CHAPTER 153

QUANTIFYING SPOIL DISPOSAL PRACTICES

by

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ABSTRACT

The results of an extensive field study undertaken in the Mersey Estuary and its approach channels are briefly described. These measurements were undertaken to obtain a quantitative understanding of the movement and circulation of water and sediment in the area. There is considerable dredging activity required in the area and the spoil from such operations is, at the present time, deposited at an offshore site in Liverpool Bay.

A simple model is presented which attempts to quantify the movement of sediment into and within the Mersey system. The field measurements showed that considerable quantities of sediment return to the docks, estuary and approach channels from the spoil ground. The model includes this fact and attempts to quantify the amounts returning to various areas. The model equations were applied to each year of the period 1955-65 to determine the various factors and to test its validity: this required the use of the annual hydrographic surveys and dredging records as well as the results of the field measurements. Finally, the model was used to compare the probable results of a number of possible schemes including re-siting of the spoil ground, pumping all dredged material ashore and free-dumping of dock dredgings in the estuary itself.

1. INTRODUCTION

The danger of spoil disposal by free dumping within long estuaries has been recognised for some time. However, offshore disposal has been regarded with favour by many Port Authorities. At present dredged spoil from the Mersey Estuary and its approach channels is deposited in Liverpool Bay, some twelve miles from the estuary entrance, in comparatively shallow water (17 ft. at LWMST and 44ft. at HWMST): the spoil ground is the area around stations BH and BG, figure 1. This spoil ground is one of the original disposal sites used by the Mersey Docks and Harbour Company since dredging operations began in 1891. Its continued use is based, partly, upon the results of a field and model investigation into the circulation pattern of Liverpool Bay and the Mersey Estuary which have been described by Price and Kendrick (1963).

The present paper describes the results of a seven-year research programme started in 1964, which was undertaken with the prime object of improving the efficiency of dredging operations in the Mersey Estuary and its approach channels through Liverpool Bay. This investigation attempted to quantify the water and sediment circulation of the study area; the calculations being based on extensive field observations.

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2. WATER AND SEDIMENT MOVEMENT WITHIN THE ESTUARY

Early work (1964-68) concentrated on the temporal and spatial measurements of water velocities, suspended solids content, salinity and temperature.

2.1 Brief description of measurements

Some forty boat-stations were established upstream of the estuary entrance as well as some five coastline stations (dock walls) for long term measurements of the amount of sediment present in the estuarine water. Usually the boat stations were chosen so that the total water, salt or sediment flux across various sections within the Narrows of the estuary could be determined from the measurements obtained. Figure 2 shows some of the stations chosen within the Narrows: these correspond to the primary sections chosen, Gladstone, Egremont, Cammell-Lairds and Dingle. The measurements were made from an anchored vessel in a routine manner: the techniques have been described elsewhere by Halliwell and O'Connor (1966) and in general were relatively straightforward. The instruments were usually of the direct reading type and measured the in-situ properties of the water. The period of measurements extended over one or more complete half-tide cycle i.e. the whole of the flood (or ebb) tide.

2.2 Summary of results and present understanding

The quantity of water passing the section per unit width (Qw) through the station during a flood or ebb tide can be obtained by integrating the velocity measurements. This integration has been carried out (using a computer) and the results for the stations at each section collected together. Figure 3 shows the variation of Qw with high water level (hwl) for stations A, B, C, D and E on Section 13 (Egremont). The results show that the relationship is linear. Any scatter of the results can be explained by variations in

(i) low water level

(ii) fresh water discharge

(iii) the exact position of the vessel

The linear variation of Qw with hwl is not surprising when reference is made to Wilton (1930) who computed the total water entering or leaving the estuary across the Gladstone section on a flood or ebb tide (Q_T) for a number of tides. Wilton's figures show that Q_T increases linearly with hwl and the relationship can be represented by the equation

$$Q_T = 101\ (H - 4.67) \text{ million cubic metres}$$

where H = hwl of the tide in metres above LBD (4.67 is the mean water level). The mean calculated value shown in figure 3 has been obtained by simply dividing the corresponding Q_T value for section 13 by the width of the section (1524m). If now one value of high water is considered then the values of Q_W given by the linear relationships of figure 3 can be used to give the distribution across the section which when integrated gives Q_T for section 13 and this can be compared directly with the quantity determined from consideration of continuity i.e. the method of cubature (Burke (1966) and Wilton (1930)). Similar comparisons can also be made for the other sections at which measurements have been made. Table 1 shows the results of just such calculations for a tide having a high water level of 8.53 m LBD. The very close agreement between the measured and calculated values of Q_T indicates that the accuracy of the measurements is very high.

Section No.	Measured Quantity Million Cu. Metres	Computed Quantity Million Cu. Metres
0	430	430
13	411	408
37	386	370
47A	370	352

Table 1: Quantity of water passing sections in the Narrows for a tide tide having a hwl of 8.53 LBD

Perhaps the most important scientific conclusion arising from the investigation by the Hydraulics Research Station, described by Price and Kendrick (1963), was, that density circulation is very important even in a well-mixed Estuary such as the Mersey. All the velocity measurements have confirmed this and they have also shown that it is important in the Bay. Although the vertical density-gradients are small (and may be almost zero at some states of the tidal flow), the longitudinal gradient is still considerable and produces a net landward movement near the bed with a corresponding increase in the seaward movement of the surface waters. The measurement of the density-currents in the Mersey has been discussed by various research workers, eg. Bowden (1965), but the phenomena is so important when considering the mechanism of sediment movement that some evidence for it is presented in figure 4. The results given in that figure show that across the whole of the Egremont section the net movement near the bed is landward with a speed of about 2500 metres per tidal cycle. Any material carried on the bed or in suspension in the bottom 25% of the depth will therefore move progressively upstream until being deposited in a comparatively slack water area or until reaching a position where the net movement is zero - this is around the Dingle Point to Eastham area of the Mersey. Figure 4 also presents the flood and ebb drifts for the stations and these show that the velocity profiles are typical for tidal flows.

The density flows for the Egremont line on spring tides have been computed and there is a net flow into the Estuary in the lower water layers of the order of 1000 m^3/s with a corresponding flow out of the Estuary equal to this density flow plus the fresh water river discharge, which is of the order of 100 m^3/s. The mean tidal flow into the Estuary through the Narrows (based on figures in table 1) throughout the flood (or ebb) tide is of the order of 20,000 m^3/s.

The total quantity of silt crossing the section per unit width Q_{ss} during a flood or ebb tide has been calculated from each set of observations. The value of Q_{ss} depends not only on tidal range but also upon season (including such environmental parameters as fresh water discharge, storm conditions, summer/winter). It is clear that the results will show more scatter than corresponding measurements of water velocity and quantities. The results for the stations on each of the four sections 0, 13, 37 and 46A have been studied and an example of the results for one such station (D) is given in figure 5. This figure shows the amount of silt in movement is much greater during the winter than during the summer and also that it increases with tidal range, as would be expected from the work of Inglis and Allen (1957) on the Thames. These results have shown that in general the movement of material along the Estuary on the ebb is approximately equal to that on the corresponding flood tide. This suggests that the material is oscillating back and forth within the Estuary and this is also confirmed by considerations of silt patterns in the Estuary as described by Halliwell and O'Dell (1969).

By considering one tide and either winter or summer conditions it is possible to obtain the total movement of silt across each section and thereby study the movement of suspended sediment along the Narrows. For this purpose a tide having 9.14 m hwl LBD during the winter conditions has been chosen. It should perhaps be noted that the conditions of 9.14 m tide and winter months are of course ideal for maximum silt movement and therefore lesser-range tides and/or summer conditions will have considerably less silt movement. Using curves such as shown in figure 5 to obtain a value of Q_{ss} the value of the total quantity of suspended silt (Q_{Tss}) crossing each section in the Narrows has been determined. (In a similar way to which the integral of the water quantities was obtained). The value of Q_{Tss} for each section in the Narrows is shown in figure 6. This figure confirms clearly that the majority of the silt in suspension is picked up from the area around the Middle Deeps and Tranmere/Brunswick and is spread out in a tongue by the ebb tide along the Narrows towards Rock Lighthouse/Gladstone and the Crosby channel. It is brought into suspension again by the flood tide and carried back into the upper Estuary. Thus large quantities of silt oscillate back and forth in the Estuary with some settling in the areas of slack water, e.g. dock entrances: Halliwell and O'Dell (1970) have shown that large quantities of silt also enter some of the docks during the levelling periods or when impounding water by pumping. The vast majority of silt therefore remains within the Estuary and is not removed by natural means.

Considerable quantities of silt are removed from the docks and dock entrances by dredging (approximately 10 million tonnes per year); the dredging spoil is dumped at the spoil grounds in the Bay. Later in the paper it is suggested that most of this material returns to the Estuary and it may be argued, therefore that it should be possible to measure this net transport of silt into the Estuary. However, if it is assumed that the net influx of silt is spread uniformly over the year then the net influx of silt per tide is only about 2% of the total amount of silt in suspension shown in figure 6 to be flooding and ebbing across sections in the Narrows. It is therefore clear that it is impossible to accurately measure this net transport across any section by measuring the difference between two large (and uncertain) quantities. Calculations based on the measurements in the Narrows and also in the Bay suggested that there is a net inflow of some 6 million hopper-tonnes per year entering the estuary.

Initially it was intended to investigate the movement of sand along the bed and in suspension at each station. However, as the investigation proceeded it became evident that the measurement of the bed load could not be done with sufficient accuracy under field conditions, and also that in certain areas (in particular the Narrows) the bed load was not important. In fact most of the sand contributing to accretion in the Mersey is thought to enter in a suspended form through the Narrows rather than bed load. This view has been supported by theoretical analysis and also by the fact that no bed load samples have been collected when using an instrument designed for this purpose (BTMA i.e. bottom transport meter-Arnhem). Consequently only the suspended-sand transport has been measured and this has been done using either a suspended Delft bottle or a simple continuous pumping technique. Sand samples have been collected at several levels during the course of the flood or ebb tide. This has enabled an estimate to be made of the net movement of sand into the estuary for various tide ranges and hence the net influx of sand into the estuary during a given time interval, e.g. one year. The measurements have shown a net transport of sand into the estuary across the Egremont section for all ranges of tide. These measurements have been used to estimate the influx of sand into the estuary for a typical year (1967) and the results are summarised in table 2.

Table 2 Monthly influx of sand into the estuary during 1967 (million tonnes)

Jan.	0.215	May	0.205	Sept.	0.280
Feb.	0.255	June	0.125	Oct.	0.340
Mar.	0.335	July	0.130	Nov.	0.230
Apr.	0.185	Aug.	0.180	Dec.	0.175

3. WATER AND SEDIMENT MOVEMENT IN LIVERPOOL BAY

Work after 1968 concentrated on establishing the residual net-tidal-flow pattern in Liverpool Bay and in ascertaining if dredged spoil could return to the estuary and approach channels.

3.1 Brief description of measurements including sampling of bottom sediments

The equipment and techniques were similar to those used for the estuary; observations being made at some thirty stations. Measurements in the Bay were much more difficult and expensive than for the Estuary and consequently the number of measurements at each station was, in general, much less than for the stations within the Estuary: usually just one flood and one ebb tide were observed. However, in addition, an extensive seabed drifter study, in which more than 7000 drifters were released at some 18 stations, was carried out. Releases were made at approximately monthly intervals and were arranged to cover tide, weather and seasonal effects over a period of more than one year.

In order to have a background knowledge of the sediments in the area, and with this a picture of the material available for transport, it was decided to take bottom samples over as large an area as possible. Samples, obtained using a Shipeck bucket sampler, were taken in the Liverpool Bay area at approximately 1.6 km intervals along parallel lines, 1.6 km apart, running approximately north-east to south-west. Samples were also taken in the River Mersey and the approach channels at much greater density than in the Bay. Other survey work included beach sampling, (for considerations of littoral drift) and a study of sand waves in the area. After separating the gravel, sand and mud fractions of each sample, the size distribution analysis of the gravel was determined by sieving, of the sand by sedimentation tube and the mud by sedimentometer. The results of this work are given by Sly (1966). Two conclusions from the geologist's work have direct bearing on the work presented in this paper. The size distribution analysis showed that sorting over most of the Bay was excellent and that transport streams extend well beyond the confines of the Bay. This means that particle size anomalies produced by dumped material are quickly removed by the dispersal of the dumpings. It also showed that accreting areas in Liverpool Bay are not only supplied with material within the Bay, but also with considerable quantities of sediment from outside the Bay. A further conclusion was that the sand deposits in the Mersey Estuary are mostly derived from the Irish Sea.

3.2 Summary of results and present understanding

The velocity measurements in the approach channel have allowed a quantitative study to be made of the water movements across the Crosby west-bank training wall, see figure 1. Of the 430 million m^3 floods or ebbing across the entrance to the Narrows (see table 1) some 235 million m^3 floods across the training wall (and through the Rock Channel) between Rock Lighthouse and Askew Spit (where the channel turns west) while some 195 million m^3 flows across it on the ebb tide. This confirms the conclusions of Price and Kendrick (1963) that there is important flood-predominance over the banks to the west of the Crosby Channel which will therefore supply material to the channels and upper estuary.

Bowden and Sharaf El Din (1966) have shown that estuarine-type circulation, with a net seaward flow in the upper layers and a landward flow near the bottom, extends to at least a distance of 18 km from the mouth of the Mersey. Measurements made at various stations (e.g. BK, BM, BN - figure 1) confirmed this and in particular confirmed Bowden's results near the spoil site (BC) which showed the residual near the bed to be towards the Mersey. This does not agree with the results of the model tests carried out by the Hydraulics Research Station, Wallingford which showed a near-bed drift seward in this area, Price and Kendrick (1963). Obviously this is of considerable practical importance and it was recommended that a sea-bed drifter study should be carried out to investigate the near-bed-water and sediment movement in Liverpool Bay and in particular at the spoil ground. This work was started in September 1969 and was later extended to include work for a Government investigation into the effects of sludge disposal in Liverpool Bay at a site approximately 55° 32'N, 3° 35'W (see figure 1). The results of this sea-bed drifter study have been described in some detail by Halliwell (1973). Seventy-five percent of all drifters released were recovered and showed that a strong landward near-bed residual movement existed over most parts of the Bay. The drifter results were confirmed by integration of current observations from some stations in the Bay: however, velocity measurements from stations in the estuary approach-channel showed that in this trained section, there was net seaward movement throughout the water depth. The grain size analysis of the bed sediments in the Bay gave further, indirect, confirmation of the near-bed residual circulation indicated by the drifters and current-measurements.

The general onshore residual currents near the bed have been chiefly attributed (see Heaps (1972)) to fresh-water run-off along with tidal mixing; naturally the effect of seabed shape is also important in some areas. The freshwater run-off (which is responsible for the horizontal density-gradients) into the Bay is from the rivers, such as the Dee, Mersey and Ribble which discharge into the eastern Irish Sea. During most of the year there is a 'boundary' between the near-bed waters entering the Dee Estuary (to the west) and those entering the Mersey Estuary: there is a corresponding boundary dividing the Mersey system from a third estuarial-type system (Morecambe Bay and Ribble Estuary) to the north.

Some of the drifter stations were at or near the present spoil disposal ground and the drifter returns from these stations indicated that some 45% reached the Mersey Estuary, while a further 23% were found just north of the estuary mouth on the beaches adjacent to the approach channel. Clearly, material from the present spoil ground may contribute to estuary, dock and approach-channel dredging. This situation is illustrated in figure 7 which shows the percentage of those drifters released at stations BC and BN which were returned from various areas: more than 500 drifters were released at each of these two stations during a period of about one year. By contrast with station BC, the drifter returns for station BN (further to the west) showed that only 9% reached the Mersey or its approach channel. This great difference is because BN lies to the west of the 'boundary' dividing the near-bed waters entering the Dee and Mersey estuaries (referred to in the previous paragraph) while BC lies within the area where near-bed waters enter the Mersey system.

4. SIMPLE MODEL OF SEDIMENT MOVEMENT

Having obtained some understanding of the sediment circulation it is necessary to quantitise in some way the material movement in the estuary and approach channels. This has been attempted by proposing the use of two equations, termed the material-balance equations:

$$\text{net sediment inflow} = \text{total dredged} + \text{decrease in capacity} \tag{2}$$

$$\text{net sediment inflow} = \begin{matrix}\text{natural inflow}\\ \text{of sediment}\end{matrix} + r \times \begin{matrix}\text{material dumped at}\\ \text{the spoil ground}\end{matrix} \tag{3}$$

where r is a factor, having a value between zero and unit

The first of these equations simply relates the net sediment inflow into an area in a given time interval to the quantity of sediment removed from that area by dredging and the change in bed levels within the area (i.e. change in capacity) during the same time interval. The second equation is based on the evidence provided by the research work, that a large proportion of the material dumped at the spoil ground is dispersed quite quickly and much of it moved towards the Mersey Estuary. The two equations can be applied to the silt and to the sand portion of the sediment separately if the relative contribution of the silt and sand to the change in capacity is known. The assumption has been made that any changes in capacity of the estuary are directly attributable to the influx of sand from Liverpool Bay; this assumption is supported by the work of Price and Kendrick (1963) and by the bed samples collected during the present research. Later calculations allowed for some contribution from the silt to the reduction in capacity of the estuary by assuming that silt accounted for 10% of the reduction in capacity: this figure is based on early work by the Water Pollution Research Laboratories (1938).

There are a number of difficulties which arise when applying these equations:

(a) The hopper quantities are known (in tonnes) but the percentage of solids in the hopper is not known and can vary considerably from one load to another. If the material in the hopper is sand with very little or no silt, the percentage (by weight) of solids may be nearly 70% whereas if the material is a loose (i.e. not consolidated) silt, the percentage (by weight) of solids may be as little as 25%.

(b) The change in capacity is measured by volume, using soundings. Usually the change is a small difference between two large quantities and because the surveys over the particular area under consideration may take a year to complete, then it follows that no great confidence can be placed in any changes in capacity over a relatively short time interval e.g. one year.

(c) Measurement of the net sediment influx is extremely difficult and if it is attempted then any estimation is measured in dry weight of material.

In order to apply the equations the units of each term must be the same so it follows that some assumptions have to be made about the specific volumes or densities of material in-situ and in the hopper. The most convenient unit to choose when applying the equations to the Mersey is the "hopper tonne".

In principle the equations (2) and (3) can be applied to any part of the Estuary and/or Bay; for example to the whole of the Mersey Estuary and approach channels or, alternatively, separately to the Estuary upstream of the Gladstone section and to the approach channels through the Bay. However, if the equations are to be applied then estimates will be required of the natural inflow of sediment into the area under consideration and also of the value for the factor r. The factor r will in general be different for sand than for silt and also different for different areas: the sum of the values for each of the areas considered cannot, of course, be greater than unitysince this would imply a source of material at the spoil ground (where it is known that there has been no erosion) which is greater than the amount deposited from dredging. Further, the value of r for a particular area may change from time to time: this will happen if something (brought about by nature or by man) changes the pattern of sediment movement; for example, a considerable change in the freshwater run-off charactersitics, or a deepening of a dredged channel and/or a change in dredging technique. Similarly the natural inflow of sediment will be a function of the area under consideration and may change with time.

Altogether, therefore, it may seem that it is too difficult to determine the necessary information to usefully apply equations (2) and (3). However, there is a considerable amount of data available from past survey and dredging records and from the field measurements made in the area: this data allows estimates of the factor r and the natural inflow of sediment for particular areas to be made. For example, the measurements given in table 2 of sand influx (equivalent to an annual 4 megatonnes in the hopper) enable some limits to be put on the values of r and natural inflow for sand entering the area corresponding to the Estuary upstream of Egremont section. Thus, since the amount of sand deposited at the spoil ground in 1967 was 8.2 million hopper tonnes then for the Estuary area

$$4.0 = \text{natural inflow} + r \times 8.2 \qquad (4)$$

Another overall figure is provided from the survey information in Liverpool Bay and the Estuary which extends back to the eighteenth century. Consideration of the surveys of Liverpool Bay show that the net annual accretion over the period 1833-1955 is something just over 2 million cubic yards of sand, which is equivalent to about 3 million hopper tonnes. If some allowance for natural inflow into the estuary is included the absolute upper limit to the total natural inflow of sand into the approach channels and Estuary is 5 million hopper tonnes and a more likely figure is 4 million hopper tonnes.

The equations (2) and (3) have been applied to the Estuary area upstream of Gladstone and to the approach channels through Liverpool Bay to check their validity and to determine reasonable values of natural inflow and the factor r. For the estuary the equations were applied to the silt as well as to the sand-type material. The results of applying the equations (2) and (3) to the approach channels (i.e. Queens and Crosby Channels) are shown in table 3. Pre-1960 the dredging was done using static-suction dredgers and in 1960 the trailer-suction dredger was introduced. It is reasonable to propose that such a change will increase the percentage of material returning from the deposit site to the channels (i.e. the factor r) because although the same percentage of material deposited at Z will move towards the estuary (say 75%) more will be intercepted (by the more efficient dredging technique) within the channels before reaching the estuary; the corresponding figure for the estuary will therefore be reduced.

Year	Total Sand Deposited at Spoil Grounds (Megatones in Hopper)	Sand Dredged from Approach Channel (Megatones in Hopper)	Estimated Decrease in Capacity (converted to Megatones in Hopper)	Assumed Return Factor (r) from Spoil Grounds	Natural Inflow of Sand into the Area (Megatones in Hopper)
1955	11.4	6.1	-	0.4	1.5
1956	12.8	7.0	-	0.4	1.9
1957	17.1	9.1	-	0.4	2.3
1958	12.6	5.6	-	0.4	0.6
1959	16.0	9.3	-	0.4	2.9
1960	14.4	9.1	-	0.5	1.9
1961	12.2	8.8	-	0.5	2.7
1962	7.7	6.2	-	0.5	2.3
1963	6.5	5.3	-	0.5	2.0
1964	6.5	5.2	-	0.5	1.9
1965	7.2	5.5	-	0.5	1.9
1966	14.8	13.1	4.7	0.5	1.0
1967	8.2	7.4	1.0	0.55	1.9
1968	6.2	5.9	-	0.55	2.5
1969	5.0	5.0	-	0.55	2.3

Notes: (a) trailer-suction dredging introduced in 1960 (b) channels deepened 1966/67

Table 3: Sand-Balance Equation for the Approach Channel through Liverpool Bay (Crosby and Queens Channels)

In 1966/67 the ruling depth in the approach channels was increased from - 7.5m L.B.D. to - 8.5m L.B.D. The assumption has been made that the only change in capacity of the channels has been that which occurred when the deepening took place, of course this is not strictly true since some variations do occur. Using these assumptions the natural inflow of sand into the channels required to fulfill the material-balance equations has been calculated and this is shown in the last columns of table 3. These indicate that there is a natural inflow of sand into the approach channels amounting to 2 megatonnes (in hopper) of sand per annum. Variations in this figure are bound to occur since for example, the natural supply of sand is likely to be affected by weather conditions in the Bay. However, the relative constancy of the figures show that the application of the equations gives a plausible quantitative explanation of the sediment movement. If, on the other hand, it is assumed that the whole of the maintenance - dredging requirement is because of natural inflow of material then explanations are required for the much larger fluctuations of natural material - inflow and of the fact that this natural inflow (into the approach channels alone) is greater than the total inflow into the whole of Liverpool Bay. Overall the model proposed seems to fit the facts reasonably well.

Once sensible values for the factor r and the natural inflow, both for the sand and silt components of the sediment, have been determined it is possible to quantify the future requirements and investigate the effects of any possible changes. Obviously it is essential to be able to do this if the overall economics of any proposal are to be considered. A number of possible situations have been examined for the Mersey, some of which are listed below:

(a) dredging methods and required depths to continue as for 1966;
(b) required depths to remain as for 1966 but all dredged spoil to be deposited "ashore" (using material to reclaim certain areas);
(c) change of site for the spoil grounds;
(d) dock dredging to be dumped in the Narrows of the estuary but all other dredging to be deposited at the spoil ground;
(e) dock dredgings to be deposited "ashore" while rest of dredging spoil continues to be deposited at the spoil ground;
(f) dock dredging to be dumped in the Narrows of the estuary, river silt to be dumped at spoil ground but all sand dredging to be deposited "ashore" to reclaim certain areas.

For all these cases it was assumed that the area would be maintained such that there would be no change in capacity of the Estuary or the approach channels. If changes in capacity are allowed then of course calculations can still be made but these capacity changes fairly quickly create changes in sediment circulation which may be difficult to estimate. Thus if certain docks are abandoned then, obviously, dredging is immediately reduced but as the river area in the vacinity of these docks accretes the capacity changes will in turn affect the water and sediment circulation.

Consider briefly the first two examples, (a) and (b), mentioned above. At first sight it might seem that if the required depths and dredging methods are not changed then there should be no change in the dredging requirements. However, it takes a number of years to reach an equilibrium situation. For example, in the year that maintenance dredging commences only the natural inflow needs to be dredged (ignoring any capital dredging) but the next year in addition to the natural inflow there is an extra inflow due to a proportion of the dredged spoil returning to the area from the spoil ground. This increase in dredging causes a further increase in inflow of material: it takes a few years before equilibrium conditions are reached. Similarly if a proportion of the material is deposited ashore all the savings in dredging will not be apparent for a number of years. On the other hand, if all of the dredged spoil is deposited ashore the savings will very quickly appear and the only dredging required will be that to cope with the natural inflow of material.

The calculations for case (a) showed that the dredging requirements for sand would increase from a total of 7 million hopper-tonnes to more than 11 million hopper-tonnes after about five years. In fact, as a definite change of policy the dredging in certain areas in the estuary was reduced or stopped and this immediately reduced the dredging totals in 68 and 69 (see table 3). For a while the movement of sediment will be more or less unaffected by this change of policy and therefore, because the only sand deposited at the spoil ground is that being dredged from the approach channels, the dredging requirements for sand can be predicted as reducing (which indeed they did - see table 3). However, eventually the changes in capacity will change the sediment movements and circulations so that the net inflow of sediment into the approach channels will increase and the dredging requirements will increase again.

Calculations involving the silt-type material were more tenuous but the equations still provided good indications of the affects of changes in spoil disposal practice. The minimum continuing dredging requirements must equal the natural inflow of silt: however, this can only be achieved if the silt is deposited ashore and it is difficult, if not impossible, to find a suitable site (which is also economic) for the purpose.

CONCLUSIONS

In order to make quantitative estimates and predictions of sediment movements in any port area it is essential to have a large number of field observations of the type described briefly in the paper. The interpretation of the field measurements is immeasurably helped by regular accurate surveys of the area and well documented dredging records over a period of years. However, one of the most difficult problems associated with any interpretation of the available data concerns the question of the actual amount of sediment within the dredger-hopper, which in turn depends on the type of material, method of dredging etc.

The work carried out in the Mersey Estuary has shown that much of the material deposited at an offshore spoil-site returns to the approach channels, docks and estuary and thereby increases the dredging requirements. Equations representing the overall movement of the quantities of sediments can be determined from the available records and these have been used to estimate the effects of various possible spoil disposal practices for the area.

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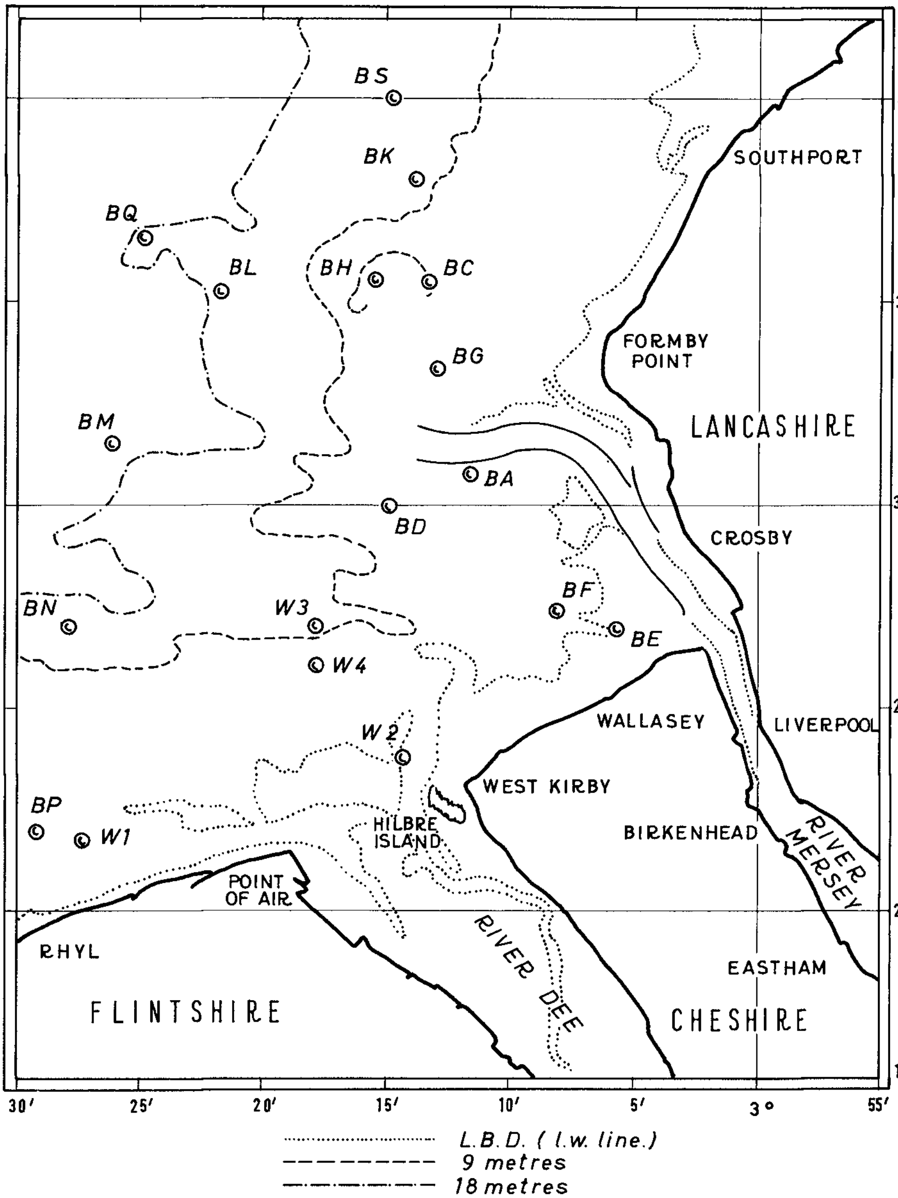


FIG.1. CHART OF LIVERPOOL BAY SHOWING POSITIONS OF STATIONS

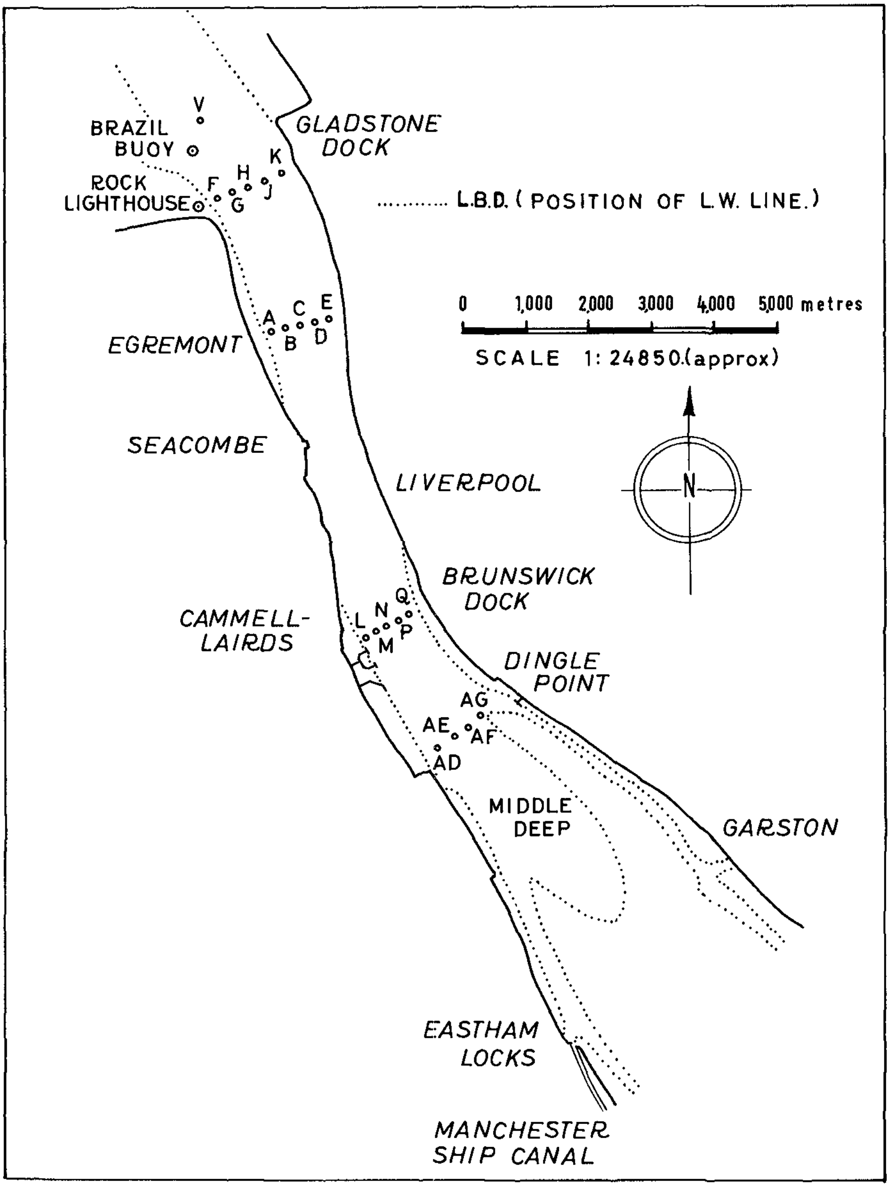


FIG. 2. OBSERVATION STATIONS IN THE NARROWS OF THE MERSEY ESTUARY.

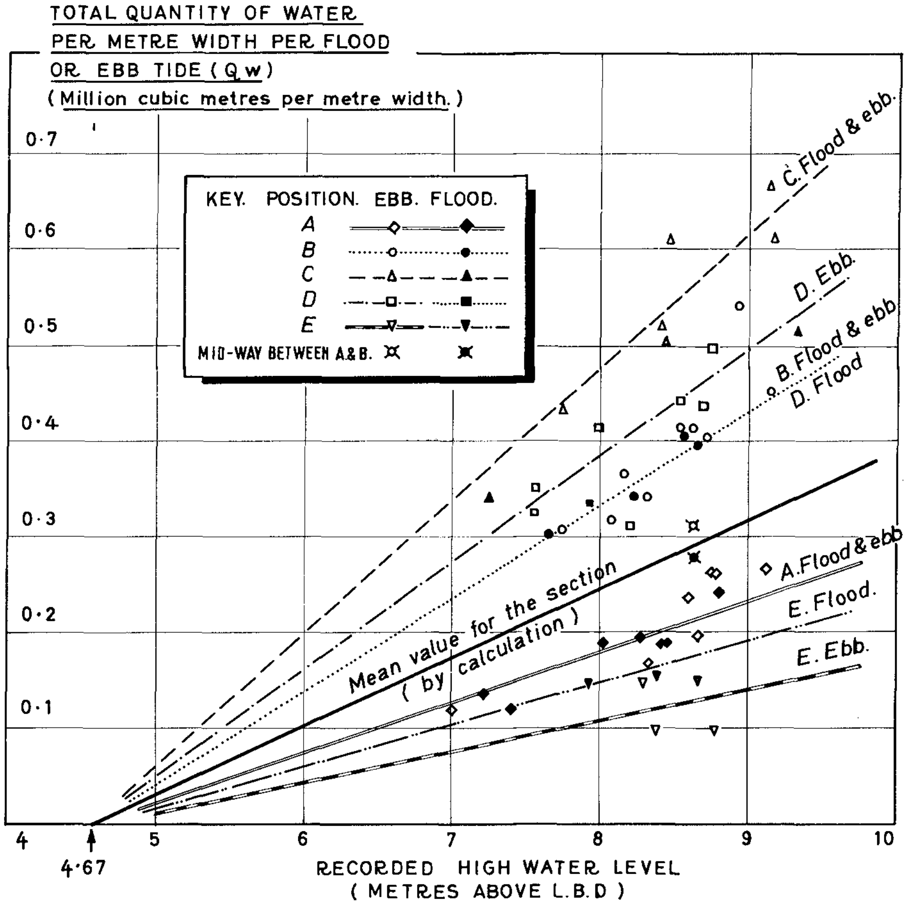
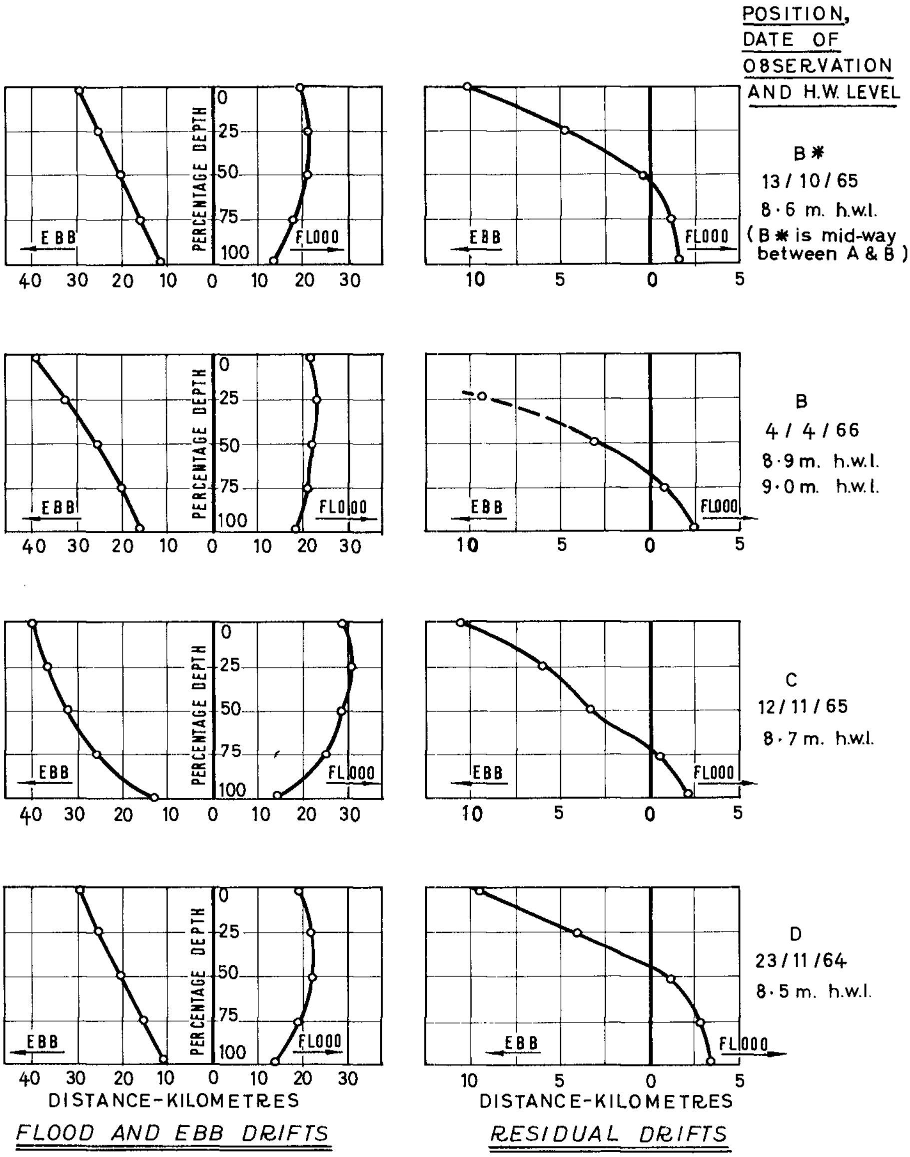


FIG. 3. VARIATION OF Qw WITH HIGH WATER LEVEL FOR STATIONS ON SECTION 13 IN THE NARROWS.



WATER DRIFTS ACROSS SECTION 13 IN THE NARROWS

FIG.4.

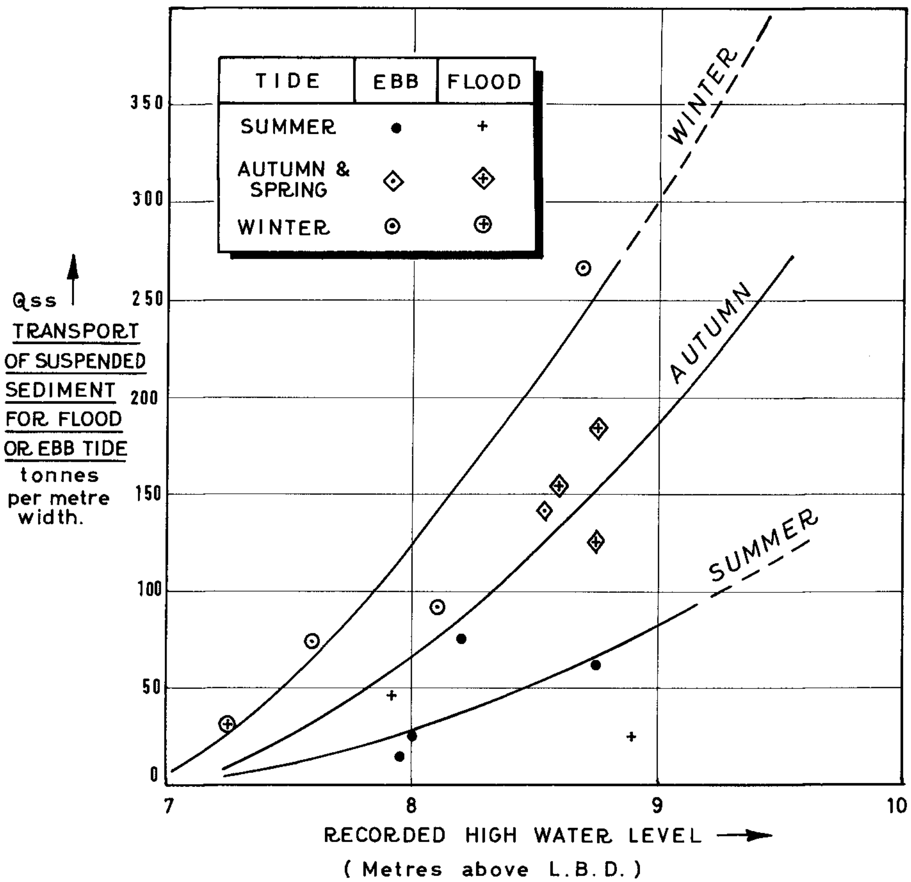


FIG.5. TOTAL TRANSPORT OF SUSPENDED SEDIMENT PER FLOOD OR EBB TIDE AT STATION D ON SECTION 13

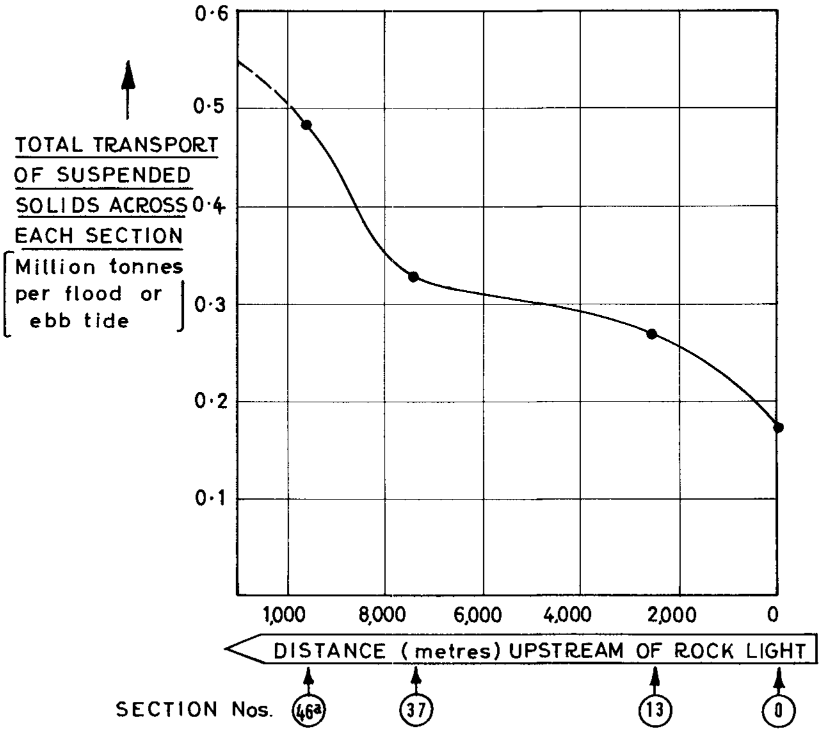


FIG. 6. TOTAL TRANSPORT OF SUSPENDED SOLIDS ACROSS SECTIONS IN THE NARROWS.
(h.w.l. = 9·14 m. L.B.D. Winter conditions)

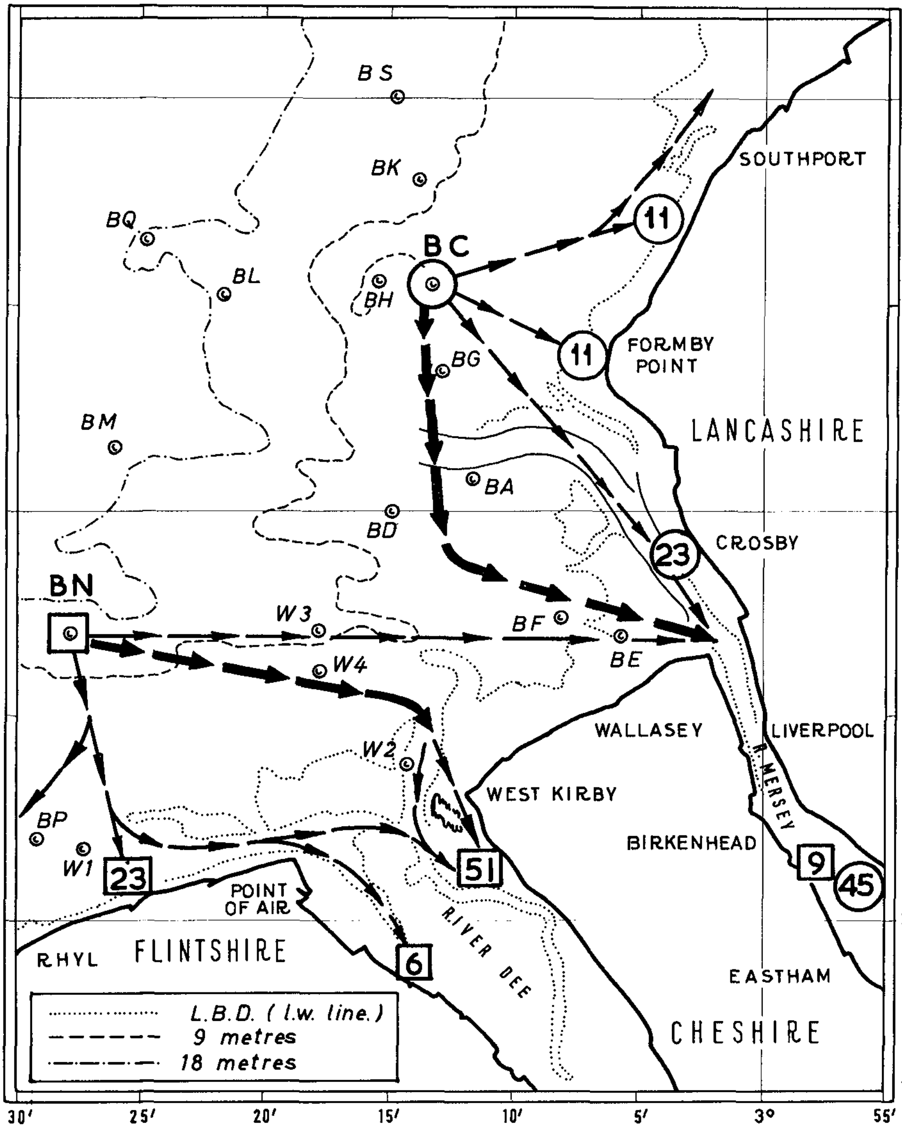


FIG.7. CHART OF LIVERPOOL BAY SHOWING STATIONS AT WHICH DRIFTERS HAVE BEEN RELEASED, AND THE COMPARISON BETWEEN THE DRIFTER RETURNS FROM STATIONS BC AND BN.