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Estuarine Sediments
Near -Bed Processes

Verification of a deposition algorithm in the Mersey estuary

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Contract

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Abstract

The processes of transport, deposition, consolidation and erosion of cohesive sediment are controlled by a complex array of physical and chemical factors which are only partly understood. Any attempt to predict the movement of cohesive sediment must first investigate the nature of the hydrodynamics of the water and then relate the movement of water to the movement of cohesive sediment. As yet, it is not possible to predict the behaviour of a cohesive sediment from its physical and chemical properties alone and the principal thrust of research has been to determine in the laboratory or in the field, for a given set of flow conditions, the behaviour of a cohesive sediment.

This report describes field measurement of the near-bed cohesive sediment processes at a site at Eastham Dock, adjacent to the Manchester Ship Canal entrance channel, in the Mersey estuary. A bed frame was deployed over 3 spring tides and 2 neap tides at this site. Continuous measurements were made of flow, suspended sediment concentrations, water pressure and bed level for approximately 3.5 hours either side of high water.

Information on the long term variation in suspended sediment concentration was retrieved from data recorded at Eastham Ferry as part of the continuous silt monitoring for the Mersey Barrage feasibility study.

The time-varying parameters measured in the field were used as input to a mathematical model, for prediction of siltation at a point. The model required information about suspended concentrations, water depths (found from the pressure measurements) and bed shear stresses (found from the velocity measurements) together with field and experimentally-determined mud characteristics (from an earlier study). Deposition, consolidation and erosion were modelled. The model prediction of depth of deposition over a spring tide (0.002m), and a neap tide (0.001m) agreed well with the field measurements.

For the long term deposition, the total mass deposited per day over a spring-neap-spring cycle was calculated from the model. This mass was converted into a depth of deposition assuming a density of 0.4tm^{-3} (a typical dry density for consolidated surface sediment) giving a long term deposition rate of 0.004m/day. This was compared with the long term siltation measured in the adjacent Ship Canal approach channel (using depth soundings from the Manchester Ship Canal Company). An allowance was made for the material which is observed to drain off the mud flats into the channel. The total area contributing to the bed level change in the channel was calculated to be twice the area of the channel. Twice the model prediction gaves a deposition rate of 0.008m per day which compared well with the measured deposition rate of in the channel of 0.009m/day.

A sensitivity analysis showed that taking different values for the critical shear for deposition and fall velocity constants influenced the predicted deposition significantly. The validated deposition algorithm, with the values of the parameters which best matched the short and long term field measurements in the Mersey estuary is:

$dm/dt = (1-\tau/\tau_d)\, c\, w_{50}$
where
τ = shear stress at the bed (Nm^{-2})
τ_d = critical shear stress for deposition
= 0.08Nm^{-2}
dm/dt = deposition rate (kgm^{-2}s^{-1})
c = time varying sediment concentration (kgm^{-3})
w_{50} = median floc settling velocity = 0.005c (ms^{-1})

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1 Introduction

The ability to predict the movement of cohesive sediment within tidal waters has a significant economical and ecological importance in the development of new engineering works and the maintenance of existing installations. Schemes such as the reclamation of intertidal flats, the construction of new berths, or the enlargement and extension of dredged channels require a sound engineering appraisal of the likely changes in the patterns of sediment movement which will result after the scheme is built.

The processes of transport, deposition, consolidation and erosion of cohesive sediment are controlled by a complex array of physical and chemical factors which are only partly understood. Any attempt to predict the movement of cohesive sediment must first investigate the nature of the hydrodynamics of the water and then relate the movement of water to the movement of cohesive sediment. As yet, it is not possible to predict the behaviour of a cohesive sediment from its physical and chemical properties alone and the principal thrust of research has been to determine in the laboratory or in the field, for a given set of flow conditions, the behaviour of a cohesive sediment.

The objective of the research is to increase understanding of near-bed processes and their influence on cohesive sediment transport processes. The knowledge acquired will enable an improvement in accuracy and precision of predictive models of cohesive sediment movement.

Additional funding for the work was provided by the Mersey Barrage Company (MBC). The company was interested in a validated deposition algorithm which could be used to predict the rate of deposition of cohesive sediment in the Mersey estuary.

The scope of work included the selection of a suitable field site for measurement of hydraulic parameters and deposition of cohesive sediment at a single point. A bed frame with associated instruments was deployed for making the measurements over three spring tides and two neap tides. The results of this field investigation, together with information about settling velocity of flocs, mud properties (measured in an earlier study) and long term suspended sediment concentrations were used as input to a siltation model.

The field site selected for the single point monitoring was the mud flats on the edge of the Manchester Ship Canal approach channel, adjacent to the QEII Dock entrance lock (Fig 1). This site was selected because it was known to be a muddy site, the mud flats were accessible and it was one of the sites from which the mud had been taken for laboratory mud properties tests. In addition, long term suspended concentrations were available from nearby and long term bed level information for the adjacent channel was also available.

Time-varying hydrodynamic parameters measured at the single point over a tide were velocities in the x, y and z directions at 0.1m and 0.5m above the bed (using electromagnetic current meters), velocities averaged over ten minute intervals at 0.1m, 0.5m and 1.0m above the bed (using Braystoke current meters) and water pressure at 0.8m above the bed. Time-varying suspended sediment concentrations at 0.1m, 0.5m and 1.0m above the bed and bed levels were also monitored simultaneously with the hydrodynamic parameters.

The siltation at a point model (SAP) was used to predict the deposition and erosion at a single point over a spring neap spring cycle. The model was then validated by comparison with bed elevations measured at the monitoring site and long term siltation data from the channel adjacent to the study point.

2 *Field Measurements*

2.1 Frame deployment

2.1.1 Instrumentation and operation

The bed frame was designed to enable simultaneous measurements of tidal and wave induced flow (Ref 1). It is triangular in shape with an open structure to offer as little resistance to flow as possible, with legs protruding into the bed to prevent movement (Plate 1).

The following instruments were mounted on the frame:
- 3 Braystoke current meters
- 4 electromagnetic current meters (EMCM)
- 3 Partech turbidity sensors
- 1 pressure sensor
- 3 ultrasonic probes

The Braystoke current meters were mounted at 0.1m, 0.5m and 1.0m above the bed and in such a way that they could swivel freely through 360 degrees to align themselves with the current. These were used to measure tidal flows and to give a field calibration of the EMCMs.

The EMCMs measured 2 components of velocities. These were mounted at 0.1m and 0.5m above the bed and set to measure in the x,y and x,z planes. The output from these was logged at 5Hz to enable high frequency wave and turbulence fluctuations to be analysed.

The Partech turbidity sensors were mounted at 0.1m, 0.5m and 1.0m above the bed in positions that would not interfere with flow around the EMCMs.

The pressure sensor was mounted at 0.8m above the bed. The output was logged at 5Hz and enabled water depth and, if necessary, wave conditions to be found.

The ultrasonic probes were mounted at approximately 0.1m above the bed, about 3 metres away from the main bedframe. These enabled the bed level change during the tide to be logged.

The output from each of the instruments was logged onto a computer over the monitoring period.

The bed frame was deployed approximately 1.5m above mean low water. The orientation of the frame was set such that the principal tidal flow would be in the x direction of the EMCMs. Cables connecting the sensors with the control units were run across the mud flats. The control units and data logging equipment were set up in a van stationed on the dock. Each tide was monitored for between 7 and 8 hours, from approximately 2 hours after low water.

Three spring tide and two neap tide high waters were monitored. The predicted high water times of the spring tides were - 0030h (20/11/1990), 1235h (20/11/1990) and 0050h (21/11/1990). The predicted neap high waters were 1715h (26/11/1990) and 1820h (27/11/1990).

2.1.2 Data Analysis

The pressure sensor, Braystoke current meters and ultrasonic probes were pre-calibrated so no extra calibration was necessary for these instruments.

The calibrations of the EMCMs tend to drift slightly so a check is made by comparing a ten minute average of the modulus of the x and y velocities with the Braystoke current meters.

The Partech turbidity sensors were calibrated before and after deployment using formazin suspensions. The formazin to silt conversion factor was found using water samples.

The mean values of water levels, concentration and shear stress over ten minute intervals for each monitoring period were found. From the tidal mean velocities at the three heights the shear stress at the bed could be calculated. A plot of velocity against log height above the bed for a particular instant in time gives a near straight line. Using the following equations the bed shear stress can be calculated:

$$u_* = k\, du/d(\ln z) \qquad (1)$$

$$\tau_b = \rho\, u_*^2 \qquad (2)$$

where

u_* = frictional shear velocity (ms^{-1})
u = horizontal velocity (ms^{-1})
z = height above bed (m)
k = von Karman's constant (0.4)
τ_b = shear stress at the bed (Nm^{-2})
ρ = water density (kgm^{-3})

An analysis procedure of the high frequency pressure and velocity fluctuations has been developed to determine the influence of waves on the bed shear stress (Ref 1). However, the wave heights during the reported deployments were very small and had very little influence over the water depth range in which the instruments operated. It was therefore unnecessary to run this analysis procedure.

2.1.3 Results

The spring tide results gave a maximum water depth of 5.5m (Fig 2). The maximum water depth on the neap tides was approximately 3.75m (Fig 3).

During the spring tides the suspended sediment concentrations highest during maximum flood flow and decreased to a minimum at about an hour after local high water (Fig 4). The maximum suspended sediment concentration at 0.1m ($0.9kgm^{-3}$) was higher than the maximum concentrations at 1.0m above the bed ($0.55kgm^{-3}$). The suspended sediment concentration at the bed was similar to the concentration at 1.0m after the initial peak apart from a small peak at around

70min before local high water and another peak at 30mins after high water. These peaks coincided with periods of low flow and are probably due to suspended sediment descending through the water column.

The neap tides showed a broadly similar pattern (Fig 5) with lower maxima ($0.25kgm^{-3}$ at 0.1m and $0.15kgm^{-3}$ at 1.0m above the bed). Once again peaks of high suspended sediment concentration were observed at 0.1m but not at 1.0m above the bed, coinciding with the periods of low flow, 20mins and 10mins before high water.

The shear stress during the spring tides (Fig 6) reached a maximum of $0.9Nm^{-2}$ about 120 minutes before high water. This dropped to virtually zero 20 minutes after high water. During the ebb tide the shear stress reached a peak 200 minutes after high water of around $0.4Nm^{-2}$.

The bed shear stress during the neap tides followed a broadly similar pattern to the spring tides (Fig 7). It reached a maximum of $0.5Nm^{-2}$ about 100 minutes before high water, dropped to a low value 30 minutes before high water. During the ebb tide the shear stress reached a peak 120 minutes after high water of around $0.15Nm^{-2}$.

On the first tide of both the spring and neap tide deployments the bed level measurement instrument malfunctioned. However, 2 sets of results were obtained for spring tides and one for a neap tide (Figures 10 and 11). The total deposition on the spring tides was 0.016m and 0.025m and on the neap tide 0.011m. The periods of bed level change coincided with periods of low shear stress.

2.2 Long Term Silt Monitoring

The mathematical model required input of a relationship between tide level and suspended sediment concentration. This required information of long term variation in suspended sediment concentration. As part of the Mersey Barrage feasibility study long term silt monitoring stations have been set up at a number of sites around the estuary (Ref 2). Measurements have been taken of suspended sediment concentrations at 1.0m above the bed at each of these sites.

The nearest location to the bed frame monitoring site was at Eastham Ferry, approximately 1km from QEII dock. Since the suspended sediment concentrations do not vary significantly over this distance the relationship between suspended sediment concentration and tidal range was taken as representative of the siltation at a point measurement site.

The mean suspended sediment concentrations over each tide, for the period May 1989 to June 1990, were plotted against tidal range. The concentration was found to vary linearly with tidal range (Fig 8).

2.3 Long term bed levels

In order to verify the mathematical model (in particular the deposition algorithm) a long term siltation rate is required for comparison with the model output. The bed levels in the Manchester Ship Canal approach channel are measured approximately twice monthly and give information conveniently close to the siltation measurement point. These were used to derive a siltation rate for comparison with the model prediction.

The depths across the channel directly out from the siltation measurement point were found for the ten months preceding the frame deployment. These were analysed to give a mean bed level for each set of measurements (Fig 9). A straight line was fitted through the points disregarding periods of dredging (when the bed level decreased). The gradient of the line corresponds to the mean daily increase in bed level and has a value of $0.009 \mathrm{mday}^{-1}$.

3 Mathematical Model

3.1 Outline of model

The siltation at a point model (SAP) is a zero dimensional model which predicts the long term changes at a point on a cohesive sediment bed. Deposition, consolidation and erosion of sediment on the bed are modelled (full details are given in Appendix 1).

The model input takes the form of field and experimentally-determined cohesive sediment parameters and time-varying parameters measured on spring and neap tides. The time-varying parameters are water depths, shear stress at the bed and suspended sediment concentrations measured during the bed frame monitoring period. The time-varying parameters are interpolated linearly between spring and neap tides, including suspended sediment concentration (see section 2.2).

3.2 Model input

The values of time varying input to the model were derived from the bed frame monitoring described above. Input values at ten minute intervals were calculated from fitted lines through the field data. These were water depths (Figs 2 and 3), suspended sediment concentrations at 0.1m and 1.0m above the bed (Figs 4 and 5) and the shear stresses at the bed (Figs 6 and 7).

At the beginning and end of the field monitoring period the shear stress was set at $0.3 \mathrm{Nm}^{-2}$. During these times the water level was below some of the instruments, thus preventing the shear stress from being calculated accurately. This was done because the shear stress at the bed is likely to remain fairly high due to the action of ripples on the water surface.

Parameters defining the erosion and consolidation characteristics of the sediment were determined in the laboratory in a previous study (Ref 3). These were also input to the model.

The deposition equation had the following form:

$$dm/dt = (1-\tau/\tau_d) c\, w_{50} \qquad \tau \le \tau_d \qquad (3)$$

where

τ = shear stress at the bed (Nm^{-2})

τ_d = critical shear stress for deposition (Nm^{-2})

dm/dt = deposition rate ($\mathrm{kgm}^{-2}\mathrm{s}^{-1}$)

c = suspended sediment concentration (kgm^{-3})

w_{50} = median floc settling velocity (ms^{-1}) = Dc^E
where D and E are constants for a particular field location

The deposition algorithm assumed that there was a critical shear stress at the bed above which no deposition took place. Below the critical shear stress the rate of deposition was dependent upon the settling velocity of flocs of the sediment. This was determined by Owen tube field tests.

Table 1 summarises the values of the parameters used in the model.

3.3 Model Results

The model was run using the input values shown in Table 1 for a spring-neap-spring cycle. The deposition on the spring and neap tides was compared to the measured bed level change on the spring and neap tides (2 sets of measurements were available for spring tides and one on a neap tide).

The depth of deposition at ten minute intervals was found from the model by converting the predicted mass of deposition to a depth by assuming a density of deposition of 50kgm^{-3}. It was assumed during calculation that the consolidation of the bed was insignificant over this time period (4 hours maximum).

The model prediction of depth of deposition over the spring (0.02m), and neap tides (0.01m) agreed well with the field measurements (Figs 10 and 11).

The average deposition per day was calculated from the sum of the deposited mass over the spring-neap- spring cycle. This was compared to the deposition rate in the channel. The predicted deposition over the spring neap spring cycle was 23kgm^{-2} in 14 days. This mass was converted into a depth of deposition assuming a density of 400kgm^{-3} (a typical dry density for consolidated surface sediment), giving 0.004m per day. The sediment deposited on the banks of the Ship Canal Approach Channel above the low water mark was observed to be suspended by ripples on the receding water surface and washed into the channel. The total area feeding the channel (above low water) is approximately equal to that below low water. Assuming equal deposition over the whole area a multiplication factor of 2 is applied to the model results, accounting for the sediment derived from above the low water level, to derive the total depth of siltation in the channel. This gives a figure of 0.008m per day. This compares very well with the measured change in the channel, 0.009m per day.

3.4 Sensitivity analysis

The value of τ_d could not easily be obtained from the field data because of a short and indeterminate time lag between a decrease in shear stress and an increase in bed level being detected. A value of 0.08Nm^{-2} was however deduced by inspection of the field data, deposition did not appear to occur above this value. Sensitivity analysis of the model to variation of τ_d was however carried out to confirm that a suitable value had been used.

The model was run with the critical shear for deposition set at 0.04Nm^{-2}, 0.08Nm^{-2} and 0.15Nm^{-2}, all other parameters being unchanged. The mean deposition per day over a spring-neap-spring cycle was compared (Table 2). The deposition was much lower with the lowest critical shear stress for deposition, reflecting the length of time in each tide over which the shear stress was below the critical value.

The field measurements of floc settling velocity (Owen tube tests and image analysis settling tests) gave high fall velocity values, and the Owen tube samples in particular were found to contain fine sand. Since the results were quite variable the sensitivity of the siltation rate prediction to variation in fall velocity coefficient, D, was tested. Here, w_{50} is expressed as a function of concentration, of the form Dc^E (D=0.005, E=1).

The model was run for three values of the fall velocity coefficient (D) 0.002, 0.005 and 0.01. The deposition rate predicted by the model using each value of the coefficient are shown in Table 2. As expected, the deposition rate increased with increasing fall velocity coefficient.

The model appears to be quite sensitive to τ_d and D. The values of τ_d and D used in the model initially (0.08Nm^{-2} and 0.005 respectively), gave deposition rates more closely comparable with the field measurements than the other values derived during the sensitivity analysis.

4 Conclusions

1. A site at Eastham Dock adjacent to the Manchester Ship Canal entrance channel was selected for measurement of siltation at a point. Field measurements of time-varying parameters were taken on 3 spring tides and 2 neap tides at this site. Continuous measurements were made of velocity, suspended sediment concentrations, water pressure and bed level for approximately 3.5 hours either side of high water (Figs 2 to 7).

2. Information about seasonal changes in suspended sediment concentration was retrieved from data recorded at Eastham Ferry as part of the continuous silt monitoring for the Mersey Barrage feasibility study. The mean concentrations over each tide were found to be linearly related to tidal range (Fig 8).

3. Information about long term siltation in the adjacent Ship Canal Approach Channel was obtained from Manchester Ship Canal Company's depth soundings of the area. The rate of deposition in the channel was calculated to be 0.009m/day.

4. The time varying parameters measured in the field were used as input to a mathematical model, for prediction of siltation at a point. The model required information about suspended concentrations, water depths (found from the pressure measurements) and bed shear stresses (found from the velocity measurements), together with field and experimentally determined mud characteristics. Deposition, consolidation and erosion were modelled. The model prediction of depth of deposition over a spring tide (0.02m), and neap tide (0.01m) agreed closely with the field measurements. The depth of deposition was calculated from the mass deposited assuming a density of 50kgm^{-3}.

5. For the long term deposition, the total mass deposited per day over a spring-neap-spring cycle was calculated from the model. This mass was converted into a depth of deposition assuming a density of 400kgm^{-3} (a typical dry density for consolidated surface sediment), giving a long term deposition rate of 0.004m/day. The sediment deposited on the banks of the Ship Canal Approach Channel above the low water mark was observed to be suspended by ripples on the receding water surface and washed into the channel. The total area contributing to the bed level change in the channel was estimated to be twice the area of the channel. Assuming equal deposition over the

whole area, the measured bed level change in the channel should be twice the model prediction. Twice the model prediction is 0.008m per day which compares well with the measured deposition rate in the channel of 0.009m per day.

6. The sensitivity analysis showed that taking different values for the critical shear for deposition and fall velocity constants influenced the predicted deposition significantly. The validated deposition algorithm, with the values of the parameters which best matched the short and long term field measurements is:

   $dm/dt = (1-\tau/\tau_d)\, c\, w_{50}$

   where
   τ = shear stress at the bed (Nm^{-2})
   τ_d = critical shear stress for deposition
   = $0.08Nm^{-2}$
   dm/dt = deposition rate ($kgm^{-2}s^{-1}$)
   c = time-varying sediment concentration (kgm^{-3})
   w_{50} = median floc settling velocity (ms^{-1})
   = $0.005c$

5 Acknowledgements

HR acknowledges the assistance of the Mersey Barrage Company for their assistance in deploying the bed frame for the collection of the siltation at a point data.

HR also expresses its thanks to the Manchester Ship Canal Company for allowing unrestricted access to the QEII dock for the siltation at a point measurements, and for supplying the depth soundings for the Ship Canal approach channel.

6 References

1. Delo E A and Diserens A P, "Estuarine sediments - near bed processes, Field measurement system", Hydraulics Research, Wallingford, Report SR 245, August 1990.

2. "Mersey Barrage feasibility study phase II Continuous silt monitoring in the River Mersey, May 1989 to June 1990", Hydraulics Research, Wallingford, Report EX 2212 October 1990.

3 "Mersey Barrage Feasibility Study Phase II, Mud properties". Hydraulics Research, Wallingford, Report EX 1988, September 1989.

Tables

Table 1 : Input to mathematical model

Test point = 1
Point elevation = -1.0 metres above CD
Base elevation = -1.0 metres above CD

Length of tidal cycle = 740 minutes
Start time of model = 0 minutes after HW
Time step = 10 minutes

Settling velocity = WSCON1 x concentration$^{\mathrm{WSCON2}}$
.00500 = WSCON1
1.0 = WSCON2

Density of new deposits = 50.0 kgm^{-3}
Crit. shear stress for deposition = .08 Nm^{-2}

Shear stress for erosion = DCON1 x density$^{\mathrm{DCON2}}$
.01300 = DCON1
.7 = DCON2

Erosion constant = .0005 kgN^{-1}s^{-1}
Crit. shear stress for erosion = .20 Nm^{-2}

Log Permeability = PERM1CONST + PERM2CONST x density
-4.25 = PERM1CONST
-.01 = PERM2CONST

Effective stress=ES1CONST + ES2CONST x density + ES3CONST x density^2
1.8 = ES1CONST
-.070 = ES2CONST
.00070 = ES3CONST
Index for steepness of conc. curve = 1.00
Index for steepness of shear curve = 2.00
Input for Spring and neap tides:

Time (mins)	**Tidesp (m CD)**	**Tidenp (m CD)**	**Cbedsp kgm^{-3}**	**Csurfsp kgm^{-3}**	**Cbednp kgm^{-3}**	**Csurfnp kgm^{-3}**	**ShearS Nm^{-2}**	**ShearN Nm^{-2}**
0.0	5.4	3.8	.224	.173	.217	.025	.085	.037
10.0	5.4	3.8	.298	.147	.108	.034	.085	.025
20.0	5.3	3.8	.366	.096	.101	.031	.018	.006
30.0	5.3	3.7	.241	.154	.085	.044	.005	.036
40.0	5.1	3.6	.189	.123	.081	.039	.011	.051
50.0	5.0	3.5	.172	.088	.080	.048	.133	.075
60.0	4.8	3.4	.173	.102	.085	.049	.287	.127
70.0	4.6	3.2	.180	.108	.088	.058	.279	.102
80.0	4.4	3.0	.210	.138	.092	.049	.228	.018
90.0	4.1	2.9	.247	.172	.093	.053	.136	.007
100.0	3.8	2.7	.303	.219	.087	.046	.116	.015
110.0	3.6	2.5	.394	.300	.088	.050	.093	.021
120.0	3.3	2.3	.421	.338	.160	.126	.054	.100
130.0	3.0	2.0	.461	.386	.124	.077	.024	.043
140.0	2.7	1.8	.376	.318	.129	.097	.092	.028
150.0	2.5	1.6	.461	.328	.136	.107	.090	.012
160.0	2.2	1.4	.530	.402	.184	.141	.052	.155

Table 1 continued

Time (mins)	Tidesp (m CD)	Tidenp (m CD)	Cbedsp kgm^{-3}	Csurfsp kgm^{-3}	Cbednp kgm^{-3}	Csurfnp kgm^{-3}	ShearS Nm^{-2}	ShearN Nm^{-2}
170.0	2.0	1.2	.446	.380	.172	.144	.166	.449
180.0	1.7	1.1	.482	.423	.150	.157	.187	.352
190.0	1.5	.9	.525	.458	.206	.128	.250	.138
200.0	1.3	.7	.572	.528	.166	.142	.225	.118
210.0	1.1	.5	.646	.517	.522	.152	.395	.100
220.0	.9	.3	.494	.405	.418	.005	.354	.200
230.0	.6	.1	.434	.135	.456	.000	.365	.250
240.0	.4	.0	.430	.000	.456	.000	.380	.300
250.0	.2	.0	.000	.000	.455	.000	.500	.500
260.0	.0	.0	.000	.000	.443	.000	.500	.500
270.0	.0	.0	.000	.000	.000	.000	.000	.000
280.0	.0	.0	.000	.000	.000	.000	.000	.000
290.0	.0	.0	.000	.000	.000	.000	.000	.000
300.0	.0	.0	.000	.000	.000	.000	.000	.000
310.0	.0	.0	.000	.000	.000	.000	.000	.000
320.0	.0	.0	.000	.000	.000	.000	.000	.000
330.0	.0	.0	.000	.000	.000	.000	.000	.000
340.0	.0	.0	.000	.000	.000	.000	.000	.000
350.0	.0	.0	.000	.000	.000	.000	.000	.000
360.0	.0	.0	.000	.000	.000	.000	.000	.000
370.0	.0	.0	.000	.000	.000	.000	.000	.000
380.0	.0	.0	.000	.000	.000	.000	.000	.000
390.0	.0	.0	.000	.000	.000	.000	.000	.000
400.0	.0	.0	.000	.000	.000	.000	.000	.000
410.0	.0	.0	.000	.000	.000	.000	.000	.000
420.0	.0	.0	.000	.000	.000	.000	.000	.000
430.0	.0	.0	.000	.000	.000	.000	.000	.000
440.0	.0	.0	.000	.000	.000	.000	.000	.000
450.0	.0	.0	.000	.000	.000	.000	.000	.000
460.0	.0	.0	.000	.000	.000	.000	.000	.000
470.0	.0	.0	.000	.000	.000	.000	.000	.000
480.0	.0	.0	.000	.000	.000	.000	.000	.000
490.0	.0	.0	.000	.000	.000	.000	.000	.000
500.0	.0	.0	.000	.000	.000	.000	.000	.000
510.0	.1	.0	.000	.000	.000	.000	.500	.000
520.0	.4	.2	.500	.000	.110	.000	.500	.500
530.0	.7	.4	.540	.500	.110	.010	.280	.500
540.0	1.0	.7	.560	.510	.111	.009	.250	.300
550.0	1.3	.9	.590	.520	.109	.118	.250	.300
560.0	1.6	1.1	.620	.530	.109	.210	.280	.002
570.0	1.9	1.4	.700	.535	.212	.238	.330	.010
580.0	2.3	1.6	.866	.538	.214	.249	.658	.067
590.0	2.6	1.8	.886	.538	.231	.209	.642	.100
600.0	2.9	2.0	.860	.538	.229	.233	.415	.233
610.0	3.1	2.2	.775	.535	.223	.207	.621	.282
620.0	3.4	2.4	.602	.502	.242	.239	.907	.368
630.0	3.7	2.6	.500	.443	.208	.201	.626	.396
640.0	3.9	2.8	.428	.379	.196	.201	.582	.484
650.0	4.2	3.0	.375	.328	.231	.261	.485	.390
660.0	4.4	3.1	.349	.323	.216	.247	.341	.386
670.0	4.6	3.3	.312	.345	.210	.233	.441	.422

Table 1 continued

Time (mins)	Tidesp (m CD)	Tidenp (m CD)	Cbedsp kgm^{-3}	Csurfsp kgm^{-3}	Cbednp kgm^{-3}	Csurfnp kgm^{-3}	ShearS Nm^{-2}	ShearN Nm^{-2}
680.0	4.8	3.4	.292	.297	.200	.225	.409	.452
690.0	4.9	3.5	.314	.302	.184	.200	.280	.362
700.0	5.1	3.6	.347	.367	.153	.140	.276	.140
710.0	5.2	3.7	.371	.399	.173	.111	.245	.052
720.0	5.3	3.8	.367	.367	.205	.088	.222	.068
730.0	5.4	3.8	.265	.309	.136	.079	.165	.057
740.0	5.4	3.8	.224	.173	.217	.025	.085	.037

Table 2 : Details of sensitivity analysis

Effect of variation of τ_d on predicted deposition

τ_d Nm^{-2}	Deposition rate m/day
0.040	0.001
0.080	0.004
0.150	0.009

Effect of variation of D on predicted deposition
$w_{50} = D\,c$, c = suspended sediment concentration

D	Deposition rate m/day
0.002	0.002
0.005	0.004
0.010	0.008

Figures

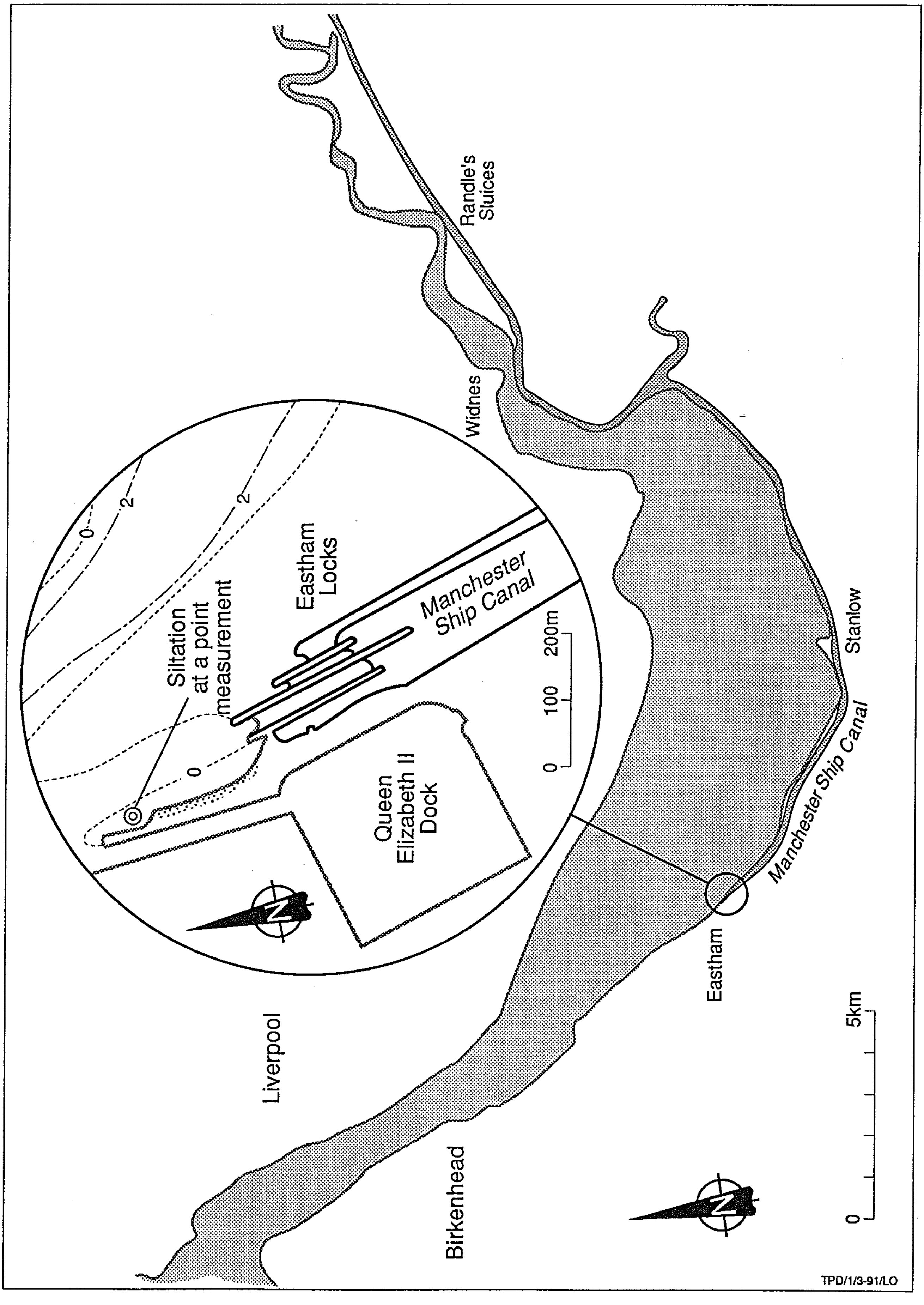

Fig 1 Location plan

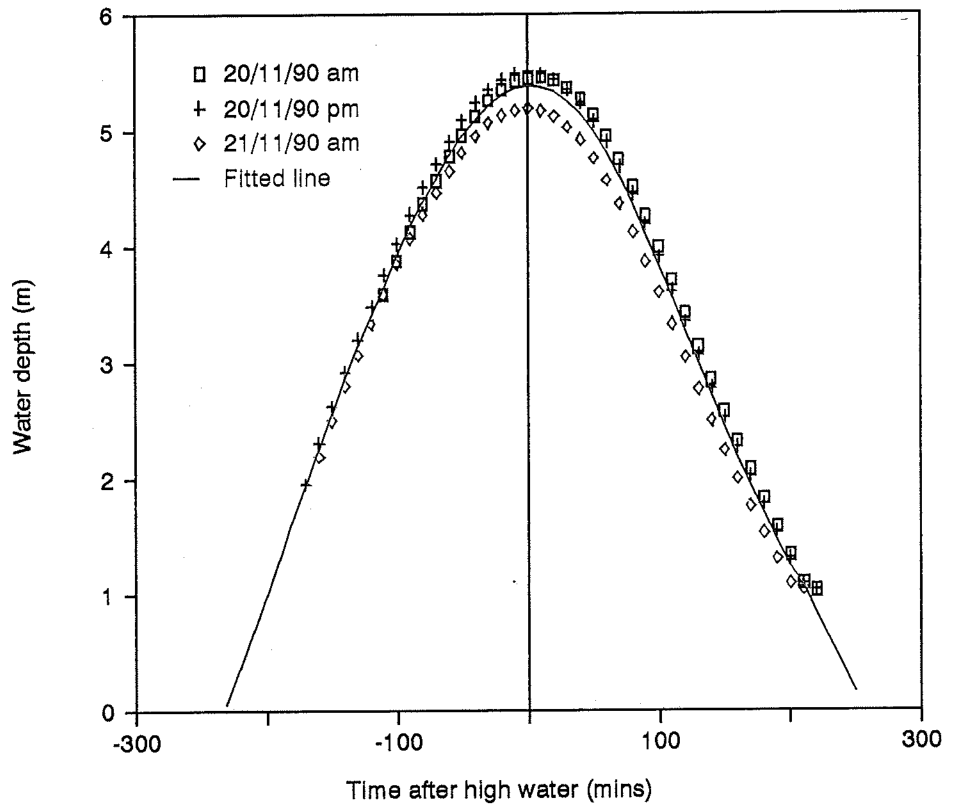

Fig 2 Spring tide water levels, field data and fitted line.

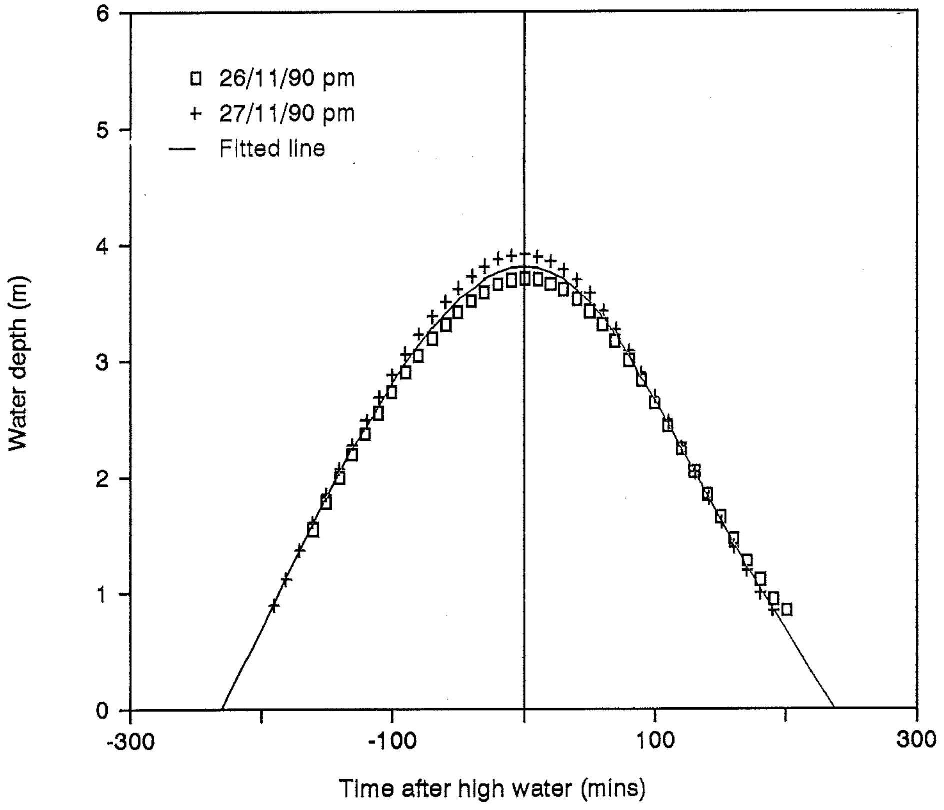

Fig 3 Neap tide water levels, field data and fitted line.

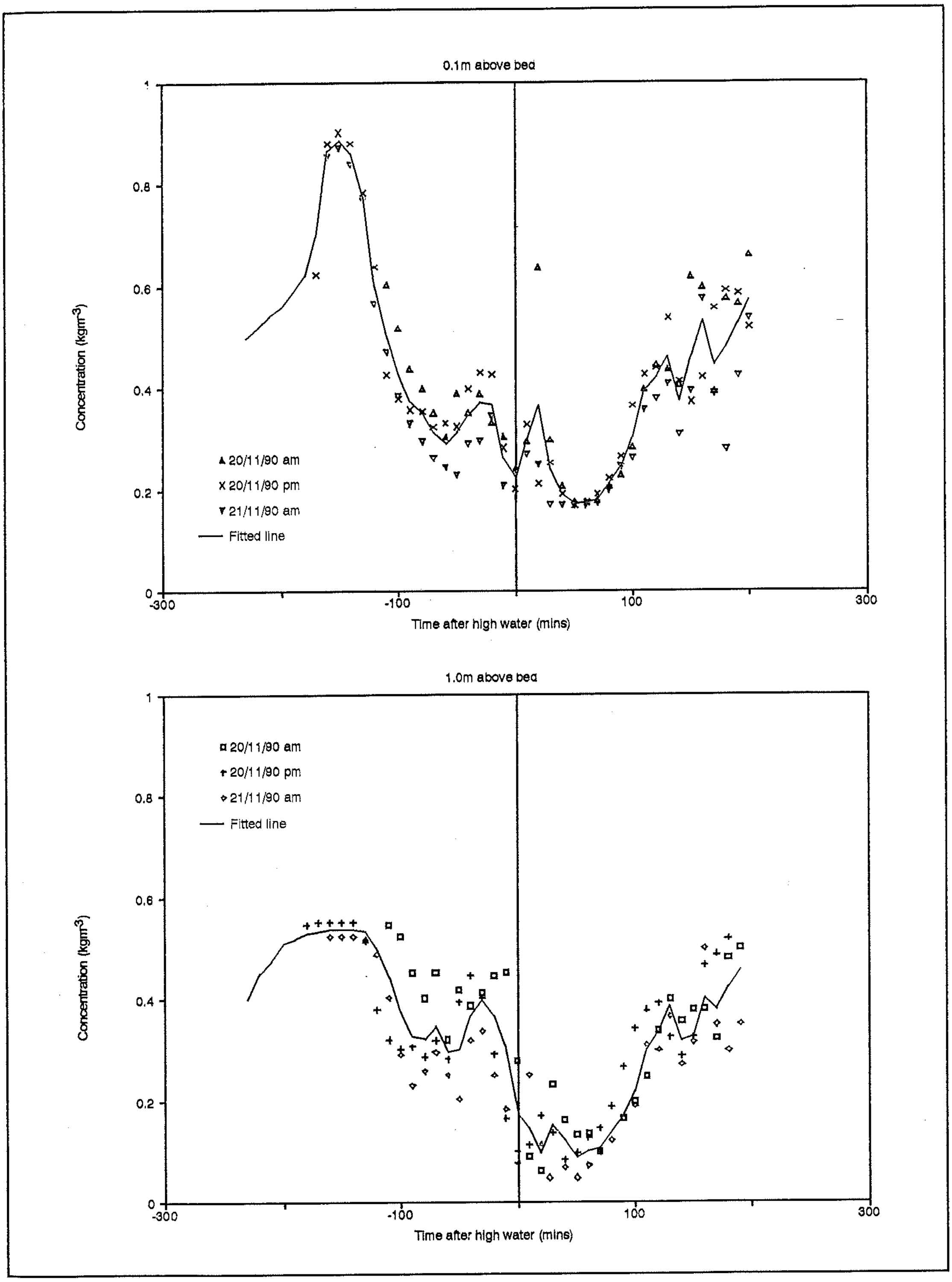

Fig 4 Spring tide suspended sediment concentration, field data and fitted line.

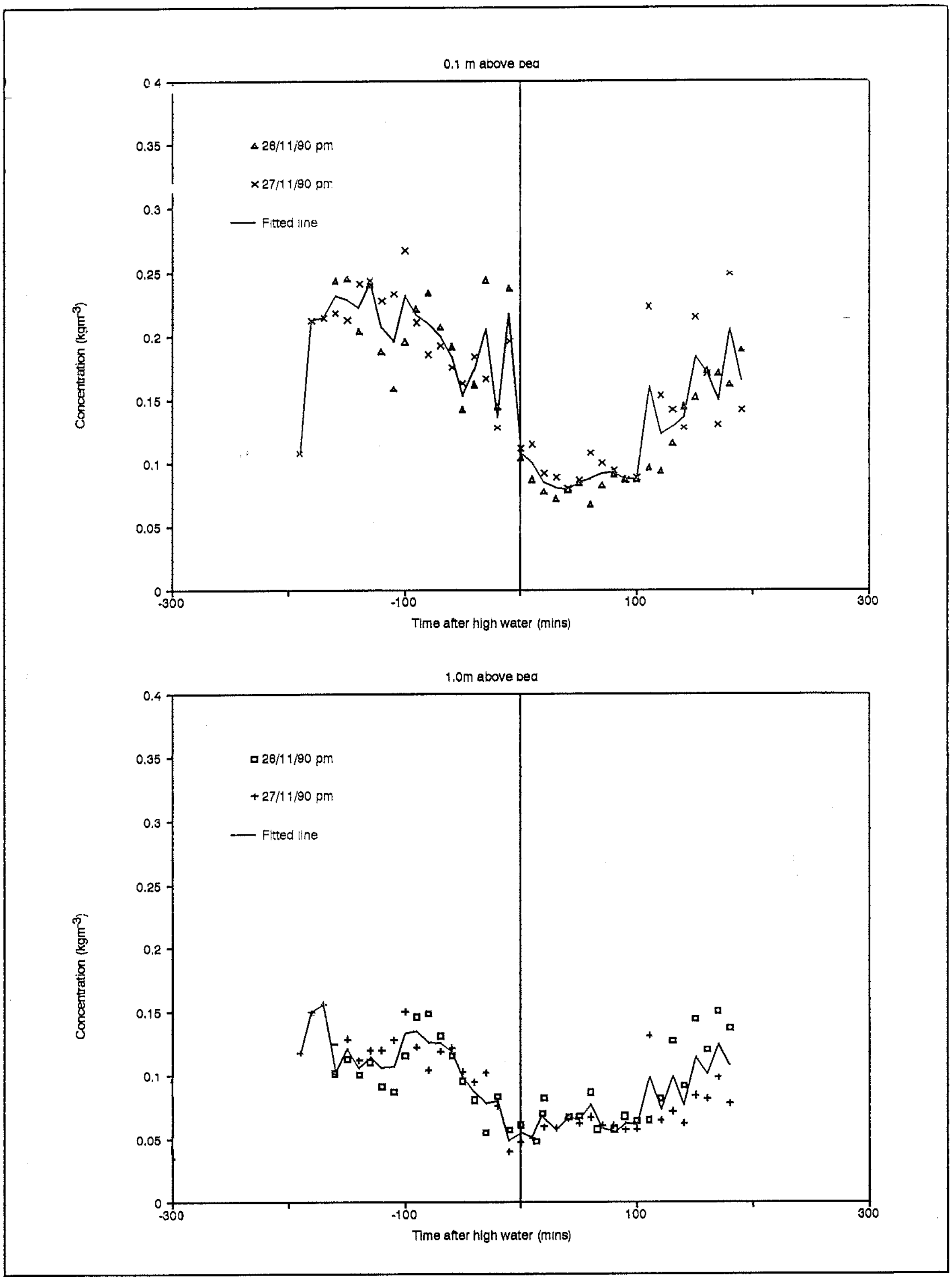

Fig 5 Neap tide suspended sediment concentration, field data and fitted line.

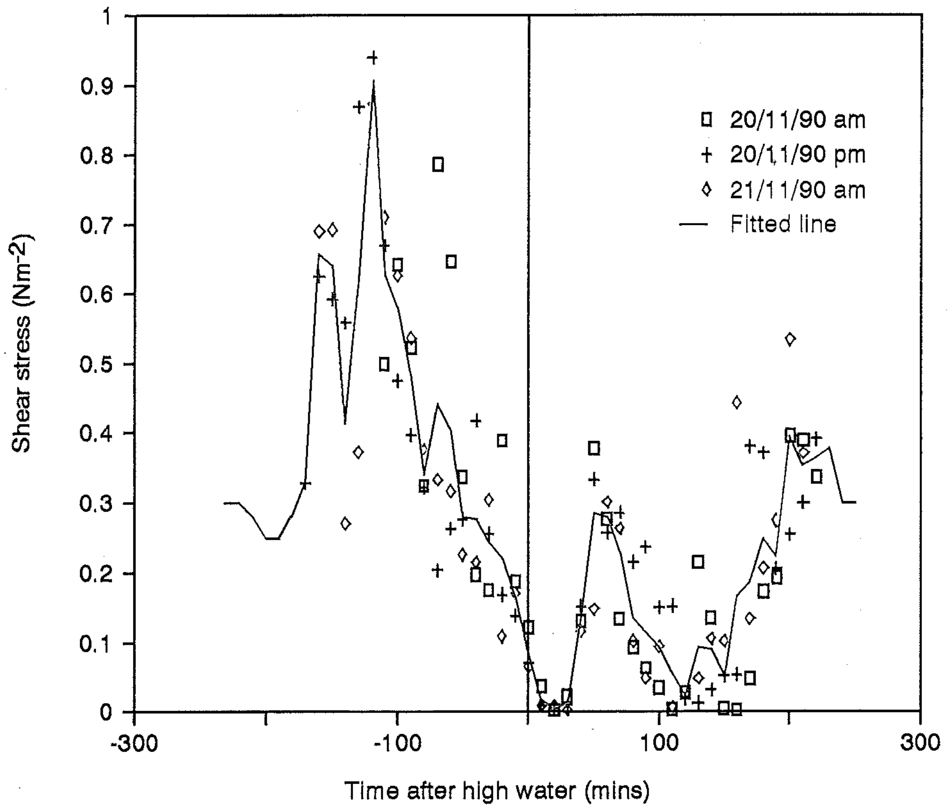

Fig 6 Spring tide shear stress at the bed, field data and fitted line.

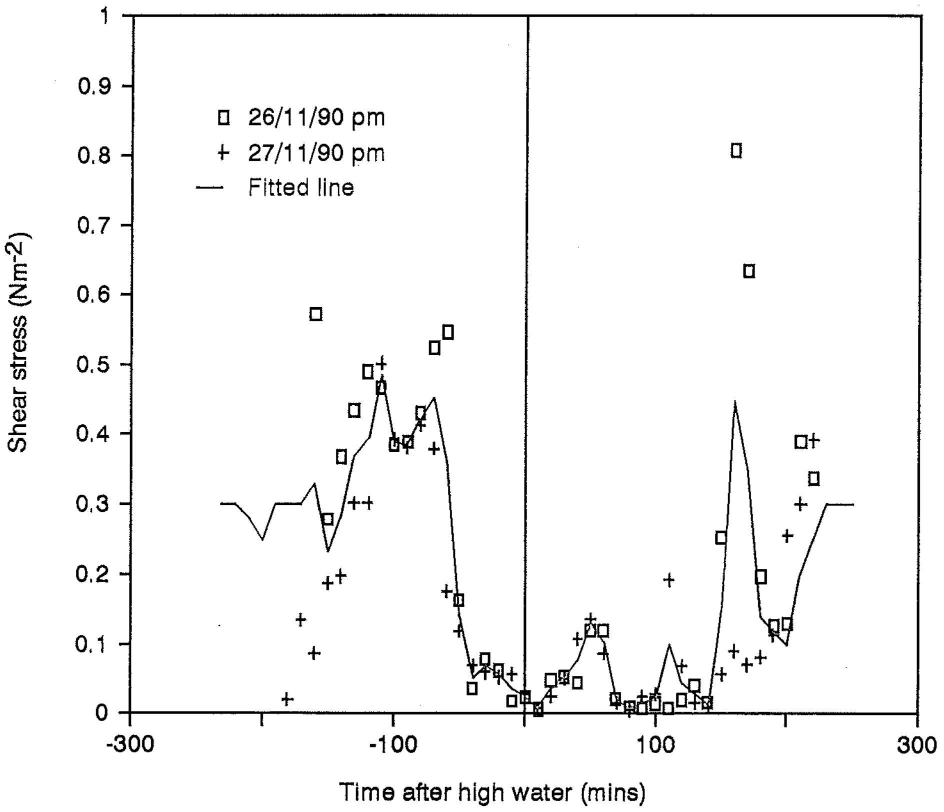

Fig 7 Neap tide shear stress at the bed, field data and fitted line.

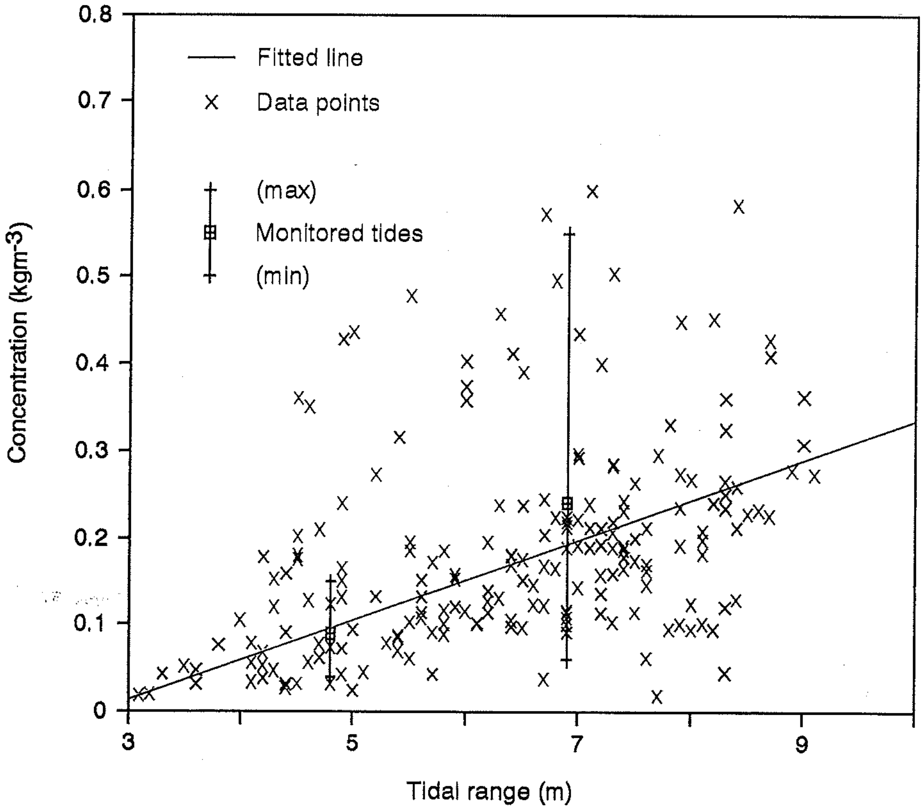

Fig 8 Tidal averaged suspended sediment concentration, field data and fitted line.

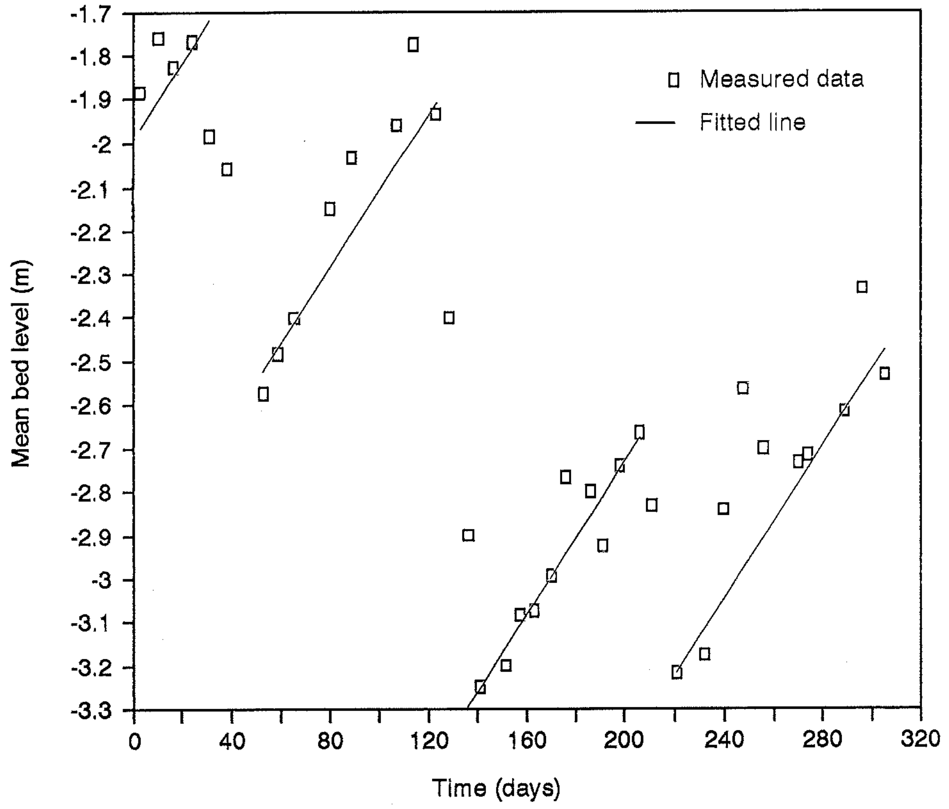

Fig 9 Mean bed level in channel.

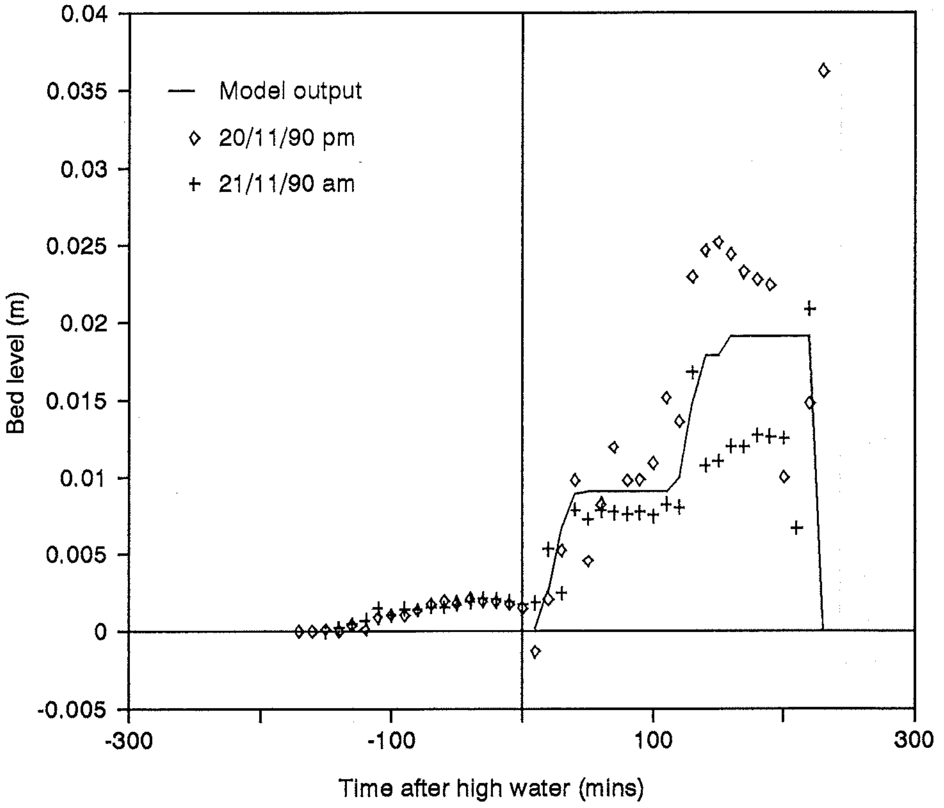

Fig 10 Spring tide bed levels, field data and model prediction.

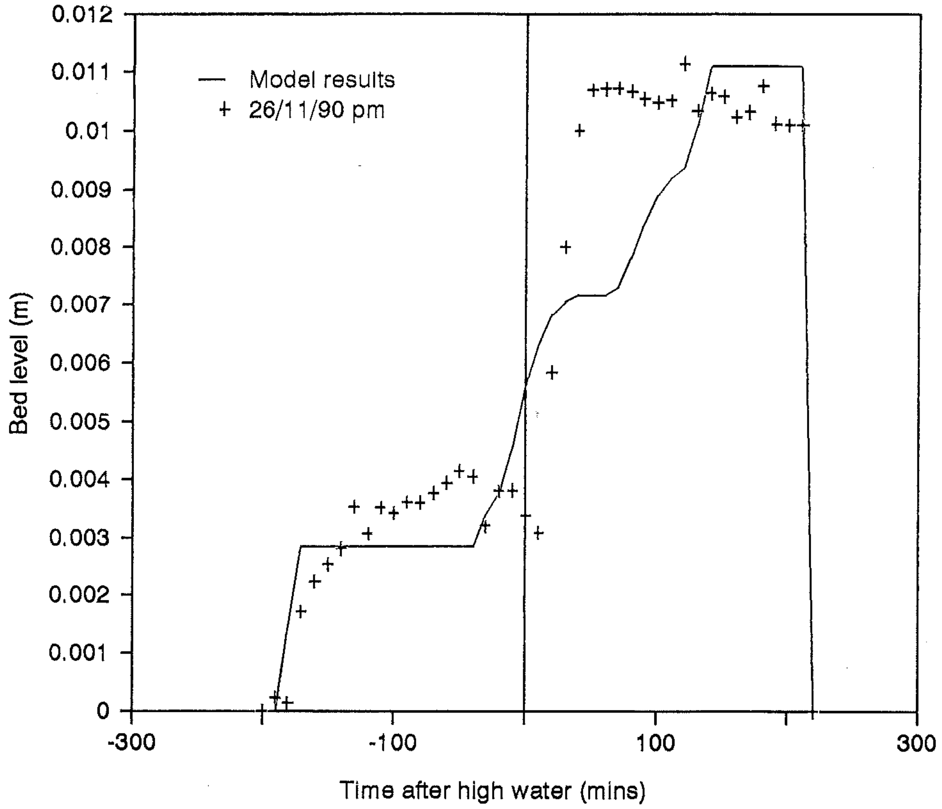

Fig 11 Neap tide bed levels, field data and model prediction.

Plate

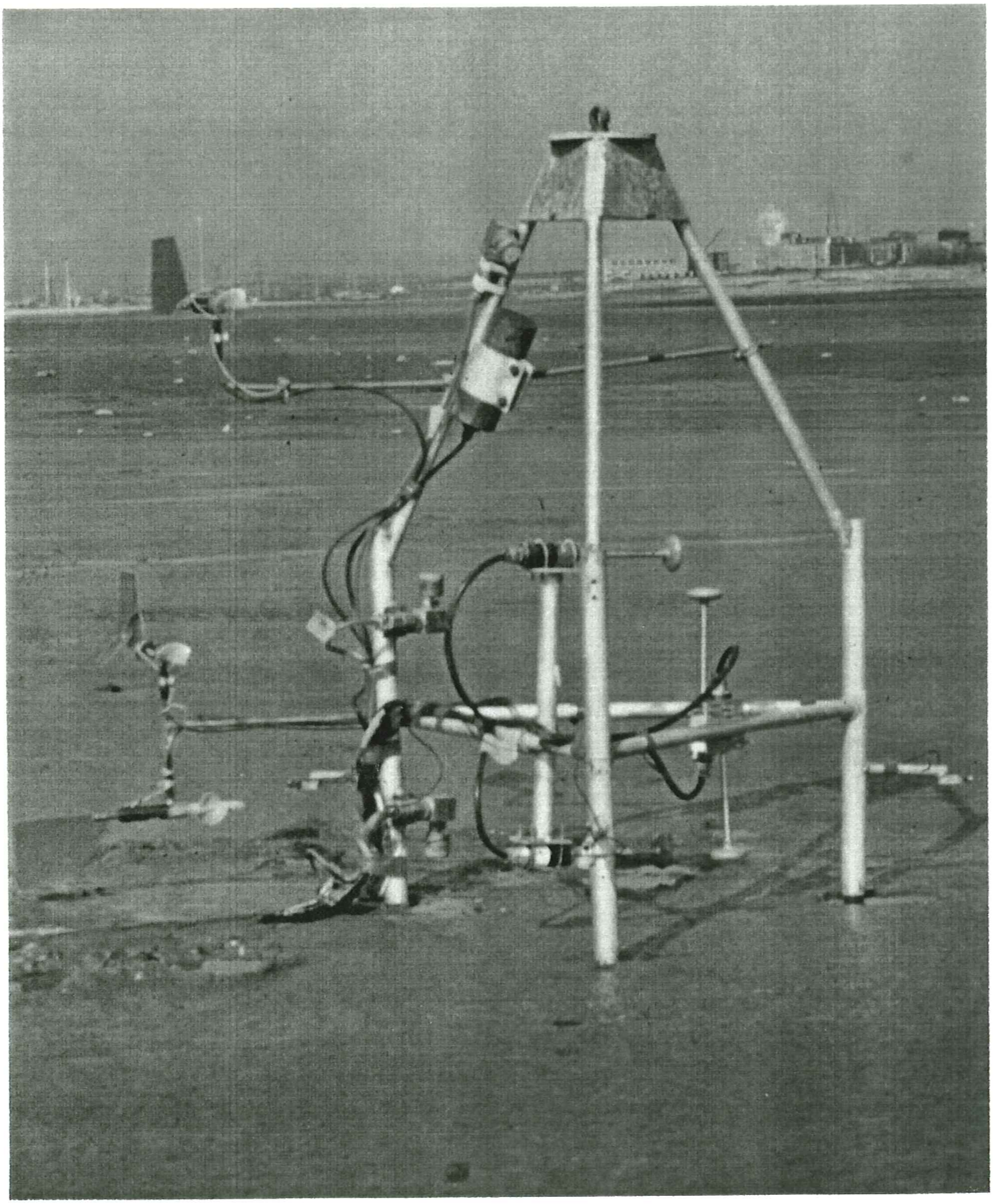

Plate 1 Bed frame

Appendix

Appendix 1

Siltation at a Point Model (SAP)

The siltation at a point model (SAP) is a zero-dimensional mathematical model which predicts the changes at a point on a cohesive sediment bed, over a period of many tides. The processes of erosion, deposition and consolidation are modelled. The model requires field and experimentally determined cohesive sediment parameters as well as knowledge of the bed shear stresses, which may be derived from either field measurement, a physical model or a numerical model.

The cohesive sediment bed in the SAP model is represented by ten discrete layers which are each assumed to be homogeneous, with a certain density and thickness. Sediment is subtracted or added to the uppermost layer, according to the processes of erosion and deposition respectively. In addition, the layers are consolidated under their self-weight and the excess pore pressures within the bed are dissipated. At each time step the density and the thickness of each layer is calculated.

The erosion of a cohesive sediment bed may be assumed to occur when the applied bed shear stress τ, exceeds the erosion strength τ_e. The rate of erosion of sediment from the bed dm/dt, may be expressed as

$$dm/dt = m_e (\tau - \tau_e) \qquad \tau > \tau_e \qquad (1)$$

The erosion shear strength, τ_e, and the erosion constant, m_e, may be found experimentally. The erosion shear strength τ_e, increases with dry density and may be related to the dry density ρ_d, in the form

$$\tau_e = A \rho_d^B \qquad (2)$$

where A and B are experimentally determined constants for a particular cohesive sediment.

The deposition of suspended cohesive sediment to the bed is assumed only to occur when the applied shear stress τ, is less than a critical shear stress τ_d. The rate of deposition may be expressed as the multiple of the near-bed concentration of suspended sediment c, the median floc settling velocity w_{50} and a probability function, such that

$$dm/dt = c\, w_{50} (\tau_d - \tau) / \tau_d \quad , \tau < \tau_d \qquad (3)$$

This gives a zero rate of deposition when $\tau = \tau_d$ and a maximum for a particular concentration of suspended sediment when $\tau = 0$. The median floc settling velocity must be determined in the field and can usually be expressed as a function of the suspended sediment concentration, where

$$w_{50} = D c^E \qquad (4)$$

where D and E are constants for a particular field location.

The consolidation of the cohesive sediment bed is modelled on the basis of three principal assumptions. The first is the assumption that the bed can be represented as discrete layers each having a particular density and thickness.

The second is that there exists an engineering relationship between the effective stress σ_v' and the dry density ρ_d of the cohesive sediment of the form

$$\sigma_v' = F + G\rho_d + H\rho_d^2 \qquad (5)$$

where F, G and H are constants. In addition, it is necessary to know the dry density ρ_{d0}, of the sediment immediately on deposition to the bed. This by definition is the density at which the effective stress is zero. The third assumption is that there also exists an engineering relationship between the permeability of the cohesive sediment k, and its dry density ρ_d, of the form

$$\log(k) = J + K\rho_d \qquad (6)$$

where J and K are constants. Laboratory experiments can be conducted in columns on deposited beds to determine the relationships given in equations 5 and 6.

Because the model is zero-dimensional the process of advection is not represented. As the model is applied to small areas it is feasible to assume that the suspended sediment concentration field may be taken to be the same at all points within the study area, although the bed shear stresses at different points may well be different. The time varying near-bed suspended sediment concentrations need to be determined for the application area, for typical spring and neap tides. This requires field measurements to be taken at least during one spring tide and one neap tide, and ideally over a period of some months.

The SAP model requires the bed shear stresses at the application point to be specified during a spring tide and a neap tide. This data may be obtained from field measurement of the near-bed velocities, or from either a numerical or physical model of the study area. Such models provide data at a number of points which enables the SAP model to be run at each of these points.