sediment from the flood and ebb tide experiments were simulated within acceptable limits using the optimised values. A slight deviation of the angle of the ebb tide simulation was thought most likely a result of the limitations of the hydrodynamic data collected at the time of the experiment.

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1 INTRODUCTION

The increase in size and draft of shipping in recent years has resulted in an increase in dredging operations throughout the world. Since dredging operations are expensive, methods are continually being sought to increase cost effectiveness. For economic reasons much of the dredged material from these operations is disposed of back into the marine environment. With the increase in dredging operations new sites for marine disposal are being sought and existing sites are being reassessed.

There are two main factors governing the suitability of a site for the disposal of dredged material. Firstly, short-term recycling of material back into the dredged area must be low enough for this method of disposal to be cost effective. Secondly, the environmental impact must be within an acceptable level.

To quantify the degree of short term re-cycling it is necessary to know the fate of the disposed material. In the past this has been done using tracer studies to look at the suitability of specific sites. However tracer studies involve considerable organization which limits the number of positions that can be investigated. Clearly a mathematical model which could predict the fate of material disposed of at any given time and position would enable more effective minimisation of short term recycling.

Due to the rising political importance of environmental issues, the affects of the disposal of polluted waste on the marine environment are being increasingly investigated. The disposal of dredged material is no exception. Sediments dredged from channels passing through industrial areas are usually high in pollutants, particularly heavy metals. The prediction of the movement of these sediments would also be of considerable benefit when assessing the environmental implications of proposed disposal schemes.

The objective of the work was to create an economic means of predicting the short term dispersion of disposed dredged material in tidal waters. This report details the application of a short term dispersal model previously developed by Hydraulics Research (Ref 1). The aim was to simulate the dispersal of muddy dredged material measured during a field study in Ban Don Bay, Thailand. The field data were collected during a study associated with the proposed enlargement of a dredged channel in the bay. This involved monitoring the dispersal of dredged material, labelled with a radioactive tracer, discharged directly from a dredger. The distribution of the sediment on the bed after disposal was found by monitoring the radio-activity on the bed. Flow conditions and water depth were measured over the experimental period. Experiments were carried out on both the flood and ebb tides.

Using the hydrodynamic data measured at the time of the study and the local bathymetry, the distribution of the disposed material on the bed was predicted using the mathematical model. The model was first calibrated on the flood tide deposition plume. The settling velocity and dispersion coefficients were adjusted to give a distribution of deposited sediment on the bed as similar as possible to that found in the field. The model was then verified by using the settling velocity and dispersion coefficients found in the calibration to simulate the ebb tide deposition plume.

2 THE MATHEMATICAL MODEL

2.1 Description of physical processes

The dispersion and deposition of suspended solids depends mainly on advection by currents, the settling of the sediment and the diffusion due to natural turbulence in the flow.

In a turbidity cloud generated from a surface source, the horizontal component of velocity of a suspended particle is determined by the flow velocity of the water into which it falls. This is known as advection.

The vertical component of velocity of a suspended solid particle depends both on the characteristics of the flow, such as turbulence, and those of the sediment, such as size, shape and density of the particles and the tendency of the sediment to flocculate. The settling velocity reflects these properties.

The spread of material away from a dense cloud is known as diffusion. Longitudinal diffusion is caused by the difference in velocities of the water at the surface and at the bed. Lateral diffusion determines the rate of spread of the cloud due to natural turbulence in the moving current. In an estuary, the scale of turbulent eddies may be laterally restricted, so the cloud may form a long thin ribbon which spreads sideways only slowly.

These physical processes can be described by the combination of three equations. These include a partial differential equation for the spread of material from a point source, an equation for the loss of material from suspension due to settling, and an equation for the movement of material by the flow.

The solution is simplified by assuming that flow velocity, depth, and turbulent diffusion remain constant over the length of the plume. It is also assumed that the flow is uni-directional, parallel to the x-direction and that the material is fully mixed throughout the depth from the point of release. The basic equation then becomes:

$$\frac{\partial c}{\partial t} + \frac{\partial (uc)}{\partial x} - D_x \frac{\partial^2 c}{\partial x^2} - D_y \frac{\partial^2 c}{\partial y^2} + \frac{W_s}{d}(c - c_e) = 0 \qquad (1)$$

where:

c	= depth averaged concentration (kgm^{-3})
d	= water depth (m)
x,y	= co-ordinate directions parallel and normal to the flow (m)
u	= flow velocity in the x direction ms^{-1}
D_x, D_y	= Diffusion coefficients in the x and y directions respectively (m^2s^{-1})
W_s	= effective fall velocity (ms^{-1})
c_e	= depth averaged background concentration (kgm^{-3})
t	= time(s)

This partial differential equation is the continuity equation for the spread of material from a point source. The terms represent the rate of change of concentration with time, the rate of decrease of concentration per unit volume by advection, longitudinal diffusion, lateral diffusion and loss of material from suspension due to settling respectively.

2.2 Solution Technique

Equation (1) can be solved for a point release of material into flowing water. This gives a ~~g~~Gaussian distribution of suspended mass at any time. The centre of the plume moves downstream at the velocity of the water with decreasing concentration as a result of diffusion and settling. However this solution is limited by the constraints of constant hydrodynamic parameters (current velocity and direction, settling rate and water depth).

To develop a model which would accurately predict the dispersion of material in tidal waters, where the hydrodynamic parameters are constantly changing, the basic solution is applied repeatedly over short time steps. The hydrodynamic parameters are re-set each time step to represent field conditions. The water depth at the position of greatest concentration is taken as representative of the area and is used in the solution of the equation. The dispersion of the plume of dredged material is given by the convolution of discretised analytic solutions.

The area for which a solution is required is divided up into a grid of cells. The analytic solution is then solved in terms of mass at the centre of each cell. It is assumed that the mass is evenly distributed throughout the depth in each cell.

The combination solution is made up by treating each cell as a point source. The distribution of the mass originating in each cell after one time step is calculated using the analytic solution. The distribution is the same for all cells, in terms of mass fraction, since the dispersion coefficients and hydrodynamic parameters are assumed to be constant throughout the area. The mass in each cell at the end of a time step can then be calculated by summing the contributions from all other cells. This mass is subsequently used as the magnitude of the point source at the start of the next time step.

Discretising the solution leads to small discrepancies in the total mass. A correction is made for this when calculating the deposited mass during each time step to conserve total mass.

2.3 Calculation of suspended solids concentration and mass on bed

The concentration at the centre of each cell at the end of a given time step, can be calculated from the mass in the cell and the depth of the cell.

The flux of material settling to the bed in a cell is directly proportional to the suspended solids concentration at that time and the settling velocity of the material. Since the suspended solids concentration in a cell changes over a time step the average of the concentrations at the start and the end of the time step is used.

3 FIELD DATA

3.1 Background of study

The field data used for simulation of the dispersal of dredged material was obtained by Hydraulics Research during a study connected with the development of coastal ports in Thailand (Ref 2).

It was proposed to increase the size of the access channel in Ban Don Bay to enable passage of larger vessels to the port (Fig 1). The scheme entailed increasing the depth of the channel to a depth of 4m and a width of 60m and extension of the channel out to a natural water depth of 4m. The original access channel followed a bearing of 30° from the mouth of the Tapi river to beyond Ko Prap island from which the new extension would take a line due north to deeper water.

Discharge of material to extensive adjacent banks, via a floating pipe, was the economically favoured method of disposal. To determine the fate of material discharged in this way a radioactive tracer study was commissioned. This tracer study included experiments on both the flood and ebb tides. The activity of the bed in the area around the point of discharge was monitored after disposal to determine the distribution of the discharged material.

3.2 Hydrodynamic data and bathymetry

Tide levels throughout the experimental period were obtained from the tidal recording station at Ko Prap island (see Fig 1). During each disposal period measurements of current speed and direction were taken 1m above the bed at 20 minute intervals, using a Braystroke directional current meter. Measurements of wind speed and estimates of wave heights were also recorded. The results of these measurements are shown in Figure 2.

The bathymetry was estimated from the admiralty chart of the region. The bathymetry used in the model simulations is shown in Figures 3 and 4.

3.3 Tracer study procedure

For the tracer study Gold 198 was chosen, since its half life of 2.7 days was suitable for the planned duration of the study. In addition the attenuation of its principle emission (gamma radiation of 0.412 Mev) in marine sediments is sufficiently low that the measured activity is not affected by overlying sediment.

A sample of sediment from the area was cleaned and labelled with the radioactive isotope immediately prior to injection. The labelled sediment was then released with the dredged material at a constant rate during each disposal period. Subsequently the radioactivity of the bed in the vicinity of the disposal site was surveyed using a radiation detector towed along the bed. The radiation readings were corrected for bed background and isotope decay.

The site of the injection area was mid way along the proposed channel extension (see Figure 1). In order to examine the behaviour of dredged material discharged on both the flood and ebb flow two injections were made either side of high water on 24 March 1982. The actual times of the injections are shown in Figure 2. The flood injection was approximately 2.5h before high water and the ebb injection approximately 2.5h after high water. The duration of each injection period was approximately 30 min in both experiments. The density of the slurry was 1100 kgm^{-1} and the pumping rate was 100 m^3h^{-1}. The bed was surveyed 1 day, 3 days and 9 days after injection.

3.4 Tracer study results

The results of the bed activity surveys were plotted on previously prepared charts. From these, contour plots of iso-activity were drawn. Since the results of the survey after 1 day were the most comprehensive only these results have been used in this report (Figures 5 and 6).

The flood deposition plume extended approximately 1000m landward and had a maximum width of about 400m. The ebb deposition plume extended approximately 7 km seaward and had a width of between 100m and 300m throughout its length. The disparity in the tracer extent is in part a consequence of the stronger velocities of the ebb flow and in part because the injections did not coincide with the mid flood and mid ebb flows. The injection after high water was followed by 5h of ebb flow, whereas, that before high water was followed by only 1.5h of flood flow.

The iso-activity lines showed that the highest activity occurred at the point of injection, the activity decreasing exponentially with distance from this point.

4 MODEL APPLICATION

4.1 Model input and output

The model was modified from that used previously (Ref 1) to allow the sediment to be input as a specified mass over a number of time steps corresponding to the period of injection. This enabled fluctuations in flow direction and velocity over the injection period to be modelled more accurately. The program was run using the hydrodynamic data collected in the field and the actual bathymetry of the area. A grid size of 30m by 30m was used in the model which covered an area of 1500m by 1500m.

The output from the model was in the form of tables and contour plots of both the suspended concentrations and total mass deposited in each cell. Each set of output was sent to a file for future inspection and analysis.

4.2 Interpretation of field data

The field data results were in the form of a contour plot of iso-activity contour lines. In order to enable a direct comparison between the model output and the field results it was necessary to determine the equivalent mass per square metre of the iso-activity contour lines. Because the counts per minute on the bed was directly proportional to mass this could be found from the ratio of total mass to total activity.

Since there appeared to be an exponential decrease in activity with increasing distance from the injection point the following equation was used to approximate the total activity in each contour band:

$$R_i = A_i \ 10 \exp \{(\log r_i + \log r_{i+1})/2\} \qquad (2)$$

where

R_i = total activity in contour band i (cpm m²)
A_i = area in contour band i (m²)
r_i = activity of contour level i (cpm)

This relationship held for all contour bands except the 500 cpm to 1000 cpm contour band of the ebb tide plume which extended in a long thin plume beyond the model limits. The activity in the area beyond the model limits was not decreasing exponentially. Hence, for the area up to the model limits equation (2) was used and for the area beyond the model limits it was assumed that the activity was constant at 500 cpm. The amount of activity within the highest contour was estimated by assuming a peak activity.

The total activity within each contour is given in Table 1. A graph of cumulative activity against area for each plume (Figs 7 and 8) enabled the amount of activity outside the range of the lowest contours to be found by extrapolation.

The total mass corresponding to the total activity was calculated from the dry density, the pumping rate, and the duration of sediment input.

The mass per unit area of material on the bed may be assumed to be proportional to the counts per minute in the same ratio as total mass to the total activity. This relationship was used to find the mass per square metre corresponding to the iso-activity lines of the field results. These values were then specified for the contours levels in the model output. This enabled direct comparison of the extent and position of the plume on the model output with the field data.

4.3 Analysis of results

The array of values corresponding to the masses on the bed at the time of the model output were processed to calculate the area and masses inside each contour band.

The area inside each contour band was calculated by multiplying the number of cells with values within each band by the area corresponding to the cell size, 900 m^2. The total mass within each contour band was calculated using the same method as the field data, substituting mass for activity in equation 2. This enabled a direct graphical comparison of the distribution of mass between the field results and the model output.

4.4 Calibration and verification

The model was calibrated by optimising the settling velocity and the diffusion coefficients to simulate as closely as possible the distribution of deposited sediment on the bed found in the field survey. The settling velocity and the diffusion coefficients in the x and y directions for the sediment were unknown parameters. Accordingly, estimated values were chosen for initial model runs and these values were modified to produce a distribution similar to that found in the field survey. A small number of runs were undertaken to ensure that the model was not over sensitive to grid size or time step.

In the course of the calibration runs it was found to be necessary to modify the equation for the rate of deposition to take into account the decrease in settling caused by horizontal flow. The horizontal flow generates a shear stress on the bed. A critical bed shear stress exists, τ_{bc}, above which there is no deposition. At shear stresses below this critical value deposition will occur (Ref 3).

The shear stress at the bed was calculated from the horizontal velocity 1m above the bed using the equation proposed by Sternberg (Ref 4),

$$\tau_b = 0.003\ \rho_w U_1{}^2 \qquad (3)$$

where

τ_b = bed shear stress (Nm^{-2})
ρ_w = fluid density (kgm^{-3})
U_1 = velocity 1m above bed (ms^{-1})

Although refinements of this relationship exist (Ref 3), this equation was chosen because of its simplicity. The accuracy of the bed shear stress calculated in this way was adequate for the application.

The amount of deposition at shear stresses below the critical value is approximated by the following equation

$$Ws = W_{50}\ (1 - \tau_b/\tau_{bc}) \qquad (4)$$

where

Ws = Effective fall velocity (ms^{-1})
W_{50} = median settling velocity of flocs (ms^{-1})
τ_b = bed shear stress (Nm^{-2})
τ_{bc} = critical bed shear for deposition (Nm^{-2})

The model was found to give more satisfactory results with a constant floc settling velocity rather than with settling velocity a function of suspended sediment concentration used previously. The median floc settling velocity was varied as part of the model optimising process.

The model was then verified by using the optimised values of settling velocity and diffusion coefficients to simulate the ebb tide deposition plume.

The parameters used in the final model runs are given in Table 2.

4.5 Comparison of model output with field data

The contour plots of the distribution of deposited sediment produced by the optimised parameters are shown in Figures 9 and 10. The simulation of the flood injection produced a deposited mass plume 1000m long and 300m wide with a bearing of approximately 180° for its long axis. The simulation of the ebb injection produced a long thin plume of between 100m and 300m wide and spread beyond the model limits, over 1500m in length. The long axis of the ebb deposition plume was orientated at a bearing of approximately 45°.

The contour plots of the model output were compared visually with the field survey results. Both the extent of the deposition plume and the relative positions and shape of the contours within the plume were compared with the field results. In addition the distribution in terms of area and masses within each contour band was compared. This data is tabulated (Tables 3 and 4) and shown in the form of histograms (Figs 11 to 14) for both the flood tide and ebb tide plumes.

The flood tide simulation (Fig 9), used for calibrating the model, compared closely in size and position with the field data (Fig 5) in size, distribution and orientation.

The distribution of the deposited sediment within the flood tide plume in the model results in terms of area and mass (Figs 11 and 12), agreed quite closely with the field data. The area within each contour band increased as the mass per unit area on the bed decreased. The distribution in terms of mass followed a different pattern. The mass increased to a peak with the largest proportion of the mass in the 0.075-0.038 kgm^{-2} band. The proportion of the mass decreased with decreasing mass per unit area. The trends were similar for both the field and model results. The mass in each contour band agreed to within 10% of the total mass.

The simulation of the ebb tide disposal used to verify the model (Fig 10) did not give quite such a close match with the field data (Fig 6). The bearing of the axis of the plume differed by about 10° from the field data. The width and the distribution within the plume did however compare well with the field data.

The distribution of the sediment within the simulated ebb tide plume (Figs 13 and 14) gave good agreement with the field data. The area within each contour band increased more markedly than that of the flood tide plume as the mass per unit area decreased. The amount of mass in each contour band also increased with decreasing mass per unit area. The distribution of mass was broadly similar for both the field and model results. The mass in each contour band agreed to within 12% of the total mass.

5 CONCLUSIONS

1. The model aimed to simulate the short term dispersal of dredged material measured during a field study in Ban Don Bay, Thailand. This study entailed monitoring of the dispersal of dredged material, labelled with a radioactive tracer. Tide levels and flow conditions were measured

during the disposal period. The experiments were carried out on both a flood and ebb tide at two positions.

2. The mathematical model took into account the hydrodynamic field data, the local bathymetry and the rate and duration of dredged material disposal. It was calibrated by optimising the coefficients of dispersion and the apparent settling velocity of the sediment to produce a distribution of deposited sediment as similar as possible to the flood tide disposal field results.

3. The model was verified by using the optimised coefficients for diffusion and apparent settling velocity, from the calibration, to simulate the distribution of sediment on the bed from the ebb tide injection.

4. The distribution of deposited sediment from the flood and ebb tide experiments (Figs 5 and 6) were simulated within acceptable limits (Figs 9 and 10) using the optimised values. The slight deviation of the angle of the ebb tide simulation is most likely a result of the limitations of the hydrodynamic data collected at the time of the experiment.

6 REFERENCES

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TABLES.

TABLE 1 : Conversion of isoactivity lines to mass per square metre

FLOOD TIDE PLUME

TOTAL MASS DISPOSED = 6600kg

= ESTIMATED VALUES

RADIO ACTIVITY (cpm)	RANGE AREA (m^2)	RANGE ACTIVITY (cpm m^2)	CUMULATIVE ACTIVITY (cpm m^2)	CUMULATIVE ACTIVITY (%)	MASS PER UNIT AREA (kgm^{-2})
<500		#$5.0*10^7$	$8.8*10^8$	100.0	
500	63750	$4.5*10^7$	$8.3*10^8$	95.2	0.004
1000	56250	$8.0*10^8$	$7.9*10^8$	90.1	0.008
2000	63125	$2.0*10^8$	$7.1*10^8$	81.0	0.015
5000	41875	$3.0*10^8$	$5.1*10^8$	58.2	0.038
10000	10625	$1.5*10^8$	$2.1*10^8$	24.4	0.075
20000	1813	$5.7*10^7$	$6.4*10^7$	7.3	0.151
>20000		#$7.0*10^6$			

EBB TIDE PLUME

TOTAL MASS DISPOSED = 6600kg

= ESTIMATED VALUES

500 α = OUTSIDE MODEL BOUNDARY

500 β = INSIDE MODEL BOUNDARY

RADIO ACTIVITY (cpm)	RANGE AREA (m^2)	RANGE ACTIVITY (cpm m^2)	CUMULATIVE ACTIVITY (cpm m^2)	CUMULATIVE ACTIVITY (%)	MASS PER UNIT AREA (kgm^{-2})
>500		#$1.1*10^8$	$8.8*10^8$	100.0	
500 α	428000	$1.5*10^8$	$7.7*10^8$	87.5	0.004
500 β	302500	$2.1*10^8$	$6.2*10^8$	70.3	0.004
1000	89300	$1.3*10^8$	$4.0*10^8$	45.9	0.015
2000	43100	$1.4*10^8$	$2.8*10^8$	31.4	0.038
5000	10000	$7.1*10^7$	$1.4*10^7$	15.9	0.075
10000	3130	$4.4*10^7$	$6.8*10^7$	7.8	0.151
>10000		#$2.4*10^7$	$2.4*10^7$		

TABLE 2 : Final parameters used in model

Diffusion coefficients, X Direction	=	5.00 m^2s^{-1}
Y Direction	=	0.50 m^2s^{-1}
Sediment median fall velocity	=	0.0015 ms^{-1}
Critical bed shear for deposition	=	0.50N m^{-2}
Time step	=	5 min
Grid size	=	30m by 30m
Model size	=	1500m by 1500m

TABLE 3 : Comparison of field data with model results, Flood tide

TOTAL AREA AND MASS INSIDE EACH CONTOUR LEVEL

= Estimated values

CONTOUR LEVEL (kgm^2)	FIELD SURVEY TOTAL AREA (m^2)	FIELD SURVEY TOTAL MASS (%)	MATHEMATICAL MODEL TOTAL AREA (m^2)	MATHEMATICAL MODEL TOTAL MASS (%)
0.004	238000	95.2	232000	88.0
0.008	174000	90.1	158000	82.0
0.015	118000	81.0	99000	72.6
0.038	54400	58.2	42300	52.0
0.075	12500	24.4	13500	28.8
0.151	1880	#7.3	3600	12.8

AREA AND MASS WITHIN EACH CONTOUR BAND

= ESTIMATED VALUES

CONTOUR BAND (kgm^2)	FIELD STUDY RANGE AREA (m^2)	FIELD STUDY RANGE MASS (%)	MATHEMATICAL MODEL RANGE AREA (m^2)	MATHEMATICAL MODEL RANGE MASS (%)
<0.004	--	#4.8	--	12.0
0.008-0.004	63800	5.1	74700	6.0
0.015-0.008	56300	9.1	58500	9.5
0.038-0.015	63100	22.8	56700	20.5
0.075-0.038	41900	33.8	28800	23.3
0.15-0.075	10600	17.2	9900	16.0
>0.15	1810	#7.3	2700	12.0

TABLE 4 Comparison of field data with model results, Ebb tide

TOTAL AREA AND MASS INSIDE EACH CONTOUR LEVEL

= Estimated values

	FIELD SURVEY		MATHEMATICAL MODEL	
CONTOUR LEVEL (kgm^2)	TOTAL AREA (m^2)	TOTAL MASS (%)	TOTAL AREA (m^2)	TOTAL MASS (%)
0.004	449000	70.3	335000	75.0
0.008	146000	45.9	154000	60.3
0.015	56900	31.4	81900	48.7
0.038	13800	15.9	28800	29.6
0.075	3750	7.8	6300	11.4
0.151	625	#2.7	900	2.7

AREA AND MASS WITHIN EACH CONTOUR BAND

= Estimated values

	FIELD STUDY		MATHEMATICAL MODEL	
CONTOUR BAND (kgm^{-2})	RANGE AREA (m^2)	RANGE MASS (%)	RANGE AREA (m^2)	RANGE MASS (%)
<0.004	--	#29.7	--	25.0
0.008-0.004	302500	24.4	180900	14.6
0.038-0.015	43100	15.5	53100	19.2
0.015-0.008	89300	14.4	72000	11.6
.075-0.038	10000	8.0	22500	18.2
0.15-0.075	3130	5.0	5400	8.7
>0.15	563	#2.0	900	2.9

FIGURES.

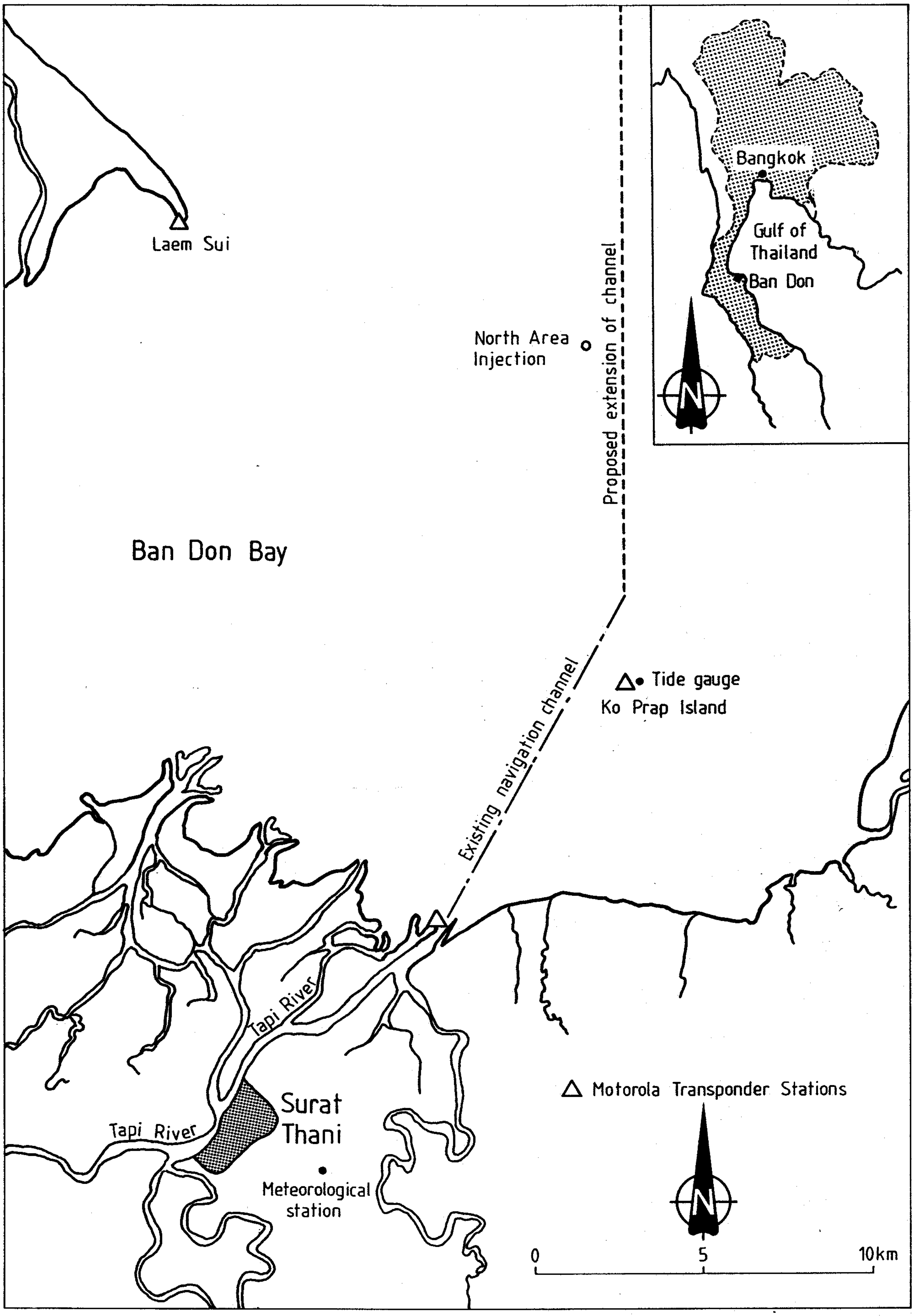

Fig 1 Field study area - Ban Don.

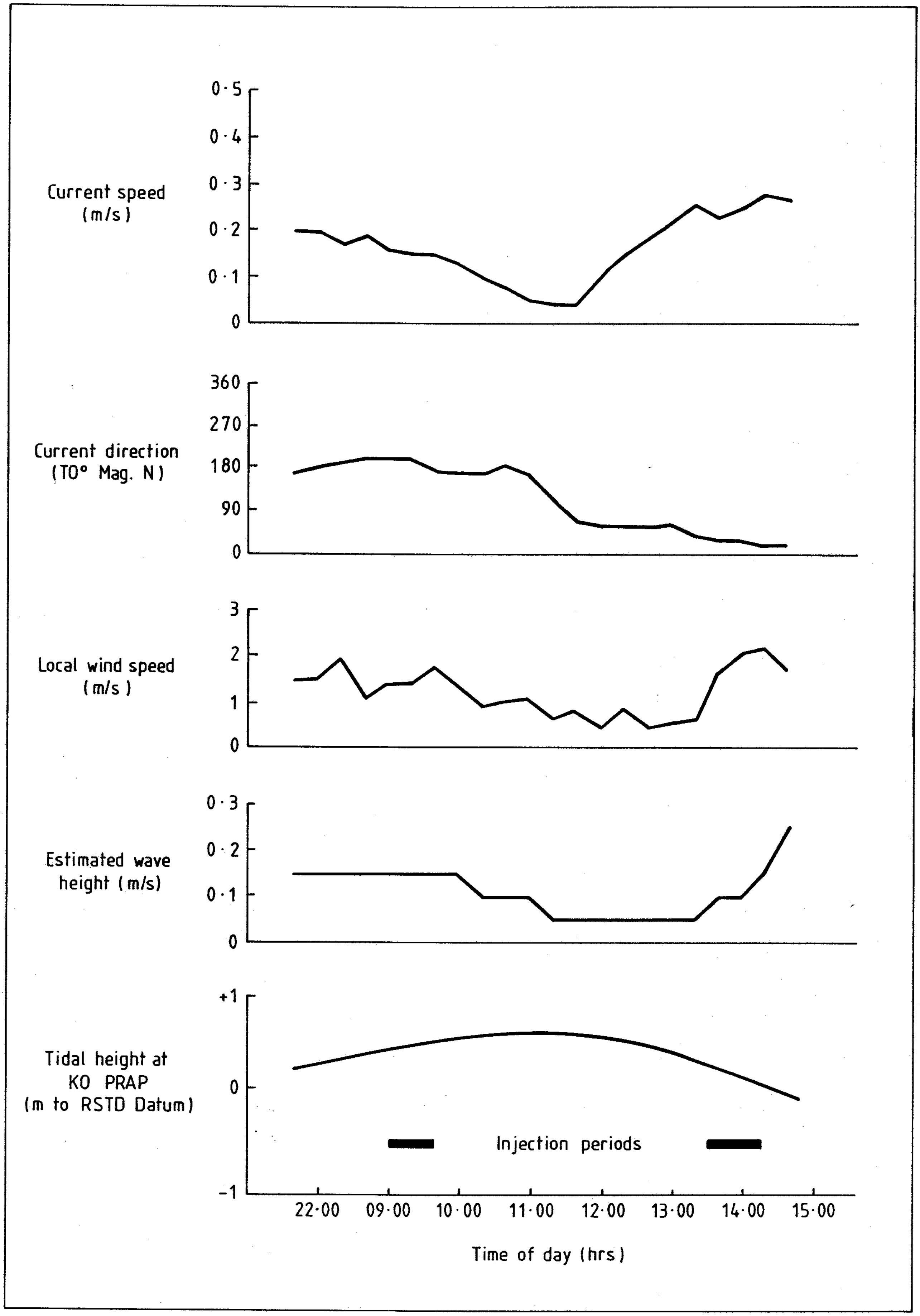

Fig 2 Hydrographic field data.

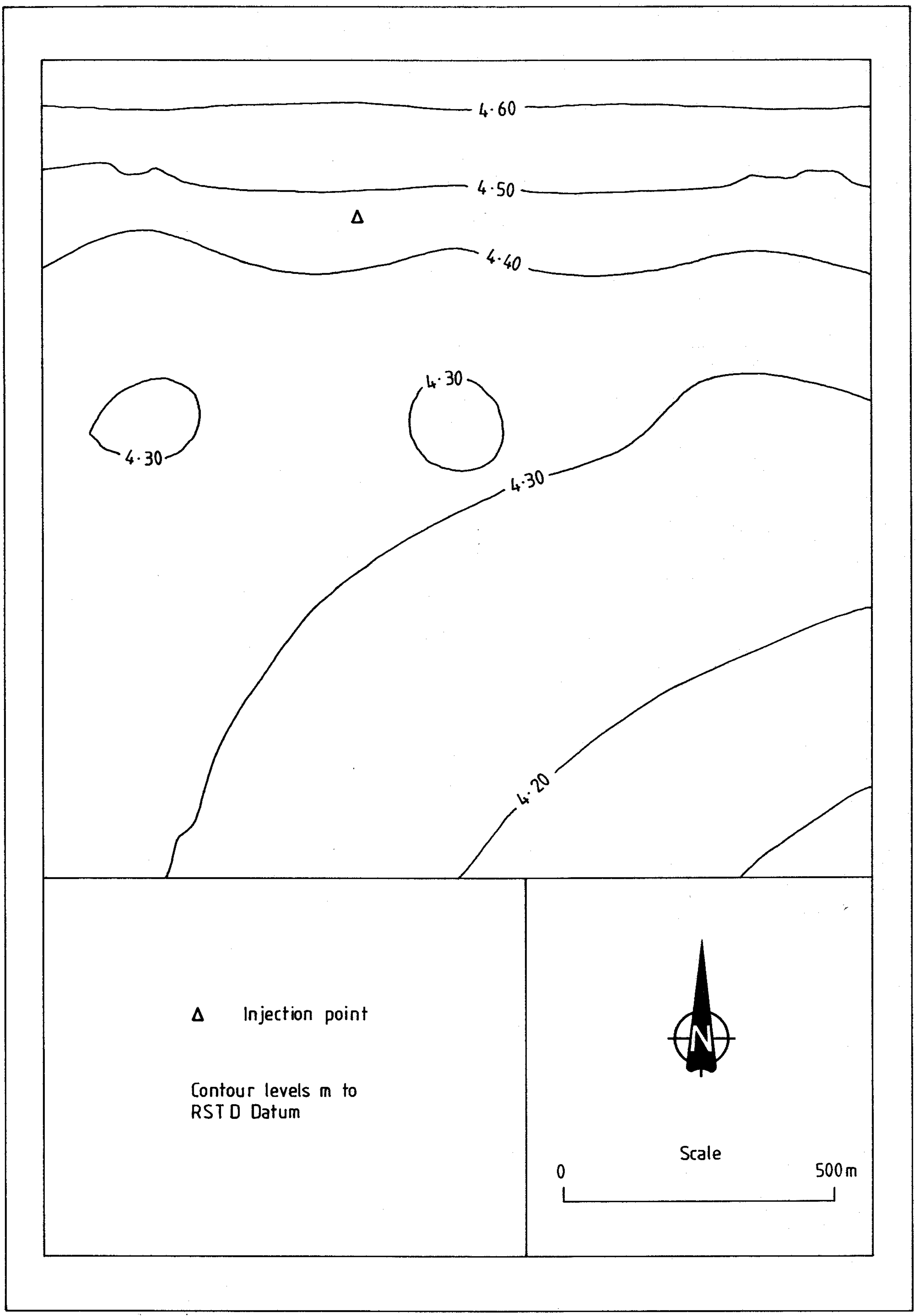

Fig 3 Bathymetry of flood tide plume model area.

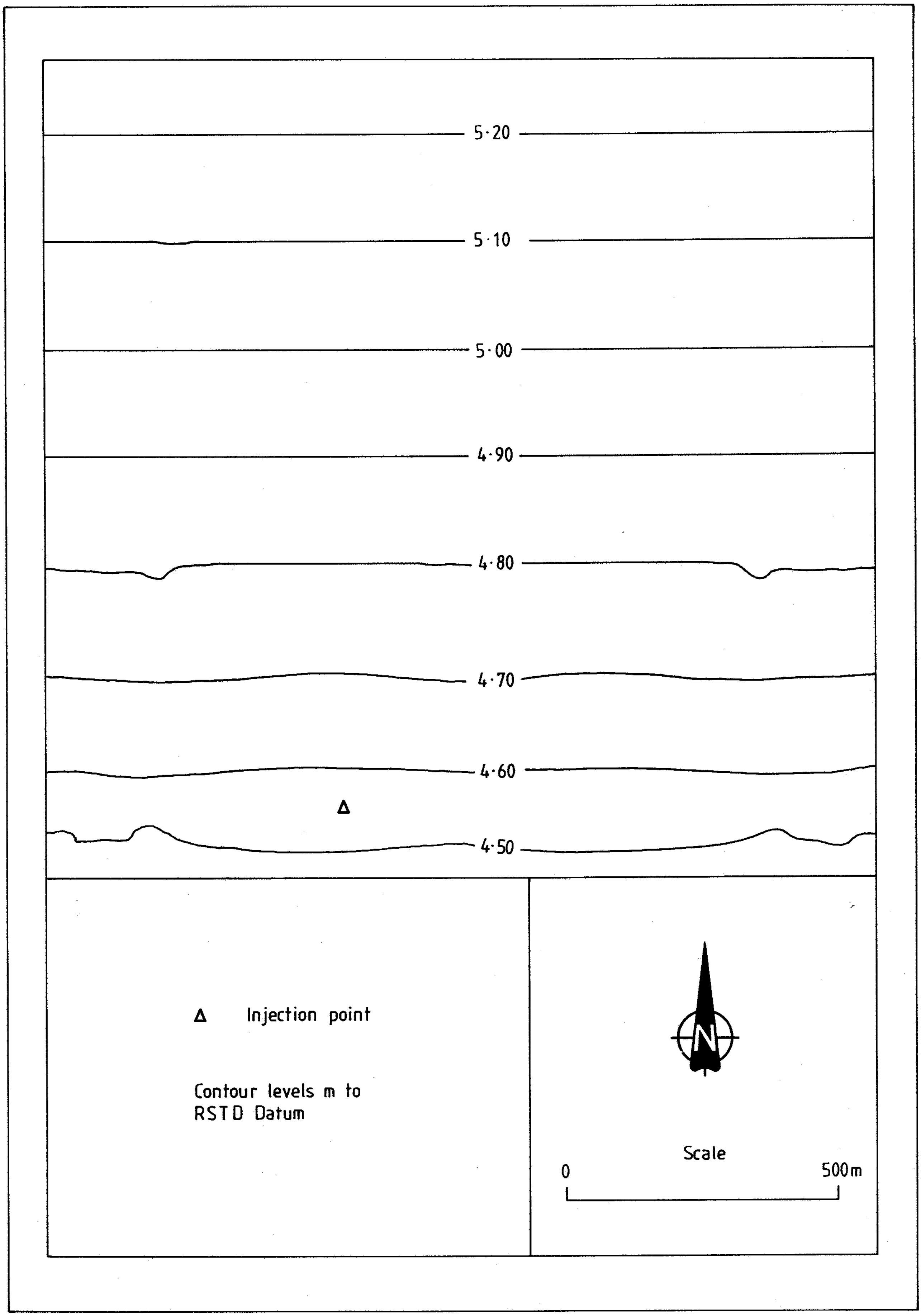

Fig 4 Bathymetry of ebb tide plume model area.

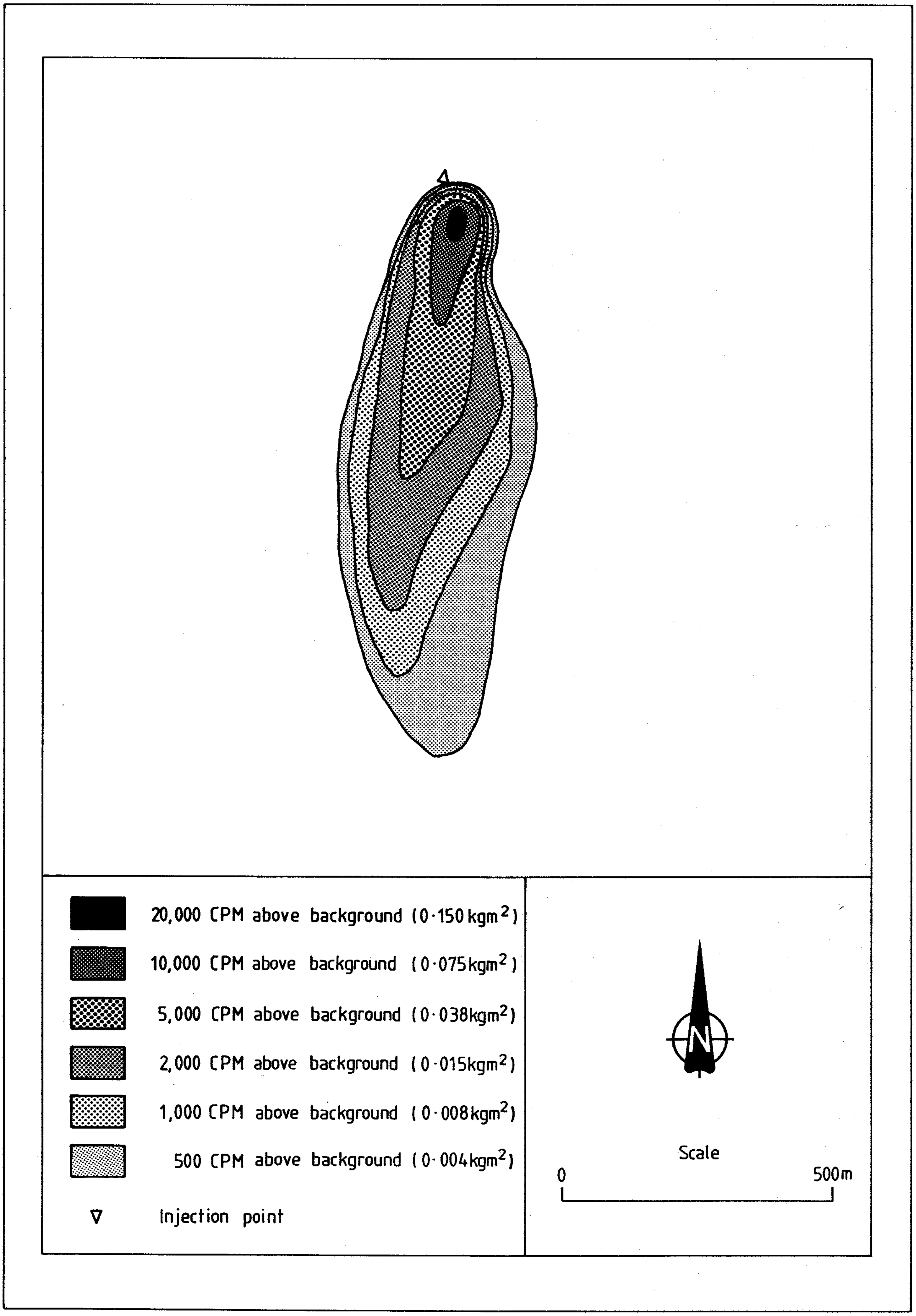

Fig 5 Flood tide plume field data distribution of mass on bed.

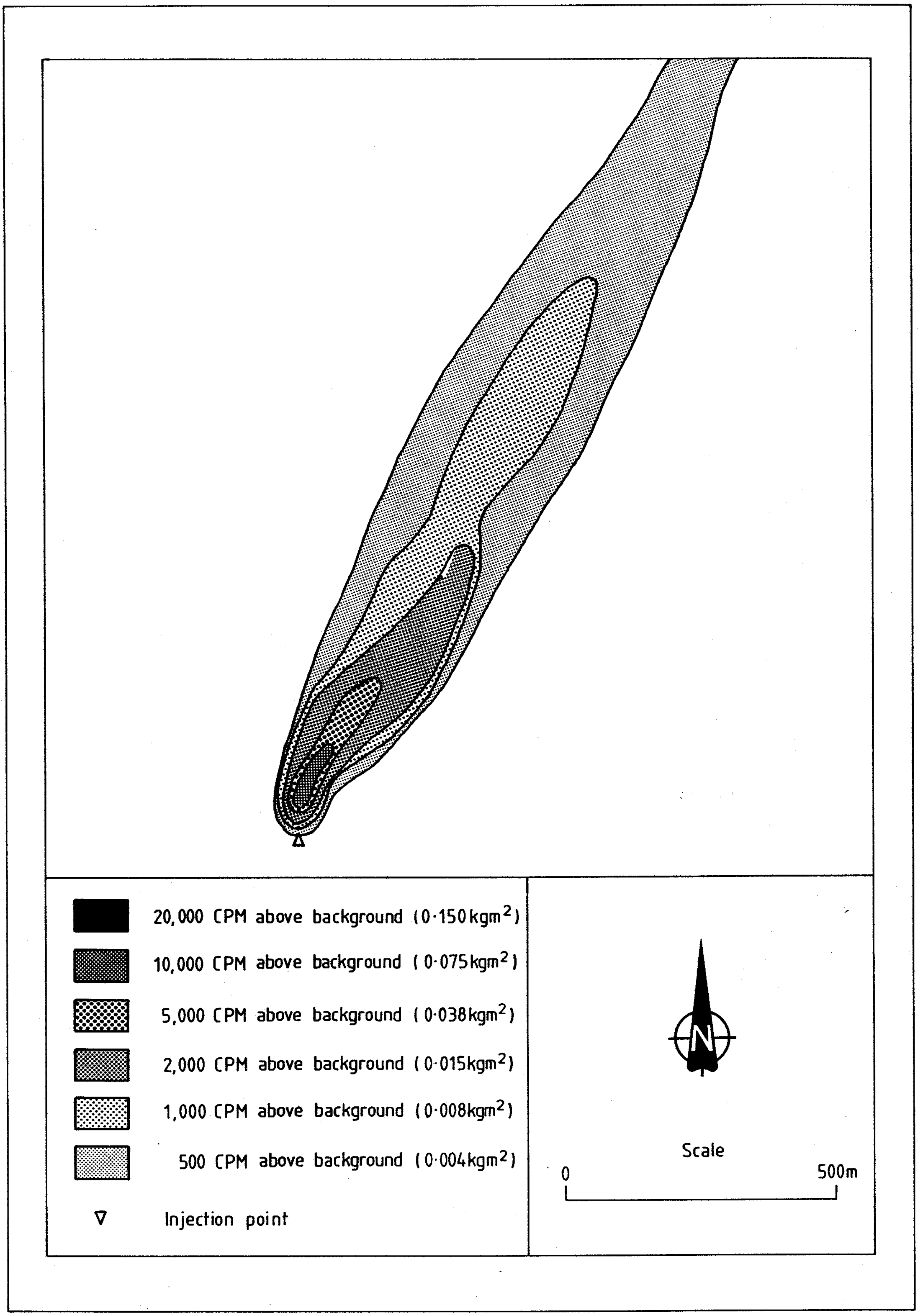

Fig 6 Ebb tide plume field data distribution of mass on bed.

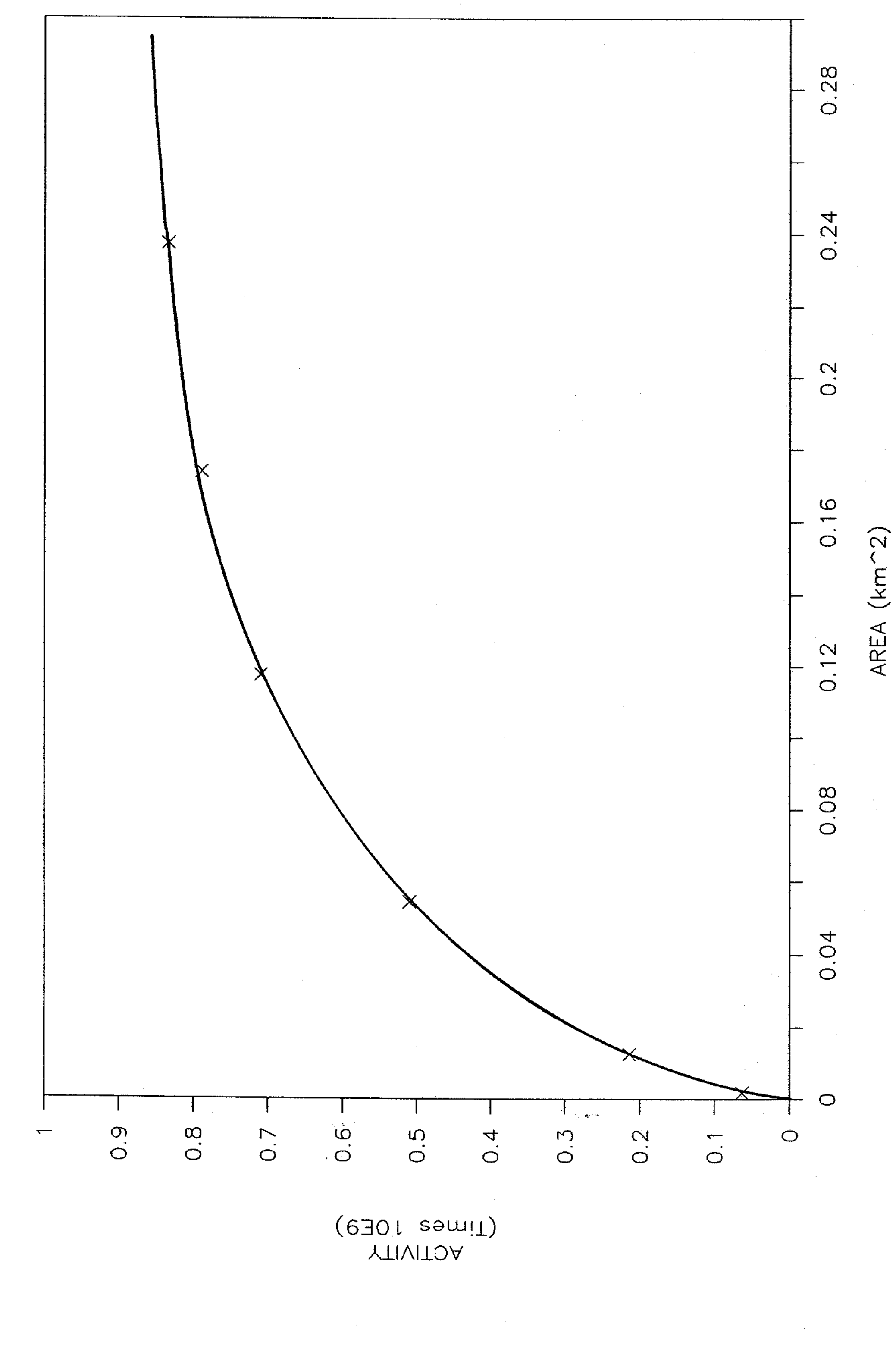

Fig 7 Total activity against area flood tide plume

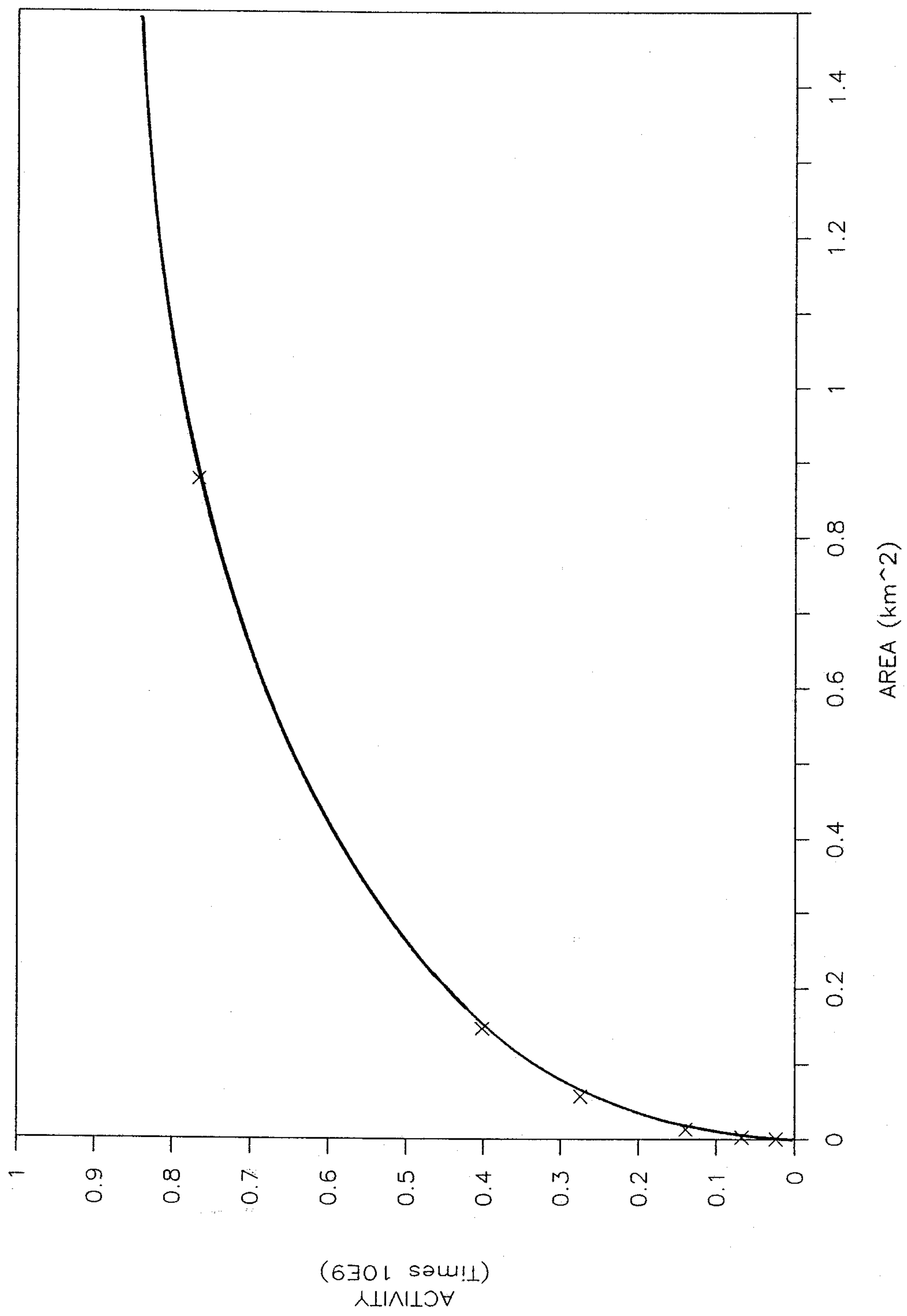

Fig 8   Total activity against area ebb tide plume

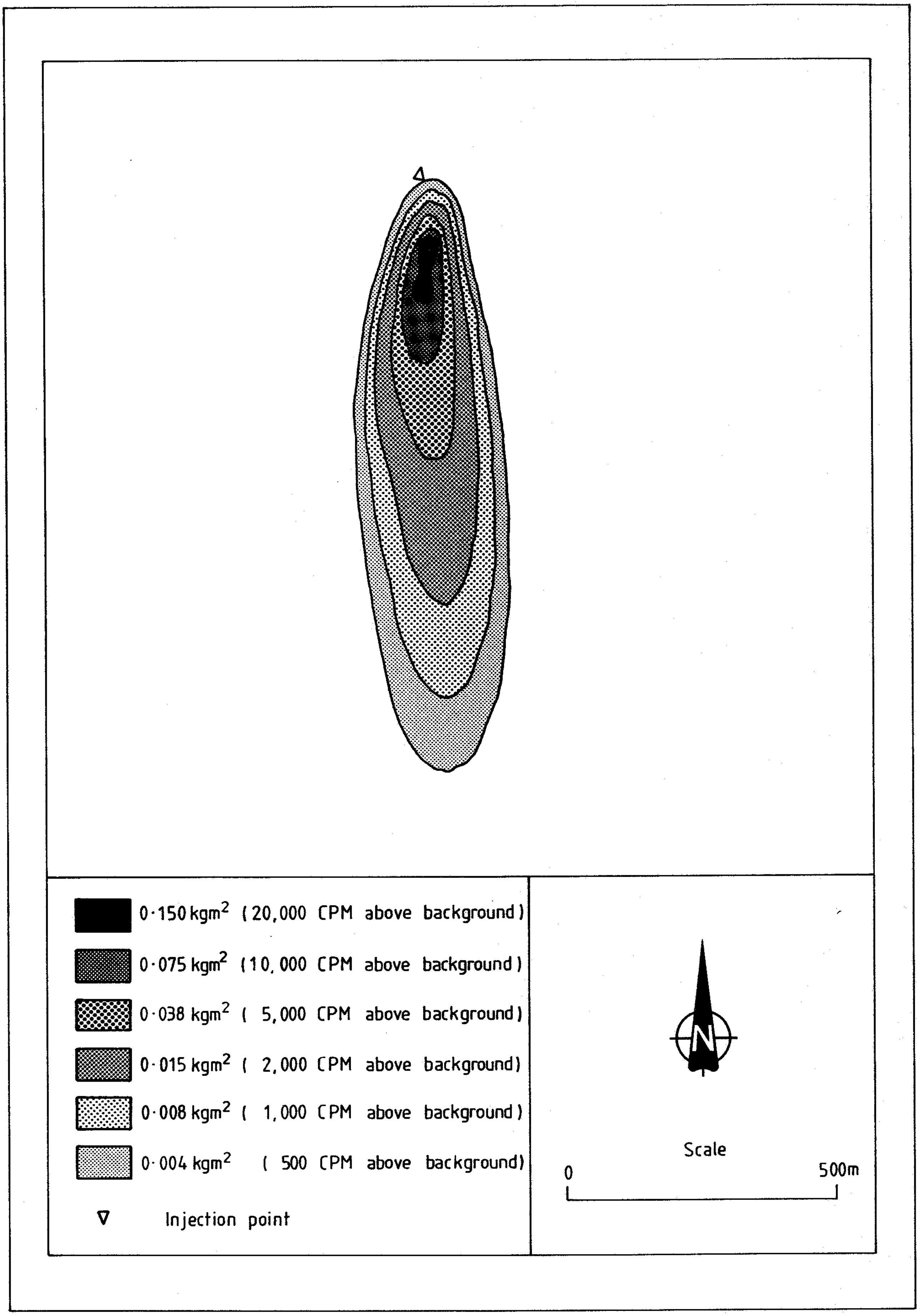

Fig 9 Flood tide model results distribution of mass on bed.

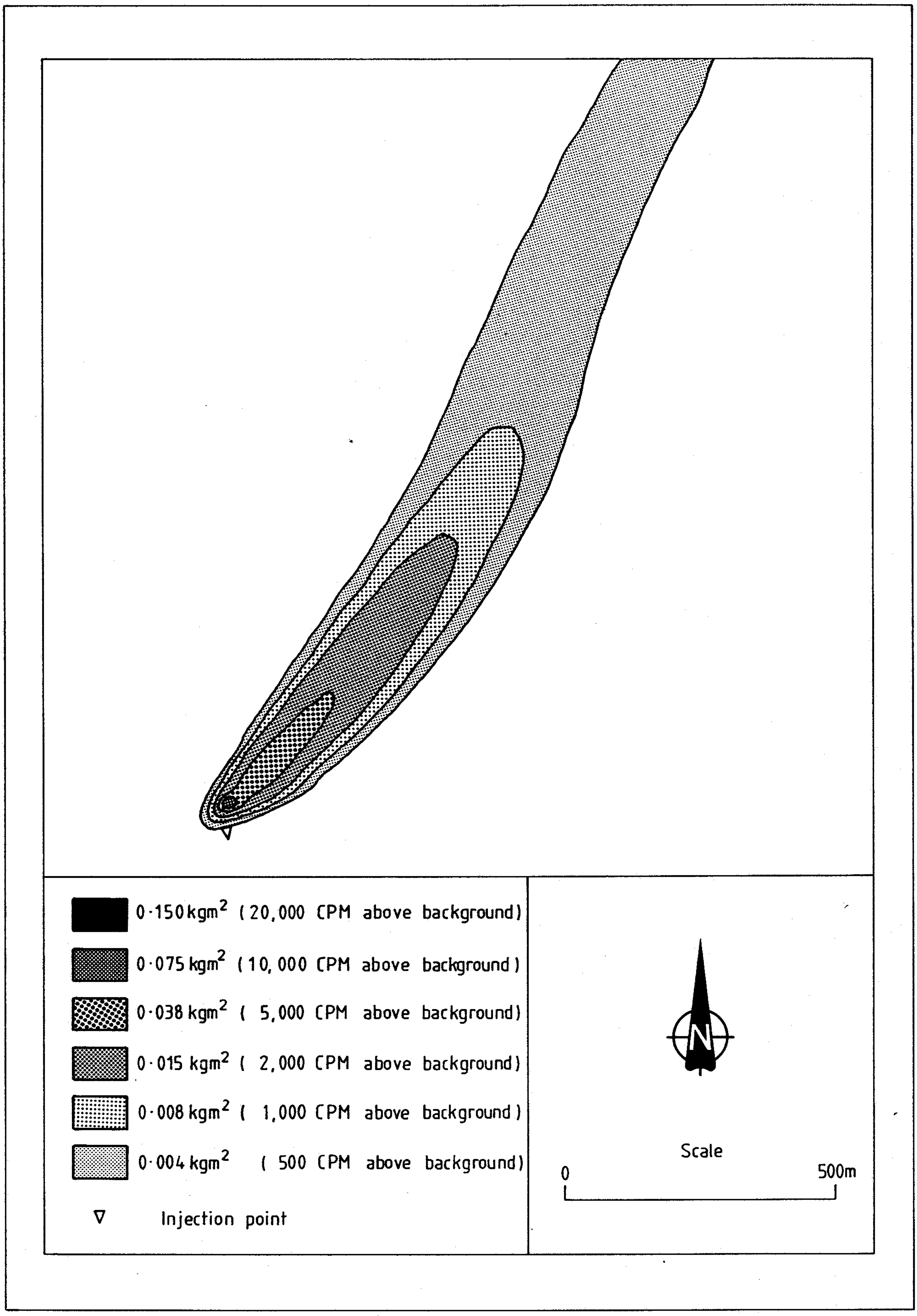

Fig 10 Ebb tide model results distribution of mass on bed.

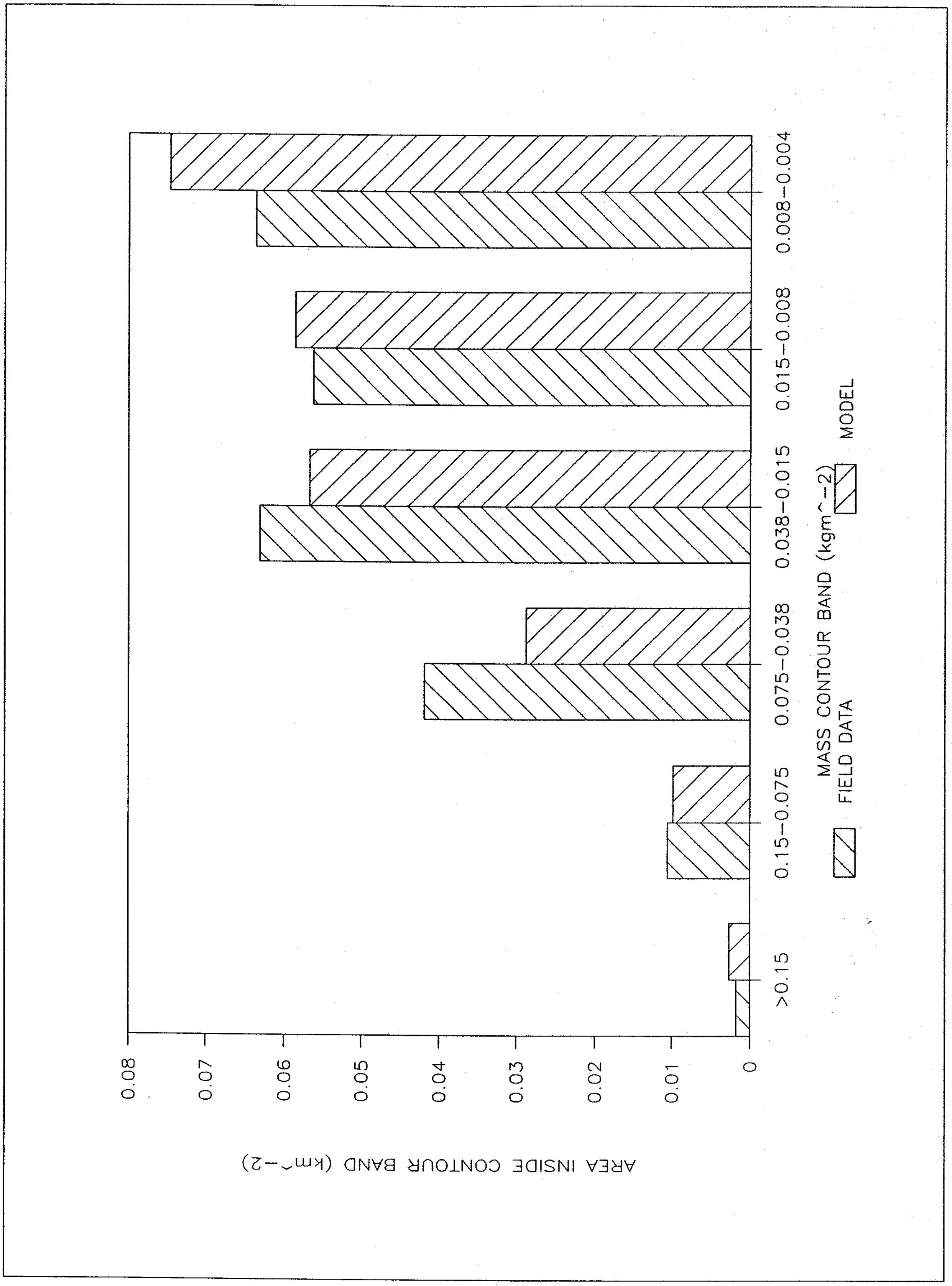

Fig 11 Comparison of areas within contour bands flood tide plume

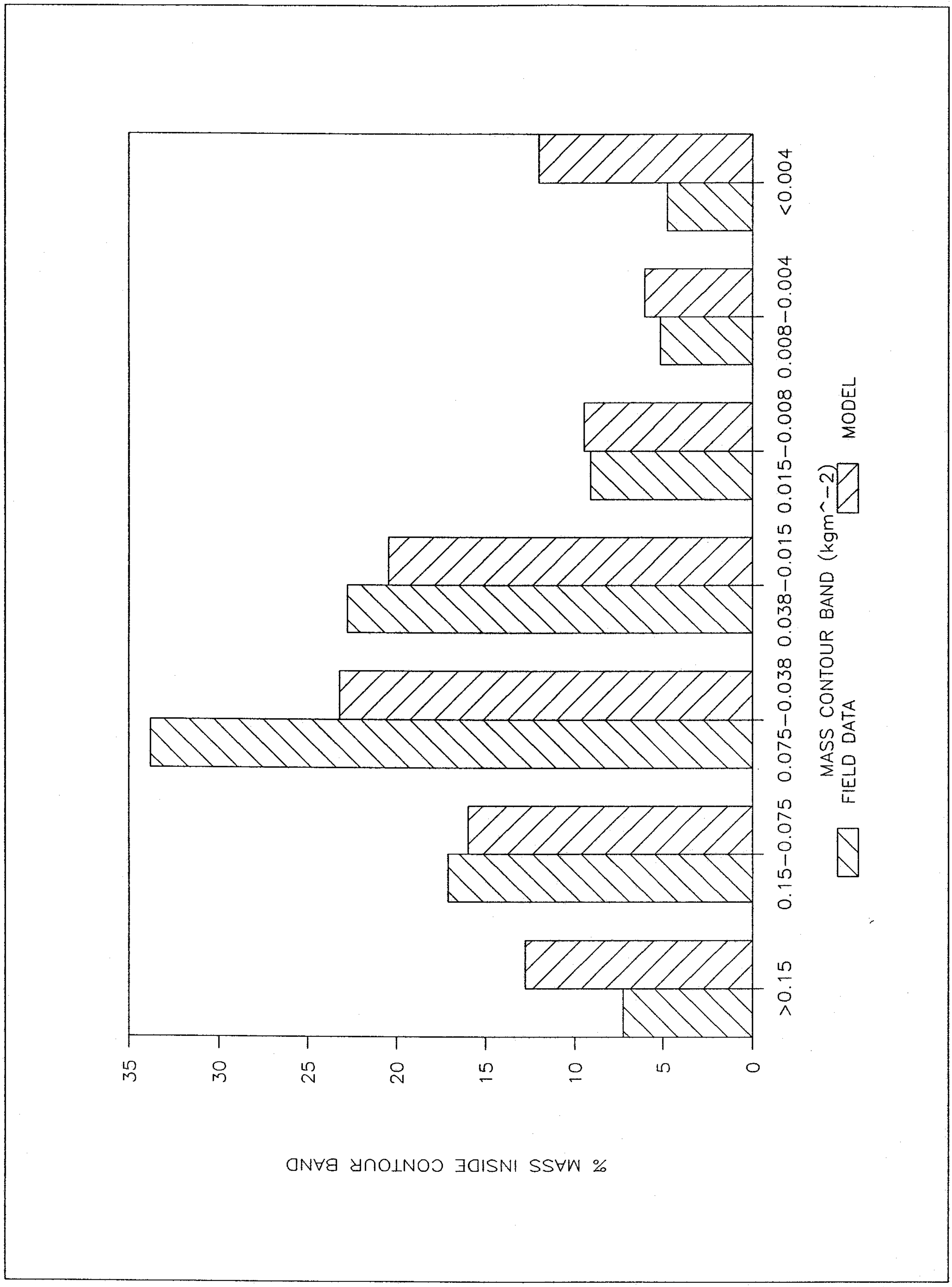

Fig 12 Comparison of masses within contour bands flood tide plume

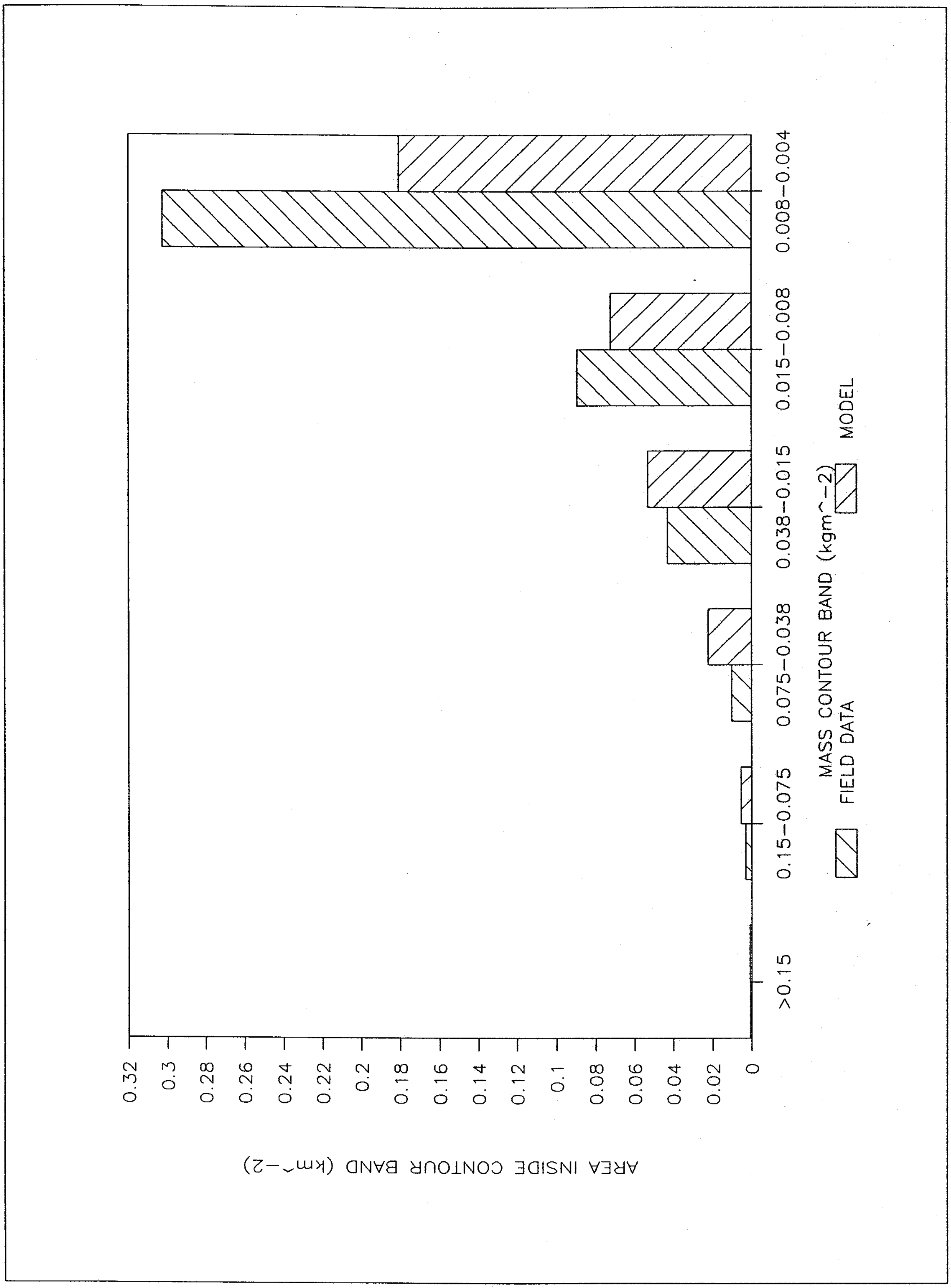

Fig 13 Comparison of areas within contour bands ebb tide plume (inside model boundary)

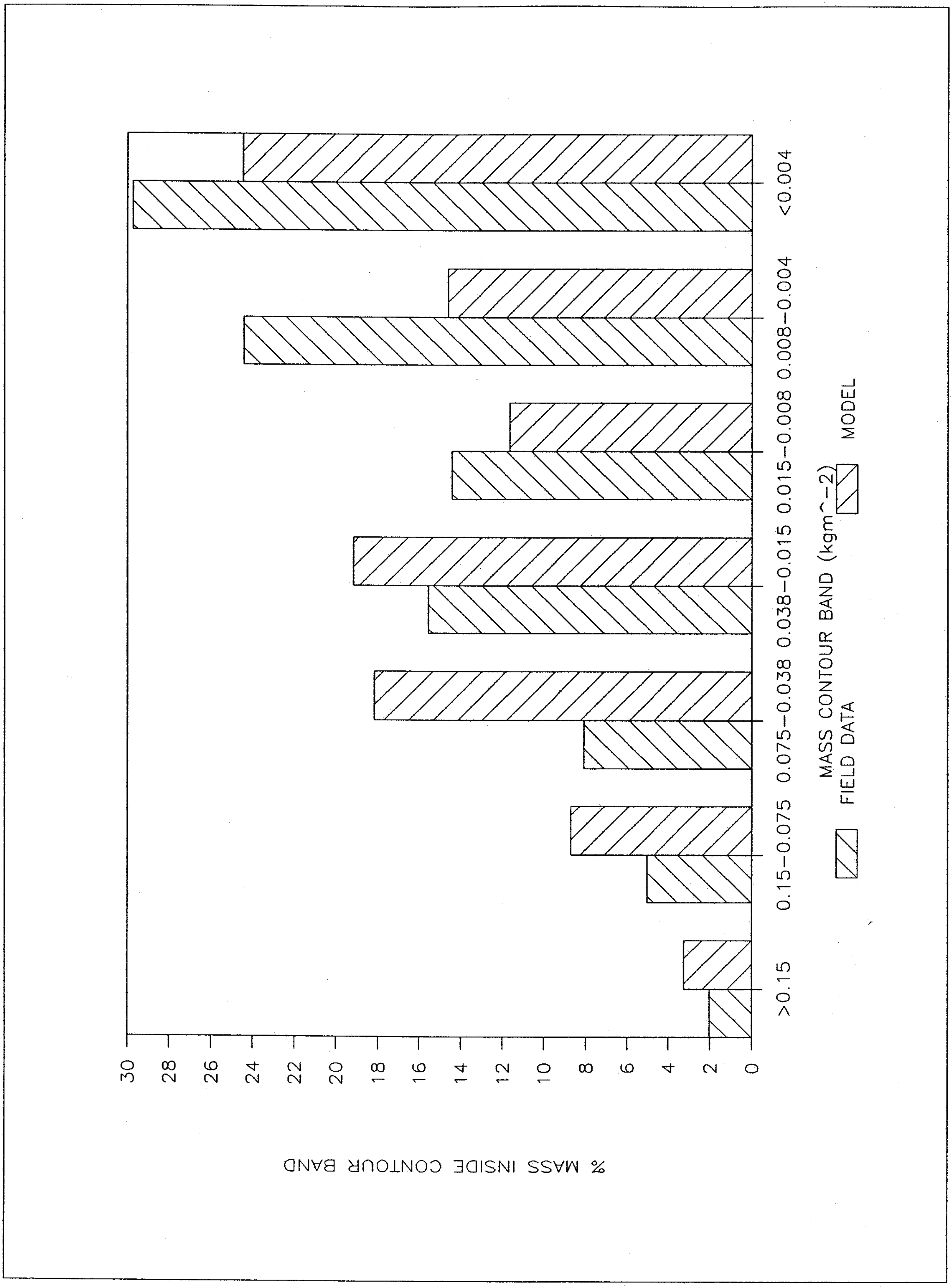

Fig 14 Comparison of masses within contour bands ebb tide plume (inside model boundary)

PLATE.

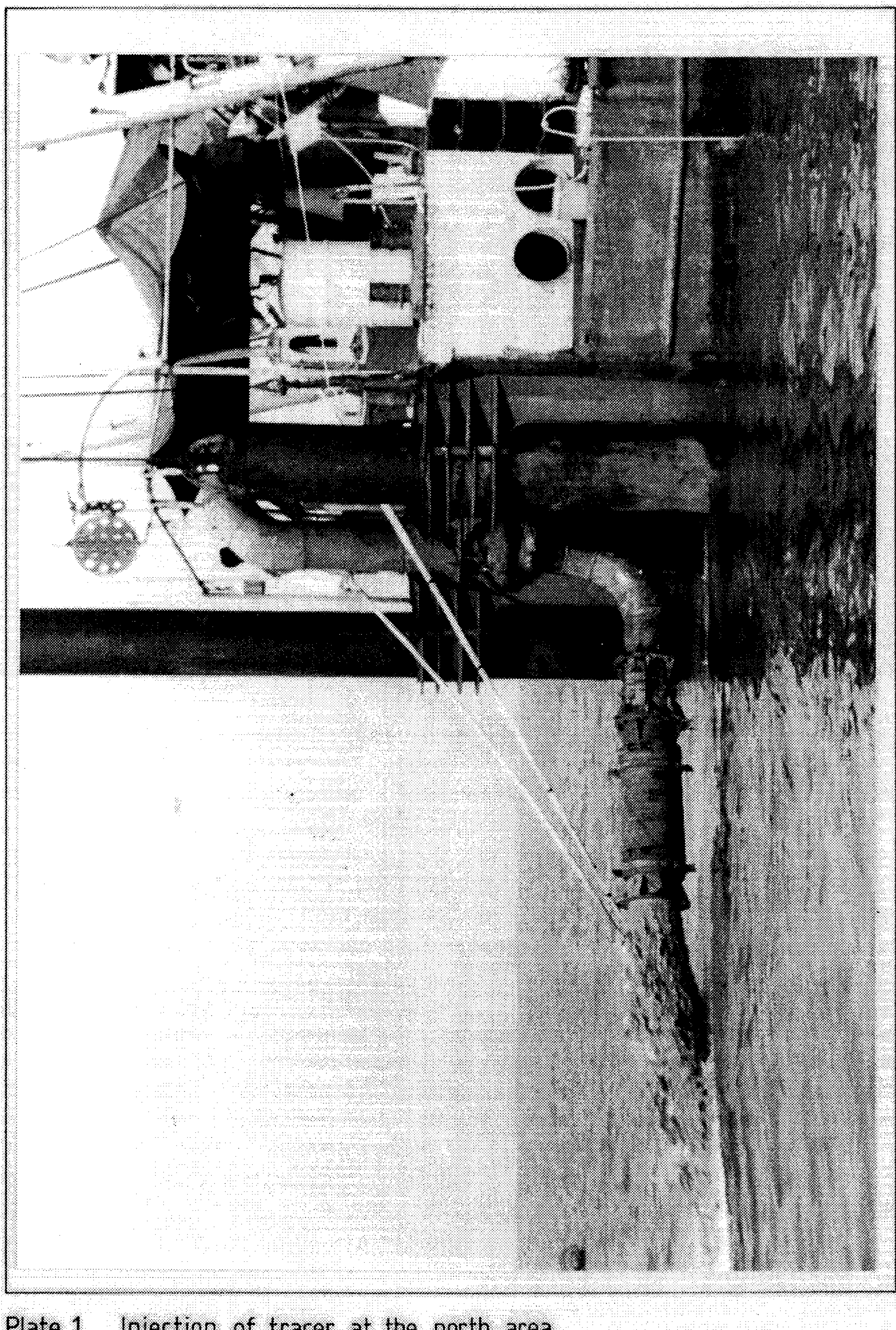

Plate 1 Injection of tracer at the north area.

APPENDIX.

APPENDIX A

NOTES ON RUNNING THE MODEL

Data input

Parameters are input to the program from three files

File 1 is a Lotus print file containing the parameters specific to the run - see table A1 for format. This include details of the grid area, the sediment input, sediment characteristics, and details of the output times and contour levels. The names of Files 2 and 3 are also contained in this file.

File 2 is a Lotus print file containing the hydrodynamic information of the model run - see Table A2 for format. This includes details of flow velocity, flow direction and tide levels at twenty minute intervals. The tide levels are quoted relative to a specific datum.

File 3 is a Lotus print file containing data on the bathymetry of the area - see Table A3 for format. The bathymetric data is in the form of depths at random positions over at least the area covered by the model. The positions are specified as real coordinates and the depths quoted to the same datum as the tide levels. The program uses a Gino call to interpolate the random points to the specified grid.

Running the model

Once the input files are written the model can be run. The model will first ask for the input parameters file name (File 1). This should be entered without the extension .PRN as the program will do this automatically. The name entered will be used as the prefix for all the output files.

The program then reads the data from File 1 and from Files 2 and 3, specified in File 1. The hydrodynamic data is listed on the screen together with the values of the diffusion coefficients, mesh size, total sediment mass and start time. It then saves a contour plot of the bathymetry and displays it on the screen. The enter key must then be pressed to continue the program.

The model then starts the simulation of the dispersal of material. During each time step the following are displayed on the screen; time, time after start of disposal, flow velocity and bearing, tide height, centroid concentration, total mass in suspension and total mass on the bed. The program will continue for half a tidal cycle unless interrupted.

Model output

The output from the model is in the form of tables of the suspended concentrations and total mass deposited in each cell and contour plots of the same data. Each set of output was sent to a file for future inspection and analysis.

The tables output file is in the form of an array of values corresponding to the concentrations in suspension or masses on the bed in each cell of the model - see Table A4 for example format. The format is such that it can be imported into a lotus spread sheet. The file name is of the form "yx.TAB" where y is the run name entered at the start of the program (the prefix of File 1) and x is a letter which changes in alphabetical order from 'A' with each subsequent file output.

The contour plots are output to a Gino graphics file for later viewing on screen and/or plotting. The file names are similar to those for the tables output except for the extension which is ".PCT.".

TABLE A1 : Format of File 1

```
Plume model input parameters.
                                                          |
Model  run details :-                                     |Notes
Input for run number    :Flood                            |Will output results to
Hydrodynamic file name :Hydro1.prn                        |Lotus Print file contai
Bathymetric  file name :Bathym2.prn                       |Lotus Print file contai
                                                          |
Study area details :-                                     |
Minimum x  :        0.0 Maximum x  :      1500.0          |Actual coordinates of a
Minimum y  :        0.0 Maximum y  :      1500.0          |Actual coordinates of a
Distance x :     1500.0 Distance y :      1500.0          |Distance between minimu
                                                          |
Disposal details                                          |
Position X :      575.0 Position Y :      1150.0          |Actual Coordinates
Total mass :     6600.0 Duration   :        0.50          |Total mass and duration
Time       :       9.00 Time step  :        5.00          |Start time (hours) Time
                                                          |
Sediment characteristics                                  |
DX         :       5.00 DY         :        0.50          |Diffusion coefficients
Ws         :     0.0015 Tocdep     :        0.50          |Fall velocity & critical
                                                          |
Output details :-                                         |
Contour plot time int. :       3.0                        |Time interval of contour

Contour  1 :      4.623 Contour  1 :       0.100     Contour 1 :        4.000
 levels  2 :      2.010  levels  2 :       0.015      levels 2 :        4.100
for bed  3 :      0.874 for sus- 3 :       0.010    for base 3 :        4.200
 masses  4 :      0.380  pended  4 :      0.0015      depths 4 :        4.300
         5 :      0.150   conc.  5 :      0.0010             5 :        4.400
         6 :      0.075          6 :    0.000150             6 :        4.500
         7 :      0.038          7 :    0.000100             7 :        4.600
         8 :      0.015          8 :    0.000015             8 :        4.700
         9 :      0.008          9 :    0.000010             9 :        4.800
        10 :      0.004         10 :    0.000001            10 :        4.900
---------------------------------------------------------------------------
```

TABLE A2 : Format of file 2

HYDROGRAPHIC DATA NORTH AREA 24 MARCH

TIME	U100	ANGLE	TIDE HEIGHT
8.00	0.20	175.00	0.17
8.33	0.20	185.00	0.22
8.67	0.16	190.00	0.26
9.00	0.18	195.00	0.30
9.33	0.15	195.00	0.33
9.67	0.14	175.00	0.37
10.00	0.14	175.00	0.40
10.33	0.13	175.00	0.43
10.67	0.09	185.00	0.45
11.00	0.08	180.00	0.47
11.33	0.05	170.00	0.49
12.33	0.04	160.00	0.50
12.66	0.04	100.00	0.50
13.00	0.03	80.00	0.50
13.33	0.10	60.00	0.49
13.66	0.13	60.00	0.47
14.00	0.17	60.00	0.44
14.33	0.20	75.00	0.40
14.66	0.25	45.00	0.35
15.00	0.22	35.00	0.30
15.33	0.24	35.00	0.25
15.66	0.28	20.00	0.20
16.00	0.27	20.00	0.15
16.33	0.27	30.00	0.10
16.66	0.26	30.00	0.05
17.00	0.24	30.00	-0.00
17.33	0.22	30.00	-0.05
17.66	0.20	30.00	-0.10
18.00	0.18	30.00	-0.15
18.33	0.16	30.00	-0.20
18.66	0.14	30.00	-0.25
19.00	0.12	30.00	-0.30
19.33	0.10	30.00	-0.35
19.66	0.08	30.00	-0.40
20.00	0.06	30.00	-0.44
20.33	0.05	30.00	-0.47
20.66	0.04	40.00	-0.49
21.00	0.04	80.00	-0.50

TABLE A3 : Format of file 3

Plume model bathymetry file

File name Bathym2
No. pts 24

X coord	Y coord	Depth	Number
0.0	0.0	4.34	24
0.0	500.0	4.35	23
0.0	1000.0	4.36	22
0.0	1500.0	4.65	21
0.0	2125.0	4.95	20
0.0	2750.0	5.25	19
500.0	0.0	4.25	18
500.0	500.0	4.30	17
500.0	1000.0	4.35	16
500.0	1500.0	4.65	15
500.0	2125.0	4.95	14
500.0	2750.0	5.25	13
1000.0	0.0	4.15	12
1000.0	500.0	4.25	11
1000.0	1000.0	4.35	10
1000.0	1500.0	4.65	9
1000.0	2125.0	4.95	8
1000.0	2750.0	5.25	7
1500.0	0.0	4.05	6
1500.0	500.0	4.20	5
1500.0	1000.0	4.35	4
1500.0	1500.0	4.65	3
1500.0	2125.0	4.95	2
1500.0	2750.0	5.25	1

TABLE A4 : Section of tables output file

RESULTS FOR TEST FLDA

MASS ON BED IN EACH GRID CELL * 1.0

MASS WAS DUMPED AT 9.00 HOURS

CURRENT TIME IS 3 HOURS 0 MINS AFTER DUMPING

	20	21	22	23	24	25	26	27	28	29
46	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
45	.000	.000	.000	.000	.000	.000	.001	.000	.000	.000
44	.000	.000	.000	.000	.001	.001	.001	.001	.000	.000
43	.000	.000	.000	.001	.002	.004	.003	.001	.000	.000
42	.000	.000	.000	.001	.006	.012	.009	.002	.000	.000
41	.000	.000	.001	.003	.013	.035	.021	.004	.001	.000
40	.000	.000	.001	.005	.028	.084	.037	.006	.001	.000
39	.000	.000	.002	.009	.058	.650	.052	.008	.002	.000
38	.000	.001	.003	.017	.102	.200	.630	.011	.002	.001
37	.000	.001	.005	.029	.141	.198	.070	.015	.003	.001
36	.000	.002	.008	.044	.150	.163	.073	.019	.004	.001
35	.000	.002	.012	.055	.130	.128	.072	.023	.006	.001
34	.001	.003	.016	.059	.104	.105	.068	.026	.007	.002
33	.001	.004	.020	.056	.084	.089	.064	.028	.009	.002
32	.001	.006	.021	.050	.071	.077	.060	.029	.010	.003
31	.001	.007	.021	.044	.060	.068	.056	.030	.012	.004
30	.002	.007	.020	.038	.052	.060	.051	.030	.013	.004
29	.002	.007	.018	.033	.046	.054	.047	.029	.013	.005
28	.002	.007	.016	.029	.041	.048	.043	.029	.014	.005
27	.002	.006	.015	.025	.036	.043	.040	.027	.014	.006
26	.002	.006	.013	.022	.032	.038	.036	.026	.014	.006
25	.002	.005	.012	.020	.029	.034	.033	.025	.014	.007
24	.002	.005	.010	.018	.026	.031	.030	.023	.014	.007
23	.002	.005	.009	.016	.023	.028	.027	.022	.014	.007
22	.002	.004	.008	.014	.020	.025	.025	.020	.013	.007
21	.002	.004	.008	.013	.018	.022	.022	.019	.012	.007
20	.002	.003	.007	.011	.016	.020	.020	.017	.012	.006
19	.001	.003	.006	.010	.015	.018	.018	.016	.011	.006
18	.001	.003	.006	.009	.013	.016	.016	.014	.010	.006