HR Wallingford

Proposed New Tonnage Lymington/Yarmouth Ferry

Mud Erosion in Lymington River

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Abstract

This report describes work commissioned by Lymington Harbour Commissioners to determine the relative magnitude of the factors affecting erosion of the mudflats and channel in Lymington River. The effect of an increase in the size of the Lymington/Yarmouth ferries was assessed by quantifying the natural and ship induced factors which could cause erosion. These factors were identified as tidal currents and ship return currents in the main channel and ship waves, wind waves and ship induced rapid water level drawdown on the inter-tidal mudflats.

Field measurements of through-depth velocity and suspended sediment concentration were used to determine the effect of tidal currents. A video camera was used to record ship induced rapid water level drawdown on the mudflats. Grab samples were collected for determination of bulk density and size analysis. Laboratory erosion tests were carried out on samples collected from the mudflats, in order to determine the shear strength of the mud.

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1. Introduction

In April 1991 Lymington Harbour Commissioners (LHC) asked HR Wallingford (HR) to conduct a study to assess the effect of increasing the size of the Lymington to Yarmouth ferries on the river channel and inter-tidal mudflats. The ferry operator, Wightlink, proposes to make the increases shown below in Table 1:

Table 1: Details of existing and new ferries

	Existing	New
Length	55m	75m
Breadth WL	12.2m	13.6m
Maximum submerged cross-sectional area	25.7m^2	27.0m^2
Draught	2.3m	2.3m
Displacement (loaded)	900 tonnes	1450 tonnes
Horsepower	2 * 400 hp	2 * 675 hp

This represents a 37% increase in water line length, 5% increase in maximum cross-sectional area, 60% increase in displacement, and no change to draught.

This report describes field, laboratory and desk studies carried out by HR Wallingford to quantify the magnitude and frequency of occurrence of the natural and ship induced factors which could cause erosion of the mud banks and channel. Each of these factors was considered in turn to see how it might change with the proposed increase in the ferry size.

The factors which could cause erosion of the mud banks and channel were identified as: tidal currents and ship return currents in the main channel and ship waves, wind waves and ship induced rapid water level drawdown on the inter-tidal mudflats.

Field measurements of through depth velocity and concentration were used to determine the effect of tidal currents. A video camera was used to record ship induced rapid water level drawdown on the mudflats and to observe ship wash. Return currents were calculated theoretically from ship and channel dimensions, and wind wave induced currents were calculated from existing wind data with the help of a numerical wave model.

2. Existing Conditions

2.1 Background

It has been observed by the staff in the Harbour Office at Lymington that the mudflats in the river have been eroding steadily over the past 15 years and that the river banks have been receding. Parts of the sheet pile outside the Harbour Master's Office have become exposed and the wave screen in front of Lymington Yacht Haven is being undermined. The wave screen running north from No. 11 Post was erected in 1990 partly to compensate for the receding river banks: erosion of the banks resulted in a longer effective fetch for generation of waves, which in turn meant larger and unacceptable wave heights at Fortuna Dock.

These observations of erosion of the river banks and mudflats are causing considerable concern. In order to quantify the actual changes to the river channel, two bathymetric charts with a time span of ten years were compared by HR. The charts were April - June 1981 (referred to as '1981') and December 1990 - January 1991 (referred to as '1991').

2.2 Comparison of bathymetry, 1981 to 1990

Bathymetric data was obtained for 1981 and 1991 surveys of the channel and nearby mud flats in Horn Reach, between the Sealink ferry terminal to the north, and Harper's Post to the south. The earlier chart shows limited information, restricted to the central part of the channel, so the comparison is restricted to this part of the channel. This area was split in two for digitising purposes and bathymetric data for the years 1981 and 1991 was digitised, thus forming four grids. The grids were created at the same scale and were 280m x 50m for the northern area and 350m x 50m for the southern area. These areas represent only the main channel and a small area either side, as these are the only areas inside the wave screen which are covered on both surveys.

Figures 1 and 2 show the bathymetry of the area for 1981 and 1991 respectively. The 1981 bathymetry showed that the channel was generally at a bed level between 2m and 3m below chart datum (CD), and 20m to 30m wide at these depths, with the exception of the region near Harper's Post where depths reached 3 - 3.5m below CD.

The 1991 bathymetry indicated a channel of approximately the same width but with bed levels of 2 - 3.5m below CD and with substantial regions below -2.5m CD. There are regions of significant change opposite the Lymington Harbour Office and in the channel near the Sealink ferry terminal, with a 1991 level below -3m CD compared to -2.5m CD in 1981. There is a small region where the depth has been reduced opposite Lymington Yacht Haven, where the 1981 level was between 2.5 to 3m below CD, and the 1991 depth is now between 2 and 2.5m below CD.

For comparison, the 1981 bathymetric grids were subtracted from the 1991 grids, creating 2 resultant grids. Figure 3 shows the residual pattern of erosion (negative) and deposition (positive) between 1981 and 1991. Erosion is clearly shown in the central part of the channel, particularly opposite the Harbour Office, with changes of around -1.0m. Smaller changes of about -0.5m are shown on the west side of the channel, near the Fortuna Pontoon. Deposition appears to have occurred on the east side of the channel, near No 13 Post, with changes of up to +1.0m.

Volumes of eroded and deposited material were calculated for 6 regions in the digitised area, shown in Figure 4. Regions A and D represented a 10 metre strip on the west side of the channel, with areas of 2800m^3 and 3500m^3 respectively, and regions C and F represented a 10m strip on the east side of the channel with areas 2800m^3 and 3500m^3. Regions B and E covered the middle 30m wide strip with areas 8400m^3 and 10500m^3 respectively. The results of the volume analysis are shown in Table 2.

Table 2 Erosion and Deposition in Horn Reach

Area	Volume Eroded m^3	Volume Deposited m^3	Volume Change m^3	Average Depth change
A	-1137	0	-1137	-0.4m
B	-2336	787	-1549	-0.2m
C	-251	1885	1634	+0.6m
D	-428	437	9	+0.0m
E	-3962	224	-3738	-0.4m
F	-418	332	-86	-0.0m
TOTAL	-8532	3665	-4867	-0.15m

These figures show a large amount of erosion, particularly in the channel, where an average of 0.2m has been lost in the northern part of the channel and an average of 0.4m has been lost in the southern part of the channel. In spite of some deposition on the west bank, which suggests a slight shifting of the alignment of the channel, overall this change in bathymetry represents a large loss of material. This material will be kept in suspension in the river and will settle out in areas where tidal currents are low, such as the marinas and mooring areas.

It has been noted that since the arrival of the 'C' class ferries in 1973, no dredging of the main channel has been necessary.

2.3 Mud properties

A laboratory study was carried out to determine the erosion strength of the mud from the inter-tidal mudflats, in order to assess whether the factors which might cause erosion would actually have any effect on the mud. Erosion tests were run on twelve box core samples which were collected during the field survey. The box cores were 220mm by 195mm by 150m deep.

2.3.1 Apparatus

A reversing flume, 27m long, 600mm wide with a maximum depth of 200mm was used to test the erosion strength of the samples. Velocities from -1 to $1ms^{-1}$ could be produced, although for these tests flows were only used in one direction. Flow was produced by the rotation of an impeller driven by a constant discharge $0.14m^3s^{-1}$ axial pump. Altering the impeller-vane pitch caused the flow velocity to increase or decrease. This was controlled by micro computer. Screens and guide vanes were placed at the entrance to provide a uniform flow. The flume had a removable sample box in the working section, which was 19m downstream from the entrance. A false bottom allowed the sample box to be placed below the flume floor with the sample surface flush with the flume bed.

The depth of flow (125mm) was kept constant for all experiments. Velocity profiles were measured using a propeller current meter of diameter 10mm. Shear stresses were then calculated from these profiles, by fitting a semi-logarithmic curve to calculate the shear velocity, u_*, and shear stress, τ_e, according to:

$u/u_* = 1/k \ln(z/z_o)$ (1)

and

$\tau = \rho u_*^2$ (2)

where

u = horizontal velocity component
u_* = shear velocity
z = distance above the bed
z_o = the intercept of the semi-log profile on the height axis
k = von Karman's constant (0.4)
ρ = density of the fluid.

2.3.2 Test details

The cores were taken from three sites on the mud flats which represented high, middle and low shore (Appendix A, Figure 2). Two cores were taken from each of six sites, as follows :-

A1, A2, B1	High Shore (taken at mid water)
B2, C1	Middle Shore (mid water)
C2	Low Shore (low water)

Each pair was mounted longitudinally in the flume with the surfaces flush with the flume bottom. Clay was moulded around the edges of the samples to ensure a smooth transition of flow from the flume bottom to sample surface.

The flume was filled to a depth of 125mm with fresh water and allowed to stabilise. The flow of water across the mud samples was increased in small steps and the mud surface closely observed for the onset of erosion. Individual particles and small flakes of mud from around breaks in the mud surface were seen to move first, but erosion was taken as the point when the undisturbed mud surface was seen to break free in the applied flow. At this flow a velocity profile was measured 300mm in front of the front mud sample, and another towards the back of the rear sample. This was to check the flow conditions in the flume and over the bed. The applied shear stresses at the point of erosion were calculated from the logarithmic velocity profiles.

2.3.3 Results

The samples were found to be of fairly soft consistency, with a bulk density of around 1400kgm^{-3}. The surfaces were bound by biological material. There were tube worm burrows evident on many of the samples, and there appeared to be higher resistance to erosion around these. This may be attributable to the slimy surface observed (worm secretions perhaps) which could bind the mud surface particles and thus increase surface cohesion. When the mud beds did erode this was characterised by a small chunk of the surface breaking away and the bed peeling away backwards from this point in irregular sheets. These eroded 'sheets' of mud were observed to be matted underneath with algal material. The exposed bed under the eroded sheets was pitted and uneven and contained ripped algal threads and worm holes protruding from the surface.

Velocity profiles for samples taken from low, middle and high shore are shown in Figure 5. In general the flume discharge required to erode the samples increased from low shore to high shore. The shear velocity, u_*, and critical shear stress for erosion, τ_e, for samples A1 to C2 are shown in Table 3.

Table 3 Flume Erosion Test Results

Shore	Sample	Shear strength τ_e (Nm^{-2})	Shear velocity u_* (ms^{-1})
High	A1	0.8 - 1.1	0.028 - 0.033
High	A2	2.7 - 3.8	0.052 - 0.062
High	B1	1.3 - 1.5	0.037 - 0.039
Middle	B2	1.1 - 2.0	0.033 - 0.045
Middle	C1	1.8 - 2.0	0.043 - 0.045
Low	C2	0.4 - 0.6	0.020 - 0.022

For high shore samples, the shear stress for erosion was in the range 0.8 to 3.8Nm^{-2}. The shear stress calculated for sample A2 was much higher than the other two high shore samples, whilst not seeming dissimilar in texture or appearance. This shear stress is also higher than expected from the flume which was used. Sample A2 may therefore be an unrepresentative result, perhaps due to the sample not being aligned horizontally. The mid shore samples eroded at shear stresses between 1.1 and 2.0Nm^{-2}. The low shore samples eroded at shear stresses between 0.4 and 0.6Nm^{-2}. In general, the applied shear stress for erosion increased from low to high shore and for the Lymington mud flats sampled the shear stresses were generally between 0.4 to 2.0Nm^{-2}.

3. Field measurements

A short field survey was conducted between 14-17 May 1991 to measure currents and suspended sediment concentrations, to collect grab samples from the channel and mudflats, to collect box cores from the mudflats, and to record on video film the rapid water level drawdown off the mudflats due to the passing ferries. This work is described in detail in Appendix A, which also contains the analysed data.

Samples of sediment from the channel contained stones and gravel in coarse sand. The analysed sample had only around 6% (by weight) of the sediment with a diameter less than 1mm, and the median particle size (50% of particles smaller than this) was around 25mm. In comparison, the sample from the mudflats was typical of a muddy sample, with around 90% of the sample less than 63 microns (0.063mm).

The continuous measurement of suspended sediment showed that concentrations at the end of the Harbour Master's Pontoon were very low, less than 20ppm, for most of the monitoring period (Appendix A). An obvious rise in suspended sediment concentration can be observed on each tide just before low water, up to around 275ppm, possibly exceeding this value on some tides. There was no indication that the suspended sediment concentration rose when a ferry passed, but this monitor was not particularly close to the channel and locally stirred up sediment may not have reached this monitor. In addition, the ferries were very frequent (approximately 4 ferries in or out through Horn Reach per hour during the busiest part of the day) and mud would not have had time to settle much between ferries.

Unfortunately, on the day of current metering, it was noted that the ferries were travelling much slower than usual, probably because they were aware that measurements were being made. Whilst this did not affect the tidal current measurements, it meant that the ship induced drawdown over the low water period was considerably less than usual. Fortunately, filming from the shore on the following day provided more realistic data.

4. Assessment of Forcing Factors on Erosion

4.1 Tidal currents

The through-depth current measurements are given in Appendix A. There was very little difference between the velocities measured near the bed and those measured near the surface. On this basis, the shear stress on the bed was calculated from the average tidal velocity and the water depth, according to the smooth turbulent law. The measurements were made on the side of the channel, where the bed is muddy, so the smooth turbulent law is valid there. The water depths and shear stresses for the monitoring period are shown in Figure 6. The maximum velocity was around $0.3ms^{-1}$, giving a maximum shear stress of $0.12Nm^{-2}$. This occurred between 1700 and 1800 hours, coinciding with the time of peak ebb flow (shown as most rapid drop in water level). Smaller peaks can be observed during the flood tide, at 0730 and 1130 hours, which also correspond with more rapid changes in water level.

However, these shear stresses are very small, and would not erode the mud tested in the laboratory. The ebb flow currents would be sufficient to resuspend soft mud which had very recently been deposited, but would not be sufficient to erode the undisturbed sediment on the banks.

The tidal velocities will remain unchanged by the proposed change to larger ferries, unless this in itself results in an increase in the tidal volume of the estuary. In recent years, the number of moorings for small boats in the river has increased, by dredging out areas of the river. Where this has involved removal of mud which was between the low and high water lines, this will have resulted in an increase in tidal volume, thereby increasing the tidal velocities at some sections. Future developments of this kind would also increase tidal velocities. However, as these developments are very small compared to the total volume of the estuary, it is unlikely that they would increase the tidal velocities by very much.

Since the neap tidal range is very small (range 1.1m compared with 2.5m for springs), it can be assumed that the effect of tidal currents is only felt on spring tides. One may assume that approximately one third of the tides are springs (based on twice the number of tides per year which exceed the mean high water spring level), and that the shear stress exceeds $0.1Nm^{-2}$ for around 30 minutes during a tide (0.04 of the tide). The percentage of the year in which the shear stress due to tidal currents exceeds $0.1Nm^{-2}$ is therefore around 1%.

4.2 Wind waves

A seasonally averaged distribution of wave heights and periods for Horn Reach was calculated from wind data collected at Calshot over the period 1960-1979 (Ref 1). Frequency distributions calculated for summer and winter are given in Appendix B. Adjustments to the wind speeds from some directions were made to account for the more sheltered conditions in Lymington River, which are not exposed to a long blow over open water.

A numerical wave prediction model was used to compute the wave height and period distributions. The prediction method was based on the Saville method for estimation of wave heights in reservoirs (Ref 2), with an allowance for shallow water effects (Ref 3). The results have been summarised in Table 4.

The shear stress exerted on the bed by the waves is largest in shallow water and decreases very rapidly for deeper water. This means that the waves will have more effect on the inter-tidal mudflats than in the channel.

Table 4 Seasonally averaged distribution of wave height, wave period and shear stress at Lymington

	50% >	10% >	1% >
Hs (m)	0.08	0.17	0.28
Ts (s)	0.9	1.3	1.5
τmax (Nm^{-2}) seasonally averaged			
at bed level +0.5m CD	0.003	0.06	0.2
at bed level +1.0m CD	0.02	0.2	0.5
at bed level +2.0m CD	0.00	0.01	0.2

Because of the rise and fall of the tide, the bed shear stresses have been seasonally averaged to include the effect of the water depth at each bed level. The mudflats at 1.0m CD are subject to the high shear stresses most often because the water is quite shallow there for a large part of the tide. The maximum shear stress exerted on the bed due to the waves only exceeds $0.5Nm^{-2}$ for about 1% of the time (~3 days a year), although this would probably be sufficient to erode the softer mud at the edge of the channel.

Excluding a general climate change, the wind waves should not change, unless (as proposed) operation of the larger ferries involves moving the wave screens to allow a wider opening at No. 11 Post. In this case, the increased fetch lengths may increase wave heights by approximately 10%.

4.3 Ship return currents

A vessel moving along a restricted waterway sets up a return current in the channel parallel but opposite to the direction of motion of the vessel. The return current acts for the period it takes the vessel to pass. The return currents depend heavily on the velocity of the ship and the cross-sectional areas of the channel and the part of the ship below the waterline. The ratio of these areas, the blockage ratio, is defined as:

$$\text{Blockage ratio} = \frac{\text{midship cross-sectional area}}{\text{waterway cross-sectional area}} \qquad (3)$$

Return currents will be most important at low water, when the blockage ratio is highest. The Wightlink ferries are the only vessels in Lymington River with a blockage ratio which is high enough to generate significant return currents. Figure 7 shows a typical cross-section of the channel in Horn Reach. The cross-section of the new ferry is also shown, with a water level at 0.5m CD. Based on an average cross-section in Horn Reach, and a low water level of 0.5m CD, the blockage ratio was calculated to be around 0.18. This compares with a blockage ratio of 0.17 for the existing 'C' class ferries, ie an increase of 5%.

These blockage ratios were calculated assuming that the ferry travels up the centre of the channel. If the ship is to one side of the channel then the return currents will be much higher on one side of the bank. This could easily be the case if small craft are obstructing the main channel, or as the ferry manoeuvres round the bends in the river. A blockage ratio can be estimated for the ferry as it turns the corners of the channel - a crabbing effect rather than a smooth turn. Based on the angle of the bend, the cross-sectional area perpendicular to the channel could increase by up to 30% as the ferry enters Horn Reach. This would increase the blockage ratio to around 0.23. In general, the ferry will be travelling slower as it turns the corners than on the straight stretches.

A method for calculating return currents is described by PIANC (Ref 4). Figure 8 is a reproduction of Schijf's diagram for calculating return currents and drawdown. Based on a blockage ratio of 0.17, and a ship speed of 5 knots, the average return current calculated from this diagram at low water is around $1.0ms^{-1}$ (compared with around $1.2ms^{-1}$ for blockage ratio of 0.18). The shear stress on the bed which results from a velocity of $1.0ms^{-1}$ is around $1.0Nm^{-2}$. Based on the laboratory tests, this is sufficient to erode the mud on the low shore and probably sufficient to erode the slightly more consolidated material on the middle of the mudflats too.

Figure 8 shows that for a given blockage ratio there is a maximum average return current and drawdown, which is determined by the limit speed of the vessel, V_L. The limit speed is a value which, for that blockage of the channel and for a vessel travelling under its own power, it is very difficult to exceed (Ref 4). Near to the limit speed, a small increase in the speed can result in quite large increases in return velocity and drawdown. The maximum return current estimated for a blockage ratio of 0.17 and for a vessel travelling at its theoretical limit speed is $1.5ms^{-1}$. An increase in blockage ratio also results in a lower limit speed. This means that the estimated blockage ratio for the ferry crabbing round the corners of the channel may increase the return currents locally to some extent but this will be limited by the limit speed of the vessel which will be lower than for the straight reaches. This will result in more scouring around the bends, an effect which has been observed by the larger increases in channel depth around No 11 and Harper's Post (Fig 2).

The ratio of maximum return current to average return current depends on the shape of the hull. Relationships have been defined for several different hull shapes, though these are mostly applicable to large inland waterways (Ref 4). A physical model study of a ship moving in a channel (Ref 5), which had blockage ratios similar to those at Lymington, indicated that the maximum return current was probably less than twice the average return current, and more like 1.3 - 1.5 times the average return current.

The percentage of time over which the return currents are expected to have any effect can be estimated from the number of ferry movements in the river. For 15,000 ferry movements in or out through Horn Reach (Ref 6), approximately one sixth of these are within one hour of low water, and the return currents act for the length of time it takes the ferry to pass (approximately 30 seconds for a ferry travelling at 4 knots). The return currents therefore act for approximately 0.25% of the year.

The magnitude of the average return current is related to the blockage ratio, which for a ferry travelling at 5 knots may increase from around $1.0ms^{-1}$ to $1.2ms^{-1}$ with the longer ferries. In addition, for the same speed of vessel, the effect will last longer. If the vessel is 37% longer, the effect would also last 37% longer. This ties in with the increase in displacement: average return currents increase by 20%, and last 37% longer, which results in around 60% more water being moved. The duration over which the return currents act could be kept the same if there were correspondingly fewer crossings with the larger ferries.

4.4 Ship waves

Ship waves vary in size and pattern, depending in part on the speed of a boat and its hull shape. The length of a vessel also tends to reduce the ship waves. The bow waves created by a ferry even at speeds up to 7 knots are not expected to be significant, because of the hull shape. Observations of vessels in Lymington River indicated that the waves caused by some of the small craft are larger than that of the ferry.

A study on boat wash (Ref 7) measured the wave height at various distances from the boat, for a large number of small boats of different shapes. These were travelling at similar speeds as those in Horn Reach (4-6mph, 3-5 knots), and in shallow water (1.7m). The waves generated were deep water waves, ie they were not 'felt' by the bottom, and would have generated the same pattern even if the water depth had been greater. Similar wave heights to those measured in that study can therefore be expected in Horn Reach from the small boats. This indicates that wave heights of the order of 0.1m could be expected, with periods of 1 to 2 seconds. This was increased to a wave height of around 0.15m at speeds of up to 7 knots. The evidence of the study suggests that there is only a small decrease in wave height further away from the boat. In shallow water (0.5m) these waves could result in shear stresses of around $0.2Nm^{-2}$ (0.3Nm-2 for 7 knots), but only for a few seconds as the point at which the wave reaches the water's edge will move along behind the passing boat. This shear stress is lower than that needed to erode any of the mudflat samples in the laboratory.

The wave heights generated by small craft in Horn Reach are not expected to increase, but the frequency of occurrence may increase as the number of small boats increases. However, if one assumed that there were the same number of small boat movements as ferry movements and that the effect lasted for 10 seconds, then the ship waves effect occurs for less than 0.25% of the time. The effect is much smaller than the effect of the return currents.

4.5 Ship induced rapid water level drawdown

The rapid water level drawdown off the banks in Horn Reach was recorded by video camera during the survey period on 16-17 May 1991. Markers were placed 1m apart in a line down the mudflat to near the edge of the channel. The horizontal distance and duration of the drawdown were then quantified by analysis of the video tape. The drawdown is only likely to have a significant effect on the mudflats around low water when they are exposed.

Figures 9 and 10 show examples of the drawdown from the video recording, as the position of the edge of the water as a time series. Typically, these show a slight rise of water level followed by a rapid reduction. The water washes back up the mudflats very quickly, usually above its initial level. A second drawdown may then be seen before the water level returns to its original level.

The maximum distance which the water level was drawn down was around 10m. This distance marked by the pegs corresponds to about 0.2m vertically. In these examples from 17 May 1991, the water was drawn off the mudflats fastest with the passing of the ferry at 09:19h (Fig 9) and returned up the slope of the mudflats fastest after the ferry at 10:03h (Fig 10). These represent water velocities of around $0.5ms^{-1}$ to $1.0ms^{-1}$ over the mudflats. These are much higher than the tidal velocities, and are also in much shallower water. These velocities would be sufficient to erode the soft deposits at the edge of the channel, and indeed, the stirred up mud can be seen in the turbulent water as it is sucked off the mudflats.

In addition to these measurements, the average drawdown expected can be calculated from Schijf's diagram (Fig 8). At low water (0.5m CD), for a blockage ratio of 0.17 and a ferry travelling at 5 knots, the average vertical drawdown expected is 0.2 - 0.3m, which supports the measured values. For the larger ferries, with a blockage ratio of 0.18, the drawdown may increase to 0.3 - 0.4m. The maximum drawdown predicted for a vessel with a blockage ratio of 0.18 travelling at its limit speed (in practice vessels rarely exceed 90% of this limit speed because of straining the engines) would be 0.5 - 0.6m.

The drawdown can be expected to be directly related to the amount of squat of the ferry. Squat has the following features:

- it varies roughly with the square of the speed of the ferry
- it increases as the underkeel clearance is reduced, and so will be worse at low water
- it is increased by the ferry sailing near to the channel bank (eg within half the beam of the ferry for separation distance between bank and side of ferry) and by blockage effects (ferry beam greater than one sixth of effective channel width)
- it is decreased by an increase in vessel length, keeping all the other parameters the same.

From the above features of squat, together with the observed drawdown of 0.2-0.3m for the existing ferry passing at low water, it is clear that the speed of the ferry is important in determining the relative effect on erosion of the banks. Since the new ferries have an increased maximum submerged cross-section, the increased blockage will result in larger drawdown, particularly at high speeds. This effect could be reduced by making restrictions on the speed of the ferry in the narrowest parts of the channel, particularly at low water. In addition, because of the increased length, the duration of the effect will increase. It appears that the main effect on the banks occurs when the water is drawn off and returns very quickly up the banks and not during the period when the water is at its minimum level. The time over which the drawdown effect is felt will be around 0.2% of the year, a little less than that of the return currents.

4.6 Discussion

The relative magnitudes of the factors contributing to erosion of the banks are summarised in Table 5:

Table 5 Relative magnitude of factors contributing to bank erosion

	Max. velocity (m/s)	Max. wave ht (m)	Bed Shear Stress (Nm^{-2})	% time	Erode Bed
Tidal velocities	0.3		0.1	1	No
Wind waves		0.28	0.5	1	Yes
Ship waves		0.1	0.2	0-0.5	No
Ship return currents	1.0		1.0	0.3	Yes
Horizontal drawdown	0.5-1.0		0.5-1.5	0.2	Yes

Only the wind waves, the ship return currents and the drawdown would be sufficient to erode the consolidated mud on the banks, although all the factors are sufficient to resuspend soft material which has only just deposited. The ship effects act fairly evenly over the whole year, whereas the wind wave effect is probably due to a few large storms. The largest shear stresses appear to be due to the return currents and drawdown, but these only act for a short period of time.

From the calculated shear stresses for the 'C' class ferries and the duration over which they act, the depth of erosion over ten years has been calculated. The erosion rate has been calculated from

$$dm/dt = E(\tau - \tau_c) \quad (4)$$

where
dm/dt = erosion rate ($kgm^{-2}s^{-1}$)
E = erosion constant (approximately 0.0005 $kgN^{-1}s^{-1}$)
τ = bed shear stress (Nm^{-2})
τ^c = critical shear stress for erosion (Nm^{-2})

The depth of erosion during the 10 year period, D, is then

D = erosion rate * 10 years (seconds) / bed density

Assuming an excess bed shear stress ($\tau - \tau_c$) of 0.2Nm^{-2}, and erosion constant of 0.0005$kgN^{-1}s^{-1}$, a bed density of 500kgm^{-3} and a duration of 0.5%, this equates to a depth of erosion of around 0.3m over a 10 year period. Although the actual values for each of these parameters may vary, this calculated depth of erosion corresponds well with the observed depth of erosion during the same period.

To estimate the effect of the new tonnage, the excess shear stress from all the factors which could cause erosion was increased by an average 10%. The duration of the erosion is assumed to remain the same, as the effect of the longer ferry is compensated for by fewer crossings. Using the same equation for erosion (Eqn 4), this gives around 0.15-0.2m depth of erosion in the first five years. Erosion of a further 0.15m is calculated for the following five years, although this is likely to be an overestimate as the blockage ratio resulting from the ferry will decrease as the channel enlarges, thus reducing the effect and slowing down the erosion.

In terms of bank erosion, the increase in depth in the channel is likely to cause the banks to recede, in order to maintain the same slope on the mud banks. For an increase in depth of the channel of 0.3m, this may result in the banks receding by up to 20m. This will be visually more obvious than the increase in depth in the channel. The erosion will be fastest immediately after the introduction of the new ferries. Assuming no reduction in the speed of the new ferries in Horn Reach compared to the existing ferries, this bank erosion could be around 10-15m after 5 years (0.15-0.2m extra depth in the channel), 20-25m after 10 years (0.3-0.35m extra depth) and 25-30m (0.35-0.4m extra depth) after 15 years.

5. Conclusions and Recommendations

5.1 Conclusions

1. A study was carried out to assess the relative magnitude of the factors which may be causing erosion of the river banks in Lymington River. These factors were identified as tidal currents and ship return currents in the channel, and wind waves, ship wash and rapid water level drawdown on the mudflats.

2. A comparison of the bathymetry in the channel in Horn Reach between 1981 and 1991 showed that a total of nearly 5,000 m^3 has been lost from the area in the 10 year period. There was some deposition on the west side of the channel, which suggested a slight shift in the alignment of the channel, but the major change was in the main channel where the depth of the channel has increased by an average of 0.2m between the Harbour Office and No 13 Post. The channel depth has increased by an average of 0.4m between No 11 Post and the Harbour Office. The sediment in the channel is now gravel and coarse sand, with a median grain size of 25mm. The sediment on the banks is muddy with 90% of the sample with a grain size smaller than 0.063mm.

3. Laboratory erosion tests measured the erosion strength of samples collected from the mudflats in front of the Harbour Office. Samples from low shore (near low water line, springs), mid shore and high shore (around mean water level) were tested. In general, the shear stress needed to erode the samples increased from low shore to high shore. The shear stresses varied from 0.4 - 0.6Nm^{-2} for the low shore sample, to 1.0 - 2.0Nm^{-2} for the high shore samples.

4. All the natural and ship induced factors exert shear stresses on the bed which are high enough to resuspend recently deposited soft mud. Only the wind waves, the ship return currents and drawdown are likely to be high enough to erode the more consolidated mud on the banks. The frequency of occurrence of each of the factors was estimated to be:

	Bed shear stress Nm^{-2}	% time
Tidal velocities	0.1	1
Wind waves	0.5	1
Ship waves	0.2	0 - 0.5
Ship return currents	0.5 - 1.0	0.3
Drawdown	0.5 - 1.5	0.2

The ship induced effects act fairly evenly over the whole year, whereas the largest wind waves are probably contained within a few storms. The dominant effects appear to be the ship return currents, the ship drawdown and the wind waves. The shear stress due to the wind waves is smaller than the other two effects, but acts for a larger percentage of the time. The calculated depth of erosion based on an excess shear stress and a duration of the year over which this acts is around 0.3m over a 10 year period, which corresponds well with the observed depth of erosion during the same period.

5. The tidal velocities will not increase, unless there are large changes to the inter-tidal part of the estuary (eg to move channel, expand mooring areas) which would increase the tidal volume of the estuary. The wind waves will not change, unless (as proposed) operation of the larger ferries involves moving the wave screens to allow a wider opening at No. 11 Post. In this case, the wave heights may increase by approximately 10%. Ship waves from the ferries are not considered significant, and may even decrease with the additional length. Return currents and drawdown are expected to increase in magnitude, because of the increase in submerged cross-sectional area of the hull. The increase is more significant at higher ferry speeds. In addition, the duration of the effect would increase with the length of the ferry, although the total percentage of the year over which the effect is felt could be maintained if the number of crossings is reduced by the same proportion.

6. The ship induced effects are very dependent on the speed of the vessel, especially at low water when the blockage effect is greatest. The blockage effect increases roughly with the square of the speed of the vessel. The erosive capacity could therefore be reduced by making restrictions on the speed of the ferry in the narrowest parts of the channel, particularly at low water.

7. In terms of bank erosion, the increase in depth in the channel is likely to cause the banks to recede, in order to maintain the same slope on the mud banks. This will be visually more obvious than the increase in depth in the channel. The erosion will be fastest immediately after the introduction of the new ferries. Assuming no reduction in the speed of the new ferries in Horn Reach compared to the existing ferries, this bank erosion could be around 10-15m after 5 years (0.15-0.2m extra depth in the channel), 20-25m after 10 years (0.3-0.35m extra depth) and 25-30m after 15 years (0.35-0.4m extra depth).

5.2 Recommendations

It is recommended that further work is carried out to measure the actual values of the ship induced return currents and drawdown with more accuracy. This could be done as part of a physical model study; it would require instruments capable of measuring velocities which change rapidly in magnitude and direction.

The shear stress on the mudflats due to the rapid water level drawdown (and return back up the bank) could be measured in a laboratory study with shear stress probes.

Long term changes in the bathymetry at a particular point of interest could be measured by using ultrasonic probes in the field - mounting these above the mudflats to measure the change in bed level.

6. Acknowledgements

HR acknowledges with thanks the assistance of Mr F V Woodford, Harbour Master of Lymington, and his staff for providing information and support during this study.

The field measurements were made by Mr M R Gradwell of the HR Field Studies Section. The laboratory erosion tests and comparison of bathymetry were carried out by Mrs H J Williamson. The wind wave model was run by Miss C E Jelliman. The report was written and the study managed by Ms M C Ockenden in the Research Department, headed by Dr W R White. Technical advice was provided by Dr E A Delo, Dr E C Bowers, Mr R W P May and Mr R L Soulsby.

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Figures

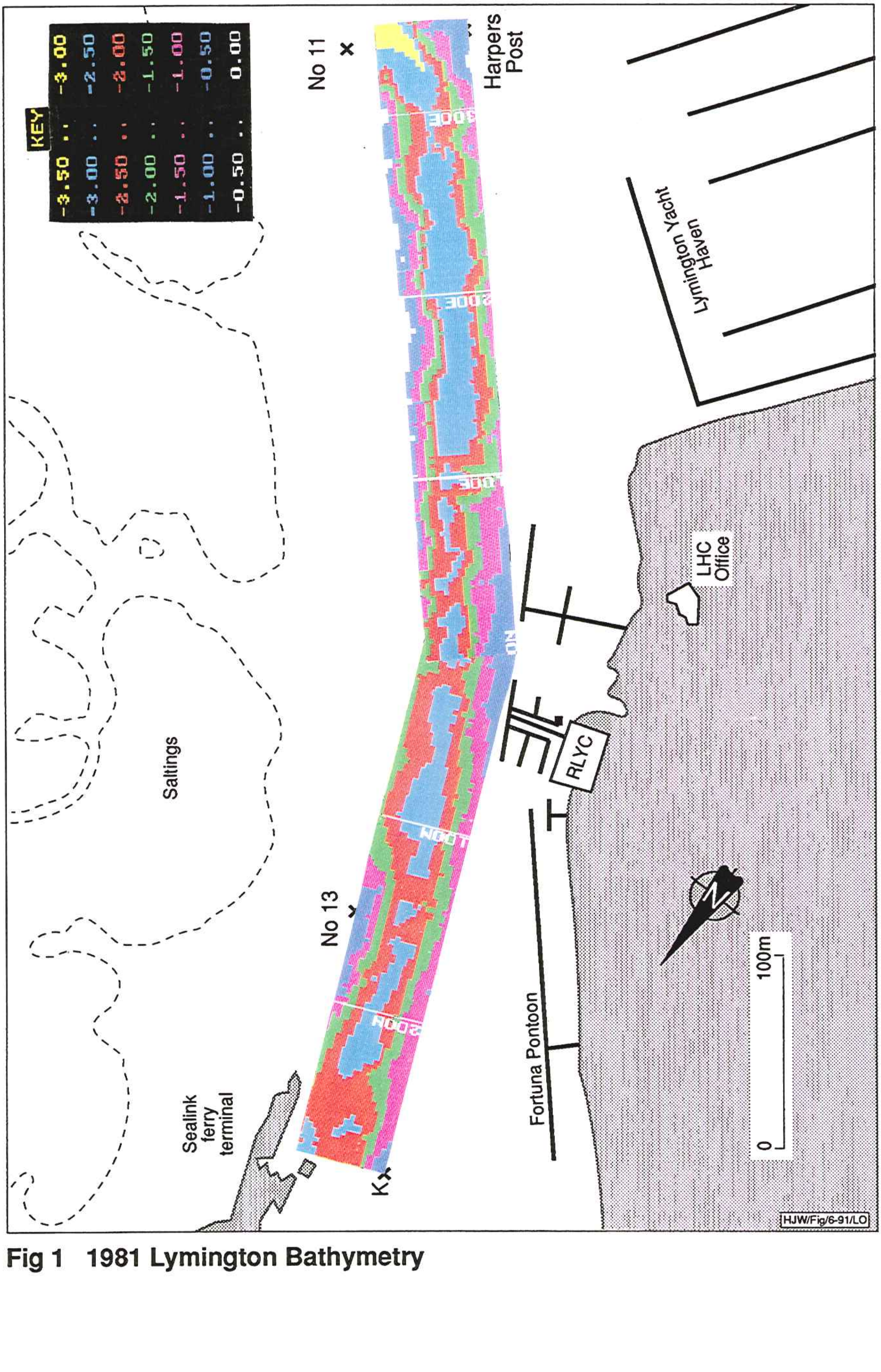


Fig 1 1981 Lymington Bathymetry

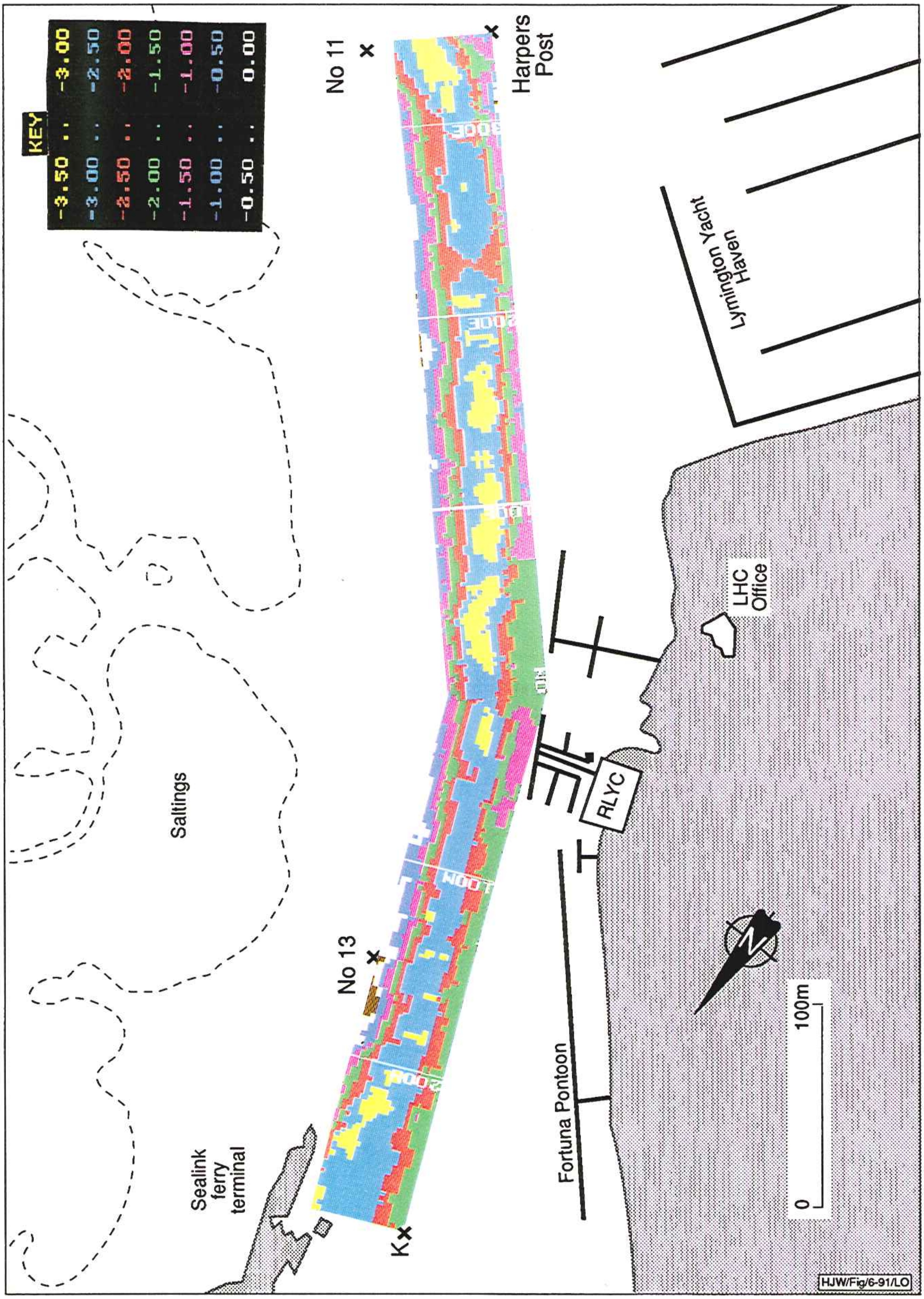


Fig 2 1991 Lymington Bathymetry

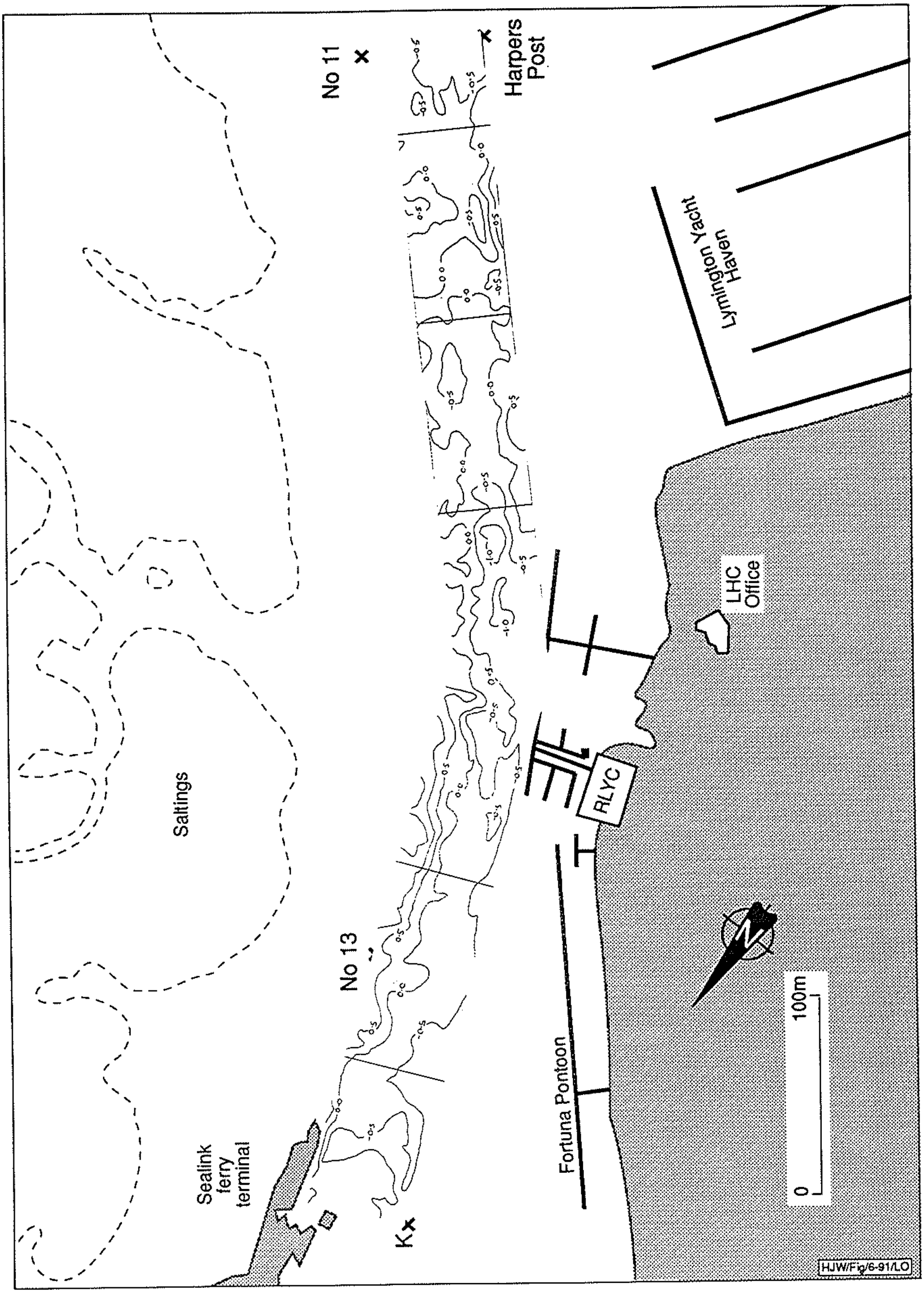


Fig 3 Residual Bathymetry (1981-1991)

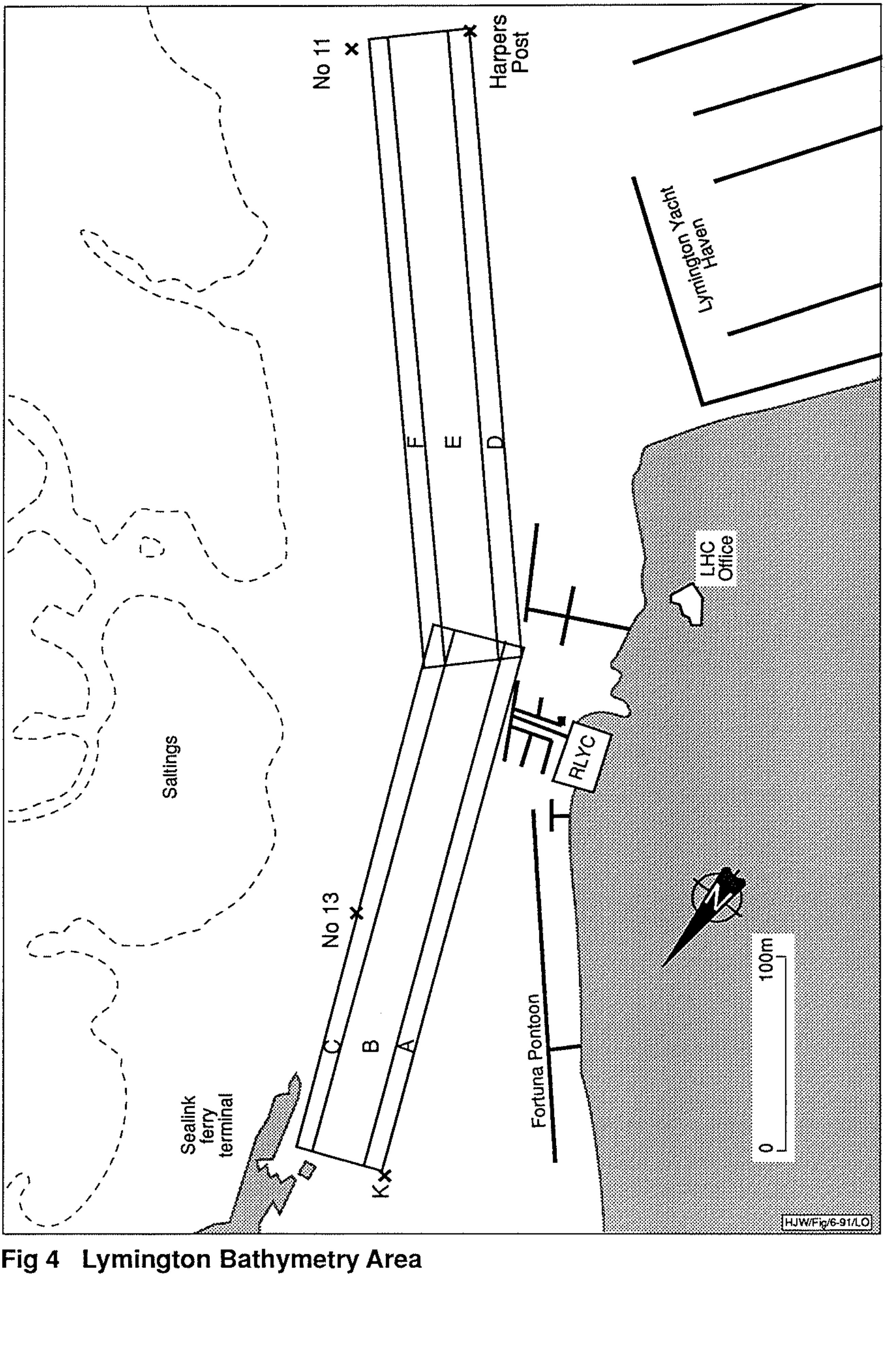


Fig 4 Lymington Bathymetry Area

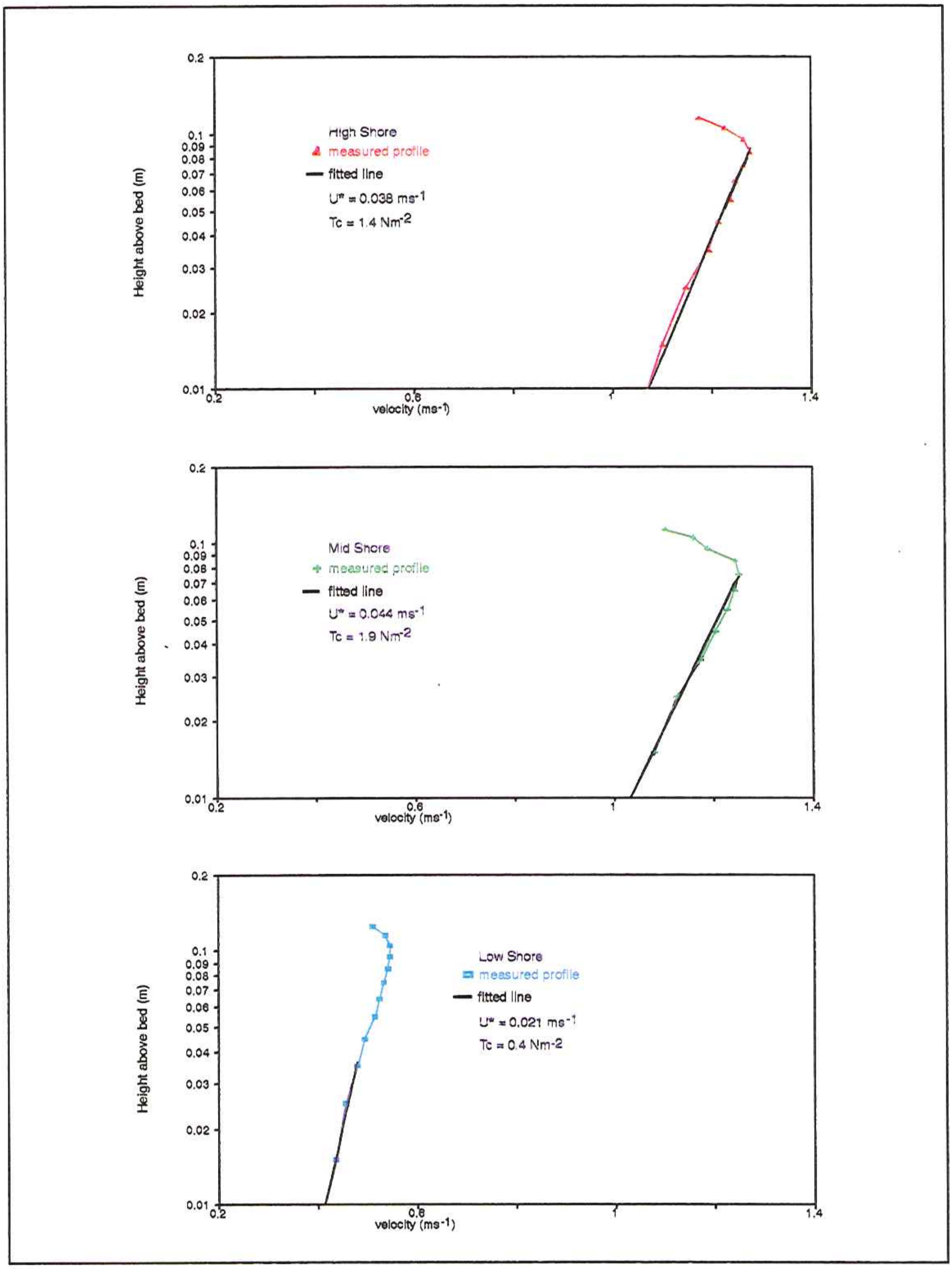


Fig 5 Velocity profiles from laboratory erosion tests; high, mid, and low shore samples

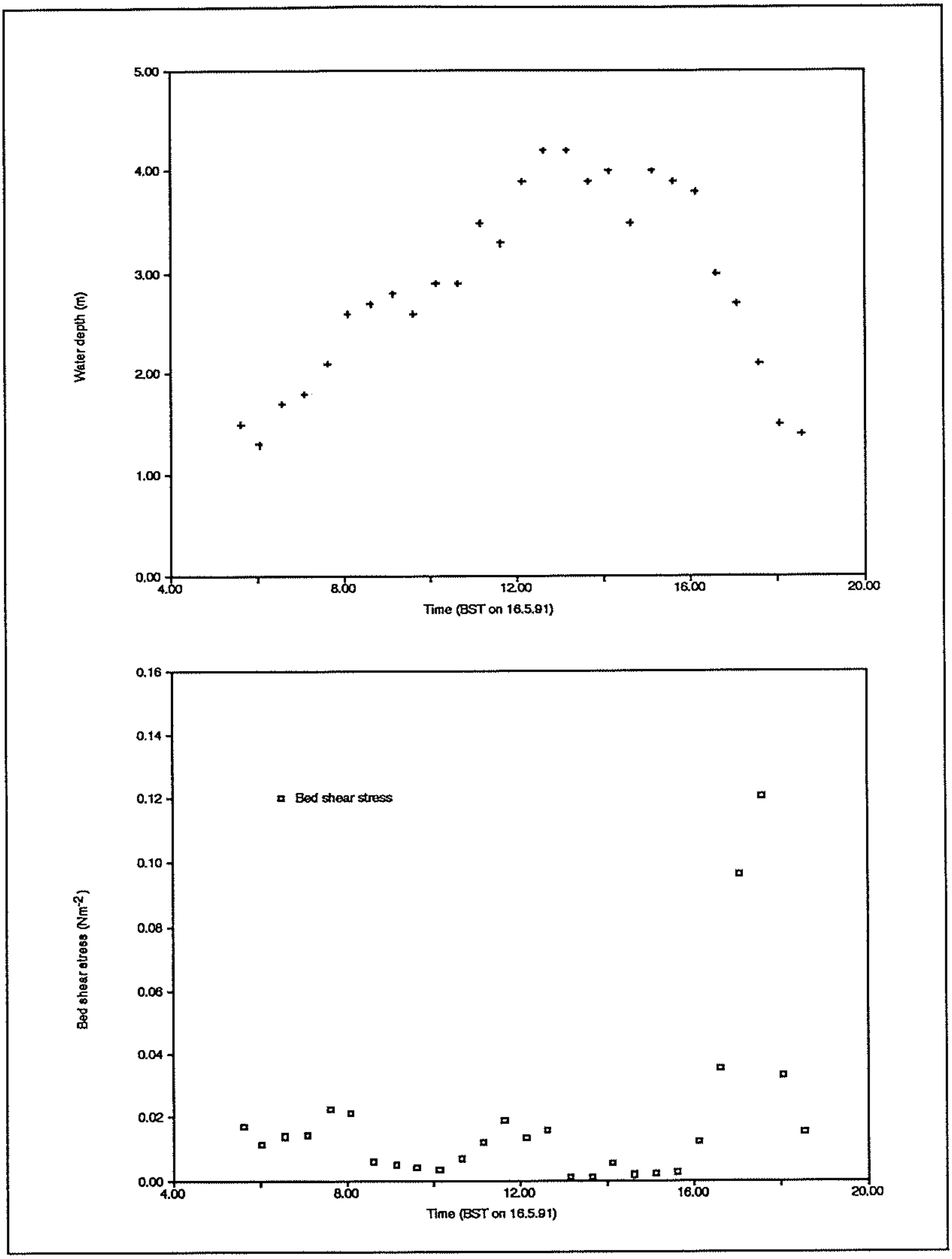


Fig 6 Water depth and bed shear stress during field measurements

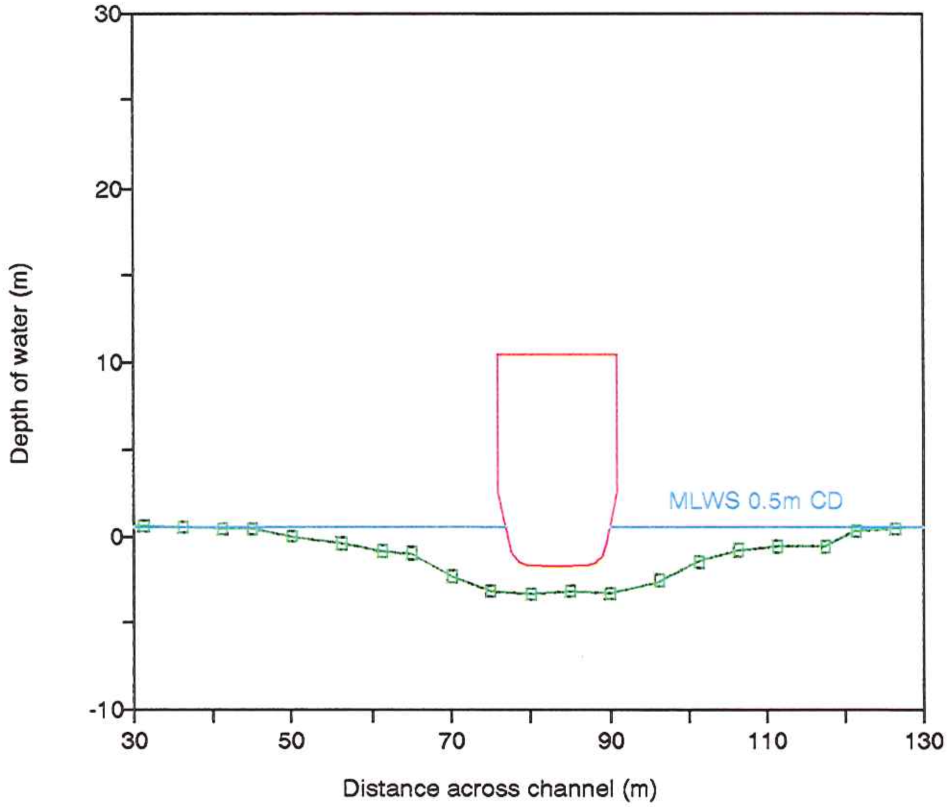


Fig 7 Typical cross-section of channel and ferry in Horn Reach, at low water

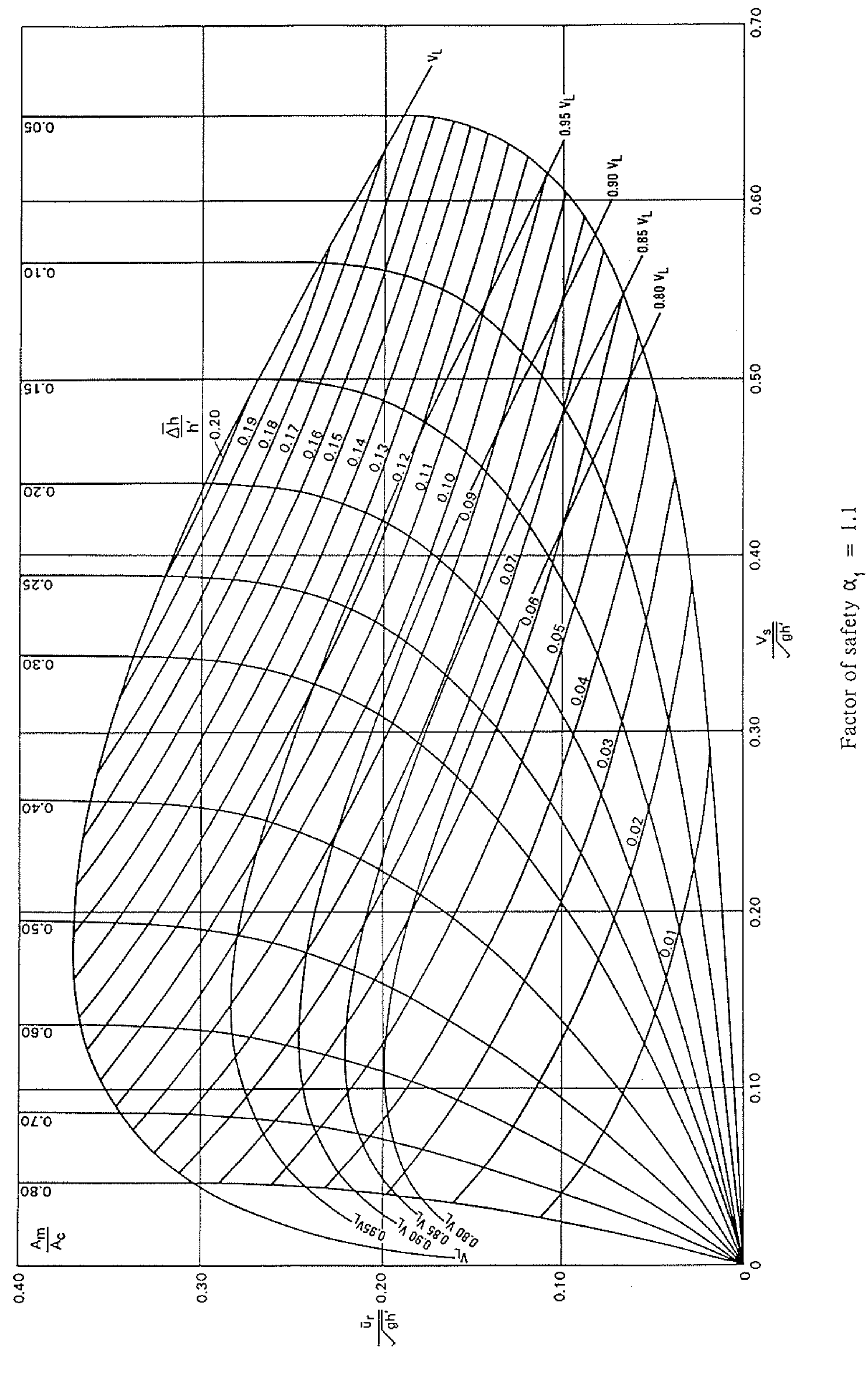


Fig 8 Schijf's chart for estimating return current and water level depression (from Ref 4: PIANC Supplement to bulletin No 57)

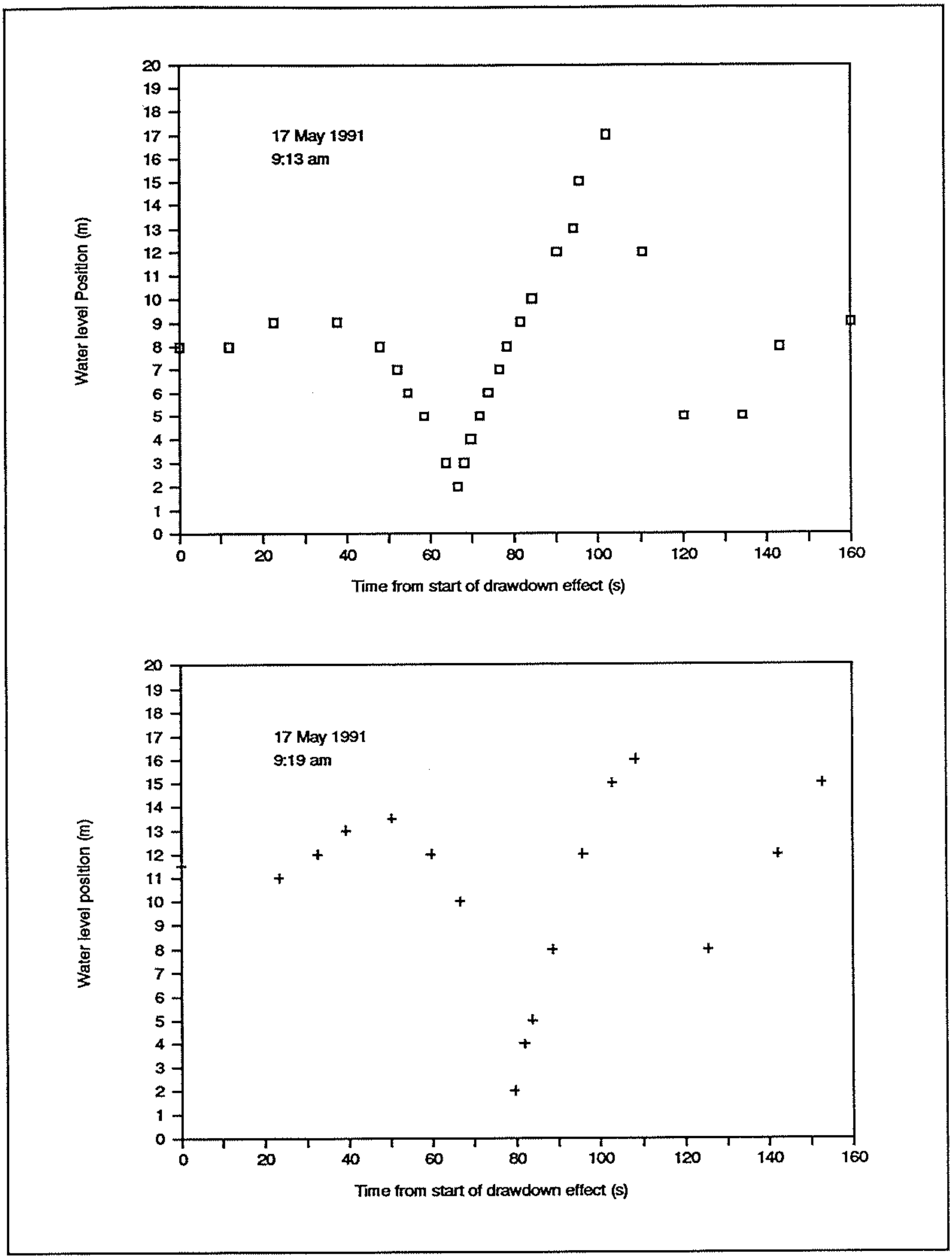


Fig 9 Rapid water level drawdown measured at 0913 and 0919 on 17 May 1991

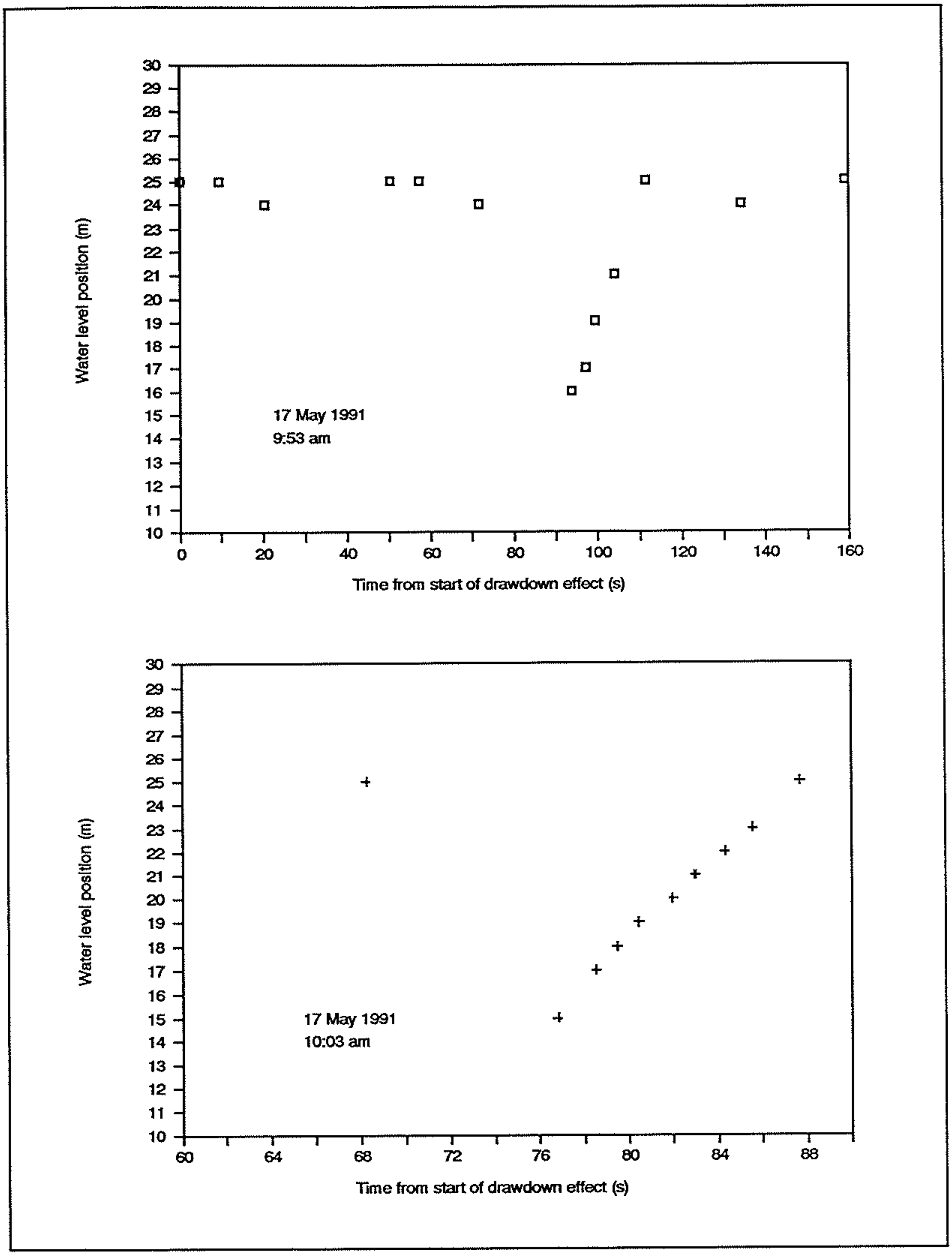


Fig 10 Rapid water level drawdown measured at 0953 and 1003 on 17 May 1991

Appendices

Appendix A

Field survey report

Introduction

A short survey was carried out between 14-17 May 1991 try to determine the effect on mudflats, adjacent to the main navigation channel, by new, larger ferries. The survey area was in Horn Reach, just off Lymington Yacht Haven.

The survey consisted of five parts:-

1. Current metering and suspended solids sampling
2. Grab sampling
3. Box core sampling
4. In-situ suspended solids monitoring
5. Video filming of drawdown of ferry wash

1. Current Metering and Suspended Solids Sampling

Through-depth velocity, direction and suspended solid concentrations, within the navigation channel (Fig A1), were measured over a 13 hour tidal cycle, using an H.R. designed 'Severn' current meter and 'CB' sampler.

A 'Severn' current meter consists of a Braystoke 001 impeller actuating a reed switch housed within the meter body; a purpose-built Marinex fluxgate compass for measuring flow direction; and a Druck PDCR 10 solid state pressure transducer. The latter enables the meter, complete with its 10kg streamline weight to be positioned at the desired elevations on the profile.

Suspended below the current meter was a 'CB' sampler, a triple water sampling array. Three open horizontal tubes, whose ends can be independently closed on command from the boat, were used to trap instantaneous samples of 500 ml in volume, from selected depths on the profile for subsequent laboratory analysis of suspended solid concentrations.

The field procedure was to repeat the full depth velocity profiles every 30 minutes. The meter was lowered until the streamlined weight touched the bed and then positioned at levels; bed + 0.5, 1.0, 1.5, 2.0, 2.5, 3.0 metres and surface - 0.5m as the water depth allowed. Impeller revolutions were counted over 100 seconds and magnetic compass readings logged manually at each level on the profile. Water samples at bed + 0.5, 1.0, 1.5 metres and manually at the surface were also taken on each profile.

All velocity records have been computed to show flow speeds in metres per second and the magnetic compass readings corrected to show true directions. For additional information, an EIL Analytical Instruments, MC5 salinity-temperature bridge was also attached to the array and measurements taken at each level on the profile. The results are shown in Table A1.

2. Grab sampling

12 bed sediment samples were taken over a high water period on 15 May 1991, using a hand-operated 2-litre Van Essen grab. The sampling positions are shown on Fig A1. Six samples were taken along the centre line of the navigation channel between beacon numbers 11 and 13, another six samples were taken along the low water mark, on the west bank, between the same beacons.

All positioning afloat was determined by horizontal sextant angles to co-ordinated shore stations. On return to the laboratory, each sample was analysed to determine the sediment density and on two representative samples; one from the centre line and one from the low water mark, full particle size analysis was carried out. The results are shown in Table A2 and Fig A4.

3. Box Core Samples

To evaluate the erosion strength of the intertidal mudflats, 12 undisturbed box core samples were obtained over a stable area of uniform mudflat, adjacent to Lymington Yacht Haven, (Fig A2). Open ended boxes (220 x 195 x 150mm deep) were pushed into the mud to within 25-30mm of the top, the surrounding mud was then dug away and a thin retaining plate slid under the bottom of the box. The sample was then put in a sealable plastic bag to retain moisture and placed in a transport box for protection.

The area of mud flat chosen for sampling was of uniform consistency and slope but varied greatly in depth between the top of the beach and the low water mark. At the top of the beach, near the Yacht Haven breakwater, the soft mud layer was 0.45 - 0.55 metres thick overlying hard greensand, whilst the thickness near the low water mark was only 0.05 -0.10 metres, again overlying hard sand/clay. Obtaining samples from the low water site proved quite difficult.

4. In-situ Measurements of Suspended Solids

A Partech Turbidity monitor was installed on the Harbour Masters pontoon near the low water mark, to measure any variations in suspended material stirred up from the bed, by passing ferry wash, (Fig A1). The Partech Turbidity monitor measures the intensity of a beam of light passing through a turbid suspension, the source and measuring device (a photocell) being in the same straight line.The obtained reading is a function of the concentration of the suspension. A Rustrak paper recorder allows a hard copy of all measurements obtained.

A pre-deployment calibration of the measuring head was carried out by immersing the head, in a lightproof box, into standard Formazin solutions of known concentrations, and noting the readings. The measuring head was calibrated over the expected concentration range 0 - 200 Formazin Turbidity Units (FTU's), the results of both the pre and post-deployment calibrations are shown below. The post survey calibration shows the instrument to have been stable over the survey period.

The head was attached to a pole, installed at a height of 0.25 metres above the bed and the Rustrak paper recorder switched on. The recording period was from 1710 hours on the 14 May 1991 to 1015 hours on the 17 May 1991. During this period time-check index marks were put onto the chart to eliminate any paper speed variations.

	Pre-survey	Post-survey
De-ionised water	0/1	3
40 FTU	28	30
80 FTU	50	53
120 FTU	70/71	72
200 FTU	100	100/102

A copy of the chart record is shown in Fig A5.

5. Video filming of Drawdown

An attempt was made to quantify the velocity of ship-induced rapid drawdown on the intertidal mudflats by making a video film of the effect of passing ferry wash on a measured section, (Fig A3).

A line of pegs at 1 metre intervals was set up normal to the wooden breakwater of Lymington Yacht Haven, from the top of the beach running down close to the low water mark at the edge of the navigation channel, a distance of some 40 metres. It was not possible to go right down to low water owing to the proximity of a number on sailing dinghies on 'swinging' moorings near the section end. This distance however, only represents a vertical height difference of approximately 0.80 metres, hence the area was only affected by ship wash for two hours flood and two hours ebb, or 4-5 sailing / arrivals each tide.

During the study period, 16 May 1991, the speed of the ferries was noted to be greatly reduced to that of normal movements. The Harbour Master commented that this was almost certainly due to the presence of the Lymington Harbour launch at anchor on the edge of the channel current metering, the line of marker pegs down the mudflat and a 'cameraman' filming the movements / effects of the ferries on the area, hence boatwash / drawdown was virtually non-existent during this period.

Filming on subsequent days however, provided better data with ferries travelling at near normal speeds.

Acknowledgments

We are indebted to Mr F. Woodford of Lymington Harbour Board and his assistant Mr A Coster for the use of the 28' harbour launch and the willing assistance extended throughout the short survey period.

The data collection and report writing was undertaken by M R Gradwell from the Field Studies Section of HR's Technical Services Department.

Time GMT Hr	Time GMT min	Total Depth (m)	Meter Depth (m)	Speed (m/s)	Dir. degrees True N	Salinity (ppt)	Temp deg C	D.O % Sat.	Suspended Partech (mg/l)	Solids Sample (mg/l)
5	38	1.50	1.00	0.06	141	31.4	12.7	0	0	13
5	35	0.00	0.50	0.14	135	33.3	12.6	0	0	48
0	0	0.00	0.00	0.00	0	0.0	0.0	0	0	0
0	0	0.00	0.00	0.00	0	0.0	0.0	0	0	0
0	0	0.00	0.00	0.00	0	0.0	0.0	0	0	0
0	0	0.00	0.00	0.00	0	0.0	0.0	0	0	0

Time GMT Hr	Time GMT min	Total Depth (m)	Meter Depth (m)	Speed (m/s)	Dir. degrees True N	Salinity (ppt)	Temp deg C	D.O % Sat.	Suspended Partech (mg/l)	Solids Sample (mg/l)
6	4	1.30	0.30	0.06	144	32.8	12.8	0	0	74
6	0	0.00	0.80	0.10	137	33.2	12.6	0	0	77
0	0	0.00	0.00	0.00	0	0.0	0.0	0	0	0
0	0	0.00	0.00	0.00	0	0.0	0.0	0	0	0
0	0	0.00	0.00	0.00	0	0.0	0.0	0	0	0
0	0	0.00	0.00	0.00	0	0.0	0.0	0	0	0

Time GMT Hr	Time GMT min	Total Depth (m)	Meter Depth (m)	Speed (m/s)	Dir. degrees True N	Salinity (ppt)	Temp deg C	D.O % Sat.	Suspended Partech (mg/l)	Solids Sample (mg/l)
6	37	1.70	0.20	0.09	322	30.9	12.6	0	0	0
6	33	0.00	0.70	0.10	319	33.4	12.8	0	0	113
6	30	0.00	1.20	0.08	331	33.3	12.6	0	0	375
0	0	0.00	0.00	0.00	0	0.0	0.0	0	0	0
0	0	0.00	0.00	0.00	0	0.0	0.0	0	0	0
0	0	0.00	0.00	0.00	0	0.0	0.0	0	0	0

Table A1 Field measurements of water depth, velocity and concentration

Table A1 continued

Time GMT Hr	Time GMT min	Total Depth (m)	Meter Depth (m)	Speed (m/s)	Dir. degrees True N	Salinity (ppt)	Temp deg C	D.O % Sat.	Suspended Partech (mg/l)	Solids Sample (mg/l)
7	9	1.80	0.30	0.08	335	33.7	12.6	0	0	55
7	4	0.00	0.80	0.11	323	33.7	12.7	0	0	243
7	0	0.00	1.30	0.09	312	33.7	12.7	0	0	205
0	0	0.00	0.00	0.00	0	0.0	0.0	0	0	0
0	0	0.00	0.00	0.00	0	0.0	0.0	0	0	0
0	0	0.00	0.00	0.00	0	0.0	0.0	0	0	0

Time GMT Hr	Time GMT min	Total Depth (m)	Meter Depth (m)	Speed (m/s)	Dir. degrees True N	Salinity (ppt)	Temp deg C	D.O % Sat.	Suspended Partech (mg/l)	Solids Sample (mg/l)
7	39	2.10	0.60	0.11	324	33.8	12.4	0	0	25
7	34	0.00	1.10	0.13	322	33.8	12.6	0	0	57
0	0	0.00	0.00	0.00	0	0.0	0.0	0	0	0
0	0	0.00	0.00	0.00	0	0.0	0.0	0	0	0
0	0	0.00	0.00	0.00	0	0.0	0.0	0	0	0
0	0	0.00	0.00	0.00	0	0.0	0.0	0	0	0

Time GMT Hr	Time GMT min	Total Depth (m)	Meter Depth (m)	Speed (m/s)	Dir. degrees True N	Salinity (ppt)	Temp deg C	D.O % Sat.	Suspended Partech (mg/l)	Solids Sample (mg/l)
8	11	2.60	0.60	0.12	321	34.0	12.7	0	0	0
8	7	0.00	1.10	0.10	313	34.0	12.4	0	0	62
8	3	0.00	1.60	0.13	311	33.9	12.4	0	0	116
8	0	0.00	2.10	0.12	340	33.9	12.4	0	0	107
0	0	0.00	0.00	0.00	0	0.0	0.0	0	0	0
0	0	0.00	0.00	0.00	0	0.0	0.0	0	0	0

Table A1 continued

Time GMT Hr	Time GMT min	Total Depth (m)	Meter Depth (m)	Speed (m/s)	Dir. degrees True N	Salinity (ppt)	Temp deg C	D.O % Sat.	Suspended Partech (mg/l)	Solids Sample (mg/l)
8	43	2.70	0.70	0.04	302	34.0	12.5	0	0	0
8	37	0.00	1.20	0.05	308	34.0	12.5	0	0	29
8	34	0.00	1.70	0.10	298	34.0	12.4	0	0	106
8	30	0.00	2.20	0.05	300	34.0	12.3	0	0	160
0	0	0.00	0.00	0.00	0	0.0	0.0	0	0	0
0	0	0.00	0.00	0.00	0	0.0	0.0	0	0	0

Time GMT Hr	Time GMT min	Total Depth (m)	Meter Depth (m)	Speed (m/s)	Dir. degrees True N	Salinity (ppt)	Temp deg C	D.O % Sat.	Suspended Partech (mg/l)	Solids Sample (mg/l)
9	15	2.80	0.30	0.06	302	34.0	12.4	0	0	26
9	11	0.00	0.80	0.05	304	34.0	12.4	0	0	0
9	7	0.00	1.30	0.06	317	34.1	12.4	0	0	61
9	4	0.00	1.80	0.06	319	34.0	12.2	0	0	179
9	0	0.00	2.30	0.04	325	34.0	12.2	0	0	647
0	0	0.00	0.00	0.00	0	0.0	0.0	0	0	0

Time GMT Hr	Time GMT min	Total Depth (m)	Meter Depth (m)	Speed (m/s)	Dir. degrees True N	Salinity (ppt)	Temp deg C	D.O % Sat.	Suspended Partech (mg/l)	Solids Sample (mg/l)
9	41	2.60	0.60	0.05	361	34.1	12.2	0	0	0
9	38	0.00	1.10	0.05	328	34.1	12.3	0	0	17
9	34	0.00	1.60	0.05	295	34.2	12.3	0	0	67
9	30	0.00	2.10	0.05	302	34.1	12.2	0	0	119
0	0	0.00	0.00	0.00	0	0.0	0.0	0	0	0
0	0	0.00	0.00	0.00	0	0.0	0.0	0	0	0

Table A1 continued

Time GMT Hr	Time GMT min	Total Depth (m)	Meter Depth (m)	Speed (m/s)	Dir. degrees True N	Salinity (ppt)	Temp deg C	D.O % Sat.	Suspended Partech (mg/l)	Solids Sample (mg/l)
10	14	2.90	0.40	0.04	322	34.1	12.2	0	0	10
10	10	0.00	0.90	0.05	320	34.2	12.1	0	0	0
10	6	0.00	1.40	0.05	317	34.1	12.2	0	0	18
10	3	0.00	1.90	0.04	339	34.1	12.2	0	0	38
10	0	0.00	2.40	0.03	27	34.2	12.1	0	0	51
0	0	0.00	0.00	0.00	0	0.0	0.0	0	0	0

Time GMT Hr	Time GMT min	Total Depth (m)	Meter Depth (m)	Speed (m/s)	Dir. degrees True N	Salinity (ppt)	Temp deg C	D.O % Sat.	Suspended Partech (mg/l)	Solids Sample (mg/l)
10	44	2.90	0.40	0.06	332	34.1	12.2	0	0	0
10	41	0.00	0.90	0.06	333	34.2	12.2	0	0	0
10	37	0.00	1.40	0.05	335	34.2	12.1	0	0	33
10	33	0.00	1.90	0.07	281	34.3	12.1	0	0	61
10	30	0.00	2.40	0.08	298	34.3	12.0	0	0	20
0	0	0.00	0.00	0.00	0	0.0	0.0	0	0	0

Time GMT Hr	Time GMT min	Total Depth (m)	Meter Depth (m)	Speed (m/s)	Dir. degrees True N	Salinity (ppt)	Temp deg C	D.O % Sat.	Suspended Partech (mg/l)	Solids Sample (mg/l)
11	16	3.50	0.50	0.05	10	34.1	12.1	0	0	37
11	12	0.00	1.00	0.09	344	34.2	12.2	0	0	0
11	10	0.00	1.50	0.09	337	34.3	12.2	0	0	0
11	7	0.00	2.00	0.09	334	34.1	12.1	0	0	29
11	3	0.00	2.50	0.11	294	34.2	12.1	0	0	39
11	0	0.00	3.00	0.07	332	34.4	12.0	0	0	110

Table A1 continued

Time GMT Hr	min	Total Depth (m)	Meter Depth (m)	Speed (m/s)	Dir. degrees True N	Salinity (ppt)	Temp deg C	D.O % Sat.	Suspended Partech (mg/l)	Solids Sample (mg/l)
11	45	3.30	0.30	0.08	355	34.2	12.2	0	0	0
11	41	0.00	0.80	0.12	353	34.3	12.1	0	0	0
11	38	0.00	1.30	0.10	361	34.2	12.1	0	0	0
11	35	0.00	1.80	0.13	338	34.4	12.0	0	0	27
11	32	0.00	2.30	0.12	350	34.4	11.9	0	0	64
11	30	0.00	2.80	0.14	332	34.4	11.9	0	0	44

Time GMT Hr	min	Total Depth (m)	Meter Depth (m)	Speed (m/s)	Dir. degrees True N	Salinity (ppt)	Temp deg C	D.O % Sat.	Suspended Partech (mg/l)	Solids Sample (mg/l)
12	14	3.90	0.90	0.14	342	34.3	12.1	0	0	49
12	12	0.00	1.40	0.14	332	34.3	12.0	0	0	0
12	8	0.00	1.90	0.06	348	34.5	11.9	0	0	0
12	6	0.00	2.40	0.07	341	34.5	11.9	0	0	34
12	3	0.00	2.90	0.07	332	34.5	11.8	0	0	no sample
12	0	0.00	3.40	0.10	327	34.5	11.9	0	0	34

Time GMT Hr	min	Total Depth (m)	Meter Depth (m)	Speed (m/s)	Dir. degrees True N	Salinity (ppt)	Temp deg C	D.O % Sat.	Suspended Partech (mg/l)	Solids Sample (mg/l)
12	44	4.20	0.50	0.11	22	34.4	12.1	0	0	0
12	41	0.00	1.20	0.12	11	34.4	12.0	0	0	0
12	38	0.00	2.20	0.12	342	34.5	11.9	0	0	0
12	36	0.00	2.70	0.09	343	34.5	11.9	0	0	36
12	33	0.00	3.20	0.10	343	34.5	11.9	0	0	43
12	30	0.00	3.70	0.10	338	34.6	11.8	0	0	45

Table A1 continued

Time GMT Hr	min	Total Depth (m)	Meter Depth (m)	Speed (m/s)	Dir. degrees True N	Salinity (ppt)	Temp deg C	D.O % Sat.	Suspended Partech (mg/l)	Solids Sample (mg/l)
13	14	4.20	0.70	0.03	296	34.5	11.9	0	0	14
13	12	0.00	1.70	0.03	11	34.5	11.9	0	0	0
13	9	0.00	2.20	0.00	360	34.5	11.8	0	0	0
13	7	0.00	2.70	0.00	9	34.6	11.8	0	0	27
13	4	0.00	3.20	0.05	302	34.6	11.8	0	0	416
13	0	0.00	3.70	0.04	268	34.6	11.8	0	0	989

Time GMT Hr	min	Total Depth (m)	Meter Depth (m)	Speed (m/s)	Dir. degrees True N	Salinity (ppt)	Temp deg C	D.O % Sat.	Suspended Partech (mg/l)	Solids Sample (mg/l)
13	46	3.90	0.90	0.04	234	34.3	12.1	0	0	0
13	43	0.00	1.40	0.03	111	34.3	12.1	0	0	0
13	41	0.00	1.90	0.02	112	34.3	12.0	0	0	0
13	37	0.00	2.40	0.00	96	34.4	12.0	0	0	32
13	34	0.00	2.90	0.03	110	34.4	11.9	0	0	48
13	30	0.00	3.40	0.03	114	34.4	11.9	0	0	367

Time GMT Hr	min	Total Depth (m)	Meter Depth (m)	Speed (m/s)	Dir. degrees True N	Salinity (ppt)	Temp deg C	D.O % Sat.	Suspended Partech (mg/l)	Solids Sample (mg/l)
14	14	4.00	0.50	0.05	31	34.1	12.2	0	0	0
14	11	0.00	1.00	0.05	353	34.2	12.0	0	0	0
14	8	0.00	2.00	0.08	324	34.3	12.0	0	0	0
14	5	0.00	2.50	0.06	315	34.3	12.1	0	0	19
14	2	0.00	3.00	0.07	318	34.4	12.0	0	0	32
14	0	0.00	3.50	0.05	315	34.4	12.0	0	0	49

Table A1 continued

Time GMT Hr	Time GMT min	Total Depth (m)	Meter Depth (m)	Speed (m/s)	Dir. degrees True N	Salinity (ppt)	Temp deg C	D.O % Sat.	Suspended Partech (mg/l)	Solids Sample (mg/l)
14	44	3.50	0.50	0.04	333	34.2	12.1	0	0	18
14	41	0.00	1.00	0.03	333	34.2	12.0	0	0	0
14	38		1.50	0.03	331	34.2	11.9	0	0	0
14	36	0.00	2.00	0.02	342	34.3	11.9	0	0	18
14	33	0.00	2.50	0.03	331	34.4	11.9	0	0	23
14	30	0.00	3.00	0.04	340	34.5	11.9	0	0	22

Time GMT Hr	Time GMT min	Total Depth (m)	Meter Depth (m)	Speed (m/s)	Dir. degrees True N	Salinity (ppt)	Temp deg C	D.O % Sat.	Suspended Partech (mg/l)	Solids Sample (mg/l)
15	15	4.00	0.50	0.00	340	34.2	12.1	0	0	22
15	12	0.00	1.00	0.03	339	34.2	12.1	0	0	0
15	9	0.00	2.00	0.03	317	34.4	12.0	0	0	0
15	6	0.00	2.50	0.06	336	34.5	11.9	0	0	77
15	2	0.00	3.00	0.04	7	34.5	11.9	0	0	28
15	0	0.00	3.50	0.07	289	34.6	11.9	0	0	23

Time GMT Hr	Time GMT min	Total Depth (m)	Meter Depth (m)	Speed (m/s)	Dir. degrees True N	Salinity (ppt)	Temp deg C	D.O % Sat.	Suspended Partech (mg/l)	Solids Sample (mg/l)
15	43	3.90	0.40	0.04	98	34.1	12.1	0	0	0
15	40	0.00	1.40	0.03	91	34.2	12.1	0	0	0
15	38	0.00	1.90	0.03	78	34.2	12.1	0	0	0
15	35	0.00	2.40	0.04	82	34.2	12.1	0	0	16
15	33	0.00	2.90	0.04	63	34.4	12.0	0	0	26
15	30	0.00	3.40	0.05	71	34.3	12.0	0	0	32

Table A1 continued

Time GMT Hr	min	Total Depth (m)	Meter Depth (m)	Speed (m/s)	Dir. degrees True N	Salinity (ppt)	Temp deg C	D.O % Sat.	Suspended Partech (mg/l)	Solids Sample (mg/l)
16	14	3.80	0.50	0.12	189	33.8	12.2	0	0	10
16	11	0.00	1.30	0.12	189	33.7	12.2	0	0	0
16	8	0.00	1.80	0.08	179	34.0	12.1	0	0	0
16	5	0.00	2.30	0.10	162	33.9	12.1	0	0	21
16	2	0.00	2.80	0.05	161	34.1	12.2	0	0	29
16	0	0.00	3.30	0.07	166	34.4	12.0	0	0	112

Time GMT Hr	min	Total Depth (m)	Meter Depth (m)	Speed (m/s)	Dir. degrees True N	Salinity (ppt)	Temp deg C	D.O % Sat.	Suspended Partech (mg/l)	Solids Sample (mg/l)
16	41	3.00	0.50	0.07	146	33.7	12.6	0	0	0
16	38	0.00	1.00	0.10	137	33.6	12.6	0	0	0
16	35	0.00	1.50	0.13	155	33.5	12.6	0	0	19
16	33	0.00	2.00	0.21	147	33.7	12.3	0	0	27
16	30	0.00	2.50	0.14	144	34.0	12.2	0	0	18
0	0	0.00	0.00	0.00	0	0.0	0.0	0	0	0

Time GMT Hr	min	Total Depth (m)	Meter Depth (m)	Speed (m/s)	Dir. degrees True N	Salinity (ppt)	Temp deg C	D.O % Sat.	Suspended Partech (mg/l)	Solids Sample (mg/l)
17	8	2.70	0.70	0.25	158	33.7	12.5	0	0	0
17	5	0.00	1.20	0.29	167	33.7	12.5	0	0	12
17	2	0.00	1.70	0.30	153	33.8	12.4	0	0	19
17	0	0.00	2.20	0.25	143	33.9	12.4	0	0	25
0	0	0.00	0.00	0.00	0	0.0	0.0	0	0	0
0	0	0.00	0.00	0.00	0	0.0	0.0	0	0	0

Table A1 continued

Time GMT Hr	Time GMT min	Total Depth (m)	Meter Depth (m)	Speed (m/s)	Dir. degrees True N	Salinity (ppt)	Temp deg C	D.O % Sat.	Suspended Partech (mg/l)	Solids Sample (mg/l)
17	38	2.10	0.50	0.29	140	33.1	12.7	0	0	15
17	35	0.00	1.10	0.27	134	33.3	12.7	0	0	20
17	30	0.00	1.60	0.35	137	33.4	12.7	0	0	34
0	0	0.00	0.00	0.00	0	0.0	0.0	0	0	0
0	0	0.00	0.00	0.00	0	0.0	0.0	0	0	0
0	0	0.00	0.00	0.00	0	0.0	0.0	0	0	0

Time GMT Hr	Time GMT min	Total Depth (m)	Meter Depth (m)	Speed (m/s)	Dir. degrees True N	Salinity (ppt)	Temp deg C	D.O % Sat.	Suspended Partech (mg/l)	Solids Sample (mg/l)
18	5	1.50	0.50	0.15	143	33.1	12.7	0	0	21
18	0	0.00	1.00	0.14	139	33.2	12.6	0	0	22
0	0	0.00	0.00	0.00	0	0.0	0.0	0	0	0
0	0	0.00	0.00	0.00	0	0.0	0.0	0	0	0
0	0	0.00	0.00	0.00	0	0.0	0.0	0	0	0
0	0	0.00	0.00	0.00	0	0.0	0.0	0	0	0

Time GMT Hr	Time GMT min	Total Depth (m)	Meter Depth (m)	Speed (m/s)	Dir. degrees True N	Salinity (ppt)	Temp deg C	D.O % Sat.	Suspended Partech (mg/l)	Solids Sample (mg/l)
18	34	1.40	0.40	0.11	139	33.1	12.7	0	0	26
18	30	0.00	0.90	0.07	132	33.2	12.6	0	0	30
0	0	0.00	0.00	0.00	0	0.0	0.0	0	0	0
0	0	0.00	0.00	0.00	0	0.0	0.0	0	0	0
0	0	0.00	0.00	0.00	0	0.0	0.0	0	0	0
0	0	0.00	0.00	0.00	0	0.0	0.0	0	0	0

Table A2

Description of Lymington Samples

Sample	Density	Description
CL1	1.73	Mud including large stone (8cm) and small stones (<1cm) and coarse sand.
CL2	2.38	Stones 2-6cm with shell and coarse sand.
CL3	2.12	Stones 1-3cm with shell including. some mud and coarse sand.
CL4	2.37	Large stones 5-8cm including mud and coarse sand.
CL5	2.39	Small to large stones 0.5-7cm.
CL6	2.39	Small to medium stones upto 5cm including small amount of mud.
LWM1	1.38	Soft black/brown mud.
LWM2	1.44	Black mud with trace of sand.
LWM3	1.50	Thick black mud with some stones under 1cm.
LWM4	1.41	Brown/black mud with trace of sand.
LWM5	1.40	Black/brown mud.
LWM6	1.34	Soft black/brown mud.

Table A2 continued Size grading of Lymington samples

Lymington CL4

Size (mm)	Percent undersize
47.63	100.00
44.45	71.70
34.93	59.90
28.58	55.10
22.23	43.90
19.05	42.00
15.88	31.60
12.70	26.90
9.52	22.90
7.94	19.80
6.35	16.90
4.76	14.80
3.35	12.90
2.36	10.70
1.70	8.60
1.18	6.60
0.85	4.90
0.60	3.10
0.43	1.70
0.30	1.10
0.21	0.80
0.15	0.50
0.11	0.30
0.06	0.10

Lymington LWM3

Size (microns)	Percent undersize
0.41	1.65
0.47	2.24
0.54	2.92
0.62	3.59
0.72	4.26
0.82	5.01
0.94	5.91
1.08	6.81
1.23	7.93
1.42	9.13
1.62	10.47
1.86	11.97
2.13	13.69
2.44	15.64
2.80	17.73
3.21	19.97
3.68	22.44
4.21	25.06
4.83	27.75
5.53	30.52
6.33	33.36
7.27	36.21
8.36	39.27
9.66	42.42
11.26	45.63
13.23	49.00
14.86	52.10
17.03	55.60
19.53	59.60
22.39	63.70
25.67	67.80
29.43	71.60
33.72	75.00
38.63	78.60
44.24	82.20
50.68	85.40
58.03	88.20
66.44	90.80
76.29	93.00
87.78	95.10
101.47	97.10
118.24	98.20
138.90	98.80
165.41	99.20
200.76	99.80
251.93	100.00

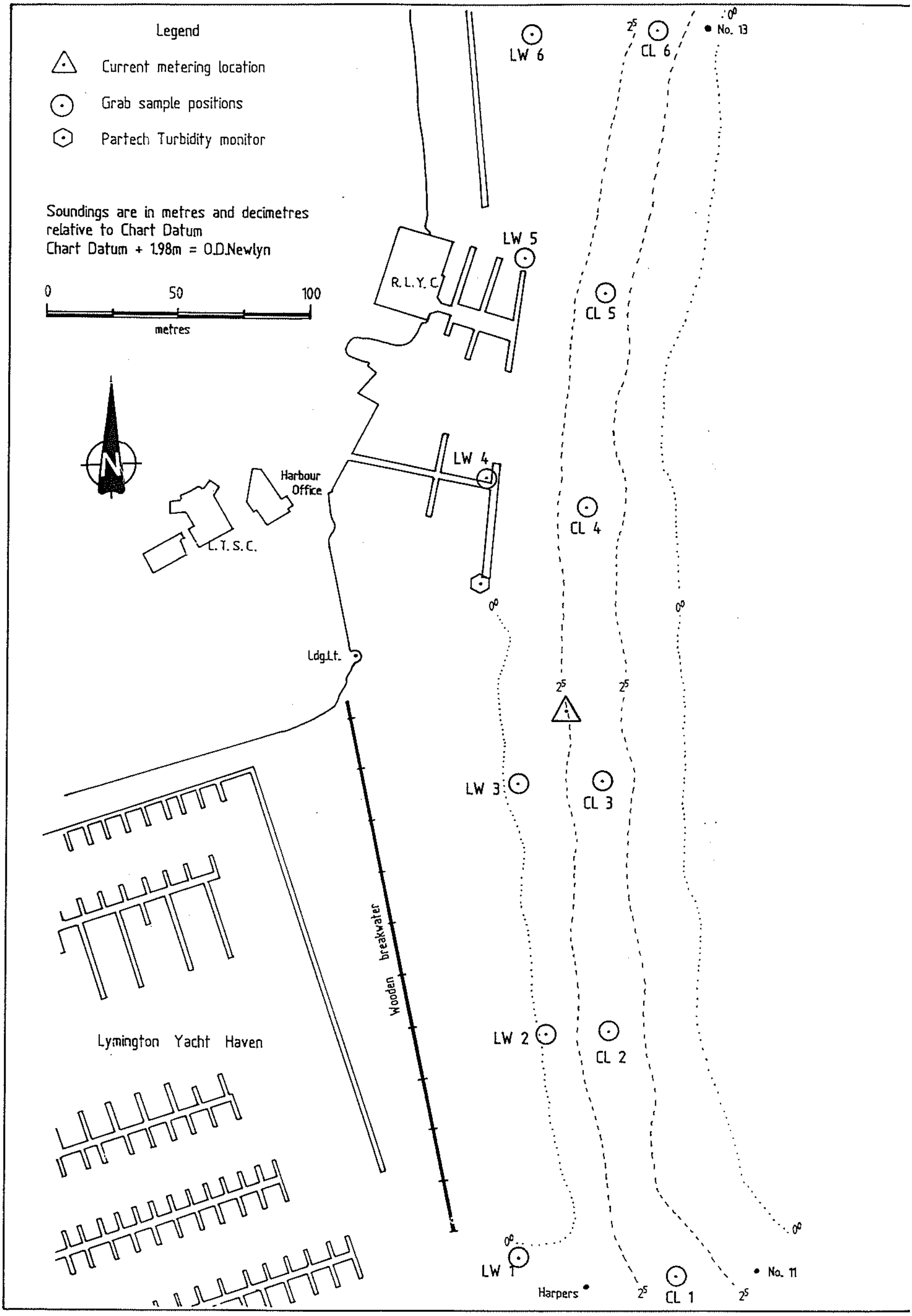
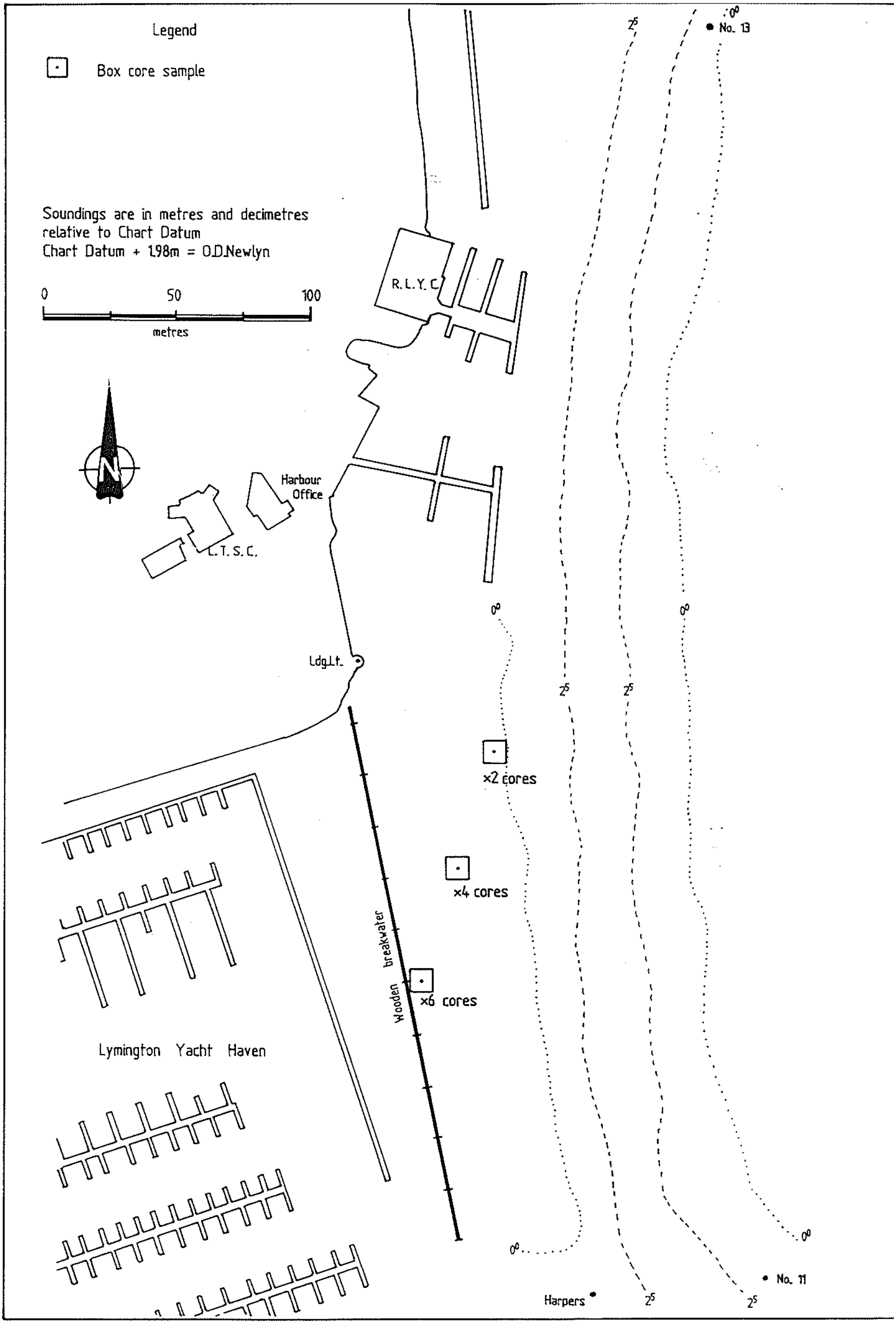
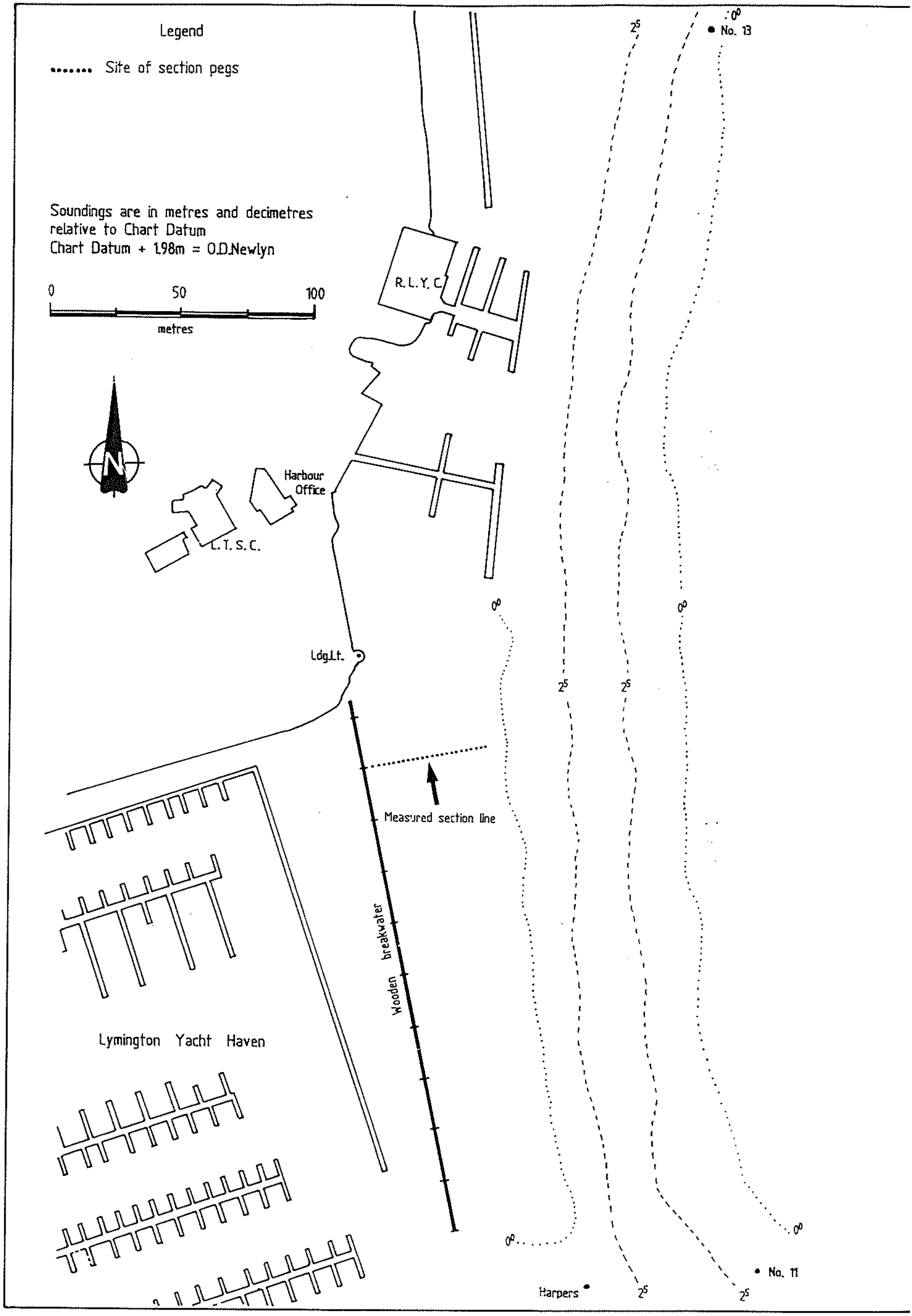


FIG. A1 Measurement locations


Legend
Box core sample
Soundings are in metres and decimetres
relative to Chart Datum
Chart Datum + 1.98m = O.D.Newlyn
0
50
100
metres
N
R.L.Y.C.
Harbour
Office
L.T.S.C.
Ldg.Lt.
×2 cores
×4 cores
×6 cores
Wooden breakwater
Lymington Yacht Haven
No. 13
No. 11
Harpers



Legend
Site of section pegs
Soundings are in metres and decimetres
relative to Chart Datum
Chart Datum + 1.98m = O.D.Newlyn
0
50
100
metres
N
R.L.Y.C.
Harbour
Office
L.T.S.C.
Ldg.Lt.
Measured section line
Wooden breakwater
Lymington Yacht Haven
No. 13
No. 11
Harpers

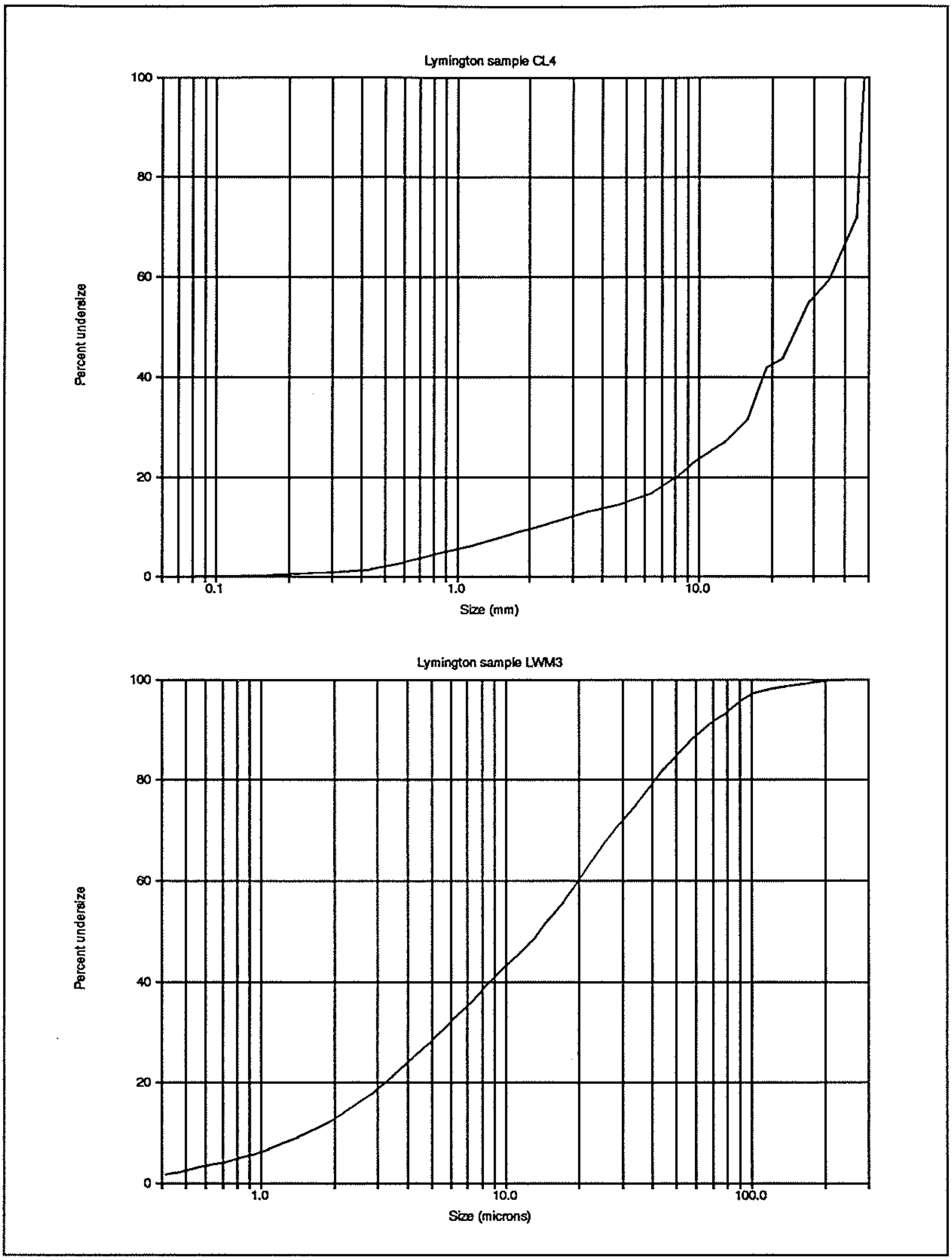


Fig A4 Size gradings of samples CL4 (channel) and LWM3 (mudflats)

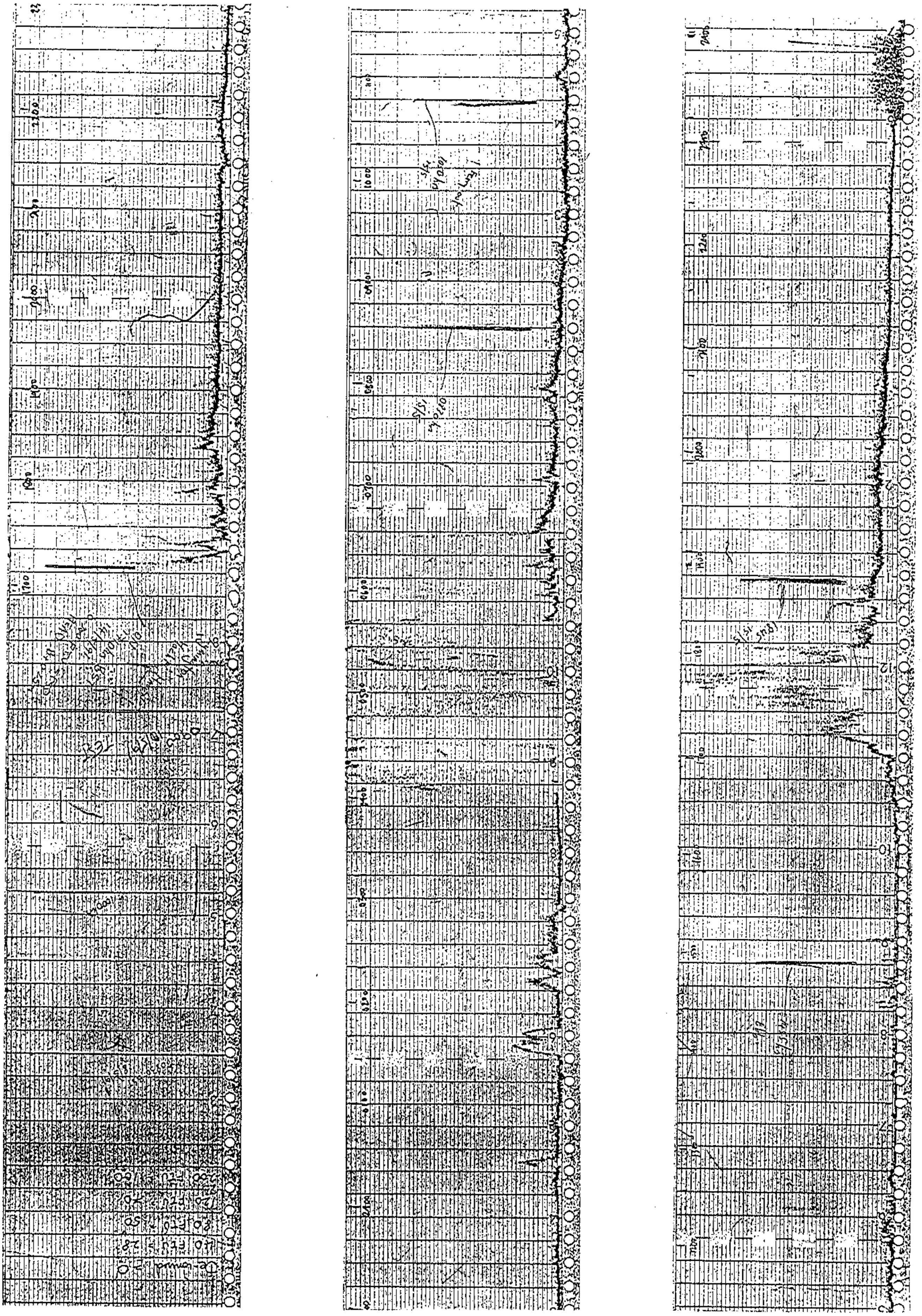


Fig A5a Suspended sediment concentration from Partech
14-17 May 1991

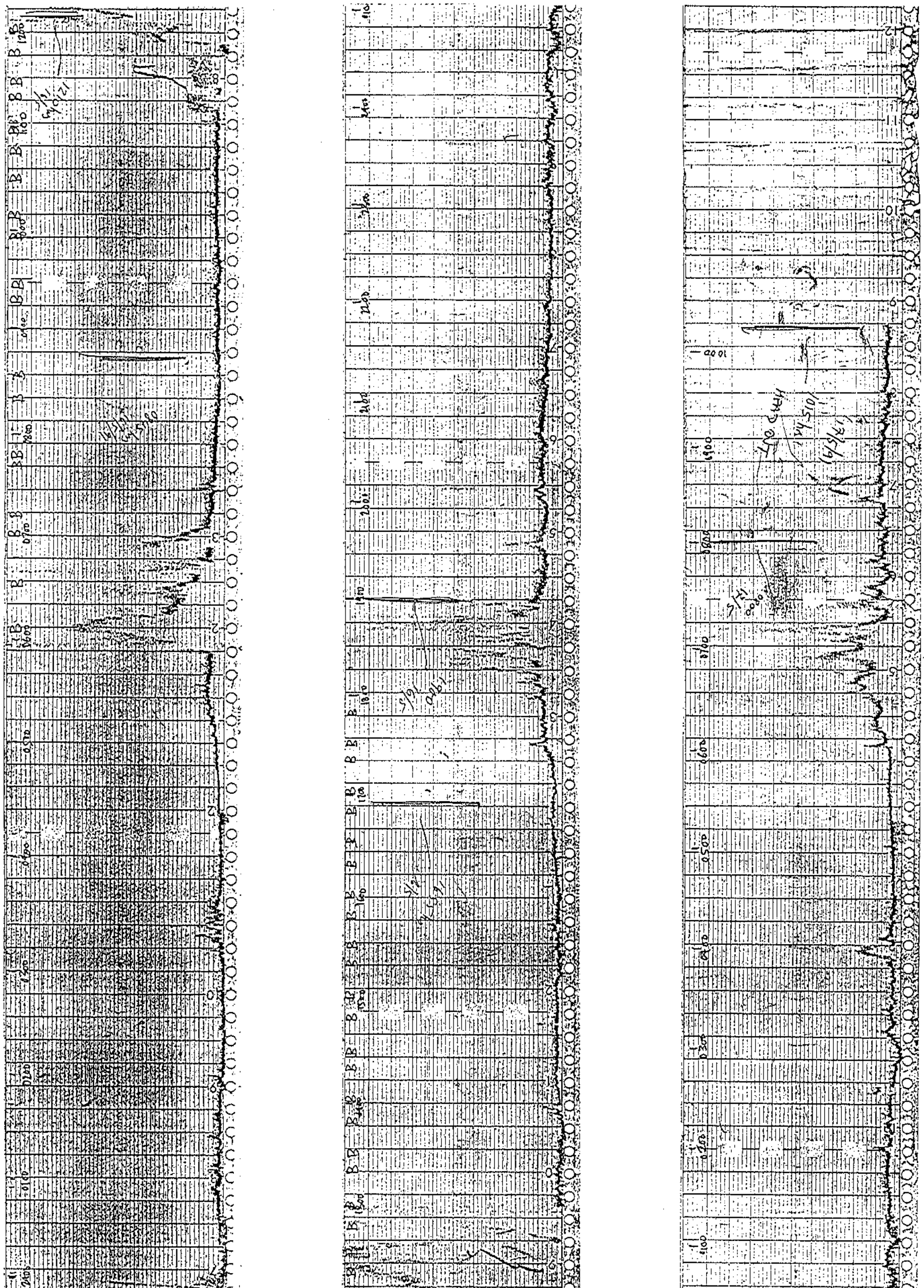


Fig A5b Suspended sediment concentration from Partech 14-17 May 1991

Appendix B

Percentage distribution of wind speeds and directions at Calshot 1960-79

Winter (November-April)

Beaufort Force	Speed (knots)		Direction (°N)												
	Range	Average	345-15	15-45	45-75	75-105	105-135	135-165	165-195	195-225	225-255	255-285	285-315	315-345	Total
0-1	0-3	1.8	-	-	-	-	-	-	-	-	-	-	-	-	7.9
2-3	4-10	7.3	4.3	3.7	2.6	2.1	2.4	1.8	1.6	2.7	7.2	5.9	3.2	3.8	41.3
4-5	11-21	14.4	3.9	3.4	3.6	3.1	2.9	2.4	2.5	4.4	7.7	4.4	3.2	3.5	45.0
6-7	22-33	25.0	0.3	0.1	0.2	0.3	0.4	0.4	1.0	1.4	0.7	0.2	0.3	0.3	5.5
≥8	≥34	37.0	0.02	-	-	0.01	0.02	0.01	0.07	0.1	0.04	0.01	0.01	-	0.28
≥2	≥4		8.5	7.2	6.4	5.5	5.7	4.6	5.2	8.6	15.6	10.5	6.7	7.6	92.1

Summer (May-October)

Beaufort Force	Speed (knots)		Direction (°N)												
	Range	Average	345-15	15-45	45-75	75-105	105-135	135-165	165-195	195-225	225-255	255-285	285-315	315-345	Total
0-1	0-3	1.8	-	-	-	-	-	-	-	-	-	-	-	-	10.2
2-3	4-10	7.3	4.4	3.5	2.7	2.3	3.5	2.4	2.0	4.2	9.0	6.9	3.8	4.6	49.3
4-5	11-21	14.4	2.5	1.6	1.3	1.7	3.2	1.4	1.5	6.4	10.1	3.2	2.8	2.7	38.4
6-7	22-33	25.0	0.06	0.02	0.04	0.1	0.1	0.1	0.3	0.7	0.4	0.06	0.07	0.07	2.0
≥8	≥34	37.0	-	-	-	-	-	-	0.02	0.04	0.01	-	-	-	0.07
≥2	≥4		7.0	5.1	4.0	4.1	6.8	3.9	3.8	11.3	19.5	10.2	6.7	7.4	89.8

Appendix C

HR Comment on proposed tank testing by Wightlink

NEW LYMINGTON/YARMOUTH FERRIES

COMMENTS ON PROPOSED MODEL TESTS

1. The specification for the tests proposed by the Vienna Model Basin (VMB) differs somewhat from that requested by Hart, Fenton and Company Limited (HFCL), and further details are needed to be certain about what is intended. In particular:

   a) VMB do not list a resistance test in the simulated channel at a second water depth;

   b) What is the difference between the "simulated" channel mentioned by VMB for tests 4 and 5 and the "imitation" of the channel in tests 8 or 9? In tests 4 and 5, is the simulated channel straight in plan with an idealised and uniform cross-sectional shape? Does test 8 fully reproduce a section of the navigation channel at Lymington with all the variations in plan and cross-sectional shape? Does test 9 differ in using a straight channel but with the same cross-sectional variations as test 8?

   c) What are meant in tests 6 and 7 by the adjustment of the water depth and the corresponding raising of the shallow water bottom?

2. Erosion due to the movement of the ferries in the Lymington River may be caused by the following factors:

   a) drawdown around the vessel causing water to flow off mud flats and saltings towards the navigation channel;

   b) return currents within the navigation channel due to the passage of the vessel;

   c) primary surge waves at the bow and stern caused by the blockage of the vessel moving in the navigation channel;

   d) secondary surface waves formed at bow and stern which propagate from the navigation channel over the mud flats and saltings.

3. The factors listed in Section 2 need to be measured quantitatively in the model in order to make useful comparisons between the new and existing ferries. It is considered that photographing the wave patterns in the tests will not alone provide sufficient quantitative information.

4. Changes in water level in the navigation channel (due to drawdown and surge waves) and on adjacent areas of mud flats (due to secondary surface waves) should be measured by gauges with a rapid response time (eg twin-wire resistance wave probes) and recorded by a logger or chart recorder for later analysis. Velocities in the navigation channel due to return currents should be measured by directional current meters since the direction of the flow will vary rapidly during the passage of a vessel.

5. The cross-sectional shape of the Lymington River varies considerably along its length and will also change with time. The model tests cannot investigate all the conditions that might be encountered, and so need to be representative of the more critical conditions. On this basis, it seems unnecessary to reproduce in full detail the plan and cross-sectional shape of a particular reach of the river. Instead, it is suggested that the tests should be carried out with simplified uniform channels having appropriate cross-sectional characteristics. Two cases might be usefully studied:

   a) a typical reach near the mouth of the river where the navigation channel is wider but the ferry will be travelling at higher speeds;

   b) a typical reach near the terminal where the ferry is travelling more slowly but the channel is narrower and the blockage ratio is higher.

The tests obviously need to investigate low-water conditions in the navigation channel, but erosion may also be caused at higher water levels : by drawdown and surge waves when the mud flats are slightly submerged ; and by secondary waves reaching the shoreline at high water levels. Depending on the wash characteristics of the ferries, these other conditions may not be critical but the test programme should be flexible in case they are.

6. The HFCL and VMB specifications do not mention the size of the test tank. The tank needs to be wide enough to allow the primary and secondary waves to develop correctly and to avoid interactions caused by waves reflecting back towards the boat. The required width will depend to a certain extend on the cross-sectional shape of the channel and the speed of the vessel, but a minimum figure of about 125m to 150m prototype is suggested. The length of the tank should be sufficient to allow uniform and repeatable conditions to be achieved at the test section.