DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

EFFECT OF DISCHARGE OF CRUDE SEWAGE INTO THE ESTUARY OF THE RIVER MERSEY ON THE AMOUNT AND HARDNESS OF THE DEPOSIT IN THE ESTUARY

WATER POLLUTION RESEARCH TECHNICAL PAPER No. 7

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DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

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ESTUARY OF THE RIVER MERSEY

The Effect of the Discharge of Crude Sewage into the Estuary of the River Mersey on the Amount and Hardness of the Deposit in the Estuary

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PREFACE

FOR many years there has been much controversy among the local interests concerned as to the possible effects of the construction of artificial works, such as canals and docks, and of the discharge of large volumes of untreated sewage on the deposition of solid matter in the Estuary of the River Mersey and on the conservancy of the river. During the past fifty or sixty years there has been a great increase in the volume of untreated sewage discharged direct into the Estuary, and the opinion has been expressed that the presence of the sewage increases the rate of sedimentation of solid matter from the waters of the Estuary and alters the character of the deposit in such a way that it is more difficult to remove by dredging. This expression of opinion led to many discussions and was the basis of opposition to several Bills promoted by Merseyside Local Authorities.

Arising from the report of the Select Committee of the House of Lords on the Bill promoted in the Parliamentary Session of 1927 by the Corporation of Birkenhead, there were numerous conferences of representatives of the local interests particularly concerned. As a result of these conferences the various interests agreed to co-operate in arranging for an independent, scientific investigation and report upon the effect of the discharge of crude sewage into the Estuary on the amount and hardness of the deposit in the Estuary. In reaching this decision to co-operate in obtaining an authoritative pronouncement on the scientific facts, the Merseyside Authorities and Companies set an excellent lead which might well be followed by others in dealing with controversial problems affecting many interests.

In 1932 the co-operating Authorities and Companies invited the Department to undertake the investigation. This invitation was accepted and the work was placed under the Water Pollution Research Board. A River Mersey Committee of the Board was appointed to draw up a detailed programme of investigation and to supervise the work, which was begun in April, 1933, and was completed during 1937. The whole of the cost has been met by the co-operating Authorities and Companies.

This Report—Water Pollution Research Technical Paper No. 7—describes the experiments and observations made and the results obtained. A summary of the report and the conclusions are given in the paragraphs numbered 1 to 37 on pages 1 to 15.

Dr. B. A. Southgate was in local charge of the work at Liverpool throughout the investigation, and he was in charge of the observations and experiments made on other rivers and estuaries for purposes of comparison with the Estuary of the Mersey. He was assisted in the chemical work by Dr. E. V. Mills, Dr. G. W. Chapman and Mr. E. W. Mitchell, and during the last year also by Mr. S. R. Swift, M.Sc. The hydrographic surveyors on the staff were Lieut. W. R. Colbeck, R.N.R. (April, 1933, to June, 1934), Lieut.-Commander C. Simpson, R.N. retd. (July, 1934, to 1937), and Mr. D. A. Collins. Commander J. Taylor, R.N. retd., and Lieut.-Commander E. V. Baker, R.N. retd., also assisted in the hydrographic work during the last year. Mr. R. Bassindale, M.Sc., made the biological observations described in Chapter V and assisted in other branches of the scientific work.

Mr. F. O. Stanford, O.B.E., M.Inst.C.E., Consulting Civil Engineer, was engaged specially to study the methods adopted in the periodic hydrographic surveys of the Estuary during the period 1861 to 1931, and to examine the data obtained from these surveys. A large part of Chapter XXI of this report is based on Mr. Stanford's report on his work.

Throughout the investigation the co-operating Authorities and Companies have all assisted in every possible way by supplying information, granting facilities for the examination of any relevant records and reports in their possession and providing facilities for the collection of samples of sea water, sewage and solid matter. The Mersey Docks and Harbour Board, through their General Manager, Sir Lionel A. P. Warner, with their vast store of information derived from systematic surveys and dredging operations over a long period, were particularly helpful. Captain F. W. Mace, O.B.E., Marine Surveyor, and Mr. T. L. Norfolk, M.Inst.C.E., Engineer, of the Docks and Harbour Board, and their staffs gave much of their time in explaining the records and the methods adopted in the surveys and in the dredging operations. Without this valuable assistance, which is much appreciated by the Department, the investigation would have lasted longer and could not have been so comprehensive.

In addition to the acknowledgments already made, the Department wishes to express appreciation of the valuable assistance rendered in various ways by other local authorities, organisations, industrial undertakings and individuals in the Mersey area. The Liverpool Tidal Institute assisted in the consideration of tidal changes in the Estuary. Assistance in obtaining data on the flow of the principal rivers and tributaries was given by the Manchester Ship Canal Company, by the City Engineers of Manchester and Salford, by the Engineers of the Mersey and Irwell Catchment Board, the Cheshire Rivers Catchment Board, the River Alt Catchment Board, and the South Lancashire Rivers Catchment Board, and by several local authorities, who also supplied data on water supplies and discharges of sewage. The Upper Mersey Navigation Commission supplied charts and other information relating to the channels in the Upper Estuary and the Manchester and District Joint Town Planning Advisory Committee supplied a map showing the positions of the sewage disposal works in the area. Professor J. H. Orton gave useful advice on the biology of the Estuary. Samples of deposits were collected from the bed of the Irish Sea by the Hydrographic Department of the Admiralty and by the Lancashire and Western Sea Fisheries Committee; these samples were useful for comparison with samples of mud collected in the Estuary.

During the course of the investigation observations were made on a number of estuaries in various parts of the British Isles. In this work valuable advice and assistance were provided by the Government of Northern Ireland, the Government of the Irish Free State, the Fishery Board for Scotland, and the Navigation Authorities for the Estuaries of the Forth (Scotland) and the Rivers Dee (Cheshire) and Ribble (Lancashire).

The Department also desires to acknowledge the assistance given by the Meteorological Office of the Air Ministry in furnishing data of the rainfall in the area draining to the Mersey Estuary.

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November, 1937.

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INTRODUCTION, SUMMARY AND CONCLUSIONS

Introduction

1. The possible effects of various factors on the quantity and character of the solid matter deposited in the Estuary of the River Mersey have been under discussion for many years between the local interests concerned. For example, the subject was discussed at some length more than fifty years ago when the Manchester Ship Canal Bills were before Parliament.

2. In the Parliamentary Session of 1927, the Corporations of Liverpool, Birkenhead, and Wallasey promoted Bills for the extension of their boundaries. These Bills were opposed by the Mersey Docks and Harbour Board, the Manchester Ship Canal Company, and Lever Brothers, Ltd., and in their Petitions against the Bills great stress was laid on the possible effect on the conservancy of the River Mersey and sea channels of the discharge into the River and Liverpool Bay of sewage and solid matter.

3. In the report of the Select Committee of the House of Lords on the Bill promoted by the Corporation of Birkenhead, the opinion was expressed that it would be to the advantage of all parties interested in the River Mersey itself and of the localities situated on its banks and in its vicinity that an inquiry should be held on the question of the effect of the discharge of sewage into the River. Following this expression of opinion there were numerous discussions between representatives of the local interests particularly concerned.

4. As a result of these discussions the Authorities and Companies whose names are set out in paragraph 5 agreed that it was desirable to obtain an independent investigation and report upon the effect of the discharge of crude sewage into the Estuary of the River Mersey on the amount and hardness of the deposit in the Estuary, which, for the moment at any rate, was the only question at issue between the parties. They also agreed to ask the Department to undertake the investigation.

5. The request to the Department was made jointly, in April, 1932, by the General Manager and Secretary of the Mersey Docks and Harbour Board and by the Town Clerk of Liverpool on behalf of the following Authorities and Companies :—

Mersey Docks and Harbour Board, Manchester Ship Canal Company, London Midland and Scottish Railway Company, Lever Brothers Limited, Weaver Navigation Trustees.

County Boroughs of Liverpool, Birkenhead, Bootle, Wallasey and Warrington.

Municipal Borough of Widnes.

Urban Districts of Bebington and Bromborough, Little Crosby (amalgamated with the Great Crosby Urban District Council), Litherland, Runcorn, and Waterloo-with-Seaforth.

Rural Districts of Runcorn, Warrington, Whiston, and Wirral.

6. The terms of reference accepted by the Authorities and Companies were :—

> "To investigate the effect of the discharge of crude sewage into the Estuary of the River Mersey on the amount and hardness of the deposit in the Estuary."

For the purpose of these terms of reference—

> "Discharge of crude sewage into the Estuary" included all sewage discharged below the highest point at which the Mersey is tidal.
>
> "Deposit in the Estuary" included all deposits within the area under the jurisdiction of the Acting Conservator under the provisions of the Act 5 and 6, Vic. cap. cx. for better preserving the navigation of the River Mersey.

7. The Authorities and Companies agreed that any Reports or other information in the possession of any of them should be available for the independent investigation of the Department on the understanding that before any statements were accepted they should be confirmed by evidence which the Department had fully and independently investigated.

8. It was further agreed that the Mersey Docks and Harbour Board, together with the other Authorities and Companies associated with them, should bear one-half of the costs of the investigation and that the other half of the costs should be borne by the Local Authorities.

9. In acceding to the request to undertake the investigation the Department stipulated, and the Authorities and Companies agreed, that on the issues of scientific fact the results of the investigation should be accepted as conclusive.

10. Prior to the investigation it was suggested, during the consideration of Parliamentary Bills, that :—

(i) The sewage in the water increases the settling rate of mud-forming materials which enter the upper basin from the sea or from other sources, and the deposition of mud on inter-tidal banks is thus increased. The properties of the mud are altered by the sewage, so that it is less easily eroded and is not subsequently washed out to sea. In consequence the tidal capacity of the upper basin is decreased, the volume of water passing through the sea channels in Liverpool Bay at every tide is reduced, and the reduction in scour leads to increased deposition of solid matter in the sea channels.

(ii) Mud, contaminated with sewage, is deposited in the channels in Liverpool Bay where it causes difficulty in dredging by obstructing the suction tubes of sand-pump dredgers and by remaining in suspension in the dredger hoppers.

11. The investigation, which was begun in April, 1933, has been directed solely towards answering the question set out in the terms of reference in paragraph 6. It has not been directly concerned, for example, with the effects of the discharges of sewage and trade wastes on the sanitary condition of the River and foreshores or on fisheries.

12. As a first step in beginning the investigation, suitable accommodation was rented in the Dock Office, Liverpool, and before the end of May, 1933, the rooms were equipped for the laboratory experiments and for the preparation of charts and other office work. Two motor boats, specially designed and equipped for the investigation, were purchased.

13. A detailed description of the investigation, which occupied about four years, is given in Chapters I to XXII. A summary of the results and conclusions is given in the following paragraphs 14 to 37. For convenience, the various

sections of the investigations are considered in the same order in the summary as in the detailed descriptions in Chapters I to XXII. Each paragraph of the summary includes a reference, in brackets, to the corresponding chapter in the detailed description; references to particular figures, tables and pages are also given.

SUMMARY

14. *General Description of the Estuary* (Chapter I).

The Estuary of the River Mersey consists of three main parts :—(*a*) *Liverpool Bay* connected by (*b*) a straight deep channel known as the *Narrows* to (*c*) a large shallow tidal basin called in this Report the *Upper Basin*. The Narrows and upper basin are together known as the Upper Estuary (Map, *Frontispiece*).

(*a*) Liverpool Bay is, in general, shallow and contains large areas of banks of sand, which are exposed at low water. The main navigable channel in the Bay has been increased in depth, especially on the Bar, by dredging operations carried on continuously since about 1890 by the Mersey Docks and Harbour Board. The material removed by the dredgers is dumped on selected sites in the Bay. At one time the navigable channel frequently changed its course but in recent years it has been stabilised by building revetments and training walls.

(*b*) The Narrows is about six miles in length, has a minimum width of about three-quarters of a mile, and its maximum depth is more than 70 feet at low water. Along the banks of the Narrows there are extensive systems of docks and the most important towns of Merseyside. The bed of the Narrows is in some places rock and in other places consists of stones, shingle and sand.

(*c*) The large tidal basin is about 23 miles in length from the Narrows to the point at which it receives fresh water from the River Mersey. It is, above Eastham, broad and shallow. Its maximum width is about 3 miles at Ince and the depth in the navigable channels above Eastham is only 1 or 2 feet at low water. At low water almost the whole of the upper basin, consisting of banks of sand and of mud, is exposed. At high tide the basin contains water which has entered through the Narrows from Liverpool Bay. The basin thus forms a reservoir which is replenished during the flood and discharges on the ebb through the Narrows and into the sea channels. The main channel through the upper basin is long and winding and frequently changes its position. These changes are sometimes brought about by erosion of the edge of the channel and sometimes by the tidal streams breaking through the banks so that the channel occupies another bed. Salt water, even at high water of spring tides, does not travel so far up as Warrington, but most of the water in the Upper Estuary at high water is of high salinity. There is a considerable amount of dredging in the Upper Estuary, mainly to keep open the navigable channel to the Manchester Ship Canal and the channels to the various docks. The Canal follows the Cheshire side of the upper basin from Eastham to a point above Widnes, whence it occupies a separate channel to a point 5 miles above Warrington.

15. *Discharges into the Estuary of Fresh Water, Sewage and Industrial Effluents* (Chapter II).

(*a*) Fresh water flows into the Estuary from a number of rivers and streams of which the River Weaver and the River Mersey, with its tributaries the Rivers Irwell and Irk, are the most important. Many of these streams receive sewage, sewage effluents and industrial effluents derived partly from water brought from outside the catchment area or from wells in the district.

(*b*) Sewage, mostly untreated, and industrial effluents from areas with a total population of 1·4 million people are discharged direct into the Estuary.

(*c*) Estimates of the volumes of water carried by the rivers and streams and of the sewage and industrial effluents discharged into the Estuary have shown that the total volume from these sources averages rather more than 1,000 million gallons per day of which 30 to 40 million gallons are crude sewage discharged direct into the Estuary (Tables 4 and 8).

(*d*) It has also been calculated that the average quantity of organic matter discharged into the Estuary is equivalent to more than 100 tons of organic carbon per day; the rivers and streams carry about 20 tons per day, crude sewage accounts for more than 70 tons, tannery effluents carry about 13 tons and in addition there is organic matter in other wastes discharged into the Estuary (Table 11).

16. *Composition of the Estuary Water* (Chapter III).

(*a*) The salinity of the water of the open sea is about 34 grammes per 1,000 grammes. In the Mersey Estuary, at high water of a spring tide, the salinity is approximately zero at Warrington, 23 at Widnes, and 32 at Rock Light; the corresponding values at low water are zero, 6, and 28. At high water of a neap tide the salinity at Widnes is about 1 and at Rock Light 30 grammes per 1,000 grammes. At high water the Upper Estuary is filled with water with an average salinity, taken over a period of neaps and springs, of about 25 grammes per 1,000 grammes (Fig. 7). The salinities of samples taken at the same time and position but from different depths are always approximately equal; this indicates that the water flows at about the same speed at all depths.

(*b*) If the Mersey Estuary were unpolluted the water would probably be nearly or wholly saturated with dissolved oxygen. In water polluted by industrial effluents and sewage, part of the dissolved oxygen is used in the oxidation of organic matter, and, although fresh oxygen is dissolved from the air, the concentration of dissolved oxygen falls below the saturation value. The lowest concentrations of dissolved oxygen in the Estuary of the Mersey occur at low water between Warrington and a point about 5 miles below Widnes, where the concentration is usually less than 10 per cent. of the saturation value and may fall to zero (Fig. 9). These values indicate the presence of a high concentration of polluting matter. At high water of a spring tide the dissolved oxygen concentration at Widnes is about 60 per cent. of the saturation value; the concentration rises to approximately 90 per cent. at Rock Light. Thus the greater part of the water in the Estuary contains 60 per cent. or more of the weight of dissolved oxygen required for saturation.

(*c*) The concentrations of free and saline ammonia, of soluble organic carbon and of sulphide are highest between Warrington and Widnes, confirming the view that the concentration of polluting material is highest in this part of the Estuary (pp. 35–36).

17. *Distribution of Sewage after Discharge into the Estuary* (Chapter IV).

(*a*) The concentration of sewage in the Estuary has been estimated from a consideration of the salinity at different positions and from the relative volumes of sewage and fresh water discharged. It is estimated that at high water of a spring tide about one-third of the total volume of Estuary water contains sewage in an average concentration of about 0·4 per cent.; about one-third contains 0·6 per cent.; one-quarter, 0·8 per cent. and the remainder (6 per cent. of the total volume) between 1·1 and 2·3 per cent. of sewage. At low water of a spring tide nearly four-fifths of the total volume contains an average concentration of 0·8 per cent.; one-fifth contains 1·2 per cent. and the remainder (2 per cent. of the total volume), which consists of the water in the shallow reaches below Warrington, contains between 2·1 and 3·2 per cent. of sewage (Table 18).

Even including the polluting material discharged in fresh-water streams and in industrial effluents, the concentration of polluting organic material in most of the water at any state of the tide is less than the equivalent of 5 per cent. of sewage.

(*b*) From a consideration of measurements of salinity and from the observation of free-drifting floats it has been deduced that the average time taken by material discharged at Warrington and remaining in suspension or solution to reach Rock Light is between 1 and 3 weeks (pp. 40–43).

18. *General Nature of the Bed of the Estuary* (Chapter V).

(*a*) In the Mersey Estuary the area of banks uncovered at low water of a high spring tide is about 37 sq. miles. Approximately half of this area is in Liverpool Bay and half in the Upper Estuary (p. 46).

(*b*) Banks in which burrowing aquatic animals live must be comparatively stable and not subject to frequent changes in position, or the animals would be washed away. The inter-tidal estuarine banks in the Mersey have been classified as "uninhabited," "sparsely inhabited" and "densely inhabited" mud and sand. In the Upper Estuary the banks consist mainly of uninhabited sand (48 per cent.), densely inhabited mud (33 per cent.) and sparsely inhabited sand (9 per cent.). The densely inhabited and relatively stable areas of mud are sharply divided from the areas of unstable, uninhabited sand. Most of the mud in the Upper Estuary occurs as a single large bank, the "Stanlow Bank", between Eastham and the Weaver Sluices. In Liverpool Bay the banks are mainly composed of uninhabited sand (67 per cent.), sparsely inhabited sand (19 per cent.) and densely inhabited sand (10 per cent.). The area of densely inhabited mud is only 2 per cent. of the total area of inter-tidal banks in the Bay. In the Upper Estuary, the mud banks lie almost entirely at a height of more than 20 ft. above Liverpool Bay Datum. Only small areas of stable mud occur on the bed of the channels in the Upper Estuary. In Liverpool Bay the greater part of the bed in the sea channels is composed of sand but there are large areas of muddy sand in some places (pp. 45–51).

(*c*) The distribution of mud banks and sand banks in the Upper Estuary is correlated with the strength of the tidal streams ; the velocity over mud banks is lower than that over sand banks, since the mud banks are higher than the sand banks and are only covered near the time of high water. In Liverpool Bay the lowest stream velocities occur over the surface of the inter-tidal banks (pp. 51–53).

19. *Composition of the Deposits in the Estuary* (Chapter VI).

(*a*) The majority of the chemical analyses of mud and muddy sand were made on samples from the mud bank between Eastham and the Weaver Sluices (the Stanlow Bank). The samples consisted of siliceous sand, mixed with varying proportions of clay and silt. The less sandy muds contain a higher proportion of moisture and organic matter than the more sandy samples ; the relations between the average silica, moisture and organic carbon contents can be expressed by smooth curves (Figs. 19 and 21). The highest concentration of organic carbon in any sample examined was less than 4·5 per cent. of the dry weight ; a few samples contained between 3 and 4 per cent. ; the majority contained less than 3 per cent. (Table 26).

(*b*) The ratio between the weights of organic carbon and of nitrogen in Mersey mud is, on the average, approximately 10 : 1 ; it varies considerably in different samples (Figs. 23 and 24).

(*c*) Mersey mud contains sulphur in the form of sulphate, sulphide and elementary sulphur. The distribution of the total amount between these three forms is dependent mainly on whether the mud has been subject to aerobic or anaerobic conditions. When sub-surface mud, containing black ferrous sulphide, is allowed to dry in the air, the sulphide is converted to elementary sulphur and iron oxide and the mud becomes brown in colour. Brown mud, from the surface of the bank, when covered with water and maintained under anaerobic conditions becomes black, owing to the conversion of sulphate to sulphide. The amount of sulphide produced can be increased by additions of a soluble sulphate. Sulphide in Mersey mud is probably formed by the reduction, during the decomposition of organic matter, of sulphate present in sea water, and the presence of sulphide cannot be taken as an indication of the presence of sewage or other polluting material (pp. 60–63).

(*d*) Samples from below the surface of the Stanlow Bank contain a greater proportion of sand than do surface samples. The composition of the mud in the sub-surface samples, some of which were apparently deposited between the years 1860 and 1890, is about the same as that of recently deposited surface samples (pp. 63–64).

20. *Possible Sources of Mersey Mud* (Chapter VII).

Mud-forming material enters the Estuary as the result of erosion of the cliffs of boulder clay on the shores of the upper basin, in suspension in fresh-water streams, and in sewage. It is also probable that mud-forming material is eroded from the bed of Liverpool Bay and of the Irish Sea and is carried into the upper basin in suspension during the flood tide.

(*a*) Boulder clay from the cliffs in the Upper Estuary contains only a small concentration of organic matter (Table 37). The mud carried by fresh-water streams has, in general, a considerably higher organic content than mud from the Stanlow Bank (Table 39). Mud from the bed of Liverpool Bay and the Irish Sea, when separated from the sand with which it is mixed, has approximately the same composition as inter-tidal mud from the Upper Estuary (Fig. 29).

(*b*) The most probable source of any large quantity of mud-forming material is the bed of Liverpool Bay and the Irish Sea. The amount of material due to boulder clay containing little organic matter and to highly organic suspended matter carried by fresh-water streams is relatively small (pp. 68–70). The quantity of inorganic suspended matter contained in sewage discharged direct to the Estuary is very small compared with the size of the Estuary and the changes in capacity which occur (p. 70). If the material is derived from Liverpool Bay and the Irish Sea it seems that it undergoes no marked change in composition between the time of its erosion and its deposition in the Upper Estuary.

(*c*) There are no data from which any estimate can be made of the quantities of mud in the Estuary at different times during the period 1861 to 1936 for which determinations of the capacity of the Upper Estuary are available.

21. *Comparison of the Composition of the Deposits in the Mersey with that of Deposits from other Localities* (Chapter VIII).

(*a*) For comparison with Mersey muds, samples of inter-tidal deposits from the following localities have been examined :—

Estuaries of the Rivers Ribble, Dee, Wye, Severn, Tamar, Deben, Orwell, Stour, Colne, Blackwater, Crouch and Roach; salt marshes in Norfolk and Essex; Morecambe Bay (England); estuary of the River Tay (Scotland); Lough Foyle (North of Ireland); estuaries of the Rivers Suir and Barrow (Irish Free State).

The water in all these localities, though not entirely unpolluted, contains smaller concentrations of sewage and industrial effluents than are present in the Mersey. In some of these localities, such as the estuaries of the Tay, Foyle and Barrow and the marshes in Norfolk and Essex, the waters are substantially unpolluted.

(*b*) The organic content of the samples of mud from the Tay, Wye, Severn and Foyle was higher than that of Mersey muds containing the same proportion of sand. The organic content of the Foyle samples in particular was very high, one sample containing as much as 10·6 per cent. of organic carbon; this is due to the presence of decomposing peat in the Foyle mud. Muds from the other localities were similar to Mersey mud in appearance and texture and their organic content was about the same as in Mersey mud containing the same proportion of sand (Figs. 32 and 33). The curve expressing the relation between the average organic carbon and silica contents of the Mersey samples is approximately coincident with the corresponding mean curve for all the muds from the other localities (Fig. 34).

(*c*) In mud from Liverpool Bay and from the Upper Estuary, for each 100 grammes of organic carbon there is present about 1 gramme of material soluble in petroleum ether. In muds from the other estuaries the proportion is rather lower. Digested sewage sludge contains about 10 grammes of ether-soluble substances for each 100 grammes of organic carbon (Table 54). The concentration of ether-soluble material was determined because it was thought that the values obtained might indicate the presence of organic matter of sewage origin in a mud. Considerable differences are, however, found in the content of ether-soluble substances in individual samples of mud from the same locality, and it is doubtful whether the observed differences between the concentration in Mersey muds and muds from the other estuaries indicate any real difference in the amounts of organic matter of sewage origin.

22. *Changes in the Composition of Muds as a Result of Storage* (Chapter IX).

(*a*) Samples of Mersey mud covered with sea water were allowed to stand in the laboratory for periods of 6 months and 1 year. During this time most of the samples lost both nitrogen and organic carbon, the proportion of nitrogen lost being rather greater than of organic carbon (Figs. 35 and 36). The carbon-nitrogen ratios in the different samples were more nearly the same after storage than before (Fig. 37). Samples with similar silica contents contained, after storage, more nearly the same concentration of organic matter than when taken from the mud bank.

(*b*) Since the carbon-nitrogen ratio of Mersey muds stored for periods of some months tends to approach a constant value, it was suggested that a comparison with the carbon-nitrogen ratio in muds from relatively unpolluted localities might indicate whether the Mersey muds are subject to frequent addition of fresh organic matter. The carbon-nitrogen ratios of 61 samples of muds as collected from estuaries in Suffolk and Essex were compared with the ratios in 5 groups, each of 61 samples, from the Mersey. In some of the Mersey groups the differences in the carbon-nitrogen ratios of the various samples were somewhat greater than in the group of Suffolk and Essex muds; in the other groups of samples from the Mersey the differences were no greater than in the samples from the comparatively unpolluted areas (Fig. 40). It is thus uncertain whether the differences observed indicate any significantly greater addition of organic matter to the Mersey muds than to the muds from unpolluted localities.

23. *Methods and Conditions of Measurement of Rate of Sedimentation of Mud* (Chapter X).

(*a*) Numerous laboratory experiments on the settling rate of Mersey muds from suspension in water have been made. The muds were taken from the Upper Estuary and from Liverpool Bay. The concentration of mud in the experiments was usually between 20 and 60 parts (dry weight) per 100,000; the concentration of mud in suspension in the Estuary water under average conditions usually falls within these limits (Fig. 83). The salinity of the water used to make up the suspensions was generally 25 grammes per 1000 grammes, since this is approximately the mean salinity of the water in the Upper Estuary at high water (Fig. 7). The quantities of sewage added ranged from zero to 5 per cent., that is, up to a concentration greater than in most of the Estuary water (Table 18).

(*b*) The results of this first series of experiments showed that :—

(i) during sedimentation initially fine particles collide and form aggregates, the size and velocity of which increase as they fall (Table 61).

(ii) as a result of (i) the average velocity of sedimentation in a column increases as the depth is increased to 40 ft., the greatest depth tried (Fig. 42).

(iii) the rate of sedimentation increases with an increase in the initial concentration of mud in suspension, owing to the more rapid formation of aggregates (Fig. 43).

(iv) the rate of sedimentation increases with an increase in the salinity of the water from 0·4 to 10 grammes per 1000 grammes, but change in salinity from 10 to 30 grammes has no appreciable effect (Fig. 44).

(v) increase in temperature from 5° to 30° C. causes an increase in the rate of sedimentation (Fig. 45).

24. *Rate of Sedimentation of Mersey and Other Muds* (Chapter XI).

(*a*) The rate of sedimentation in saline water of mud from the Stanlow Bank in the Upper Estuary is substantially the same as that of mud from the bed of Liverpool Bay (Fig. 46).

(*b*) The settling rate of Mersey mud is rather lower than that of muds from the estuaries of the rivers Deben, Stour, Colne, Blackwater, and Crouch and from salt marshes at Hamford Water (Fig. 47). These localities are comparatively unpolluted, and the mud taken from them has approximately the same composition as that of Mersey mud (Chapter VIII). Aggregates, similar in appearance and size to those formed in Mersey mud, were also formed as the Suffolk and Essex muds settled from suspension.

(*c*) The rate of sedimentation of the mud carried in suspension in the estuary of the river Wye in Monmouthshire is considerably lower than that of Mersey mud (Fig. 48). The Wye mud contains approximately the same concentration of organic matter as Mersey mud (Chapter VIII) and its low settling rate may be due to differences in the composition of its inorganic constituents.

25. *Rate of Sedimentation of Mud immediately after Mixing with Sewage* (Chapter XII).

(*a*) The change in the settling rate of initially finely-divided Mersey mud in saline water caused by the addition of sewage depends on the depth through which the mud settles. The rate of sedimentation through depths of 4 inches is not significantly changed by the addition of settled sewage in amounts equivalent to as much as 5 per cent. of the volume of the suspension (Table 65). In columns 4 feet in depth a small increase in the settling rate of the mud is caused by the addition of 5 per cent. of crude unsettled sewage; in columns 9 feet in depth the increase is greater, but the settling rate of mud through a distance of 40 feet is unaffected by the addition of 5 per cent. of settled or unsettled sewage (Fig. 50). The effect of the addition of sewage on the rate of sedimentation is apparently dependent on the state of aggregation reached by the mud in falling through columns of different lengths. In all these experiments the mud was initially in a finely-divided condition.

(*b*) With depths of 9 feet, in which the greatest effect with 5 per cent. of sewage was observed, no significant increase in the rate of sedimentation of initially finely-divided mud in saline water was caused by the addition of 0·5 to 1 per cent. of sewage; there was a very slight increase with 2 to 3 per cent., and a significant increase with 5 per cent. (Fig. 52). With 5 per cent. of settled sewage there was an increase in the settling rate of the mud at temperatures of 7°, 17° and 24° C. (Fig. 53).

(*c*) The effect of sewage on the settling rate was approximately the same with muds from the Severn Estuary and from comparatively unpolluted estuaries in Essex as with mud from the upper basin of the Mersey (Fig. 54).

26. *Effect of Stirring on the State of Aggregation of Mud in Suspension* (Chapter XIII).

(*a*) When a suspension of finely-divided Mersey mud in saline water was stirred vigorously and then poured into another vessel and allowed to settle, the rate of sedimentation was usually increased as the result of the preliminary stirring. The effect of stirring differed considerably with different samples of mud; with some samples little change occurred and with others the increased rate of settling through depths between 4 inches and 40 feet was considerable (Fig. 56). No marked change appeared to occur, during stirring, in the particle size of the mud, but when the suspension was allowed to stand, aggregates were formed more rapidly in suspensions previously vigorously stirred than in unstirred suspensions.

(*b*) When a fine suspension of Mersey mud in saline water was stirred gently, large fragile clots were rapidly formed. The size of the aggregates was greatest with slow rates of stirring just sufficient to maintain the clots in suspension. When stirring was stopped, the clots fell rapidly from suspension with little further aggregation (Fig. 58).

(*c*) The changes in the state of aggregation of mud caused by gentle stirring were similar with samples from comparatively unpolluted estuaries in Essex as with samples from the Mersey (Fig. 59).

(*d*) When a layer of mud is gently eroded by a moving stream of saline water above it, the mud comes into suspension in the form of large aggregates similar to those formed by gently stirring a suspension of fine particles of mud (Fig. 60).

27. *Effect of Stirring with Sewage on the Rate of Sedimentation of Mud in Different States of Aggregation* (Chapter XIV).

(*a*) The settling rate of initially finely-divided Mersey mud in saline water, which was increased by vigorous stirring of the suspensions, was further increased when 5 per cent. of settled sewage was added either before or during stirring. The increase due to the added sewage was considerable when the mud was settled through columns 4 feet in depth; with columns 9 feet and 20 feet in depth the effect of sewage was less and there was no effect when the mud was settled through a depth of 40 feet. The addition of 0·1 to 0·3 per cent. of sewage caused no further increase in the rate of settling through a depth of 9 ft. after vigorous stirring and the increase with 3 per cent. was only small (pp. 113–114).

(*b*) When unsettled sewage, in concentrations of 1 to 5 per cent., was added to suspensions of mud in saline water and the mixtures were gently stirred for 1 to 2 hours, the settling rate of the large aggregates formed was greater than in suspensions similarly stirred but to which sewage had not been added. When, however, suspensions of the mud were stirred gently for 30 to 60 minutes so that the mud formed large aggregates, and 5 per cent. of unsettled sewage was then added, the settling rate of the mud after further stirring was not affected by the presence of the sewage (Fig. 76). In other experiments mud was allowed to settle from saline water to the bottom of a vessel, unsettled sewage in concentrations up to 5 per cent. of the volume of the saline water was added, the mud was brought into suspension in the form of large aggregates by gently stirring the supernatant liquid, and the mixture was stirred gently for a further period of several hours. The settling rate of the mud under these conditions was not affected by the addition of the sewage (pp. 117–120).

(*c*) The settling rate of mud in suspension is thus only increased by the addition of sewage when the mud is initially in a finely-divided condition and is not affected when the mud is in the form of large aggregates.

28. *State of Aggregation of the Suspended Matter in the Mersey and in other Estuaries* (Chapter XV).

(*a*) The mud carried in suspension during the run of the tide in the Mersey Estuary is generally in the form of large, fragile aggregates. The rate of sedimentation of these particles is similar to that of mud which has been stirred gently in suspension in saline water or has been eroded from the bottom of a vessel by a slowly moving stream of water (Fig. 80). It has been shown (Chapter XIV) that the rate of sedimentation of such particles is not affected by the presence of sewage in concentrations up to 5 per cent. of the volume of the suspension.

(*b*) The mud carried in suspension in the comparatively unpolluted estuaries of the rivers Suir and Barrow (Irish Free State) occurs in the form of aggregates which in size and properties are similar to those found in the Mersey Estuary (Fig. 82).

29. *Rate of Sedimentation of Suspended Matter in the Mersey and in other Estuaries* (Chapter XVI).

(*a*) During each flood and ebb of the tide, mud is eroded from the bed of the Mersey Estuary and is carried in suspension by the moving water. Almost the whole of this material settles to the bottom during each slack water period of 1 to 2 hours, even in the Narrows where the depth at low water is 40 to 70 feet (Fig. 83). This high rate of sedimentation is due to the fact that the mud is carried in the form of large aggregates which settle rapidly when the turbulence of the water is reduced.

(*b*) The concentration of material carried in suspension is considerably higher at spring tides than at neaps, although the mean maximum stream velocity during springs is less than 1 knot greater than during neaps (Fig. 85). The data obtained during determinations of the rate of erosion of mud (Chapter XIX) suggest that little mud is eroded until the stream velocity exceeds a minimum critical value; when this has been reached and the mud has been brought into suspension, a smaller velocity is sufficient to prevent sedimentation.

(*c*) The rate of sedimentation of mud during slack water in the Mersey is approximately the same as that of mud in the River Suir (Irish Free State), which is only slightly polluted, and in the Firth of Forth, in which the concentration of polluting matter is also considerably smaller than in the Mersey (Fig. 86).

30. *Concentration of Organic Matter in Mud Settled from Suspensions Immediately after Mixing with Sewage* (Chapter XVII).

(*a*) When finely-divided Mersey mud settles from suspension in saline water no change occurs in its content of organic matter (Table 88). When sewage is added to the suspension, part of the organic matter of the sewage is carried down by the mud as it settles. The quantity of organic matter carried down increases as the concentration of added sewage is increased from 0·1 to 5 per cent. (Fig. 90). For a given concentration of sewage the quantity of organic matter carried down is greatest when initially finely-divided mud falls through only a short distance and becomes smaller as the depth through which the mud settles is increased (Fig. 89). This is attributed to the formation, in deep columns, of large clots of mud which do not take up the organic matter of sewage to the same extent as the fine particles (pp. 135–137).

(*b*) When a suspension containing mud and sewage in saline water is allowed to settle, only part of the organic matter of the sewage is carried down by the mud (Fig. 93). The sewage remaining in suspension or solution cannot be removed by bringing the settled mud again into suspension and allowing it to re-settle (Fig. 97). Part of the remaining sewage, however, can be removed by adding a quantity of fresh mud (Fig. 98).

(*c*) When mud is repeatedly settled from a succession of suspensions of sewage in saline water, its content of organic matter increases as the result of each sedimentation; the concentration of organic matter in the mud can in this way be raised to a high value (Fig. 96).

(*d*) Organic matter added to mud by allowing the mud to settle from suspension in water containing sewage is only feebly attached and can be removed by settling the mud from suspension in clean water, or part of it can be removed by sedimentation from water containing a relatively small quantity of sewage (pp. 139–140).

(*e*) The organic matter associated with Mersey mud as found in the Estuary, however, is firmly attached and is not removed by settling the mud from suspension in clean water (p. 140).

31. *Composition of Mud Settled from Previously Stirred Suspensions containing Sewage* (Chapter XVIII).

(*a*) When a suspension of mud in saline water containing sewage is stirred vigorously and then allowed to settle, the amount of organic matter in the sediment is greater than in the deposited solids from a similar suspension which has not been stirred vigorously before sedimentation (pp. 143–146). The proportion of the sewage carried down decreases as the depth through which the mud settles is increased (pp. 146–147).

(*b*) In some experiments saline water containing mud in suspension was stirred gently until large clots of mud were formed; sewage in concentrations of 1 to 5 per cent. was added, and slow stirring of the mixture was continued (Table 93). In other experiments mud was eroded from the bottom of a glass vessel and was brought into suspension, in the form of large clots, in water containing 2 to 5 per cent. of sewage; the mixture was then gently stirred for a period of 1 to 3½ hours (Table 94). When suspensions treated in either of these ways were allowed to settle, a considerable amount of the organic matter of the sewage was deposited with the mud. It had previously been shown that the rate of sedimentation of the mud in these experiments was not affected by the presence of the sewage (Chapter XIV).

(*c*) When saline water containing up to 5 per cent. of sewage and no mud in suspension is stirred gently, the sewage forms aggregates of solid matter which settle readily on allowing the mixture to stand, though not so rapidly as the aggregates formed by gently stirring suspensions of mud in saline water. The amount of organic matter settled in 1½ hours through a depth of 9 feet from the sewage in a mixture of sewage and saline water is as great as from the same amount of sewage in a suspension of mud in saline water similarly treated (pp. 149–150).

(*d*) In the Estuary of the Mersey as the quantity of suspended matter decreases at slack water, the concentration of organic matter in the material remaining in suspension increases. This, with the results mentioned in (*c*) above, indicates that the flocculated particles or aggregates of mud in the water of the Estuary settle more rapidly than the flocculated particles formed from the sewage (pp. 150–152). Part of the organic matter of the sewage, which owing to its low rate of sedimentation remains in suspension at slack water, is doubtless carried out to sea during each ebb tide.

32. *Rate of Erosion of Mersey and Other Muds* (Chapter XIX).

(*a*) There appears to be little erosion of mud from the surface of the banks in the Upper Estuary. The banks are, in general, higher than 20 feet above Liverpool Bay Datum and are covered only near the time of high water when the stream velocity is low. Considerable erosion of mud often takes place, however, from those edges of the banks which are exposed to the full force of the tidal streams. When this occurs the edge of the mud bank often forms a vertical face or " fret " and large pieces of mud are torn from it and dispersed in the water (p. 153).

(*b*) Erosion of mud was studied in the laboratory by a method in which the conditions of erosion in the Upper Estuary were reproduced as nearly as possible (pp. 153–154). The resistance of Mersey mud to erosion, as measured by this method, increases as the mud dries in the air, that is, with a decrease in moisture content (Fig. 111).

(*c*) Experiments with samples from the Stanlow Bank showed that the resistance to erosion was least with those samples containing the highest proportion of sand and the smallest proportion of clay (Fig. 112). In comparing the results of these experiments due allowance was made for the moisture content of the samples as tested.

(*d*) The resistance of Mersey mud to erosion is slightly less than that of muds from the comparatively unpolluted estuaries in Suffolk and Essex, allowance being made for the different moisture and silica contents of the samples (Fig. 114).

(*e*) In the Mersey, mud which has settled to the bed of the Estuary during slack water is eroded and brought into suspension during each flood and ebb tide, provided the stream velocity is sufficiently high. Erosion of different muds under these conditions was studied in the laboratory (pp. 159–160). The erosion of Mersey mud was not appreciably affected when 5 per cent. of sewage was added to the water from which the mud settled (Table 104). Under similar conditions the rate of erosion was approximately the same for Mersey mud as for muds from the Suffolk and Essex estuaries and from the estuaries of the rivers Wye and Severn (Table 105).

(*f*) During the period 1931 to 1936, when the channel through the Upper Estuary moved so as to flow past the outer edge of the Stanlow Bank, approximately half a square mile of the bank was washed away. The volume eroded was 6 to 7 million cubic yards, or about 0·6 per cent. of the total capacity of the Upper Estuary. The Stanlow Bank is usually protected from erosion by the presence of high sand banks between it and the main channel (pp. 161–163).

33. *Dredging in the Sea Channels in Liverpool Bay* (Chapter XX).

(*a*) Since the year 1890 there has been continuous dredging of different parts of the sea channels in Liverpool Bay. Suction dredgers are used. Where the bottom is sandy no difficulty is encountered, but where it is composed of muddy sand the mud often causes delay by blocking the suction tubes. Moreover, the suspension of mud pumped into the hoppers of the dredgers does not easily settle and part of the mud is discharged with the water overflowing from the hoppers.

(*b*) The records of operation of two dredgers for the period 1909 to 1935 have been examined in detail. The returns show that muddy sand is more difficult to dredge than clean sand but there is no evidence of any increase in the difficulty of dredging from 1909 to 1935 (pp. 164–166).

34. *Methods Used in Measuring the Capacity of the Upper Estuary* (Chapter XXI).

(*a*) In the years 1861, 1871, and 1881, and thereafter at intervals of five years, the Mersey Docks and Harbour Board surveyed the Upper Estuary and calculated its capacity between Rock Light and Warrington. It is on these measurements that opinions on the effect of the discharge of sewage on the deposition of material in the Estuary during recent years have been based. The original records and calculations have been examined in detail.

(*b*) During the present investigation a small compartment of the Estuary was surveyed and its volume was calculated independently by the Mersey Docks and Harbour Board and by the Department's staff. Good agreement was obtained, the difference between the two values being no greater than 0·2 per cent. of the volume of the compartment (Table 118).

(*c*) Several methods by which the capacity of the Upper Estuary can be calculated from the measurements made by sounding and levelling are available and the result obtained depends to some extent on the method chosen. All these methods, however, including that adopted by the Mersey Docks and Harbour Board, give approximately the same results for the changes in capacity (pp. 182–185).

(*d*) The original records available for the survey in the year 1861 are not in agreement one with another; there is in consequence some uncertainty in the values calculated from the records for that year (p. 184). With this exception it is concluded that the values obtained by the Mersey Docks and Harbour Board for the changes in capacity of the Upper Estuary between successive surveys are substantially correct.

35. *Changes in the Capacity of the Upper Estuary and in the Position of the Banks and Channels* (Chapter XXII).

(*a*) The following values of the capacity of the Upper Mersey Estuary between Rock Light and Warrington, from the bed to the highest level at any position reached by a tide rising in the Narrows to a height of 31 feet above Liverpool Bay Datum, have been obtained by re-calculation from the original data by the method used by the Mersey Docks and Harbour Board (Table 119) :—

(Capacity in millions of cubic yards)

Year:	1871	1881	1886	1891	1896	1901	1906	1911	1916	1921	1926	1931	1936
Capacity:	955	962	1,003	948	976	980	991	974	957	944	939	939	951

Between 1871 and 1886 the capacity rose by 48 million cubic yards or by 5·0 per cent. of the total capacity in 1871. It declined by 55 million cubic yards during the period 1886 to 1891, that is by 5·5 per cent. of the 1886 value, but rose again by 43 million cubic yards to 991 million cubic yards in 1906. Between 1906 and 1926 there was a loss of 52 million cubic yards, equivalent to about 5·2 per cent. of the 1906 value. The loss between 1906 and the most recent survey in 1936 (the results of which were communicated to the Department by the Mersey Docks and Harbour Board after the body of the present report had been written) is approximately 4·0 per cent. The capacity of the Upper Estuary was approximately the same in 1936 as in 1916, 1891 and 1871.

(*b*) During the period 1906 to 1931 the reduction in capacity in the Upper Estuary, between Rock Light and Runcorn, was approximately 50 million cubic yards (Table 121, Column E). Part of this reduction was due to the building of shore works. The losses in capacity, at different levels, not directly due to the building of shore works, were, during the period 1906 to 1931 (Table 128) :—

Below Liverpool Bay Datum (L.B.D.) ..	22·5	million cu. yds.
0 to 10 feet above L.B.D.	9·1	,, ,,
10 to 20 feet above L.B.D.	8·4	,, ,,
20 feet above L.B.D. to high water ..	4·3	,, ,,

These losses are equivalent to the uniform deposition of material to the following depths (Table 129) :—

Below L.B.D.	0·88 yard
0 to 10 feet above L.B.D.	0·40 ,,
10 to 20 feet above L.B.D.	0·29 ,,
20 feet above L.B.D. to high water	0·20 ,,

Mud is found in the Upper Estuary almost entirely on banks of a height greater than 20 feet above L.B.D.; banks which do not reach this height are composed mainly of sand. The reduction in capacity between 1906 and 1931 was thus due mainly to the deposition of sand. Of the total reduction of 50 million cubic yards only about 17 per cent. occurred in areas in which the bed is now composed of mud, and this 17 per cent. includes almost the whole of the reduction in volume (12 per cent. of the total reduction) caused by the building of shore works during the period.

Conclusions

36. The investigation described in this Report has led to the following conclusions :—

(i) The main sources of mud found in the Estuary of the Mersey are material eroded from the bed of the Irish Sea, material eroded from cliffs of boulder clay forming the shore in parts of the Upper Estuary and material carried by fresh-water streams. The most likely source of any large quantity of new mud which may from time to time enter the Upper Estuary is the bed of the Irish Sea and Liverpool Bay.

(ii) The quantity of inorganic suspended matter, including road washings, in sewage discharged direct to the Estuary is very small compared with the size of the Estuary and the changes in capacity which occur. It is calculated that the quantity discharged in a year is about 25,000 cubic yards or 0·0025 per cent. of the capacity of the Upper Estuary.

(iii) The concentration of organic matter in mud (calculated on dry weight) from the Upper Estuary of the Mersey is approximately the same as in mud from the bed of the Irish Sea and Liverpool Bay and from various relatively unpolluted estuaries in England, Scotland and Ireland.

(iv) Sewage, in the concentration in which it is present in the Estuary of the Mersey, has no appreciable effect on the composition of the mud and other solid matter deposited in the Estuary.

(v) Mud in suspension in the water of the Estuary of the Mersey and in relatively unpolluted estuaries is almost entirely in the form of flocs or aggregates and not in the form of finely divided particles. The rate of sedimentation of mud in this condition is not affected by sewage in the concentration found in the Estuary of the Mersey.

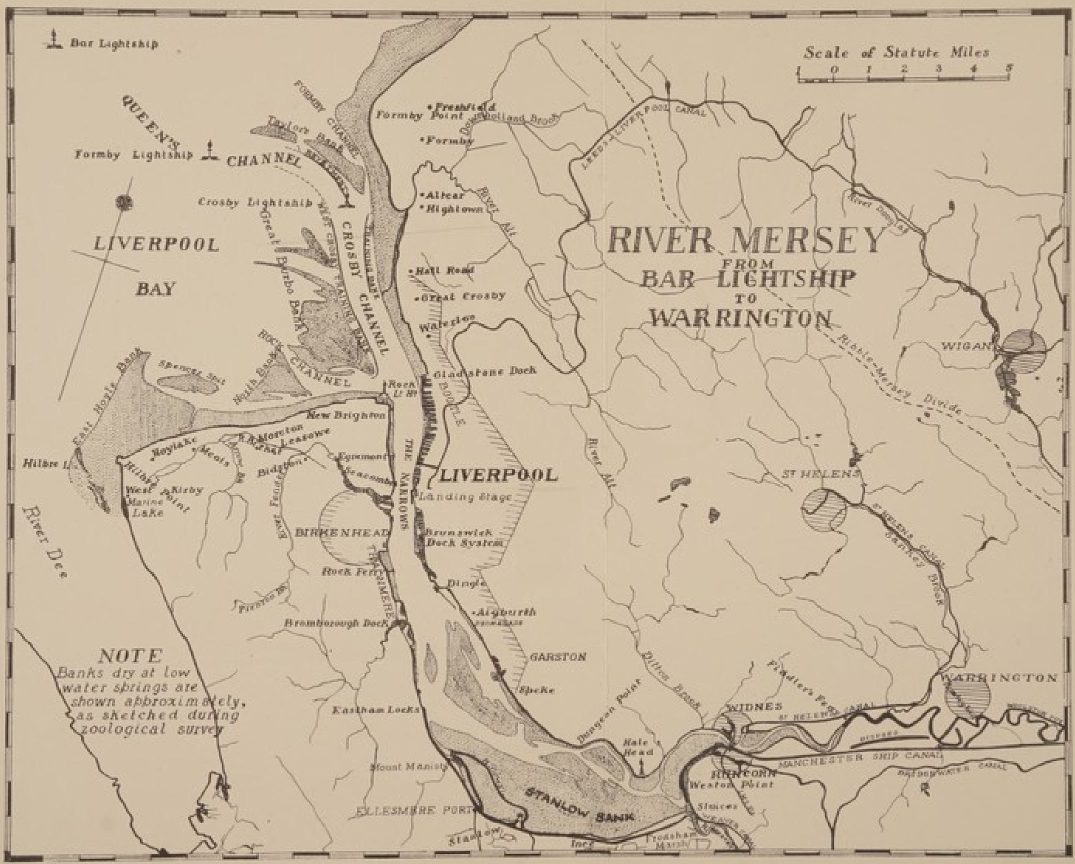
(vi) The resistance of Mersey mud to erosion by water is about the same as that of mud of similar composition from relatively unpolluted estuaries; the resistance is not affected by previous sedimentation of the mud from water containing sewage in the concentration present in the Estuary.

(vii) The Stanlow Bank contains most of the mud in the Upper Estuary. During the greater part of the last forty years this bank has been exposed only to low stream velocities since it is not covered until near the time of high water and it has been separated from the main channel by banks of sand. In 1931, however, the channel moved so as to expose the bank near the Weaver Sluices to high stream velocities. An area of approximately half a square mile of the mud bank was washed away during the period 1931–1936; the volume eroded was approximately 6 million to 7 million cubic yards or about 0·6 per cent. of the capacity of the Upper Estuary. This shows that the bank is not stable but is rapidly eroded when exposed to the full strength of the tide.

(viii) There is no evidence of any increase during recent years (1909–1935) in the difficulty of dredging material from the sea channels in Liverpool Bay.

(ix) During the period 1871–1936 the capacity of the Upper Estuary of the Mersey fluctuated between 939 and 1,003 million cubic yards. It was approximately the same in 1936 as in 1871. The reduction in capacity from 991 million cubic yards in 1906 to 939 million cubic yards in 1931 was mainly due, not to the deposition of mud, but to the deposition of sand in the deeper parts of the Upper Estuary.

37. In direct answer to the terms of reference (see paragraph 6) it is concluded that the crude sewage discharged into the Estuary of the River Mersey has no appreciable effect on the amount and hardness of the deposits in the Estuary.



RIVER MERSEY
FROM
BAR LIGHTSHIP
TO
WARRINGTON
Scale of Statute Miles
Bar Lightship
Formby Lightship
Crosby Lightship
QUEEN'S CHANNEL
CROSBY CHANNEL
ROCK CHANNEL
LIVERPOOL BAY
Formby Point
Formby
Altcar
Hightown
Hall Road
Great Crosby
Waterloo
Gladstone Dock
BOOTLE
LIVERPOOL
Landing Stage
Brunswick Dock System
Dingle
Aigburth
GARSTON
Speke
New Brighton
Egremont
Seacombe
BIRKENHEAD
Rock Ferry
Bromborough Dock
Eastham Locks
Hoylake
West Kirby
Hilbre I.
River Dee
East Hoyle Bank
North Bank
THE NARROWS
TRANMERE
Mount Manisty
ELLESMERE PORT
Stanlow
STANLOW BANK
Ince
Frodsham Marsh
Hale Head
Dungeon Point
WIDNES
RUNCORN
Weston Point
Sluices
MANCHESTER SHIP CANAL
BRIDGEWATER CANAL
WARRINGTON
ST HELENS
WIGAN
River Alt
Ditton Brook
Sankey Brook
Ribble-Mersey Divide
LEEDS & LIVERPOOL CANAL
River Douglas
NOTE
Banks dry at low water springs are shown approximately, as sketched during zoological survey

CHAPTER I

GENERAL DESCRIPTION OF THE ESTUARY

The Estuary of the River Mersey forms part of the boundary between the counties of Lancashire and Cheshire on the west coast of England, and lies between the estuaries of the River Ribble on the north, and of the River Dee on the south. The Estuary system consists of three distinct parts: *Liverpool Bay* connected by the *Narrows* to the upper basin which with the Narrows forms the *Upper Estuary*. Liverpool Bay is roughly rectangular in shape. It is in general shallow and contains extensive sand banks exposed at low water. Through it there runs a deep, S-shaped channel which is the main navigable channel used by ships entering and leaving the deep, straight channel known as the Narrows. The length of the Narrows is about 6 miles, the minimum width about three-quarters of a mile and the maximum depth at low water more than 70 feet. Along the east bank the Narrows is lined by a continuous system of docks, behind which stand the towns of Bootle and Liverpool. On the west bank there are also extensive systems of docks and a number of towns, the largest of which are Birkenhead and Wallasey.

Above the Narrows is the upper basin of the Estuary. This basin is about 23 miles in length from the Narrows to the point where the fresh water of the River Mersey discharges into it. The upper part is broad and shallow. Its maximum width of about 3 miles is at Ince. The depth in the channels at low water is not more than one or two feet. At low tide, almost the whole of the area of the upper part of the basin consists of drying tidal banks. At high water, however, the basin is filled with water which has entered through the Narrows from Liverpool Bay, so that the Upper Estuary forms a reservoir which is filled during the flood tide but from which, on the ebb, water runs out into the sea channels. The range of tide at Liverpool is very large, and amounts to more than 31 feet on an extraordinary spring. The volume of water in the Upper Estuary at high water of spring tides is thus considerable and approaches a maximum of about 1,000 million cubic yards.

At a point about 19 miles above Rock Light (Sketch Map) the Upper Estuary becomes much narrower where it passes through a gap in the rock. Near this position are the towns of Widnes on the Lancashire side and Runcorn on the Cheshire side, and here the Estuary is spanned by a railway bridge and a transporter road bridge. Above Widnes there is a much smaller basin, also mainly shallow at low water; about 5 miles above Widnes this contracts to a narrow channel which continues for a further 5 miles to the town of Warrington, where the river is spanned by the first fixed road bridge.

The fresh water entering the Estuary comes from a number of streams of which the River Weaver and the River Mersey with its tributaries, the Rivers Irwell and Irk, are the most important. These two river systems account for about 70 per cent. of the total flow of fresh water. The River Mersey enters the Estuary over a weir a short distance above Warrington. Except at the highest tides, this point represents the limit of the tidal part of the Estuary. The Weaver discharges on the Cheshire side of the Estuary about 3 miles below Widnes. The remaining streams are very small in comparison; the most important are Sankey Brook, which enters between Warrington and Widnes, the River Gowy from the Cheshire side, 16 miles below Warrington, and the River Alt which flows into Liverpool Bay on the Lancashire side. The mean flow of all the fresh-water streams during a year of average rainfall is of the order of 6 million cubic yards per day. The Estuary receives water draining mainly from part of south and east Lancashire and part of Cheshire; the total catchment area is about 1,805 square miles.

Charts are available showing the positions of the channels in Liverpool Bay from 1689. The main channel has altered in direction but the general arrangement of channels and banks has remained much the same from 1689 to the present time. Up to the year 1891 there was a shallow bar at the seaward end of the navigable channel, where the depth of water at low tide was only about 10 feet. In 1891 dredging was begun in order to improve the navigation and has been continued ever since. As a result of this work, the depth over the Bar was increased to about 24 feet, and the minimum depth in the main channel is now not less than

26 feet. Between 1891 and 1932 nearly 180 million cubic yards of material were removed from the banks and channels in Liverpool Bay. This is equivalent to a layer nearly 2 feet 6 inches in depth over the whole area of 70 square miles of the Bay. Almost the whole of the dredging is carried out by means of suction dredgers. In this method of dredging, a long steel tube is lowered to the sea bed and a mixture of water and the material of which the bottom is composed is pumped into hoppers in the dredger. The heavy material sinks to the bottom of the hoppers and the water flows over the top of the hoppers back into the sea. When a load has been obtained the dredger steams to a deposit site where the material is dumped. The deposit sites used are, in general, not very far from the positions where the dredgings are obtained, and it is possible that some of the material finds its way back into the sea channels, from which it has again to be dredged.

In the year 1900, the construction of a revetment was begun on Taylor's Bank to prevent the main channel from eroding the bank and so forming an acute bend (Fig. 119). This revetment is still being extended in a seaward direction. In 1923, the construction of training walls was begun along both sides of the channel where it leaves the Narrows. The south training bank, which is built along the outside of the Burbo sand bank, is still being extended seaward in conjunction with the revetment on the other side of the channel. In addition to these works, certain other alterations have been made in Liverpool Bay. For example, between 1889 and 1905 a channel appeared which cut the Great Burbo Bank into two parts. This channel was stopped by dumping clay in it. The main channel has now a pronounced S bend. Near the Crosby Lightship it has become narrow but its depth at this point is greater than 60 feet below the low water level of a spring tide. It is difficult to estimate the extent to which changes in the shape and depth of the channel are due to natural causes and the extent to which alterations have been brought about as a result of artificial works in the Bay.

The tidal banks and the greater part of the bed of the Bay covered by water at low tide consist of sand, but there are patches of muddy sand in some places. In the Crosby Channel there is also an area where the bottom consists of peaty material and boulder clay. Both the muddy sand and the peat on the bottom cause difficulties in dredging. When the suction tube of a dredger is lowered into muddy sand, it is liable to become choked by mud sticking to it. In addition, when the material is pumped into hoppers, although the sand settles to the bottom, the lighter mud flows out of the hopper with the water; it is thus difficult to obtain a full load of spoil. In the Crosby channel it is impossible to dredge boulder clay or peat by the suction method and at times the bed has been lowered by the use of bucket dredgers. Usually, however, the hard bottom is covered by a thin layer of sand and the difficulty of removing this by suction dredgers arises from the shallow depth of sand, since it is necessary to move the dredger many times before a full load can be obtained. Very little information is available on the changes which have taken place in the area of the bed of the Bay covered by muddy sand, but it is evident that mud has been present in the Bay for many years since in an early survey carried out in 1736 the bottom was reported as " soft ground " in many places.

The bed of the Narrows is on the whole regular and flat and consists in many places of bare rock, sometimes covered with stones, shingle or sand. In the Upper Estuary, the Lancashire shore consists for a large part of its length of cliffs of a reddish boulder clay, and there is evidence that this has been eroded at some places during recent years. In the upper part of the basin there are salt marshes, which appear to be old mud banks colonised by vegetation. The tidal banks on the Lancashire side of the Upper Estuary consist mainly of sand, but on the Cheshire side there is an extensive mud bank which adjoins the shore and stretches for a distance of about 7 miles from the confluence of the River Weaver almost to Eastham. Thus, unlike many estuaries in which the tidal banks are composed of a mixture of sand and mud, the Mersey Estuary has banks of comparatively clean sand, sharply separated from banks of mud containing little sand. Although surveys giving the depth of water in the upper basin were carried out by the Mersey Docks and Harbour Board in 1861, 1871 and 1881 and since then at 5-yearly intervals, there is little evidence of the nature of the material of which the tidal banks were composed before the present investigation. It was stated in the Acting Conservator's Report for 1857 that part of the deposits in the Upper Estuary were of soft black mud. It was also stated in 1884, by the Engineer to the promoters of the Manchester Ship Canal Bill, that the sand in the Mersey was mixed with a certain amount of alluvium, which added to its adhesive properties and enabled it to form "frets." Dr. C. Burghart, giving evidence during the proceedings on this Bill in 1884, reported that he had examined about 50 samples of water from the Upper Estuary and that they contained, in suspension, sand mixed with "humus matter" which clogged filter paper. It seems likely, therefore, that there was mud in the Upper Estuary in 1884. There are also in the Upper Estuary, particularly on the Lancashire side, the remains of mud banks, the greater part of which appear to have been washed away, and there are marshes consisting of mud of the same nature as that found in the upper basin but which are now covered with vegetation.

The channel through the upper basin is long and winding and frequent changes in its position occur. These changes are sometimes brought about by the erosion of material from the edge of the channel and sometimes result from the breaking through of the channel to occupy a new bed.

Salt water, even at high tides, does not travel so far up the Estuary as Warrington, but the greater part of the Upper Estuary at high tide contains water of high salinity. The velocity of the tidal stream does not, in general, greatly exceed 4 knots, although there are places where higher velocities occur. During spring tides there is a small bore above Widnes and the head of this wave is followed by a very fast and turbulent current.

A considerable amount of dredging is done in the Upper Estuary; the average quantity of material removed between 1901 and 1931 was approximately 2·3 million cubic yards per year. The whole of this dredging is done in the lower part of the basin below Eastham and is mainly to keep open the navigable channel to the Manchester Ship Canal and the channels into various dock systems. There have been alterations in the shore line of the Estuary as the result of building artificial works. Thus, at different times, part of the foreshore at Tranmere has been enclosed and the Bromborough and Gladstone Docks and the Aigburth Promenade have been built out over the foreshore. The greatest change was brought about by the building of the Manchester Ship Canal between 1887 and 1894. This canal not only caused an alteration in the shore line of part of the Upper Estuary, but also considerably altered the methods of discharge of fresh water into the tidal basin. The canal begins at Eastham on the Cheshire side and follows this shore of the Estuary to a point a little above Widnes. For part of this distance the seaward wall of the canal is built on the original foreshore of the Estuary. Above Widnes the canal leaves the Estuary and continues as a separate channel to a point about 5 miles above Warrington, after which it occupies the original bed of the River Mersey or its tributaries to Manchester. The canal is tidal from Eastham to Latchford Locks, which are about 2 miles above Warrington, but Estuary water flows into the canal at Eastham only on tides rising at Prince's Pier to a height greater than 26 feet 2 inches above Liverpool Bay Datum. One of the major effects of the building of the Canal is that the estuary of the River Weaver, with some marsh land, is now cut off from the estuary of the Mersey. The water from the Weaver now flows first into the Ship Canal, from which an equivalent volume of water is let out into the Mersey Estuary by means of adjustable sluices. The sluices are operated so that the whole of this flow occurs during the first part of the ebb tide.

The towns on the banks of the Estuary stand in three main groups. The area behind both shores of the Narrows is almost completely built up, the chief towns being Liverpool (population 855,500), Bootle (population 76,800), Birkenhead (population 159,500) and Wallasey (population 89,000). Above the Narrows on the Cheshire bank there are smaller towns, including Bebington (population 32,100) and Ellesmere Port (population 23,500). In the upper half of the Upper Estuary there are no towns of any size on either bank until the narrow gap where Widnes (population 40,500) stands on the Lancashire bank and Runcorn (population 50,000) on the Cheshire bank. Between this point and Warrington (population 79,300), which stands at the head of the Estuary, there are no towns.

The Mersey is an important waterway and the trade carried on it is one of the chief sources of the wealth of Merseyside. On the Lancashire side of the Narrows there is a continuous system of docks seven miles in length, and on the Cheshire side there are important docks at Birkenhead. Higher up the Estuary on the Lancashire side is the port of Garston, the channel to which is used by big ships only at about the time of high water. Large ships also enter the Manchester

Ship Canal during a period of four hours on either side of high water. In the upper basin itself there are no channels of navigable depth at low water but at high water a large carrying trade is done by small steamers and barges, some of which are bound for Widnes while others lock into the Manchester Ship Canal. At high water also, small vessels use the channel between Widnes and Warrington, the upper part of which is dredged.

Considerable volumes of sewage and trade wastes are discharged into the Estuary. Almost the whole of the sewage from the towns on the Estuary banks is discharged in an untreated condition and the sewers carry also most of the trade wastes of the district. The industries on Merseyside are varied in character. They include groups of industries which give rise to polluting effluents; of these one of the most important is tanning. Many of the fresh-water streams flowing into the Estuary pass through thickly populated industrial areas and are heavily polluted when they enter the Estuary. While little information is available on the changes which have occurred in recent times in the volume and character of industrial effluents discharged, there is no doubt that, with the growth of population and changes in sanitation, the volume of sewage entering the Estuary has increased within recent years.

Since the year 1858 the Navigation Authority for the Estuary has been the Mersey Docks and Harbour Board. The upkeep of buoys in the upper part of the Upper Estuary and certain other duties, however, are carried out by the Upper Mersey Navigation Commission, while certain other work in the Estuary is done by other authorities, for example, by the Manchester Ship Canal Company and the London Midland and Scottish Railway Company. The Mersey Docks and Harbour Board surveyed the Upper Estuary and measured its capacity in 1861, 1871 and 1881, and since that time they have made surveys at five-yearly intervals. They also carry out the dredging in Liverpool Bay and survey and mark the navigable channels and banks in this area. In recent years Parliamentary Bills, which might result in the discharge of additional sewage into the Estuary, have been opposed on the ground that the discharge of crude sewage makes it more difficult to keep open the navigable channels. The opinion has been expressed that the discharge of crude sewage causes deposition of mud in the Upper Estuary and changes the nature of the deposits in such a way that they are less easily eroded by the tidal streams. It was accordingly said that discharge of crude sewage led to a decrease in the tidal capacity of the Upper Estuary and thus reduced the quantity of water available for scouring the sea channels on the ebb tide, and that this decrease in the scour in the sea channels resulted in increased deposition in them, thus increasing the amount of dredging necessary to maintain a navigable depth. The presence of sewage was also believed to have led to the deposition in the sea channels of muddy material which is difficult to dredge.

The Mersey Docks and Harbour Board have held that in order to keep open the sea channels in Liverpool Bay the tidal capacity of the Upper Estuary must be maintained and for this reason the building of the Manchester Ship Canal was opposed by them in the years 1885 to 1888 on the grounds that the construction of the Canal, especially in the form first proposed, would lead to the silting up of the upper basin.

Fig. 1.

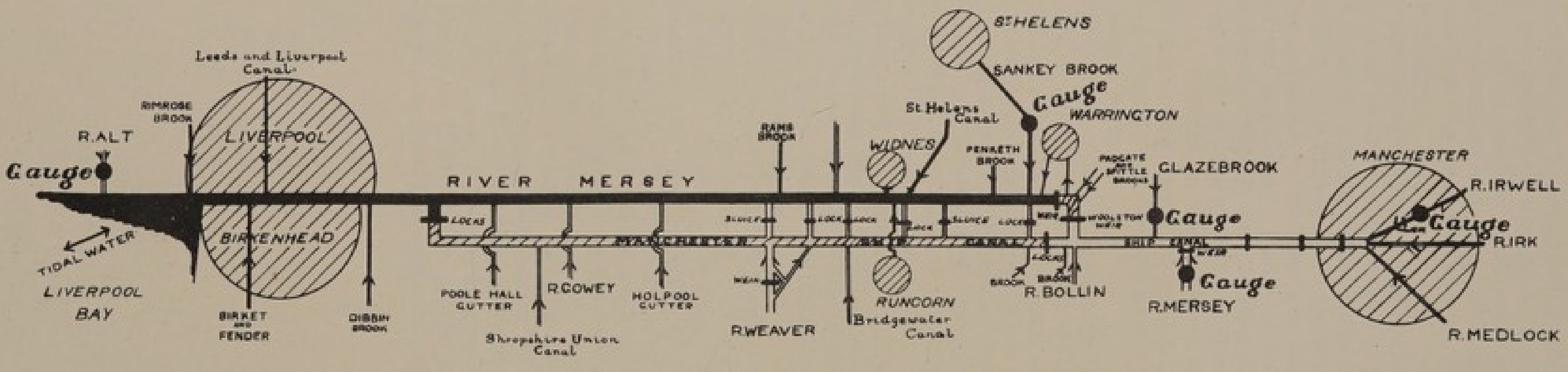


DIAGRAM SHOWING SOURCES OF WATER ENTERING THE ESTUARY OF THE RIVER MERSEY.

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CHAPTER II

DISCHARGES INTO THE ESTUARY OF FRESH WATER, SEWAGE, AND INDUSTRIAL EFFLUENTS

The chief rivers discharging into the Mersey Estuary are the River Mersey and its tributaries which drain a large part of East Lancashire, some smaller streams which drain part of South Lancashire, and the river Weaver which, with other small streams, runs through part of Cheshire to the southern bank of the Estuary. A large part of the country through which these rivers run is industrial in character. In consequence there are numerous canals in the district and into these, in many cases, the water from the rivers has been diverted, the flow now being controlled by weirs and sluices. In addition a considerable volume of water is discharged into the rivers in the form of sewage effluents or industrial effluents. This water is in many cases brought into the district from outside catchment areas while some is pumped from wells within the area draining to the Mersey Estuary. It is thus difficult to gauge the flow of the rivers discharging into the Estuary and the relations which have been found to exist between the rainfall and run-off for certain other districts cannot be expected to hold in so artificial a system. The fresh water entering the Estuary may be considered under two heads:

(1) Water entering by streams and tributaries, which may contain sewage, sewage effluent, and industrial effluents. Part of the water used for domestic and industrial purposes is obtained from districts outside the catchment areas of the streams and part is pumped from wells in these areas.

(2) Sewage or industrial effluents discharged directly into the Estuary or into canals connected with it. The sewers carry the rainfall of the urban areas on the banks of the Estuary as well as domestic sewage and industrial effluents.

Fresh-Water Discharges

A diagram of the main routes by which fresh-water streams discharge into the Estuary is shown in Fig. 1. The natural river system was considerably altered when the Manchester Ship Canal was constructed. The rivers Irwell and Irk now enter the Ship Canal at Manchester and the River Mersey joins the Canal at Irlam, seven miles lower down; the Canal thus runs in the original bed of the Mersey or its tributaries, the bed having been lowered considerably by dredging. Four miles below Irlam, where the river Bollin joins the Mersey, the Canal and the river separate, part of the water passing over Woolston Weir above Warrington into the Estuary and part through locks at Latchford into the tidal section of the Ship Canal. This water finally enters the Estuary through various locks and sluices lower down, the most seaward point of entry being at Eastham which is roughly half way between Rock Light and Widnes. The flow of water over Woolston Weir is controlled by sluices.

The river Weaver is now cut off from the Estuary by the Manchester Ship Canal and its water enters the canal at Frodsham Marsh below Widnes. The flow into the Ship Canal is controlled by an adjustable weir and by sluices and the water finally passes into the Mersey Estuary mainly through the Weaver sluices which are opened only during the first four hours of the ebb tide.

The flow from the streams and tributaries entering the Estuary on the Lancashire side is complicated by the St. Helen's Canal and the Leeds and Liverpool Canal which take some of the water from the catchment areas of the various streams.

A rough estimate of the total quantity of fresh water entering the Mersey Estuary has been made by various methods. Where possible the fresh-water streams have been directly gauged by current meter and a record has been obtained of the height of the streams over as long a period as possible. In other cases information has been obtained from Local and Navigation Authorities and for some streams an estimate of the mean flow has been made from a consideration of the rainfall and size of the catchment area. Where streams have been directly gauged, the methods used have been in general those recommended by Hogan[1]. An account of the methods used is given in the Appendix to this Report. During part of the time when gauging was being carried out the flow of the streams was abnormally low owing to a period of drought, so that the estimated flow under average conditions of rainfall is only approximate.

The catchment areas of the streams discharging into the Estuary are shown in Fig. 2 and the areas are given in Table 1 (p. 211). In Fig. 3* are shown the positions of sewage disposal works in the area drained by the Upper Mersey and its tributaries, indicating the extent to which the flow of the streams in this district may be affected by water brought in from outside sources.

In Table 2 (p. 212) are given the observed discharges from streams which it was possible to gauge by means of current meters or floats. The mean flow under average conditions for all streams discharging into the Mersey, estimated from direct measurements or from information from other sources, is shown in Table 3 (p. 213), where the methods used in computing the flow of each stream are indicated. A summary of the data in Table 3 on the flow of fresh water into the Estuary is given in Table 4.

TABLE 4—*Estimated Daily Addition of Fresh Water to the Mersey Estuary*

Source.	Estimated daily flow (millions of gallons).	Percentage of total.
R. Mersey and its tributaries	523	52·1
R. Weaver	183	18·2
Other streams	213	21·2
Rainfall carried by sewers ..	39	3·9
Rainfall over surface of Estuary and Manchester Ship Canal	46	4·6
Total	1,004	100·0

The water brought down by most of the main streams entering the Estuary is polluted by discharges of treated sewage and of trade effluents, and the organic matter entering the Estuary in fresh-water streams represents a significant proportion of the total amount of organic matter discharged into the Estuary. Thus the River Mersey and its tributaries drain an area of 785 square miles in which the bulk of the population and industries of East Lancashire are concentrated. No attempt has been made to determine directly the amount of polluting material discharged into the upper reaches of the fresh-water rivers, since during their passage to the Estuary the quantity of organic matter carried in the water may be reduced, partly by self-purification processes and partly by sedimentation. In this investigation, therefore, the composition of the fresh water has been examined at the points of discharge into the Estuary. It is difficult, however, to obtain a reliable estimate of the quantity of organic matter brought in by streams. Thus, the depth of the fresh-water Mersey has been increased by dredging to form the Manchester Ship Canal, the velocity in the river is consequently low and suspended matter settles to the bottom and forms a sludge. In times of low river flow, the concentration of organic matter in suspension in the water passing into the Estuary is relatively low, since some of the organic matter remains on the bed of the river. In times of spate, however, part of this material is brought into suspension and the concentration in the water entering the Estuary is considerably increased. Results of determinations of the concentration of organic matter in the chief streams are given in Table 5 (p. 215). Most of the determinations were carried out at a time of dry weather and the concentrations of organic matter observed probably represent minimum values. In Table 6 an estimate has been made of the total weight of organic matter, both soluble and insoluble, entering the Estuary from the main streams during a period of 24 hours.

* Compiled from information supplied by the Manchester and District Joint Town Planning Advisory Committee.

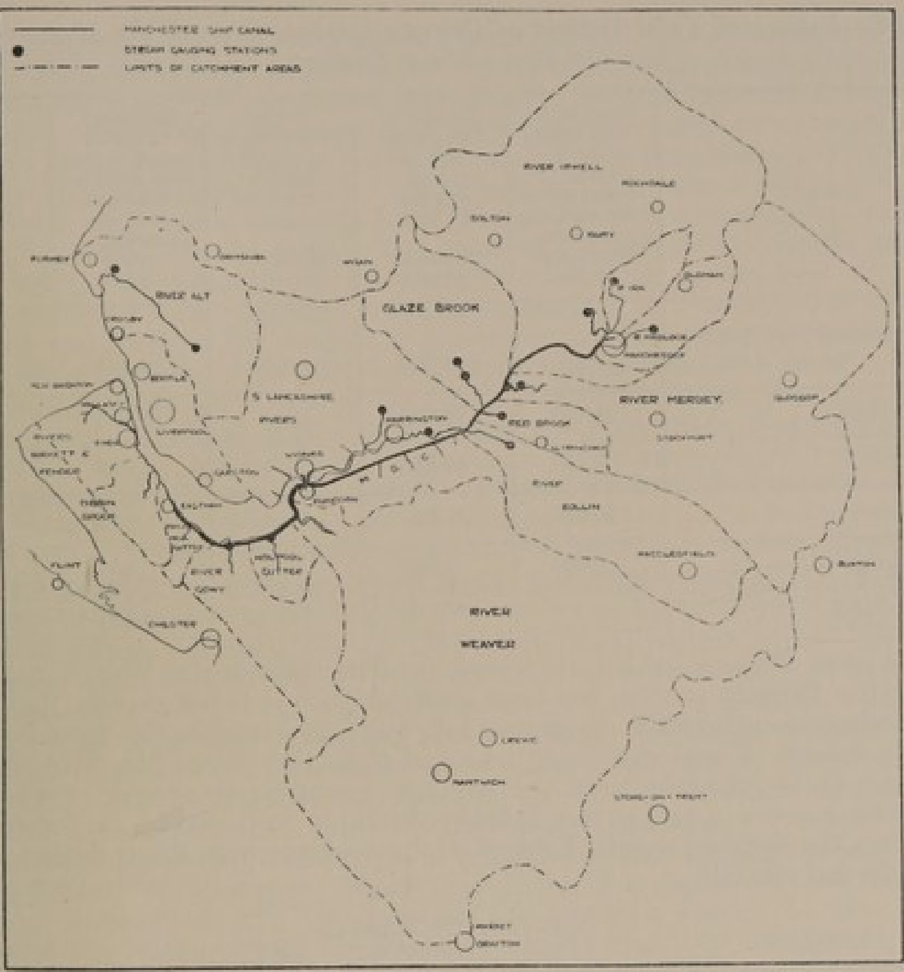

FIG. 2—*Catchment Areas of Streams discharging into the Mersey Estuary*

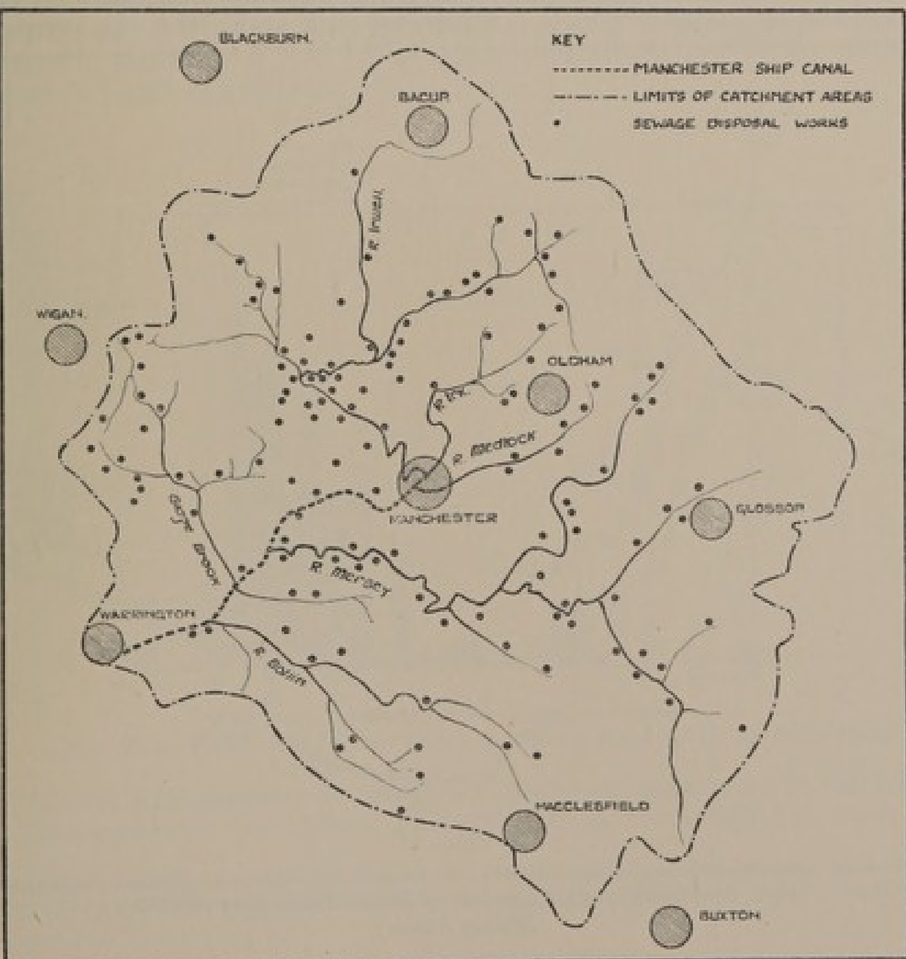

FIG. 3—*Sewage Disposal Works in the Mersey and Irwell Catchment Areas*

TABLE 6—*Estimated Total Weight of Organic Carbon entering the Mersey Estuary in Fresh-Water Streams*

Stream.	Mean daily flow from which amount of organic carbon was calculated. (thousands of gal.)	Estimated mean daily flow of stream. Average for year. (thousands of gal.)	Mean concentration of organic carbon observed. (parts per 100,000)	Estimated weight of organic carbon from observed flows and observed concentrations. (lb. per day)	Per cent. of total organic carbon from all fresh-water streams.
River Mersey at Howley Weir	104,000	523,000	2·79	27,420	62·3
Sankey Brook	10,460	52,330	13·3	13,800	31·4
River Alt	6,580	45,020	2·4	1,650	3·8
River Gowy	4,600	24,920	1·4	640	1·5
Holpool Gutter	1,560	4,360	2·9	460	1·0
Total				43,970	100·0

The river Weaver, which discharges into the Manchester Ship Canal before entering the Estuary proper, has been omitted since it is not certain that all the suspended organic matter it discharges into the Canal reaches the Estuary, a considerable volume of material being removed from the bed of the Ship Canal by dredging. It is probable that the average quantity of organic matter from fresh-water sources entering the Estuary during a year would be found to be larger than the figures given in Table 6 if observations were taken during a whole year of normal rainfall.

SEWAGE DISCHARGES

Information on the volume of sewage entering the Estuary has been obtained from the local authorities. The positions of the main sewer outfalls are shown in Fig. 4 and the estimated population served by each sewer with the average water

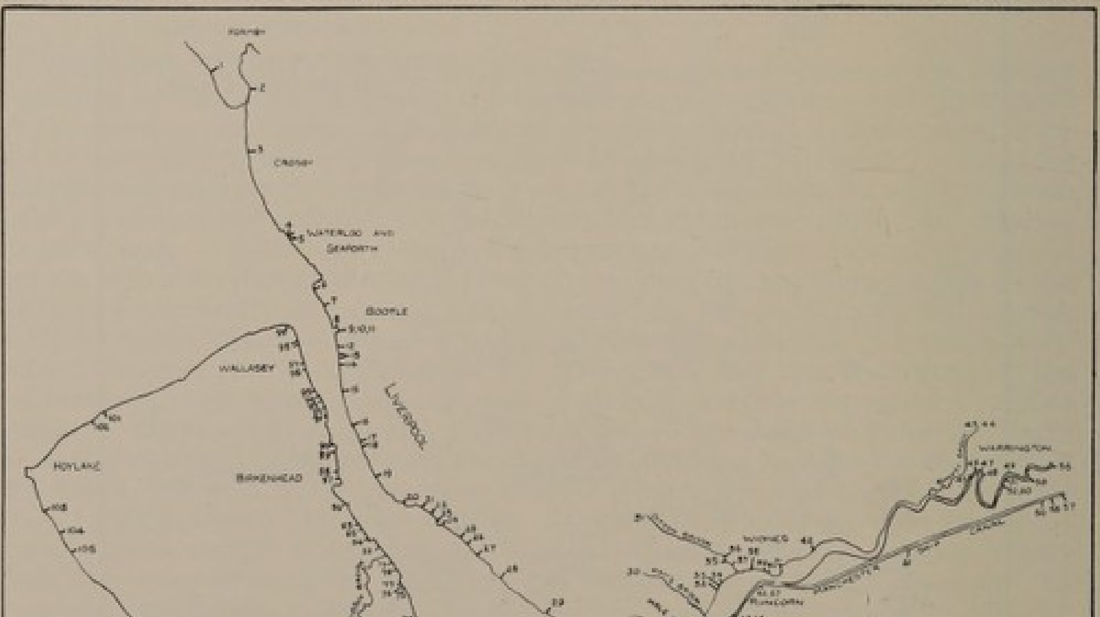

FIG. 4—*Positions of the Out-falls of Sewers discharging into the Mersey Estuary*

consumption per head per day is given in Table 7 (p. 217). In some cases it has not been possible to determine the population served by individual sewers belonging to a local authority but the population served by a group of adjacent sewers has in all cases been estimated. In the case of Liverpool, the populations connected to individual sewers are not known with accuracy and the population served by each sewer has been calculated from the total population and from a comparison of the flow through each sewer observed from comparable series of gaugings taken by the City Engineer. In the Mersey area most of the industrial effluents produced are carried in the sewers, and the water contributing to the flow of sewage consists partly of water supplied by local authorities to domestic and industrial consumers and partly of water which is pumped for industrial purposes from private wells or other sources. It is therefore difficult to estimate the volume of sewage discharged per head per day and the figure obtained is larger than the amount usual in a non-industrial area. No attempt has been made to gauge the flow from sewers directly, since they all discharge at levels below the high water mark and are tide-locked for part of the day; in consequence the flow of sewage is reduced at high water and correspondingly increased at low water. The sewage from a few districts with only relatively small populations is treated by various methods before being discharged; in some of these cases partial treatment only is given. Most of the sewage discharged between Warrington and the sea is, however, unsettled* sewage.

The first large volume of sewage entering the tidal reaches of the Mersey is at Warrington where part of the town is connected to a water-carriage system but in the older part of the town the dry disposal system is still used. Seaward of Warrington the next large discharges are at Widnes and Runcorn, both of these towns discharging unsettled sewage from the whole of their areas. Between Widnes and Garston the only large discharges are on the Cheshire bank where the sewage from Ellesmere Port enters. From Garston to Rock Light at the seaward end of the Narrows there are large discharges of unsettled sewage from the greater part of the populations of Liverpool, Bootle and Litherland on the Lancashire shore and from Birkenhead and Wallasey on the Cheshire shore. In the Estuary seaward of the Narrows only the Lancashire shore has been considered; in this section the unsettled sewage of Waterloo and Crosby is discharged through pipes running over the foreshore and sewage is also discharged from Formby after treatment in septic tanks. The distribution of the sewered population along the Estuary is shown in Fig. 5. The major part of the load is in the Narrows between Rock Light and Garston.

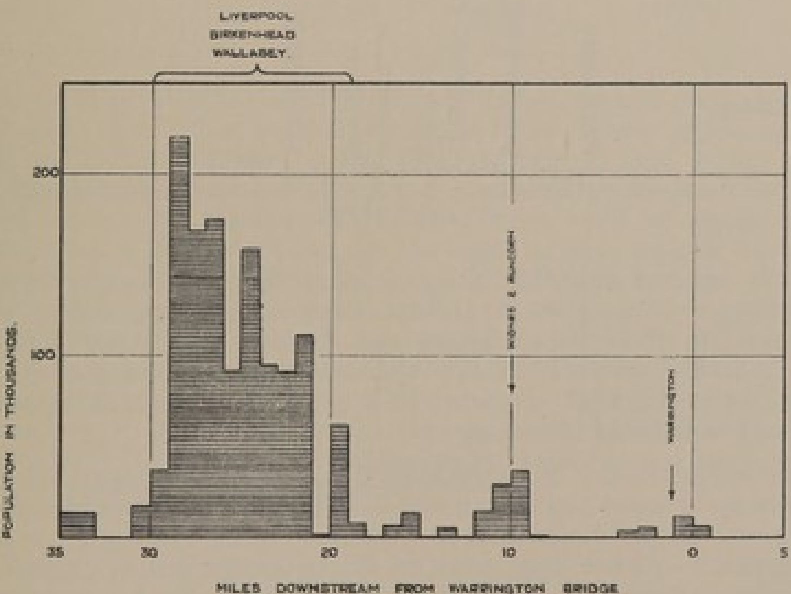

FIG. 5—*Distribution of Sewered Population on the Shores of the Mersey Estuary*

It is difficult to estimate the changes which have taken place in the volume of sewage discharged into the Mersey during the period from 1861 for which records

* The term "unsettled sewage" as used in this Report refers to crude sewage, taken from sewer outfalls, and from which no solid matter has been removed by sedimentation or other treatment.

of the capacity of the Estuary are available. The total populations of the main towns on the Estuary banks in 1861, 1901 and 1931 are shown in Fig. 6; the population of these towns has approximately doubled between 1861 and 1931. While

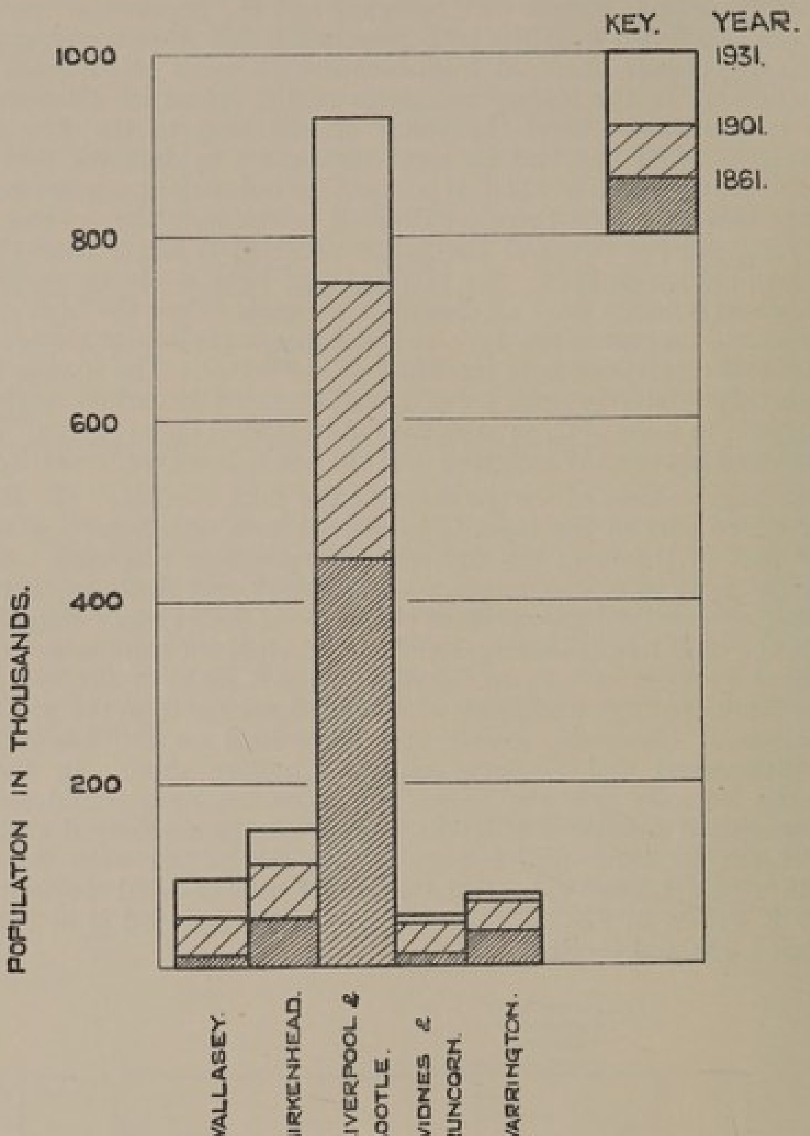

FIG. 6—*Growth of Population in the Chief Towns on the Mersey Estuary from* 1861 *to* 1931

precise records are not available it seems clear that the relative increase in the volume of sewage discharged is greater than the corresponding increase in population, since in 1861 not all houses were drained by a water-carriage system. Conversion from dry systems to the water-carriage system was carried out at different periods in different districts; it has not been possible to obtain exact information on the dates of the changes.

Since the sewers in the Merseyside area carry both domestic sewage and industrial wastes no attempt has been made to determine by direct measurement the weight of organic matter discharged in domestic sewage per head per day. Very little work appears to have been done on the concentration of organic matter in sewages of different types but some figures are available for domestic sewage from non-industrial districts in Norbury (Croydon) and from parts of Birmingham (2). In 18 samples of sewage, 15 from Norbury and 3 from Birmingham, the mean concentration of total organic carbon was 46 parts per 100,000, the minimum being 27·0 and the maximum 63·0 parts per 100,000. The mean value of 46 parts per 100,000 has been taken as representing an average value for domestic sewage and on this basis the approximate weight of organic carbon discharged in domestic sewage into the Mersey has been calculated (Table 8). The water consumption per head per day in this calculation has been taken as 25 gallons; this is the estimated consumption for Waterloo and for Wallasey, neither of which towns contains any large industrial works. The higher water consumption in other Merseyside districts is partly due to the use of water for industrial purposes. The largest total output of organic carbon in domestic sewage entering the Mersey is from Liverpool, which discharges over 60 per cent. of the total amount. The Boroughs of Bootle, Liverpool, Birkenhead and Wallasey together account for nearly 85 per cent. of the total organic matter discharged in sewage.

TABLE 8—*Estimated Discharge of Organic Carbon into the Mersey Estuary in Domestic Sewage*

Water Consumption per Head of Population per Day estimated at 25 Gallons

District.	Sewered population.	Estimated flow of domestic sewage per day. (gal.)	Estimated weight of organic carbon discharged per day (assumed organic carbon content of sewage 46 parts per 100,000). (lb.)	Per cent. of total organic carbon discharged in sewage.
Formby U.D.C.	7,970	199,000	915	0·6
Gt. Crosby U.D.C.	18,290	457,000	2,105	1·3
Waterloo and Seaforth U.D.C.	17,000	425,000	1,955	1·2
Borough of Bootle	76,800	1,920,000	8,840	5·5
County Borough of Liverpool ..	855,540	21,390,000	98,300	61·1
Whiston R.D.C.	10,710	268,000	1,240	0·8
Municipal Borough of Widnes ..	40,530	1,013,000	4,670	2·9
Warrington U.D.C. & R.D.C. ..	19,250	481,000	2,210	1·4
Runcorn U.D.C. and R.D.C. ..	49,950	1,250,000	5,750	3·6
Ellesmere Port U.D.C.	23,500	588,000	2,710	1·7
Bebington U.D.C.	32,100	803,000	3,700	2·3
County Borough of Birkenhead	159,480	3,987,000	18,360	11·4
County Borough of Wallasey (discharging to Mersey)	89,000	2,225,000	10,250	6·4
Total	1,400,120	35,006,000	161,000	100·2

A check on the estimated total weight of organic carbon discharged in sewage can be obtained from other published data. From figures given by the Royal Commission on Sewage Disposal, it has been calculated that on the average the sewage discharged per person per day has a biochemical oxygen demand of about 0·136 lb. of oxygen[(3)]. Similar values have been used by American workers. Some information is also available on the ratio of the organic carbon content and the biochemical oxygen demand of unsettled domestic sewage. Values of 0·78 and 0·55 have been given for this ratio by Lovett and Garner[(4)] and by Mohlman and Edwards[(5)] respectively. Taking a mean value of 0·67 the estimated discharge of organic carbon per day into the Estuary from a population of 1·4 million persons can be calculated. The value obtained is 127,000 lb. of organic carbon per day, which is of the same order as the value of 161,000 lb. obtained by the alternative method (Table 8). Both calculations, however, rest on data inadequate to give more than a rough approximation.

INDUSTRIAL EFFLUENTS

In estimating the quantity of polluting material entering the Estuary a general survey of the industries of the district and of the effluents they discharge has been made, but the survey is by no means exhaustive and only the major industries have been considered. The main industrial areas coincide generally with the main areas from which domestic sewage is discharged. At the head of the Estuary the industrial undertakings are concentrated in Warrington and their effluents are discharged into the reaches of the Estuary below Howley Weir. Further downstream there are important industries in Widnes and Runcorn; their effluents are carried mainly by the municipal sewers. Below Widnes on the Lancashire shore of the Estuary there are few industrial discharges upstream of Liverpool. On the Cheshire shore there are industries in Ellesmere Port and Bebington. The towns of Liverpool, Bootle and Litherland contain numerous industrial works the effluents from which are carried with the domestic sewage, and there is on the Cheshire bank of the Narrows a further centre of industry in Birkenhead; the Borough of Wallasey is mainly residential. There are few industries of importance seaward of the Narrows except those situated on the banks of the River Alt into which their effluents are discharged.

The trade of Liverpool is largely concerned with the handling and transport of goods, but there are numerous industries of different kinds without any group of undertakings being predominant; thus there are important tanneries, breweries, flour mills, galvanising plants, sugar refining factories and tar distilleries. There are also several industries in Birkenhead, among which flour-milling is important. In Widnes and Runcorn there are large chemical manufacturing plants, soap factories, galvanising works and tanneries; in Warrington the making of galvanised goods and wire ropes is an important industry and there are large soap works, tanneries and industries associated with tanneries, producing products such as glues and gelatine. The industries of Ellesmere Port include large flour mills and paper mills. On the River Alt there are important jam, food products, and artificial silk factories.

During this investigation most of the large Merseyside industrial undertakings were asked for information on their manufactures and the effluents they discharged and visits were paid to a large number of factories. An examination of effluents of the varied types produced was thought to be outside the scope of the investigation, but the effluents from tanneries, which form one of the largest groups of industries on Merseyside, were examined in some detail. From a preliminary examination of the effluents discharged into the Estuary it appeared that the effluents from tanneries formed the most important industrial source of organic matter discharged. A more complete examination of these effluents was therefore made in order to estimate the minimum quantity of organic matter entering the Estuary from industrial sources and to obtain an estimate of the relative importance of domestic sewage and of industrial effluents in contributing to the total weight of organic matter discharged into the river.

In all, 25 tanneries were visited, and the processes carried on and the volume and nature of the effluents produced were observed. The method of tanning hides varies in different tanneries but the processes employed and the effluents produced are essentially similar in all of them. Hides are first soaked in water in pits where the skins become soft and workable. After soaking for a period which differs in different tanneries the water is run off and forms one of the effluents produced, known as " soak water ". The hides are then steeped in similar pits in water containing lime to which sodium sulphide and other chemicals are often added; the water which is run off at the end of this treatment is known as " lime water ". After removal of the hair, the hides are placed in pits containing tanning materials in water, and when the leather is finally removed from these pits the liquor run off is known as " spent tan liquor." A quantity of water, which varies in different tanneries, is also used for washing the hides between these processes, but the amount is so variable that no analyses of these effluents were made. The combined effluent from a tannery is usually run into channels where lime and insoluble organic matter settle from it; this is dug out at intervals and disposed of in various ways. The liquor which runs off, consisting of a mixture of soak water, lime water, spent tan liquor and wash water, constitutes the effluent from the tannery; in most tanneries this is run into a sewer and discharged into the Estuary. Some analyses of the three main types of tannery effluents are given in Table 9.

TABLE 9—*Analyses of Tannery Effluents*

Reference No. of tannery.	Kind of effluent.	Organic constituents (parts per 100,000).	
		Organic carbon.	Nitrogen (Kjeldahl).
26	Spent tan liquor	1,510	25
23	,, ,, ,,	3,010	118
23	,, ,, ,,	1,260	21
7	,, ,, ,,	900	25
18	,, ,, ,,	1,210	16
18	,, ,, ,,	960	21
11	,, ,, ,,	1,000	25
8	,, ,, ,,	2,240	66
13	,, ,, ,,	750	9
	Mean	1,430	36
7	Soak water	174	3·7
18	,, ,,	176	—
11	,, ,,	144	3·2
13	,, ,,	126	2·1
	Mean	155	3·0
7	Lime water	341	9·8
18	,, ,,	224	—
11	,, ,,	151	5·4
8	,, ,,	456	16·6
13	,, ,,	92	4·5
	Mean	253	7·3

In Table 10 (p. 219) is given an estimate of the weight of organic carbon discharged per day from each tannery in the district, based on the average composition of each type of effluent and the corresponding volume discharged daily from each tannery.

A rough comparison can now be made of the load of organic matter discharged into the Estuary from fresh-water streams, in domestic sewage, and in tannery effluents (Table 11). The estimated weight of organic matter contained in tannery effluents is about 13 per cent. of the total organic matter discharged, and it is certain that this figure under-estimates the importance of industrial effluents as a whole in contributing to the load of organic matter entering the Estuary. It is probable that the quantity of organic matter from fresh-water streams has also been under-estimated, since the figures on which the estimate is based were obtained during periods of low fresh-water flow and the quantity of organic matter brought down increases during spates.

TABLE 11—*Estimated Weight of Organic Carbon entering the Mersey Estuary from Various Sources*

District.	Total organic carbon (lb. per day).				Percentage of total organic matter entering estuary.
	Fresh-water streams.	Sewage.	Tannery effluents.	Sum.	
Warrington to Sankey Brook	41,200	2,200	13,560	56,960	24·2
Sankey Brook to Widnes	—	10,430	7,760	18,190	7·7
Widnes to Garston	1,100	3,950	—	5,050	2·2
Garston to Rock Light	—	139,500	8,970	148,470	63·1
Rock Light to Formby	1,650	4,980	—	6,630	2·8
Total	43,950 (18·7%)	161,060 (68·4%)	30,290 (12·9%)	235,300	100·0

The main discharge of organic material is in the Narrows, where nearly two-thirds of the total enters the Estuary, but the shallow and narrow reaches between Warrington and Widnes are heavily polluted, nearly one-third of the total quantity of organic matter being discharged in this section of the Estuary.

SUMMARY

An estimate has been made of the relative quantities of organic matter discharged into the Mersey Estuary from different sources. The fresh-water streams entering the Estuary are, in general, heavily polluted by sewage effluents and trade effluents. In the tidal reaches, sewage, mostly in an untreated condition, from a population of about 1·4 million persons, is discharged, together with trade effluents from a variety of manufacturing processes. An estimate has been made of the weight of organic matter discharged in effluents from the tanning industry, one of the largest sources of industrial pollution in the area of the Estuary. It is estimated that the total weight of organic matter discharged into the Estuary is equivalent to not less than 100 tons of organic carbon per day. Of this total quantity about 19 per cent. is brought in by fresh-water streams, about 68 per cent. is contained in sewage and about 13 per cent. in tannery effluents discharged direct into the Estuary. The relative importance of the discharges from other types of industrial works has not been assessed.

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CHAPTER III

COMPOSITION OF THE ESTUARY WATER

A general chemical examination of the water in the Estuary between Warrington and the sea has been made to determine the distribution of fresh and salt water and to estimate the extent to which the water is polluted.

The distribution of salt and fresh water in the Estuary is important, since it is known that the rate of settling of suspended matter in water is influenced by the concentration of salt, and since data on the distribution of salt water can be used in estimating the concentration of sewage in different parts of the Estuary.

Distribution of Salinity

The total concentration of salts in water from the open sea does not differ greatly in different parts of the world and is approximately constant at about 34 gm. per 1000 gm. of sea water; the figure giving the concentration in gm. per 1000 gm. is known as the " salinity ". It is known that the chloride content of sea water is very nearly proportional to the total concentration of salts so that the proportions of salt water and fresh water in an estuarine sample of diluted sea water can be calculated from the chloride content.

During the investigation, numerous determinations of salinity were made on samples taken at various states of the tide. These determinations were made mainly with the object of ascertaining any relationship which might exist between salinity, and thus the proportion of sea water, and concentration of dissolved oxygen at different depths. The results are given in Table 12 (p. 220). In addition, many samples were taken at high and low water at known positions in the Estuary; the salinity of these samples is given in Table 13 (p. 229). The number of samples examined was insufficient to show the effect of fresh-water spates on the salinity distribution in the Estuary, but the results give the average salinity at high and low water during both spring and neap tides; this information is shown diagrammatically in Fig. 7. In the Mersey Estuary, as in other estuaries

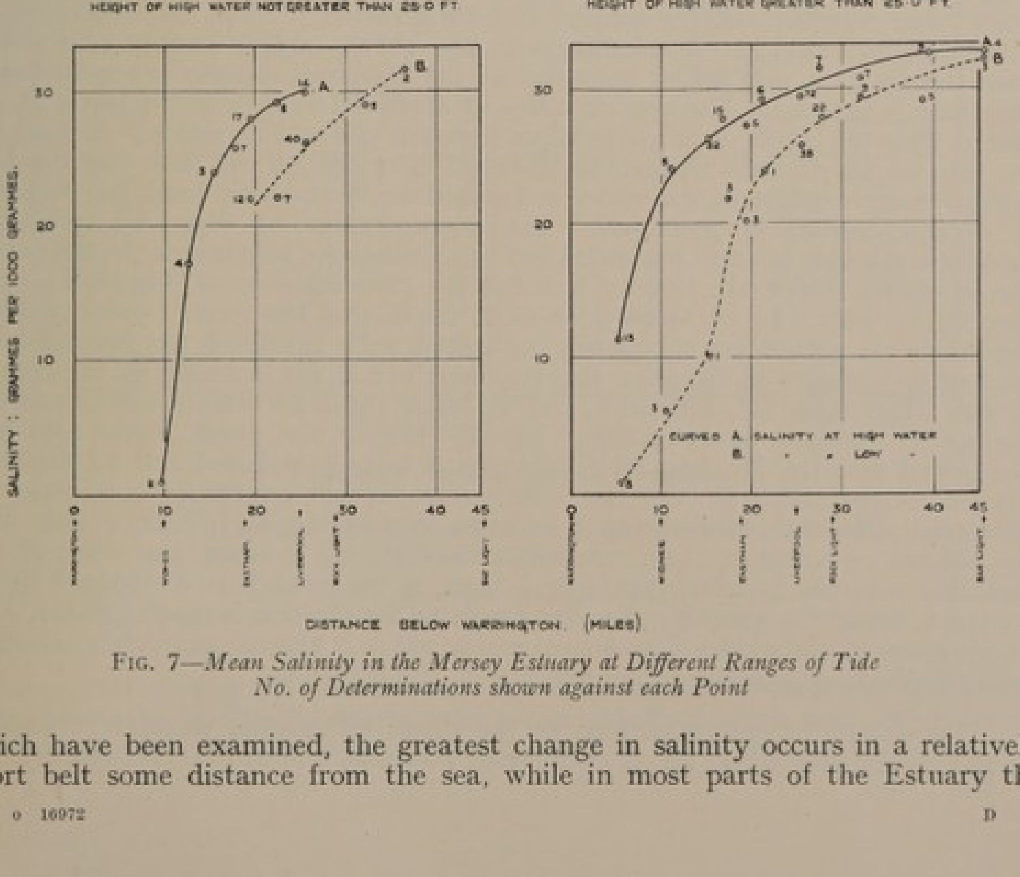

FIG. 7—*Mean Salinity in the Mersey Estuary at Different Ranges of Tide*
No. of Determinations shown against each Point

which have been examined, the greatest change in salinity occurs in a relatively short belt some distance from the sea, while in most parts of the Estuary the change in salinity is more gradual. Thus in the Mersey at high water of a spring tide the salinity between Widnes and the Bar Lightship increases from about 22·0 to 33·0 gm. per 1000 gm., that is the proportion of sea water increases from about two-thirds at Widnes until at the Bar Lightship the water is almost wholly sea water.

In calculating the mean salinity values given in Fig. 7, samples taken at all depths were included, since it was found that in the Mersey there is very little difference between the salinity of surface and sub-surface water. This may be seen from Table 12, where numerous determinations at the same positions but at different depths are included. In some estuaries there is a considerable difference in the salinity of samples taken at the same time at a given position but at different depths. Thus in the Tees Estuary[1] it has been found that the water at the bottom is very much more saline than that at the surface, the isohalines in a vertical section along the Estuary being almost horizontal. This layering of the water in the Tees and in similar estuaries occurs when the fresh water flow is considerable in comparison with the size of the estuary, so that the fresh water tends to flow to the sea over the denser salt water below. In addition, the bed of the Tees Estuary is regular and there are no inter-tidal banks in the main channel, so that the layering of the water is not destroyed by turbulence caused by unevenness of the Estuary bed. In the Mersey, however, there are extensive inter-tidal banks and the quantity of fresh water coming in is small compared with the total volume of water in the Estuary. Under these conditions the vertical salinity gradient is inappreciable. A vertical salinity gradient can be set up only when the velocity of the tidal stream is different at different depths, and the absence of a gradient in the Mersey indicates that the velocity is roughly the same from the surface to the bottom; this is borne out by direct measurements of the velocity at different depths.

Dissolved Oxygen Concentration

When organic material is discharged into a river much of it is gradually decomposed by bacterial action into simpler substances and oxidised by dissolved oxygen in the water. Water exposed to air at atmospheric pressure is saturated with dissolved oxygen when it contains about 1 gm. of oxygen per 100 litres, the exact value depending on the salinity and temperature. When this concentration is reduced by oxidation of substances in the water, further oxygen is dissolved from the air at a rate which increases as the dissolved oxygen concentration in the water is reduced. The concentration of dissolved oxygen in the water at any time is thus the result of an equilibrium between the rate at which it is used and the rate at which fresh oxygen is absorbed from the air, so that the dissolved oxygen concentration in the water is lowered as the amount used for oxidation of organic matter is increased. The concentration of dissolved oxygen is therefore related to the concentration of oxidisable substances in the water, and in waters which are heavily polluted the concentration of dissolved oxygen may fall to zero. In an estuary which is unpolluted the water, under ordinary conditions, is almost or completely saturated with dissolved oxygen from the head of the estuary to the sea; this has been found, for example, in the estuary of the River Tay in Scotland[1] and in other estuaries which were examined during the present investigation. In the Mersey the fresh water which is discharged into the Estuary at Warrington is heavily polluted and its dissolved oxygen concentration is very low. Moreover, further quantities of sewage and industrial effluents are discharged between Warrington and Widnes and, since the volume of water in these reaches of the Estuary is small, the effect of this polluting material is relatively large. Most of the sewage is discharged in the Narrows, where the quantity of water available for dilution is much greater, while at the seaward end of the Narrows sea water which is almost completely saturated with dissolved oxygen enters the Estuary on the flood tide.

The results of determinations of the dissolved oxygen content of samples of Mersey Estuary water taken at different positions and at different states of the tide are given in Table 12 (p. 220) and are shown graphically in Fig. 8, where the curve expressing the relation between the average salinity and dissolved oxygen

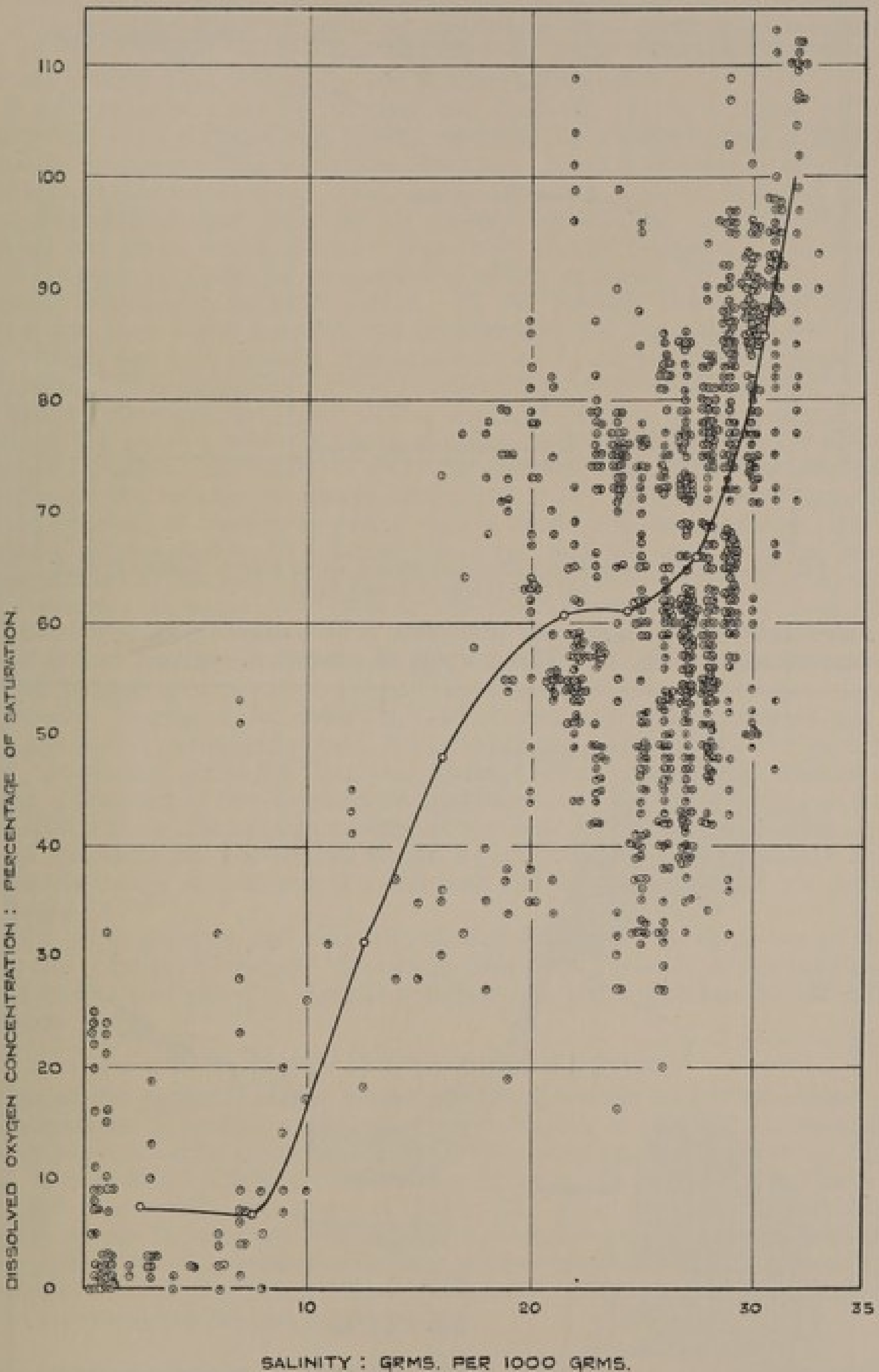

Fig. 8—*Dissolved Oxygen Concentration in the Mersey Estuary in Water of Different Salinities*

The Curve shows the Mean Values

concentration throughout the Estuary has been drawn. From this curve and from the curves in Fig. 7, showing the mean salinity at high and low water at different positions in the Estuary, further curves have been constructed. In these curves (Fig. 9) are shown the mean dissolved oxygen concentrations at high and low water of a spring tide at different positions in the Estuary from a point

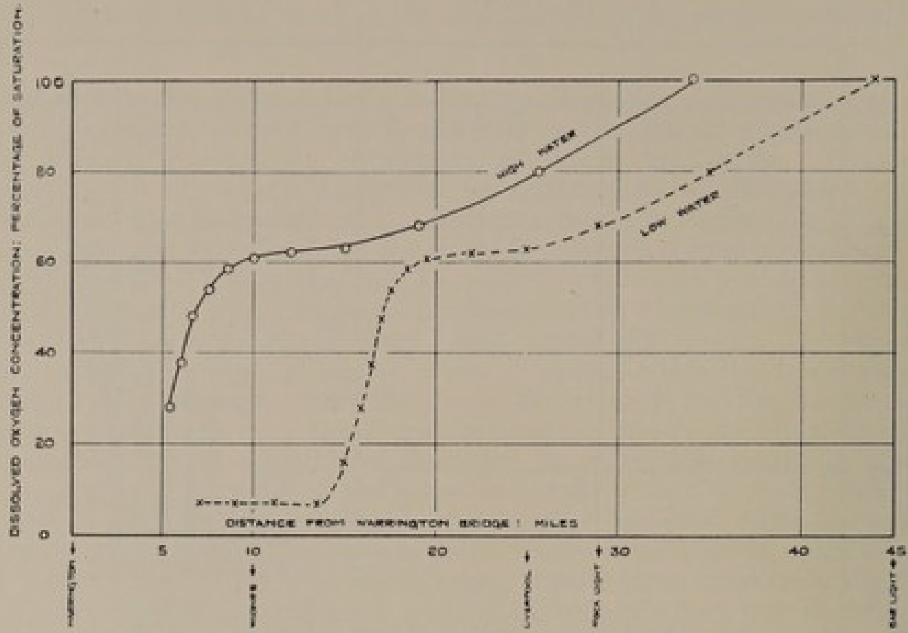

FIG. 9—*Mean Concentration of Dissolved Oxygen in the Mersey Estuary at High and Low Water of Spring Tides*

five miles below Warrington to the sea. The same information is shown diagrammatically in Fig. 10. The amount of oxygen in solution in the water in

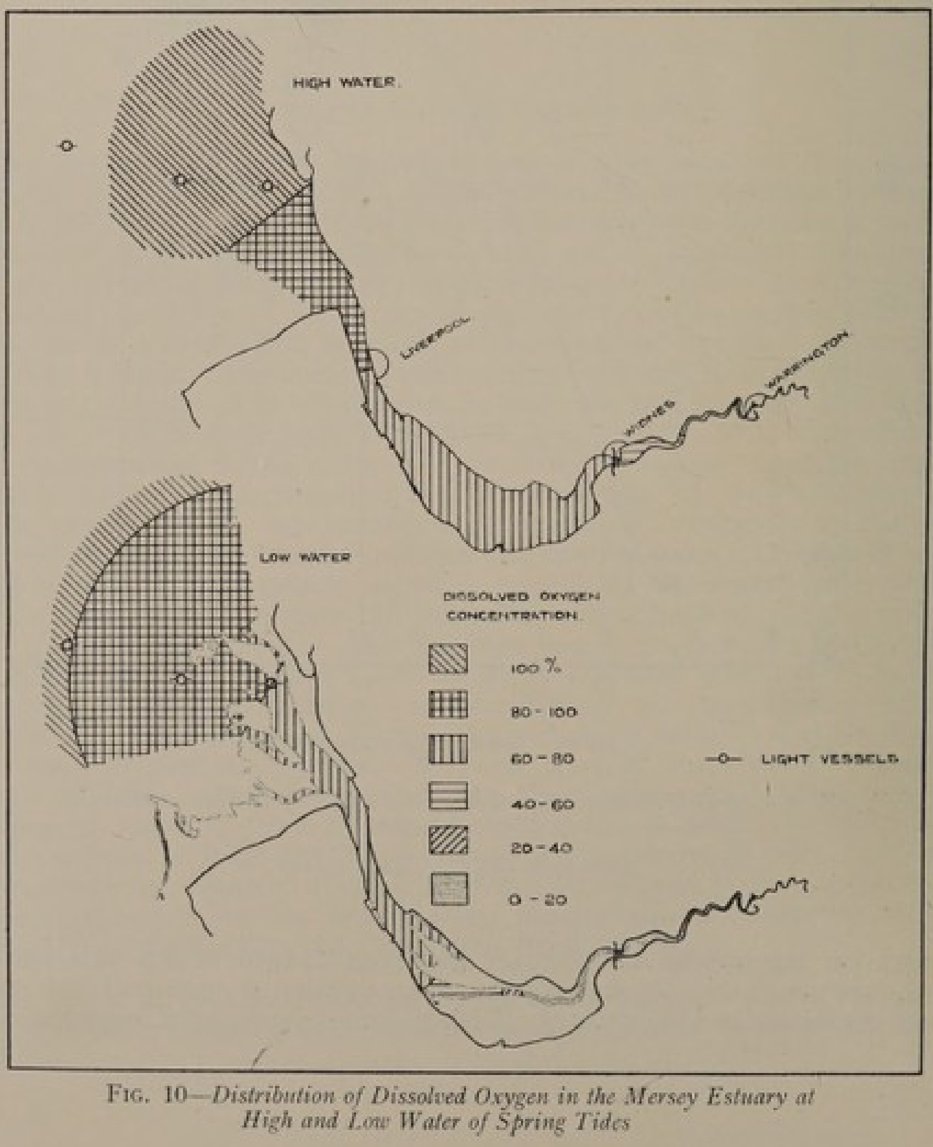

FIG. 10—*Distribution of Dissolved Oxygen in the Mersey Estuary at High and Low Water of Spring Tides*

the reaches of the Estuary between Warrington and Widnes is relatively low, but in the main body of the Estuary water, that is in the water which lies between Widnes and the sea at high tide, the dissolved oxygen concentration rises slowly from about 60 to 100 per cent. of the saturation value as the sea is approached. The deoxygenating effect of polluting material is thus much more severe at the head of the Estuary, where the quantity of water available for dilution is relatively smaller than it is in the reaches further seaward.

It will be seen from Fig. 8 that the dissolved oxygen content of Mersey Estuary water of a given salinity is very variable, and it has not been found possible to explain the cause of the variations observed. In an estuary in which the input of polluting material does not vary significantly from day to day, and in which the hydrographical conditions do not change appreciably, the concentration of dissolved oxygen is usually largely dependent on the temperature of the water and is lowered by a rise in temperature, which increases the rate of oxidation of organic matter by bacterial action. In the Mersey, however, no consistent relation has been found between the concentration of dissolved oxygen and the temperature, and it is thought that this relation is complicated by other factors which affect the consumption or the re-absorption of dissolved oxygen. The rate of solution of oxygen by water is, for example, known to be increased if the surface of the water is agitated, as it is in the Estuary during rough weather. It is possible, too, that the input of polluting material may vary from day to day, for although the volume of sewage discharged is not likely to alter appreciably, the consumption of oxygen is partly due to trade effluents, some of which are discharged intermittently. It is known, however, that fluctuations in the dissolved oxygen content of the Estuary water do not occur rapidly since it has been found that if samples of water are taken at the position occupied by a float allowed to drift for 12 hours with the tidal stream in the Estuary, the dissolved oxygen content of the samples remains reasonably constant. It was thought, also, that the dissolved oxygen concentration might bear some relation to the range of tide in the Estuary. During spring tides the tidal stream runs at a high speed and more suspended matter, principally mud, is carried in the water than is the case during neaps. It seemed probable that the presence of this suspended matter might result in a lowering of the dissolved oxygen content of the water, either as a result of the oxidation of the organic matter of the mud or by the contribution by the mud to the bacterial population of the Estuary water. No consistent relation between the range of tide and the dissolved oxygen concentration has, however, been found.

At a given position and time the dissolved oxygen concentration is approximately the same at all depths; this can be seen from Table 12, where the dissolved oxygen contents of series of samples taken at the same positions but at different depths are given.

Other Dissolved Constituents

One of the products of the decomposition of sewage and other similar nitrogenous material is ammonia, and the concentration of free and saline ammonia in water is often taken as an indication of the concentration of polluting material which it contains. A few determinations of ammonia in the Mersey have been made and the results are given in Table 14. The greatest concentration of ammonia occurs in water of low salinity in samples taken between Widnes and Warrington. The values observed in these reaches are high and indicate substantial pollution of the water by nitrogenous organic matter. The concentration of ammonia falls to low values as the sea is approached.

Table 14—*Concentration of Free and Saline Ammonia in Mersey Estuary Water*

Salinity (gm. per 1,000 gm.).	No. of samples.	Free and saline ammonia (parts N per 100,000).		
		Mean.	Minimum.	Maximum.
0 to 3	6	0·68	0·50	1·24
12 to 25	5	0·04	0·02	0·08
25 to 30	24	0·02	0·01	0·03
30	5	0·004	0·002	0·009

A few determinations of the concentration of organic carbon in solution were made and the results are given in Table 15. The concentration of soluble organic carbon is highest in the upper reaches of the Estuary.

TABLE 15—*Concentration of Soluble Organic Carbon in Mersey Estuary Water*

Salinity (gm. per 1,000 gm.).	No. of samples.	Soluble organic carbon. Mean values (parts C per 100,000).
0–0·5	8	1·37
9	1	1·46
20–25	4	0·58
26–29	5	0·34

In Table 16 are shown the results of some determinations of sulphide in the Estuary water. Sulphides can be produced from sewage or other organic matter under anaerobic conditions but, in addition, in the Mersey a considerable quantity of sulphide is discharged in effluents such as those from tanneries where sodium sulphide is used to remove the hair from hides. It is believed also that some sulphide drains into the Estuary from the heaps of waste material which were produced when the " black ash " process of soda manufacture was in use in the district. Soluble sulphide has been observed only in the reaches between Widnes and Warrington.

TABLE 16.—*Concentration of Sulphide in Mersey Estuary Water*

Position.	No. of samples.	Sulphide (parts S per 100,000).		
		Mean.	Minimum.	Maximum.
Warrington to Widnes	19	0·21	0	1·08
Below Widnes	3	0	0	0

HYDROGEN ION CONCENTRATION

The hydrogen ion concentration of sea water lies between values represented by pH 8·0 and 8·3[2]. The observed pH values of some of the fresh-water streams entering the Estuary and of the Estuary water itself are given in Table 17. The reaction of some of the fresh-water streams, particularly that of Sankey Brook, varies considerably from time to time and may indicate that the stream carries intermittent discharges, some of which are of an acid and some of an alkaline nature. In the Estuary water, the mean pH value rises steadily from 7·2 at Warrington to 8·0 near the sea, but considerable variations from these mean values have been observed. It is possible that the samples with an abnormal reaction were taken from the neighbourhood of sewers discharging trade wastes containing acids or alkalis. Thus discharges from tanneries are usually alkaline since they contain water which has been used in liming pits, while the effluents from galvanising processes contain partly neutralised acid which has been used for cleaning steel. The extreme pH values recorded in the Estuary were 7·1 and 8·4; these values fall within the range which may be observed in an unpolluted estuary.

TABLE 17.—*pH Value of the Estuary Water and of some Fresh-Water Streams which discharge into it*

	No. of samples.	*p*H value.		
		Mean.	Maximum.	Minimum.
River Alt	1	6·6	—	—
Dibbin Brook	1	7·6	—	—
River Gowy	1	7·2	—	—
Rams Brook	1	7·8	—	—
Ditton Brook	2	8·0	8·1	7·8
Sankey Brook	56	8·1	8·6	7·0
River Mersey at Howley Weir..	30	7·2	7·3	6·8
River Mersey at Warrington Bridge	8	7·2	7·4	6·8
Mersey Estuary—				
Salinity 0–5	27	7·2	7·3	7·1
5–10	3	7·3	7·6	7·2
10–15	8	7·4	7·8	7·3
15–20	37	7·6	8·1	7·2
20–23	23	7·7	8·2	7·3
23–26	56	7·7	8·2	7·2
26–29	121	7·8	8·3	7·4
> 29	158	8·0	8·4	7·3

SUMMARY

The distribution of salinity in the Estuary at high and low water of spring and neap tides is described. There is no pronounced difference between the salinity of the water at different depths in any part of the Estuary. The concentration of dissolved oxygen at any given position is very variable. In the greater part of the Estuary water the mean value lies between 60 and 100 per cent. of the saturation value. The lowest concentrations are found in the shallow reaches above Widnes, where often at low water there may be little or no dissolved oxygen. The results of determinations of the concentration of free and saline ammonia, soluble organic carbon and sulphide are given. The concentrations of these substances, which may be regarded as indicators of the presence of polluting material, were greatest in the higher reaches, and fell off in the more seaward part of the Estuary. No abnormal values of hydrogen ion concentration were found in any part of the Estuary.

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CHAPTER IV

DISTRIBUTION OF SEWAGE AFTER DISCHARGE INTO THE ESTUARY

Concentration of Sewage

In attempting to assess the effect of sewage on the mud carried in suspension in the Estuary water, it is essential that an estimate of the approximate concentration of sewage at different points in the Estuary should first be obtained. When an effluent is discharged into a fresh-water stream, its concentration at a point sufficiently far below the outfall to allow of complete mixing can be calculated from the relative volumes of the effluent and the stream. The determination of the concentration of sewage in the Estuary, however, is a more difficult problem. In the Estuary the sewage is discharged into a body of water the main movement of which is oscillatory as the result of tidal action. At the same time fresh water enters continuously from rivers draining into the Estuary, and on every tide part of the water near the mouth of the Estuary is carried out to sea and is replaced by new sea water. The water which is available for the dilution of the sewage is thus the fresh water entering the head of the Estuary and the new sea water entering at the mouth. In the case of the Mersey, however, the fresh water coming in from many of the tributary streams is itself polluted. If no change took place in the composition of sewage and industrial effluents after their discharge, the concentration which they would finally reach in the Estuary would be that resulting from their dilution with the fresh water and sea water which enter from streams and from the sea. It is known, however, that changes do take place in the composition of the organic matter of sewage when it is diluted with the water of the Estuary. This decomposition is partly brought about by the oxidation of organic matter by the oxygen dissolved in the Estuary water and is the cause of the low level of dissolved oxygen observed. In addition, part of the organic matter of sewage may be removed by sedimentation and retained in the Estuary. In these circumstances the most satisfactory method of measuring the concentration of sewage at any time would be by a chemical method, by which the concentration at any point in the Estuary could be directly determined. No satisfactory direct method of this kind is, however, available, as the constituents of sewage which it is possible to estimate chemically are also present in the mud which is carried in suspension by the Estuary water. Other investigators have, for example, determined the concentration of both the carbon and nitrogen contained in the organic matter of sewage, but organic matter is also a constituent of mud, and in the Mersey it is difficult to differentiate by determinations of this kind between sewage and mud in suspension.

An estimate of the concentration of sewage in the Mersey has, however, been made by another method. From the value of the mean salinity at different points along the Estuary the proportion of fresh water at these positions can be calculated. The volume of fresh water entering the Estuary from streams is known approximately, as is also the volume of water entering in the form of sewage. If it is assumed that complete mixing of the sewage and fresh water has occurred, the concentration of sewage at any point can be calculated from the percentage of fresh water present and from the proportion of sewage to fresh water entering the Estuary. It is assumed, also, in this calculation that when the water discharged in the form of sewage passes out to sea, the organic matter passes out with it. During a year of average rainfall, the estimated volume of fresh water discharged into the Estuary from streams, together with the volume of rain falling on the surface of the Estuary, is roughly 1003 million gallons in 24 hours (Chapter II); the estimated volume of domestic sewage discharged in 24 hours is 35 million gallons. The volume of sewage is calculated on the assumption that the water consumption of the sewered population per head per day is 25 gallons; the figure does not include any allowance for trade wastes. On this basis, however, the proportion of the total input of fresh water which is discharged into the Estuary in the form of domestic sewage is approximately 3·4 per cent. From this figure and from salinity determinations in the Estuary, an estimate can be made of the concentration of sewage at high and low water at different points. The mean values of the salinity are taken from Fig. 7, and the estimated concentrations of sewage are shown in Table 18.

TABLE 18—*Estimated Concentration of Sewage in the Mersey Estuary at High and Low Water of a Spring Tide*

Compart-ments between sections.	Distance, below Warrington Bridge. (miles)	Mean salinity (gm. per 1000 gm.).		Proportion of fresh water (per cent.).		Estimated concentration of sewage (per cent.).		Approximate volume of water (millions of cu. yds. on a 31 ft. tide).		Percentage of total volume of water in Estuary.	
		High water.	Low water.	High water.	Low water.	High water.	Low water.	High water.	Low water.	High water.	Low water.
0 to 47	29–22½	30·0	26·4	11·8	22·3	0·40	0·76	311·6	148·8	34·3	77·9
47 to 67A	22½–18	28·4	21·9	16·5	35·6	0·56	1·21	307·6	39·1	33·9	20·5
67A to 83	18–12½	26·0	13·0	23·5	61·8	0·80	2·10	229·4	(2·0)	25·3	(1·0)
83 to 100	12½–10	23·2	5·9	31·8	82·6	1·08	2·81	33·9	(0·5)	3·7	(0·3)
100 to 160	10–0	11·0	2·4	67·6	92·9	2·30	3·16	25·2	(0·5)	2·8	(0·3)

In this Table the compartments into which the river is divided are those used by the Mersey Docks and Harbour Board in their calculations of the capacity of the Estuary. The volume of water in each portion is included to indicate the relative capacity of the compartments in which the concentration of sewage has been estimated. At high water the capacity of each compartment is taken as the volume of water which lies below the highest level reached by a spring tide, which at Prince's Pier rises to a height of 31 feet above Liverpool Bay Datum. The method by which these volumes were calculated from soundings made by the Mersey Docks and Harbour Board is described in Chapter XXI. The volume at low water of a spring tide between Sections 0 to 47 and 47 to 67A was taken as the volume of water lying below Liverpool Bay Datum. This method gives a reasonably accurate estimate seaward of section 67A, but above this point the bed of the Estuary rises considerably and part of the low water channel lies above Liverpool Bay Datum. In the reaches between Widnes and Warrington at low water, the volume of water in the channels is mainly that resulting from the fresh-water flow, except that " ponding " occurs in some places. It is difficult, therefore, to obtain an accurate estimate of the volume of water in these reaches at low water, and the figures given in brackets in Table 18 are only a rough approximation.

The estimated average concentration of sewage in about 99 per cent. of the water in the Estuary at high water does not exceed 0·8 per cent. and in 98 per cent. of the total volume at low water it does not exceed 1·3 per cent. In obtaining these figures, however, only the domestic sewage discharged into the Estuary has been considered. It was calculated (Table 11, Chapter II) that, of the total amount of organic matter discharged into the Estuary, the proportion discharged in the form of domestic sewage was not greater than about 68 per cent.; in making this estimate only a part of the trade wastes discharged was considered. If it is assumed that 50 per cent. of the total organic matter discharged is in the form of sewage, the highest concentration of organic matter between Sections 0 and 67A at low water would be equivalent to a concentration of sewage of about 2·5 per cent. These figures give only the order of the amount of sewage present, but it may be said with certainty that in the bulk of the water in the Estuary, at both high and low tide, the concentration of organic matter does not exceed the equivalent of 5 per cent. of sewage.

While this estimate may be reasonably accurate for the main volume of water in the Estuary below Widnes, it is probable that the effective concentration of sewage in the shallow reaches above Widnes is considerably higher than the figures calculated from the fresh water distribution. In these reaches the water from the Mersey, which is the main source of the new water available for the dilution of sewage, is itself polluted, and moreover a considerable proportion of the total load of organic matter is here discharged into a relatively small volume of tidal water. It has been shown that the high concentrations of organic matter present in these reaches result in a lower dissolved oxygen concentration than in any other part of the Estuary.

Some idea of the extent of the pollution of the Estuary by sewage can be obtained by a comparison of the volume of sewage discharged per day and the total volume of water in the Estuary. The total volume of water in the Estuary between Rock Light and Runcorn Bridge at a high spring tide is roughly 32,000 million gallons at low water and 150,000 million gallons at high water; the volume of sewage discharged (not including trade effluents) is about 35 million gallons per day. The quantity of domestic sewage discharged in one day, therefore, is about 0·11 per cent. of the volume of the Estuary at low water and 0·23 per cent. of its volume at high water.

Time of Retention in the Estuary

It is important in estimating the effect of polluting material in an estuary to obtain an estimate of the length of time which the material spends in the estuary before being carried out to sea. The seaward drift of water is due to the input of fresh water from rivers, usually at the head of the estuary, and the speed with which fresh water passes out to sea depends to a large extent on the size of the estuary and the relative volume of fresh water discharged into it. Under constant conditions of fresh-water flow and of range of tide the quantity of fresh water which passes out to sea during a tidal period of 12 hours would be equal to the volume of fresh water which enters the estuary during the same time. In the Mersey this condition does not actually occur, since the salinity of the water in the Estuary is constantly changing as a result of changes in tidal conditions. If, however, the mean salinity over a long period and also the mean flow from fresh-water streams are known, the average length of time taken by fresh water to pass through the Estuary can be calculated. From the mean salinity, that is approximately the mean of the average salinity at high water and at low water for both spring and neap tides, and the corresponding mean capacity of the Estuary the mean volume of fresh water in the Estuary is first calculated. This volume, divided by the volume of fresh water discharged per day, represents the average time in days which would be taken by fresh water to pass from the head of the Estuary to the sea. The same length of time will be spent in the Estuary by sewage and other material, provided that it remains in suspension or solution in the water. An estimate of the time of retention in the Mersey Estuary of material discharged at different points is given in Table 19.

Table 19—*Estimated Time taken by Fresh Water to Pass Through the Mersey Estuary*

Compartments between sections.	Distance below Warrington Bridge. (miles)	Approximate position of compartments.	Volume of fresh water in compartment. Mean of high and low water Springs and Neaps. (millions of cu. yds.)	Estimated time taken by fresh water to pass through compartment. (days)
160 to 100	0 to 10	Warrington to Widnes ..	5·7	1·0
100 to 83	10 to 12½	Widnes to Hale	4·2	0·7
83 to 67A	12½ to 18	Hale to Mt. Manisty ..	23·0	3·8
67A to 47	18 to 22½	Mt. Manisty to Dingle ..	34·6	5·8
47 to 0	22½ to 29	Dingle to Rock Light ..	36·9	6·2
160 to 0	0 to 29	Warrington to Rock Light ..	109·2	17·5

The volume of fresh water was calculated from the data given in Table 18, where the capacity and the proportion of fresh water at a spring tide are given, and from similar figures referring to neap tides, that is for tides rising to a height of not more than 25 ft. above Liverpool Bay Datum at Prince's Pier. The method appears to give reasonably accurate results. In the Tees Estuary where nearly all the fresh water enters at a single point and where the water in the greater part of the Estuary is confined to a single channel, it was found that the time of retention of fresh water, calculated from salinity observations, agreed well with the similar figure found by the direct observation of floats[1]. It is probable that the greatest uncertainty occurs in the estimated time taken by fresh water to pass through the higher reaches of the Estuary.

In addition to the method which has been described, an attempt has been made to measure directly the rate of travel of fresh water through the Mersey Estuary, by observing the position of a float allowed to drift freely. To obtain the mean value for the residual drift of a float seawards it is necessary to observe its position over at least one period of fourteen days, since the drift of the float on any day depends on the tidal range. A fortnight, that is a half lunation, contains both spring and neap tides, allowing a mean result to be obtained. It was not found possible to follow a float during the hours of darkness owing to the difficulty of fixing its position and to the danger of stranding the boat on sand banks in the Estuary. Observations were, however, carried out during the period 28th August to 10th September, 1935, when the float was followed from 8 a.m. for a period of 12 hours on each day. There was one break in the sequence of drifts on 9th September, when the motor boat broke down and it has been necessary to use estimated figures for this day.

Each float drift was begun in mid-stream at a position about 1½ miles above Rock Light. During the run of the float, station pointer "fixes" were taken every fifteen minutes. The chief weakness of the method is that a float allowed to drift freely is liable to be held up by stranding or by being caught in a back-water. Its speed also depends to some extent on whether it remains in the centre of the channel or is out of the main current. Usually the float was allowed to drift by itself but if it stranded a second float was put in the water in mid-stream and, generally, an attempt was made to keep the float in a representative body of water. A series of float drifts taken over a fortnight really represents a single determination of the mean rate of travel seawards, and the result obtained is for this reason likely to be less accurate than that obtained from salinity measurements taken over a period of a few years. The data obtained from float observations are given in Table 20 (p. 233) and a summary of the results is shown in Table 21.

TABLE 21—*Summary of Results obtained from Float Drifts from Egremont Pier between 28th August and 10th September, 1935, divided into Springs and Neaps*

Date.	SPRINGS.					
1935	Time that float travelled on		Distance float travelled on		Average velocity on	
	Flood (hrs. min.)	Ebb (hrs. min.)	Flood (ft.)	Ebb (ft.)	Flood (knots)	Ebb (knots)
Aug. 28 ..	5·23	6·38	72,270	62,020	2·21	1·54
,, 29 ..	5·15	6·45	55,580	54,650	1·74	1·33
,, 30 ..	4·45	7·10	56,280	80,855	1·95	1·86
,, 31 ..	5·29	6·05	64,200	68,960	1·93	1·87
Sept. 1 ..	5·15	6·45	67,140	74,655	2·10	1·82
,, 2 ..	5·30	6·30	66,040	63,930	1·98	1·62
,, 10 ..	5·30	6·30	55,525	76,770	1·66	1·94
Total ..	37·07	46·23	437,035	481,840	1·94	1·71
Per cent. ..	80·0	100	90·7	100	100	88·1
Average distance water travelled seaward per tide (Springs) 6,400 ft. ,, ,, ,, ,, ,, per day ,, 12,800 ,,						
1935	NEAPS.					
Sept. 3 ..	5·15	6·45	54,868	70,189	1·72	1·71
,, 4 ..	6·00	6·00	60,236	49,155	1·68	1·35
,, 5 ..	6·15	5·45	50,384	49,329	1·33	1·41
,, 6 ..	6·15	5·45	54,224	45,500	1·43	1·30
,, 7 ..	5·30	6·30	42,317	42,366	1·27	1·07
,, 8 ..	4·45	7·15	15,401	46,285	0·63	1·05
,, 9 ..	5·15	6·45	35,463	61,527	1·11	1·50
Total ..	39·15	44·45	312,893	364,351	1·31	1·34
Per cent. ..	87·7	100	85·87	100	97·8	100
Average distance water travelled seaward per tide (Neaps) 7,351 ft. ,, ,, ,, ,, ,, per day ,, 14,702 ,, Average distance water travelled seaward per tide (Springs & Neaps) 6,876 ft. ,, ,, ,, ,, ,, per day ,, ,, ,, 13,752 ,,						

On some days the float travelled a greater distance on the flood than on the ebb, and on other days it moved further on the ebb than on the flood. The average excess distance travelled on the ebb over that travelled on the flood was greater during neaps than during springs, and it is thought that this may be due to the greater effect of the fresh water flow during neaps, when there is a smaller volume of water in the Estuary than there is during springs. During the whole fortnight the float travelled a distance of about 96,000 feet further on the ebb than it did on the flood, the average daily excess being about 6,900 feet. This represents the average daily distance moved seaward during one of the two tides which occur in 24 hours, so that the average distance per day is twice this amount, that is about 13,800 feet. The float was in all cases started at the same point and this rate of travel applies only to material discharged at all states of the tide at that point, that is, at a distance of $1\frac{1}{2}$ miles above Rock Light. If it is assumed that the residual rate of travel of the float would have been constant throughout the

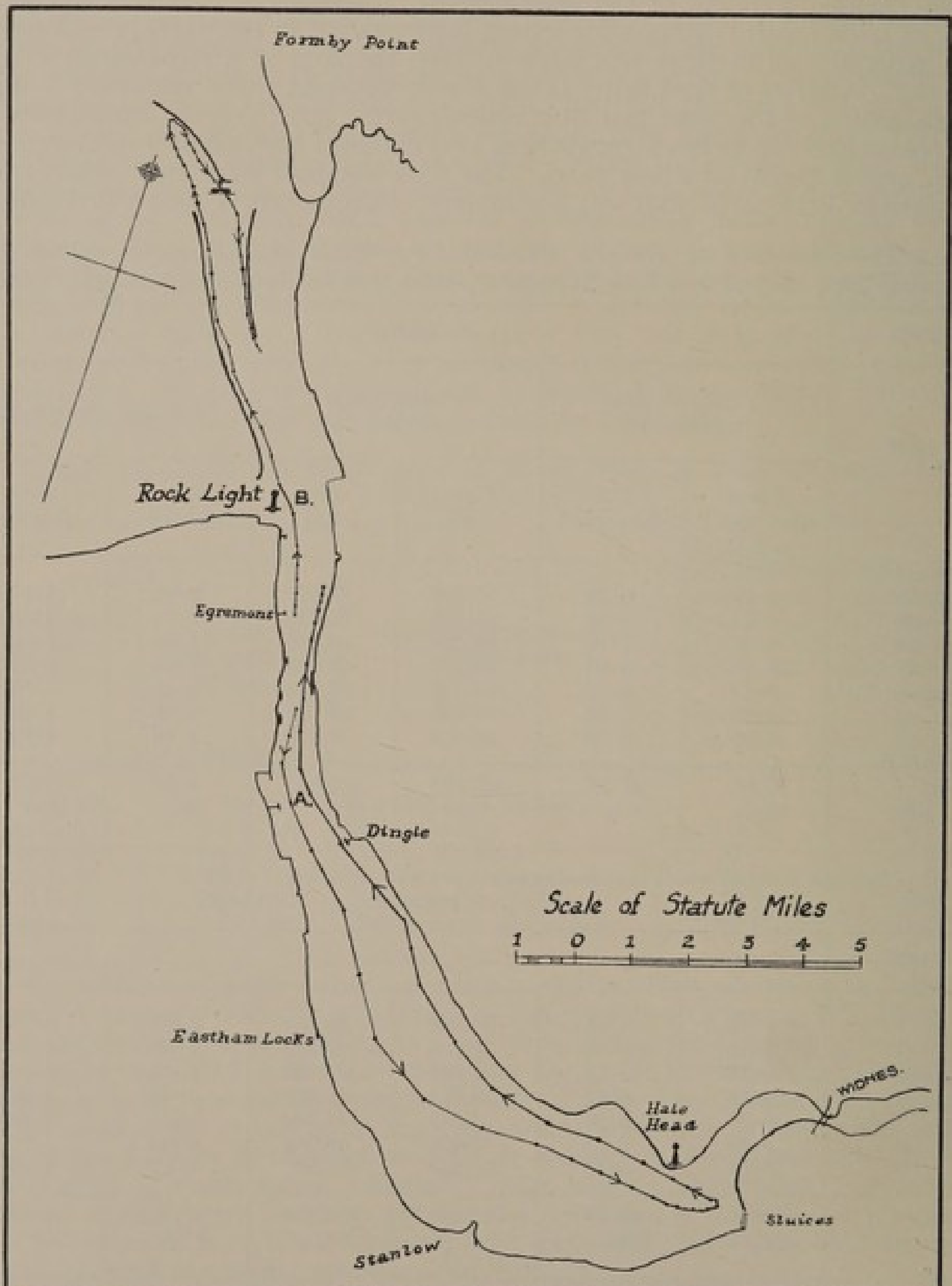


Fig. 11—*Two Typical Float Runs in the Mersey Estuary* (*12 hours' duration*)
Started A. *At the beginning of the Flood* (*Springs*)
B. *At the beginning of the Ebb* (*Neaps*)
The Points on the Float Tracks indicate Fixes by Sextant Angles

Estuary, the time taken for it to pass from Warrington to Rock Light would have been 11·2 days. This figure compares with the value of 17·5 days obtained from a consideration of the salinity of the Estuary. In view of the approximate nature of the methods available the figures agree reasonably well and indicate that the average time of retention of material discharged at Warrington and remaining in suspension or solution is probably 1 to 3 weeks, while material discharged in the Narrows probably passes out to sea after a period of not longer than 1 week. The sewers usually discharge into the Estuary below half tide level; as the greater part of the flow of sewage thus occurs when the tide is below half tide level, the time of retention of the sewage is probably somewhat greater than that calculated from float observations in which the float was started at all states of the tide.

In these measurements the value which has been discussed is the residual seaward movement of water or other material in the Estuary. This relatively small residual seaward movement is the difference between the long distances travelled upstream on the flood and downstream on the ebb. The total distances travelled by floats during a tidal period may be seen from Table 20 and two examples of observed float drifts are shown in Fig. 11. Material discharged in the Narrows at low water may travel upstream almost as far as Widnes on a spring tide but unless retained on the banks or foreshore, it will return at low water to a point below the position at which it was discharged. The residual rate of travel seawards in the Narrows discussed above refers to the movement of the centre of oscillation of material discharged at a given point. When the centre of oscillation has reached Rock Light, the material at high water will be in the Upper Estuary above this point while at low water it will be in Liverpool Bay below it. A longer time than that calculated will thus be required before the material is completely out of the Upper Estuary at high water. The Upper Estuary is, however, an enclosed system and it is impossible for material to escape from it except by way of the Narrows. Liverpool Bay, on the other hand, is an open system and some of the water which passes into it from the Narrows during the ebb tide does not return into the Upper Estuary during the flood tide but is replaced by water from the sea.

Observations have been taken from the three Light Vessels and at two boat stations in Liverpool Bay in an attempt to obtain some information on the rate at which fresh water in the Bay passes out to sea. In the method used, observations of the speed and direction of the tidal streams at depths of two fathoms and at 3 feet from the bottom were made at hourly intervals. The results were analysed by the method recommended by the Hydrographic Department of the

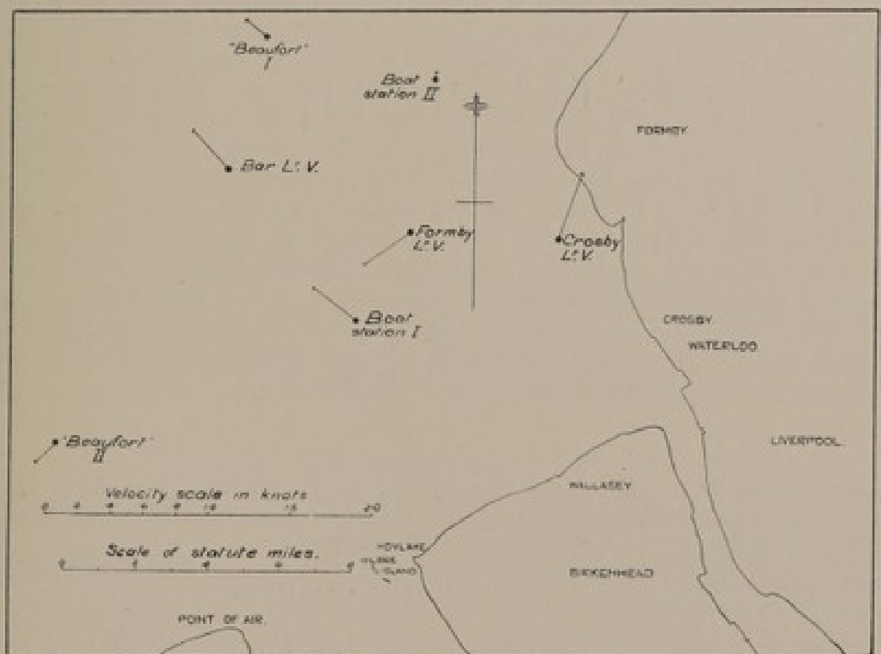


Fig. 12—*Liverpool Bay, showing Positions where Tidal Stream Observations were taken for Periods of 13 or 25 Hours at a Depth of 2 Fathoms*
The Arrows indicate the Direction and Velocity of the Current

Admiralty[2]. In this method, the tidal streams, which are assumed to be equal in strength and opposite in direction on the flood and ebb, are separated from the residual current on which they are superimposed and the average strength and direction of this current is computed. The currents at the five stations, with those at two additional stations for which data were supplied by the Hydrographic Department of the Admiralty, are shown in Fig. 12. The currents have a general set to the north-west, that is, out of Liverpool Bay, and there is a drift of approximately 0·3 knot at the Bar Light Vessel. This drift would represent a travel of 7 nautical miles per day. From float measurements it was calculated that the average excess distance travelled seaward in the Narrows was about 2 miles per day, and it is difficult to account for the much greater current found at the Bar. The Bar Light Vessel is anchored in deep water some miles seaward of the channel which runs between sand banks through the Bay, and at this position the current should not be unduly influenced by the presence of the channel. The currents at the Formby and Crosby Light Vessels, however, are controlled by the shape of the channel, the currents setting towards the concave side. If, however, the resultant of the currents at the two positions is computed, it is found to have almost exactly the same direction and nearly the same speed as the current at the Bar Light Ship. It is possible that the high current drift observed at the Bar may be due in part to the influence of the River Dee. It is possible also that there may be a circulatory movement of water in the Bay, although this has not been detected during the present investigation. Such a system might, for example, be set up if there is a current drift to the eastward inshore along the Welsh coast.

From the open nature of Liverpool Bay, it must be a matter of considerable difficulty to estimate the rate at which substances discharged into it would pass out into the open sea. It seems probable, however, that this rate may be considerably higher than the rate of travel downstream of water in the enclosed upper basin of the Estuary.

Summary

From determinations of salinity at high and low water in the Estuary, the mean proportion of fresh water at different positions has been calculated. The proportion of the total volume of fresh water entering the Estuary which is discharged in the form of sewage has also been estimated and the concentration of sewage in the Estuary water under average tidal conditions has been computed. At high water the average concentration of sewage in 99 per cent. of the Estuary water is estimated not to exceed 0·8 per cent., and at low water not to exceed 1·3 per cent. in 98 per cent. of the total volume. In these calculations the organic matter discharged in the form of industrial wastes has not been considered.

Estimates of the time taken by sewage to pass through the Upper Estuary to Liverpool Bay have been made by two methods. In the first method, based on the volume of fresh water in the Estuary and the volume of fresh water entering the Estuary daily, the estimated time taken for material to travel from Warrington to Rock Light was 17 to 18 days. In the second method, based on observations of free-drifting floats, the seaward rate of travel of material discharged in the Narrows was estimated at rather more than 2 nautical miles per day. If this rate of travel were constant throughout the Estuary, the time taken by material to travel from Warrington to Rock Light would be about 11 days. Current observations in Liverpool Bay suggest that water passing into the Bay from the Upper Estuary is rapidly replaced by new sea water.

References

(1) Alexander, W. B., Southgate, B. A., and Bassindale, R. Survey of the River Tees. Part II. The Estuary—Chemical and Biological. Department of Scientific and Industrial Research, Water Pollution Research Technical Paper No. 5. H.M. Stationery Office, 1935.

(2) Instructions for reducing and analysing tidal stream observations. H.D. 290. Published for the Hydrographic Department, Admiralty, by H.M. Stationery Office [1929].

CHAPTER V

GENERAL NATURE OF THE BED OF THE ESTUARY

AREA AND STABILITY OF INTER-TIDAL BANKS

A map showing the general features of the Mersey Estuary and of Liverpool Bay is given as a frontispiece to this Report. In Liverpool Bay the navigable channel has a depth at low water of roughly 25 to 60 feet; the greater part of the remainder of the area is covered by comparatively shallow water or consists of tidal banks. Connected with both the Lancashire and Cheshire shores are fringes of tidal banks, and on the Lancashire side the river Alt passes through the shore banks to discharge into the main channel. In addition to the main channel there are subsidiary channels, which have cut off some of the shore banks to form islands at low water; the most important of the island banks are the Burbo Bank and Taylor's Bank. The stream through the Narrows flows through a geological fault, which has been flooded by the sea and has a maximum depth of over 70 feet at low water. The total length of the Narrows is about 6 miles and its minimum width three quarters of a mile. The only tidal banks in this part of the Estuary consist of narrow fringes on both shores. Above the Narrows a comparatively deep channel, which in places is kept open by dredging, runs along the Cheshire side to Eastham where the Manchester Ship Canal begins, while another channel, also dredged, runs close to the Lancashire bank to the port of Garston. Above this point, however, the tidal basin becomes very shallow and at low water almost the whole of the area is occupied by dry banks. These banks are not all covered by neap tides but are entirely covered by high spring tides. The length of the shallow part of the Upper Estuary, that is, from Dingle to Runcorn Gap, is about 13 miles and the maximum width is about 3 miles. At Runcorn the basin narrows and passes through a rocky gap. Above this point it again broadens out into a smaller shallow basin, which later becomes narrower and continues as a narrow channel to Warrington. At Warrington the fresh water from the River Mersey enters the Estuary over a weir, and this point has been taken as the end of the estuarine part of the system, although at very high spring tides tidal water flows over the top of the weir and continues upstream for a further distance of about 5 miles. The distance between Runcorn and Warrington is about 10 miles.

During the present investigation the tidal banks, both in the Bay and in the Upper Estuary, have been examined generally and a more detailed examination has been made of those which are considered to be of greatest importance.

In Liverpool Bay the island banks should obviously be considered as part of the Mersey system, but the exact limits of the shore banks which should be considered are more difficult to define. The arbitrary limits chosen were, on the Lancashire coast, a line joining Formby Church and a landmark on the shore (The Flagstaff), this line being continued out over the shore banks into the Bay. On the Cheshire coast another line, drawn from the Point at Hoylake to Hilbre Island Mark, was used as the limiting line for the shore banks. It is difficult to say, however, which part of the banks in this region belongs to the Dee system and which part to the Mersey. Within the area bounded by these two lines and by the Cheshire and Lancashire coasts, the area of tidal banks examined at low water during spring tides was approximately 18·9 square miles. Of this area about 5·5 square miles are occupied by the Burbo Bank and Taylor's Bank, which are islands, and about 13·4 square miles by the remaining shore banks. The total area examined was considerably less than that shown on the Mersey Docks and Harbour Board chart for 1931, where a total drying area of about 26·5 square miles is given. This, however, is the area which dries on the low water of a spring tide rising to a height of 31 feet above Bay Datum at Prince's Pier. Except during these high spring tides the two banks, Spencer's Spit and the North Bank on the Cheshire coast, are cut off from the shore by shallow channels. In many places the banks in Liverpool Bay rise sharply on the side nearest the river entrance and slope gradually away in a seaward direction.

In the Upper Estuary the area of the banks exposed at low water increases above the Narrows. In Table 22 the relative area of the Upper Estuary covered by inter-tidal banks is shown for each of the compartments used by the Mersey Docks and Harbour Board in calculating the capacity of the basin.

TABLE 22—*Relative Areas of Inter-Tidal Banks in Different Parts of the Estuary*

Compartments between sections.	Distance below Warrington Bridge (miles).	Surface area of compartment (sq. miles).	Area of inter-tidal banks (sq. miles).	Area of inter-tidal banks (percentage of total area of compartment).
0 to 21	29 to 26	2·385	0·317	13
21 to 47	26 to 22·5	3·060	0·527	17
47 to 58	22·5 to 20·5	3·717	1·047	28
58 to 67A	20·5 to 18	5·904	3·298	56
67A to 74	18 to 15	6·538	4·966	76
74 to 83	15 to 12·5	7·373	6·601	90
83 to 100	12·5 to 10	2·096	1·664	79
100 to 120	10 to 7·5	0·941	0·670	71
0 to 120	29 to 7·5	32·014	19·090	60

The total area of tidal banks in the Upper Estuary between Sections 0 to 120, that is, between Rock Light and a point just below Fiddler's Ferry, was about 19·1 square miles in 1931; thus of the total area of about 37 square miles of tidal banks in the Upper Estuary and in the Bay, approximately half were in the Bay and half in the Upper Estuary.

The general nature of the material forming the tidal banks and the bed of the channels in the Upper Estuary and in the Bay has been determined in the tidal banks by walking over and inspecting them at low tide, and in the bed by taking samples by dredging. During the examination of the tidal banks a general survey was made of the animals and plants inhabiting them, particular attention being paid to the burrowing animals living below the surface. This examination was made in order to obtain an estimate of the relative stability of the banks in different parts of the Estuary, since, in order that a tidal bank may support a population of burrowing animals, it is necessary that it should be comparatively stable. In a shifting bank burrowing organisms are liable to be crushed, suffocated or washed away. It is necessary, however, in making this comparison to take into consideration any other factors such as unsuitable conditions of salinity which might limit the distribution of burrowing animals. The survey was carried out mainly between May and October, 1933. The limits of the different types of bank were fixed by sextant angles and plotted by station pointer; in general, only the surface of the tidal banks was examined and the material of which this was composed was divided into " uninhabited ", " sparsely inhabited " and " densely inhabited " sand or mud, according to the relative density of the population of burrowing animals it supported. The position of the banks of each type is shown in Fig. 13C for the Upper Estuary and in Fig. 14C for Liverpool Bay.

In the Upper Estuary the banks which line the low-water channel from Bromborough to Runcorn are largely composed of uninhabited sand which is often coarse and is frequently found in waves up to about 3 feet in height. The hollows between these waves are often covered by a thin layer of soft mud, which appears to have settled there on the previous ebb tide, since it is easily disturbed and the sand underneath is clean. Above Dungeon Point the sand grains appear to be finer and the surface of the banks is not in the form of large waves, although it may be rippled in places. The clean uninhabited sand gives way to flat wet patches of sand containing a few worms, usually the lug worm, *Arenicola marina*, and occasionally a small bivalve, *Macoma balthica*. This sand contains a little mud and its surface is usually flat. The main bank of densely inhabited sand adjoins the large mud bank at Stanlow and contains a fair proportion of mud. This type of sand is inhabited mainly by a crustacean, *Corophium volutator*, and the bivalve, *Macoma balthica*. A small tube-building worm, *Pygospio elegans*, is abundant in parts and the rag worm, *Nereis diversicolor*, occurs occasionally.

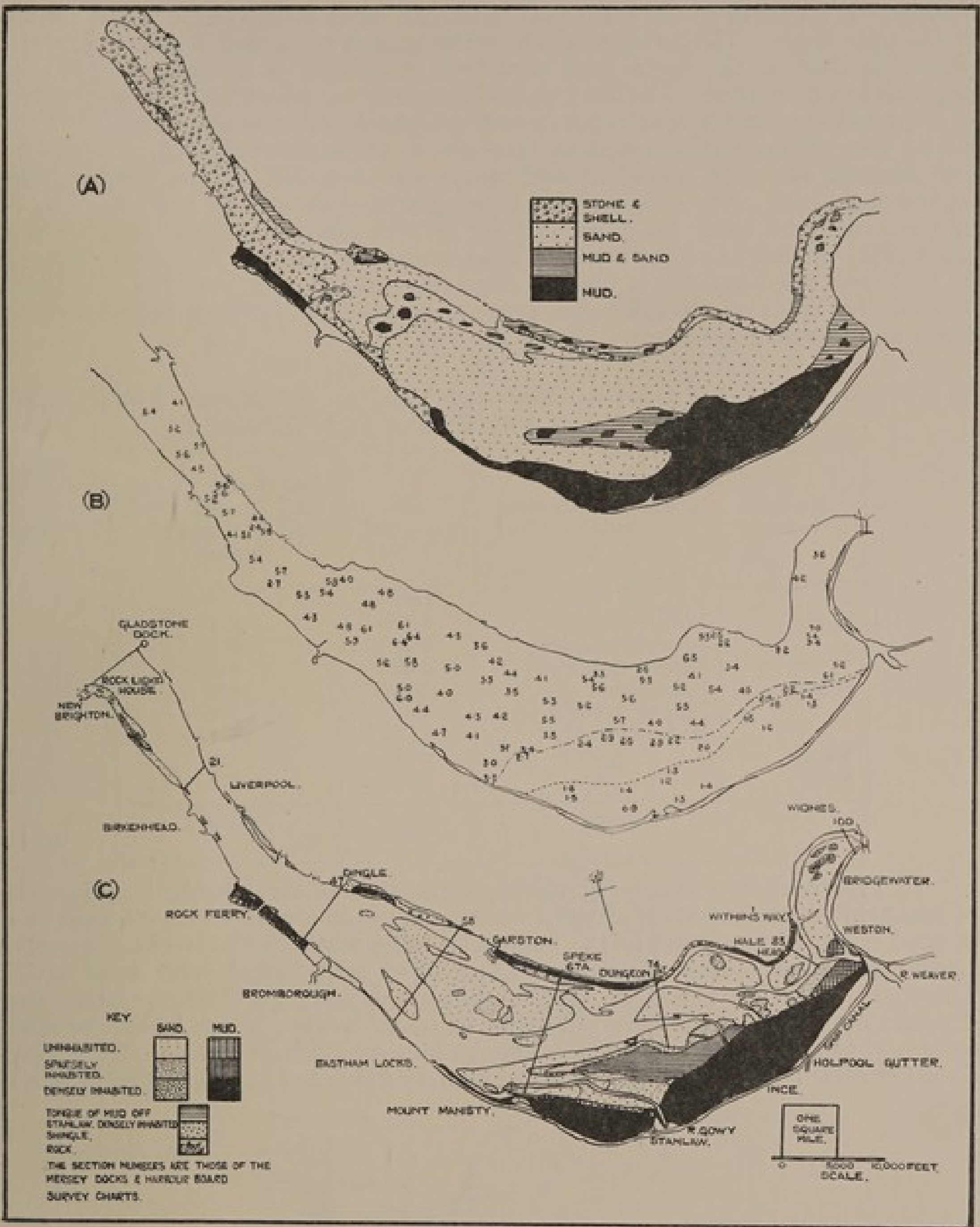


FIG. 13—(A) *General Nature of the Bed of the Upper Mersey Estuary*
(B) *Maximum Stream Velocities (ft. per sec.) referred to a 27-ft. Range of Tide. Dotted Lines show Limits of Areas in which Stream Velocities do not exceed 2·0 and 3·0 ft. per sec.*
(C) *Inhabited and Uninhabited Mud and Sand Banks in the Upper Mersey Estuary*

Only a small area of the Upper Estuary is covered by uninhabited mud, and where this occurs the mud forms a thin and unstable deposit. In 1933 there was a large patch of sparsely inhabited mud in the neighbourhood of the Weaver Sluices, but the greater part of this was later washed away. Except for small patches at Rock Ferry and along the Lancashire shore, the main bank of densely inhabited mud is confined to the Cheshire bank between Eastham and the Weaver. This mud is often very soft but after a period of neap tides it may become quite hard. Its surface is usually brown, though black mud occurs in some places below the surface. Its characteristic inhabitant is *Nereis diversicolor*, which occurs in abundance, while *Macoma balthica*, *Corophium volutator* and the small red oligochaete worm, *Clitellio arenarius*, are also very common. On its landward side the bank passes into a marsh thickly covered with vegetation which is used for grazing sheep. At Ince, a tongue of mud, called in this Report the " Stanlow

Tongue," is attached to the main mud bank and forms a high bank off the mouth of the river Gowy. The material of which the bank is composed is similar in some places to that of the main mud bank but in general it is different both in appearance and texture. The mud on the Tongue is mixed with a high proportion of sand and the surface is at times almost completely covered with sand. There are no deep drainage gullies such as there are on the main mud bank. *Corophium* and *Macoma* are more abundant and *Nereis* less abundant on the Tongue than on the main bank. The charts of the Upper Estuary show that, while the height of the main mud bank has been at least 20 feet above Liverpool Bay Datum since 1921, the height of the Stanlow Tongue was less than 20 feet above Datum in 1921, and some parts of it rose by more than 10 feet between 1926 and 1931. The relative areas of these different types of bank in the Estuary between Rock Light and Runcorn are shown in Table 23.

TABLE 23—*Inter-Tidal Areas of Mud and Sand in the Mersey Estuary from Runcorn Gap (Section 100) to Rock Light (Section 0)*

Type of bank.	Density of burrowing animals.	Area (sq. miles).	Area of each type of bank (percentage of the total area of banks).
Sand ..	Uninhabited	8·90	48·4
	Sparsely inhabited ..	1·67	9·1
	Densely inhabited ..	0·68	3·7
Mud ..	Uninhabited	0·09	0·5
	Sparsely inhabited ..	0·61	3·3
	Densely inhabited ..	6·10	33·1
Shingle ..	—	0·23	1·2
Rock ..	—	0·13	0·7
	Total ..	18·41	100·0

In Liverpool Bay about two-thirds of the area of tidal banks is composed of uninhabited sand which is often in waves; as in the Upper Estuary a thin film of mud is sometimes found in the hollows of these waves. The banks along the Lancashire shore consist in part of uninhabited sand mixed with some mud. There are extensive banks of sparsely inhabited sand, particularly along the Cheshire coast. The banks are inhabited by many species, which include several species of tube-building and other worms besides burrowing bivalves. The cockle *Cardium edule* is common. The banks of densely inhabited sand in different parts

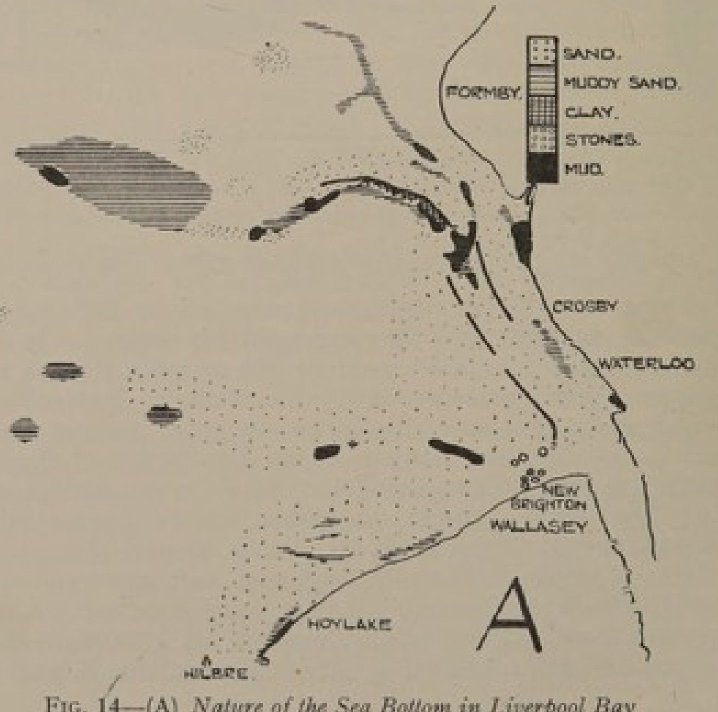


FIG. 14—(A) *Nature of the Sea Bottom in Liverpool Bay*

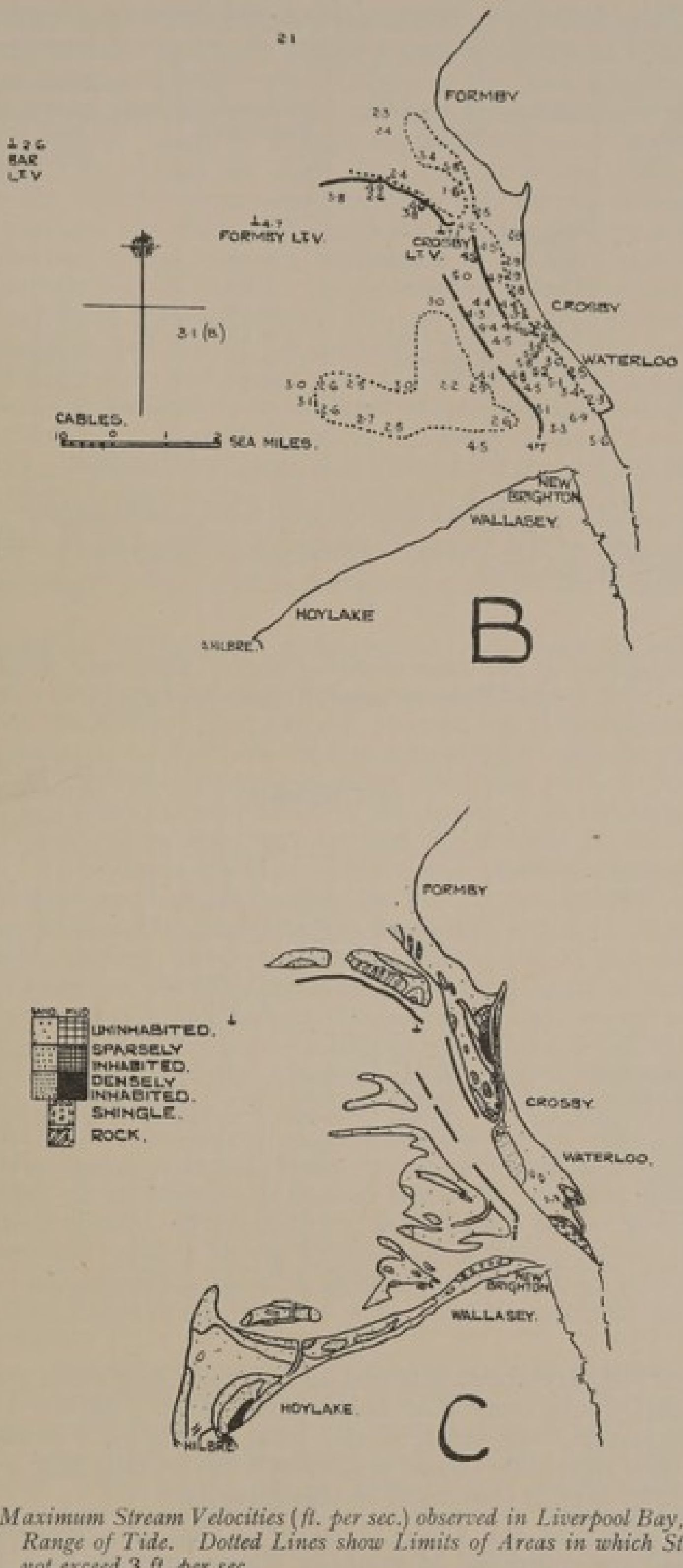


FIG. 14—(B) *Maximum Stream Velocities (ft. per sec.) observed in Liverpool Bay, referred to a 27-ft. Range of Tide. Dotted Lines show Limits of Areas in which Stream Velocities do not exceed 3 ft. per sec.*
(C) *Inhabited and Uninhabited Sand and Mud Banks in Liverpool Bay.*

of Liverpool Bay contain different species. There are only small areas of uninhabited or sparsely inhabited mud and these appear to consist of a thin layer of ephemeral mud overlying sand. Densely inhabited mud is confined to two areas in sheltered positions, one in the valley of the Alt and one at Hoylake; this mud contains *Nereis*, *Corophium*, cockles, and *Macoma*. Small areas of shingle and rock are found at Gladstone Dock and on the Cheshire coast. The relative proportions of the different types of bank in the Bay are given in Table 24.

TABLE 24—*Inter-Tidal Areas of Mud and Sand in Liverpool Bay*

Type of bank.	Density of burrowing animals.	Area (sq. miles).	Area of each type of bank (percentage of the total area of banks).
Sand ..	Uninhabited	12·64	67·0
	Sparsely inhabited ..	3·49	18·5
	Densely inhabited ..	1·80	9·6
Mud ..	Uninhabited	0·16	0·8
	Sparsely inhabited ..	0·17	0·9
	Densely inhabited ..	0·35	1·9
Shingle ..	—	0·26	1·4
	Total ..	18·87	100·1

The relative areas of the various types of sand and mud are widely different in Liverpool Bay and in the Upper Estuary; a comparison of the proportions of each type is shown in Table 25.

TABLE 25—*Comparison of the Inter-Tidal Areas of Sand and Mud Banks in the Upper Estuary and in Liverpool Bay*

Type of bank.	Density of burrowing animals.	Area (sq. miles).			Area of each type of bank (percentage of the total area of banks).		
		Liverpool Bay.	Upper Estuary.	Total (Upper Estuary and Liverpool Bay).	Liverpool Bay.	Upper Estuary.	Total (Upper Estuary and Liverpool Bay).
Sand ..	Uninhabited	12·64	8·90	21·54	67	48	58
	Sparsely inhabited	3·49	1·67	5·16	18	9	14
	Densely inhabited	1·80	0·68	2·48	10	4	7
Mud ..	Uninhabited	0·16	0·09	0·25	1	1	1
	Sparsely inhabited	0·17	0·61	0·78	1	3	2
	Densely inhabited	0·35	6·10	6·45	2	33	17
Shingle ..	—	0·26	0·23	0·49	1	1	1
Rock ..	—	0	0·13	0·15	0	1	0
	Total	18·87	18·41	37·28	100	100	100

In the Upper Estuary about half and in Liverpool Bay about two-thirds of the total area of tidal banks consist of uninhabited sand. In the Upper Estuary, however, approximately one-third of the total drying area consists of densely inhabited and thus relatively stable mud, while in the Bay only a negligible proportion of the total area is composed of this material.

A notable feature in the Upper Estuary is that the inter-tidal banks, the surfaces of which are composed of mud, lie almost entirely at a height of more than 20 ft. above Liverpool Bay Datum. For example, the main mud bank adjoining the Cheshire coast lies entirely above this height, and its edge is sharply differentiated from the sandy banks which adjoin it and which have a height of less than 20 ft. above Datum. In the Upper Estuary the greater part of the surface of banks lying above the 20-ft. contour consists of mud. The small sand banks above the 20-ft. contour are mostly above Hale, where the general level of the bed of the Estuary begins to rise steeply. In the Bay, however, the inter-tidal banks more than 20 ft. above Datum are not all composed of mud; thus the Great Burbo Bank, which has a maximum height of about 23 ft., consists almost entirely of sand.

In Figs. 13(A) and 14(A) is shown the whole of the information available on the nature of the bed of the Upper Estuary and of Liverpool Bay in 1933. This information was collected partly by walking over the inter-tidal banks and partly by the examination of numerous samples dredged from that part of the bed which is covered at low water. Many of the inter-tidal banks were re-surveyed in 1935, and their outline, as shown in Fig. 13(A), consequently differs slightly from that shown in Fig. 13(C), which was based on the survey carried out in 1933. In the Upper Estuary the chief additional information obtained in 1935 was on the nature of the bed of the Narrows, which was found to consist mainly of stone and shingle, with bare rock in places. At the mouth of the Narrows there is an area covered with clean sand. In the Upper Estuary there are only small areas of mud which are covered at low water; these occur mainly at the upper end of the Narrows. Dredgings were not taken over the whole area of Liverpool Bay, but the samples obtained indicate that the greater part of the bed consists of clean sand; some patches of mud were found in the Rock Channel and larger areas in the main channel. A line of dredgings also showed the presence of mud or of muddy sand in the Formby Channel, and the Admiralty Charts of the district show that this is continuous with a belt of muddy sand extending northward on the bed of the Irish Sea. The largest area of mud found in the Bay occurred in a patch about 3 miles in length, stretching as far seaward as the Bar Light Vessel.

Stream Velocities in Channels and over Banks

The causes which lead to the deposition of different types of material on different parts of the Estuary bed are not known, but it seems probable that the nature of the material of which the bed is composed at any period is dependent on the strength of the tidal streams passing over that part of the bed. During the present investigation, observations of the strength of the tidal streams have been made at 8 stations in the Narrows and 80 stations in the Upper Estuary below Runcorn. In addition 24 float drifts were observed, most of them passing through the Narrows and into the upper basin. At positions which did not dry out at low water observations were taken for a full period of flood or ebb. The greater part of the Upper Estuary, however, dries out at low water; here the positions were manned on the flood as soon as a dinghy could be dragged or floated to the station, and were abandoned on the ebb at the last opportunity of floating the dinghy off again. For stream velocities greater than about 1 foot per second the velocity was measured by a Watts current meter; below this velocity the stream was measured by captive floats, the amount of line which ran out in a given time being observed. Difficulties were experienced in using both methods. The current meter was found to work badly in rough water in the Upper Estuary, where a great deal of turbulence is caused by wave action. The captive floats used were almost entirely submerged, but were found to be affected to a small extent by the surface current set up by wind or by wave motion. The effect of wind might be considerable when a tidal stream of low velocity was being measured. In float drifts the kites used were much deeper and were less affected by surface conditions.

Owing to the frequent movement of the banks and channels in the Upper Estuary, especially above Dungeon Point, the current conditions at any position do not as a rule remain constant for more than a day or two. The most stable conditions occur over the Stanlow Bank, which does not rapidly change its position or height. Thus in the Upper Estuary the stream velocities observed at any position are not constant for that position, but indicate only the stream velocities found in that part of the Estuary over a bank of the same height as that which was present on the day when the observations were made. In general, in all parts of the Upper Estuary the stream velocity in the channels was always found to be greatest before the banks were covered. After the banks were covered there was no large difference between the stream velocity in positions over the banks and in the channels.

In Liverpool Bay work with a small boat could only be carried out in calm weather. Current observations, however, were taken from the three Light Vessels in the main channel, hourly readings being taken for periods of 24 hours. These observations were made at the surface and at a depth of 2 fathoms with captive floats and at a distance of 3 ft. from the bottom with an Ekman current meter. Similar observations were made at two other positions in the Bay. At other stations the stream velocity was measured with a Watts current meter or with captive floats, in some cases working from a small boat over drying banks as in the Upper Estuary. Float drifts in the main channel and from the dredging deposit sites were also observed. In addition to observations taken at 20 fixed stations in the Bay during the present investigation, information has been obtained where possible on stream observations made by the Hydrographic Department of the Admiralty.

It was found impossible to determine the stream velocities at all stations on the same range of tide and the velocities observed have, therefore, been reduced to the velocities for a standard tide with a range of 27 feet. The calculated velocity was obtained from the observed value by the following equation :—

$$\text{Velocity for 27-ft. range} = \frac{\text{Velocity observed} \times 27}{\text{Range of tide in feet on day of observations.}}$$

This method is probably admissible for tidal streams in the main channel in Liverpool Bay, but it gives only a rough approximation for tidal streams taken over drying banks; in such positions the velocity observed is dependent on the height of the bank in relation to the surrounding banks. It is considered, however, that the results obtained by this method do give a rough picture of the general distribution of tidal velocities in the Estuary.

In the Bay the highest stream velocity was found in the Crosby Channel between 1 and 2 hours after low water, the streams becoming slower as the inter-tidal banks were covered. In the Narrows the strength of the tidal stream rises to a maximum at about half tide. At higher positions in the Upper Estuary the stream velocity curve during the tidal period is asymmetrical. At the beginning of the flood the stream, especially in the channels, runs at a very high speed, but as soon as the banks are covered the velocity drops to about half its maximum value. During the ebb the stream runs at a more steady rate and does not usually reach the same high velocity as at the beginning of the flood. These conditions are particularly pronounced above Runcorn, where at spring tides there is a small bore at the beginning of the flood. Two typical stream velocity curves, one from observations in the Narrows and one off Hale Lighthouse, are shown in Fig. 15. In Figs. 13(B) and 14(B) are shown the maximum stream velocities found in the Upper Estuary and in the Bay, reduced to the estimated velocities for a tide of a range of 27 feet. Contours have been drawn for velocities of 2 and 3 feet per second. In the Upper Estuary the contours follow closely the line of the Stanlow Bank, over which no velocity greater than 3 feet per second was found. In Liverpool Bay the contour for 3 feet per second similarly follows the general outline of the Great Burbo Bank.

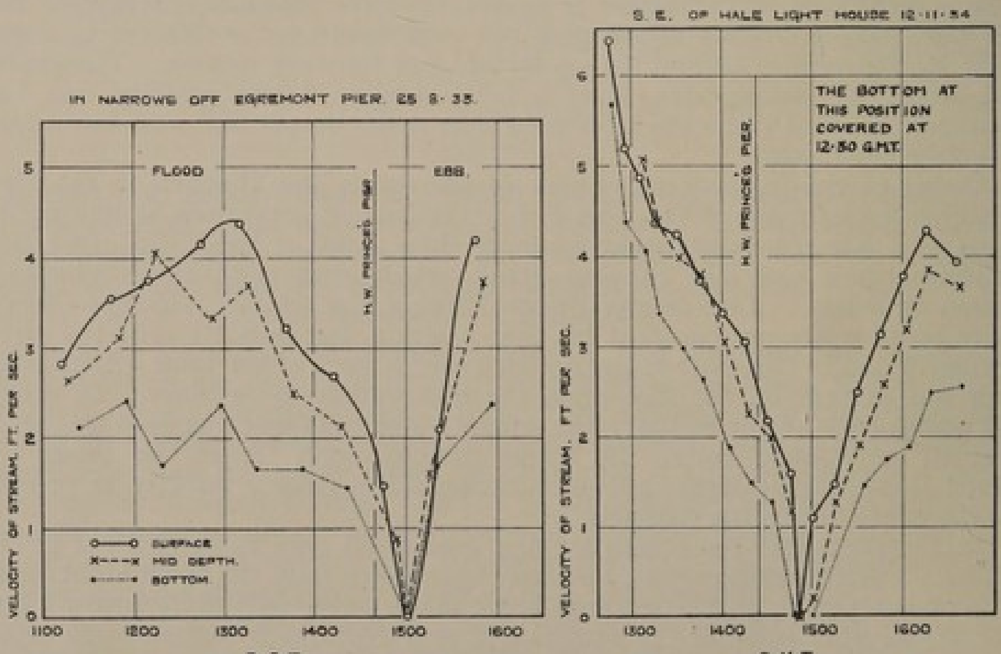


FIG. 15—*Typical Stream Velocity Curves in Two Positions in the Upper Mersey Estuary*

The difference between the strength of the tidal stream in the channel running on the outside of the upper part of the Stanlow Bank and the strength of the stream over the surface of the bank is indicated by Fig. 16. This figure refers to

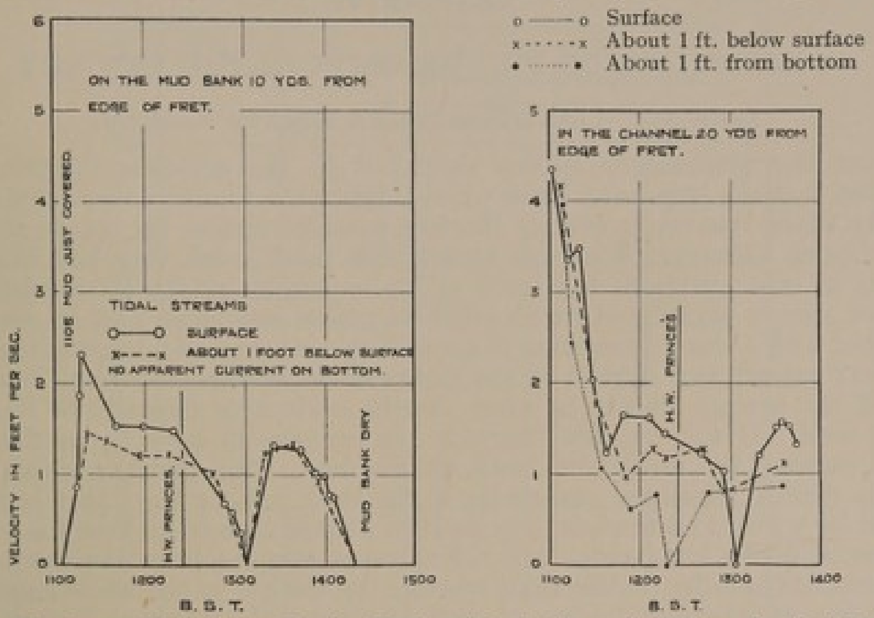


FIG. 16—*Stream Velocity over Stanlow Bank and in the Channel adjoining the Mud Bank*

two sets of observations taken at the same time, one at a position in the channel a few yards outside the edge of the Stanlow Bank and a second at a position over the surface of the bank, also a few yards from the edge. In the channel the stream velocity during the time that the bank was uncovered was relatively high; by the time the bank was covered the velocity had dropped considerably and the speed of the current over the bank never exceeded 2·5 feet per second. The highest velocity recorded over the bank occurred immediately after it had been covered.

It seems evident that the sharp division in the Upper Estuary between the mud banks and sand banks is correlated with the equally sharp division in the velocity of the tidal streams. The Stanlow Bank occupies an area over which the stream velocity is now low, while high sand banks in the centre and on the Lancashire side of the basin are subject to relatively high stream velocities. In order to alter this distribution of mud and sand it would appear that a change in the position of the main channel in the Upper Estuary must first occur. The factors which determine the position of the channel are not known, but it would seem that its position is not primarily determined by the difficulty of erosion of the banks between which it passes, since for the greater part of its length it is contained by banks mainly composed of sand which would be easily eroded if other factors tended to cause the channel to alter its course.

SUMMARY

In 1933 a survey of the drying banks in the Upper Estuary and in Liverpool Bay was made and the banks were classified as "uninhabited," "sparsely inhabited" or "densely inhabited" sand or mud according to the numbers of burrowing animals they contained. The density of burrowing animals is related to the stability of the banks, since a permanent burrowing population can exist only in a bank which is not subject to frequent movement. The banks in the Upper Estuary consisted mainly of inhabited mud and uninhabited sand. In the Bay there was very little mud; about two-thirds of the total area of drying banks consisted of uninhabited sand and most of the remainder was inhabited or sparsely inhabited sand. An examination of dredged samples showed that mud or muddy sand occurred on the bottom in some parts of the Bay which are covered at low water; in the Upper Estuary, very little mud was found at the bottom of the low water channels.

The distribution of mud and sand in the Upper Estuary is correlated with the strength of the tidal streams; the velocity over the surface of mud banks is lower than that over sand banks, since the mud banks are higher than the sand banks and are covered only near the time of high water. In the Bay the stream velocities are lowest over the surface of the drying banks.

CHAPTER VI

COMPOSITION OF THE DEPOSITS IN THE ESTUARY

Inorganic Constituents and Organic Content

From the preliminary survey described in the previous Chapter, it was concluded that the large mud bank which adjoins the Cheshire shore and stretches from the River Weaver to Mount Manisty contains almost the whole of the mud in the Upper Estuary. Mud was found over small areas only and in negligible amounts in other parts of the basin. The remainder of the inter-tidal deposits consisted almost entirely of sand, which in places was clean and in other places was mixed with a small proportion of mud. If the presence of sewage in the Estuary water has caused any change in the composition of the inter-tidal deposits the effect of the sewage should be most clearly evident in deposits of mud rather than in sand. It was decided, therefore, to examine in some detail the deposits of mud forming the main mud bank off Stanlow. The area examined in detail is clearly defined, since the outer edge of the bank is for a large part of its length bounded by a fret, and there is in general an abrupt transition from the mud bank to the sand banks lying outside it. Numerous samples from the Stanlow Bank were examined in order to determine whether the bank is on the whole homogeneous in character or whether patches of mud of abnormal composition occur. There are no large sewers discharging over any part of the Stanlow Bank; the only discharges directly affecting it are those from three small sewers which empty into gulleys draining the bank. Most of the large sewers emptying into the Estuary are situated in positions past which the tidal stream runs strongly, as for example in the Narrows, and consequently there are no large deposits of mud in the immediate neighbourhood of these outfalls.

The majority of the samples from the Stanlow Bank were taken from the surface, though some were taken at different depths below the surface and from the sides and bottom of drainage gulleys in the bank. The position of each sample was fixed by sextant angles between permanent marks on the shore.

The methods of analysis of the samples were chosen mainly to yield information on the nature of the inorganic constituents and on the concentration of organic matter. For the inorganic constituents, the methods usually employed in soil analysis were used, determinations being made of silica, " sesquioxides ", and, in some cases, iron, calcium and magnesium. In the Mersey, the sand appears to consist almost entirely of silica. On the Stanlow Bank this is mixed with varying proportions of clay and silt to form mud. Silts, which consist of relatively coarse particles, and clays, which contain finer particles, in general contain alumino-silicates of varying composition; most of them include not only silica and alumina but also iron and calcium. In the analysis of soils, alumina and ferric oxide can be conveniently determined together, and this value, usually called in soil literature " sesquioxides ", is often taken as a measure of the amount of alumino-silicates. " Sesquioxides ", as determined gravimetrically, may contain phosphorus and other elements, the proportion of which is however usually small compared with the amount of alumina and iron. Clay also contains a fairly high proportion of water which is not lost by drying at 105° C. in the determination of moisture, but is lost when the mud is ignited. The material lost on ignition therefore consists mainly of the bound water of the clay with organic matter and the carbon dioxide from any carbonates present. As a measure of the amount of organic matter in mud the concentrations of organic carbon and of Kjeldahl nitrogen were determined. Besides giving information on the amount of organic matter in a mud, some information on the nature of the organic matter is given by the ratio of the amount of organic carbon to nitrogen.

The results of analysis of the samples of mud from the Stanlow Bank and of a few samples from other parts of the Upper Estuary are given in Table 26 (p. 240). In Fig. 17 is shown the relation between the silica and sesquioxide contents of the samples examined. The relation between the sesquioxide content, which may be taken as a measure of the amount of clay and silt present, and the silica content is a straight line, which, if produced, would cut the axis for silica at a value of about 100 per cent. silica, representing a pure siliceous sand. The relation may be taken to indicate that the samples from the Stanlow Bank consist of a

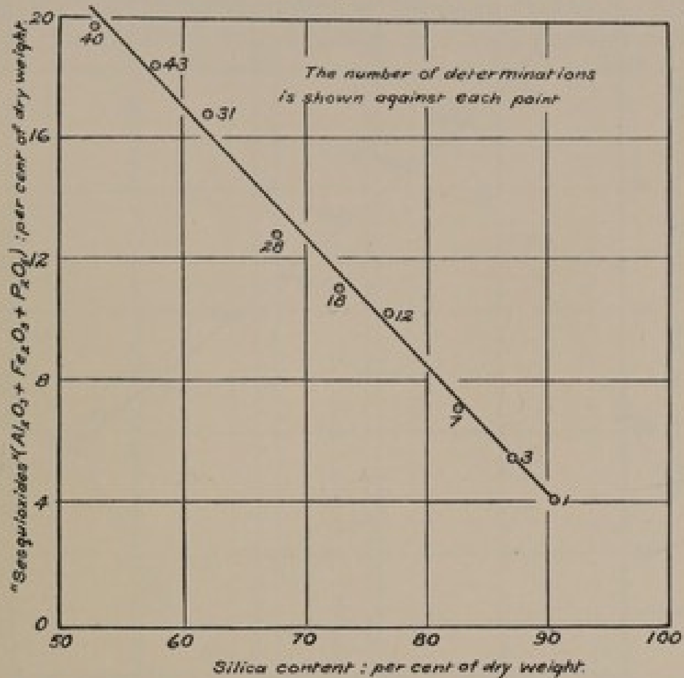


FIG. 17—*Relation between the Contents of Silica and Sesquioxides in Samples from Inter-Tidal Deposits in the Upper Mersey Estuary*

mixture of varying proportions of clay and silt, containing alumino-silicates, with siliceous sand. There are also well defined relationships between both the alumina and ferric oxide contents and the silica content (Fig. 18).

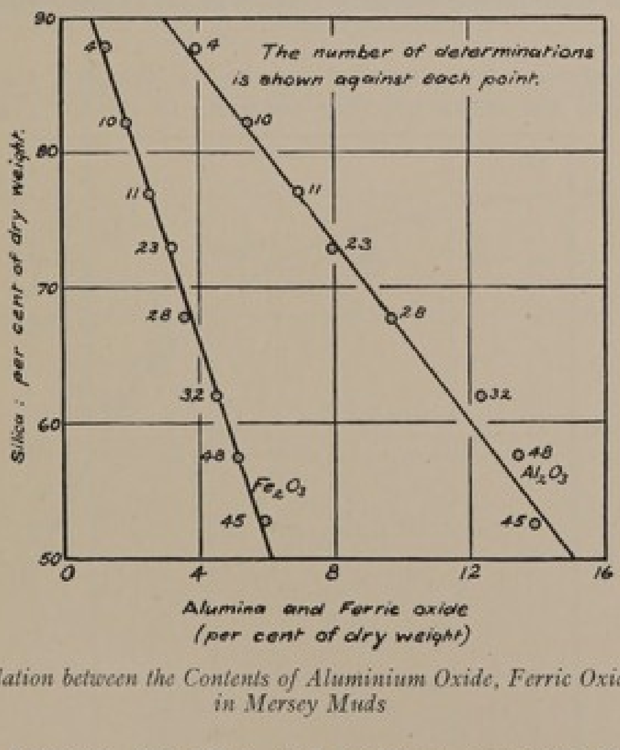


FIG. 18—*Relation between the Contents of Aluminium Oxide, Ferric Oxide and Silica in Mersey Muds*

The relation between the silica and moisture contents of Mersey muds is shown graphically in Fig. 19. The samples examined were taken in both wet and dry weather after neap tides, in which the Stanlow Bank is in places uncovered at high water, and after spring tides in which all the bank is covered. The moisture content of the bank fluctuates considerably according to whether or not it has recently been covered with water, but if the mean of all the samples is taken it is evident that the mean moisture content is related to the proportion of sand

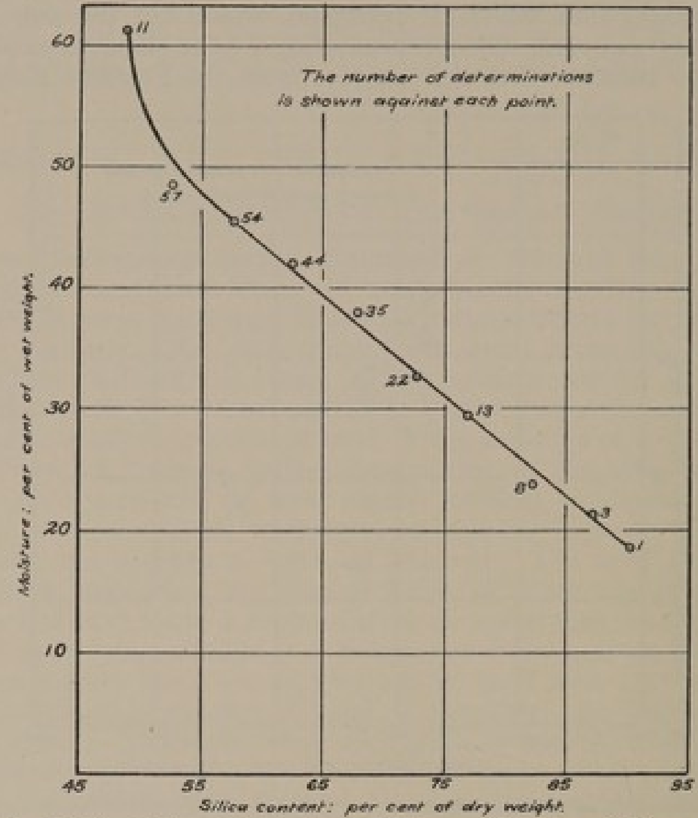
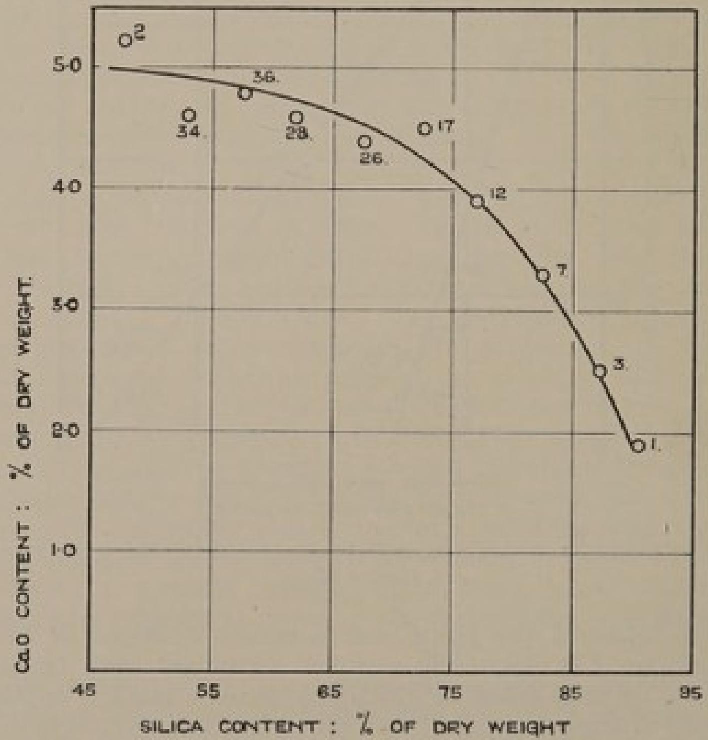


FIG. 19—*Relation between the Contents of Silica and Moisture in Mersey Muds*

present. For the greater part of the silica range the silica-moisture curve is a straight line; the departure from this relationship in samples with a low silica content is due to the fact that a number of samples of slurry were included. The slurry consisted of semi-liquid recently eroded mud, usually found on the sides of drainage gulleys.

In Fig. 20 is shown, for a smaller number of samples, the relation between the mean silica and the mean calcium contents of muds. The curve indicates

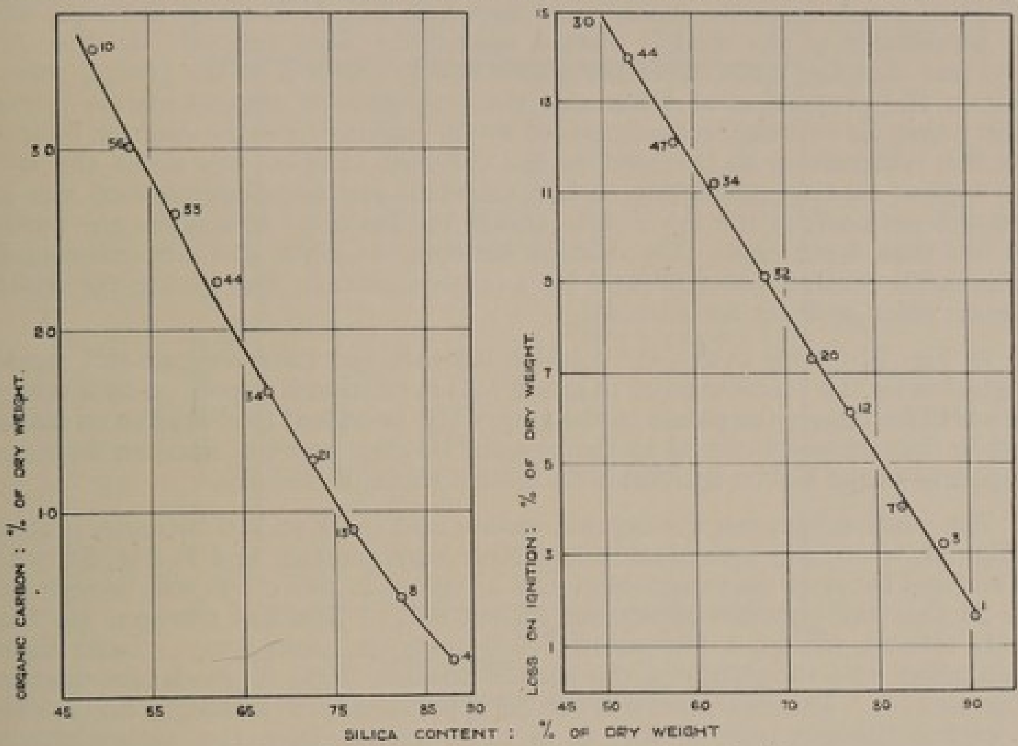


The number of determinations is given against each point

FIG. 20—*Relation between the Contents of Silica and Calcium Oxide in Samples from the Inter-Tidal Banks of the Upper Mersey Estuary*

that there is a general relation between these two quantities; it is probable that the amount of calcium is considerably influenced by the presence of fragments of the calcareous shells of marine animals.

In Fig. 21 is shown the mean relation between the silica and the organic carbon contents of the Stanlow muds. There is a well-marked relation between



The number of determinations is shown against each point

FIG. 21—*Relation between the Content of Silica and the Content of Organic Carbon and Loss on Ignition in Samples from Inter-Tidal Deposits in the Upper Mersey Estuary*

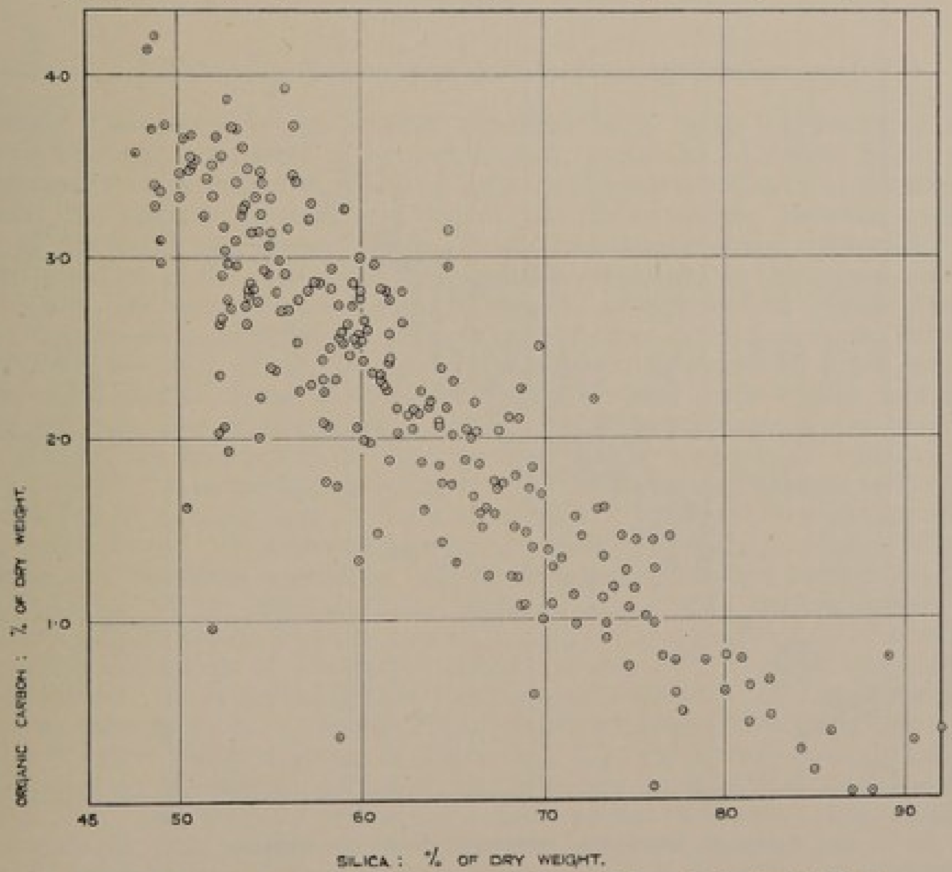


FIG. 22—*Relation between the Contents of Silica and Organic Carbon in Muds from the Upper Mersey Estuary*

the proportion of silica in the samples and the amount of organic carbon present, the relation between the two quantities being expressed by a curve which for the greater part of the silica range is almost a straight line. This important relation is shown in another form in Fig. 22 where the values for the organic carbon and silica contents of individual samples are plotted. The extent of the departure of individual points from the mean curve shown in Fig. 21 is about the same when any constituent of the mud is plotted against the silica content. In Fig. 22 it is evident that the majority of the points shown conform to the general relation between the proportion of silica and the proportion of organic matter present. A few points lie outside the band formed by the majority but the diagram indicates that the composition of the mud in the different samples was about the same. The highest content of organic carbon found in any sample examined was less than 4·5 per cent. of the dry weight and in the majority of samples the amount was less than 4 per cent. The relation between the silica and nitrogen contents of the muds examined is expressed by a curve similar to that giving the relation between silica and organic carbon.

In Fig. 21 is also shown the relation between the silica content and the loss on ignition for the Stanlow series of muds. This relation is expressed by a straight line which fits closely the points on the graph. It is evident that the loss on ignition must be largely proportional to the amount of clay present, since an important component of the loss on ignition is the bound water of the clay.

The relation between the organic carbon and the Kjeldahl nitrogen is shown in Fig. 23, where the individual values have been plotted, and in Fig. 24, where the relation between the means of groups of values is given. It will be seen from Fig. 23 that the contents of organic carbon and of Kjeldahl nitrogen are fairly closely related, though a few points fall outside the main array. Some factors which affect the variability of the carbon-nitrogen ratio in muds are discussed in Chapter IX. The mean curve in Fig. 24 approximates to a straight line in which the carbon-nitrogen ratio is 10. It is often stated that the carbon-nitrogen ratio is an indication of the source of the organic matter in mud, the ratio being

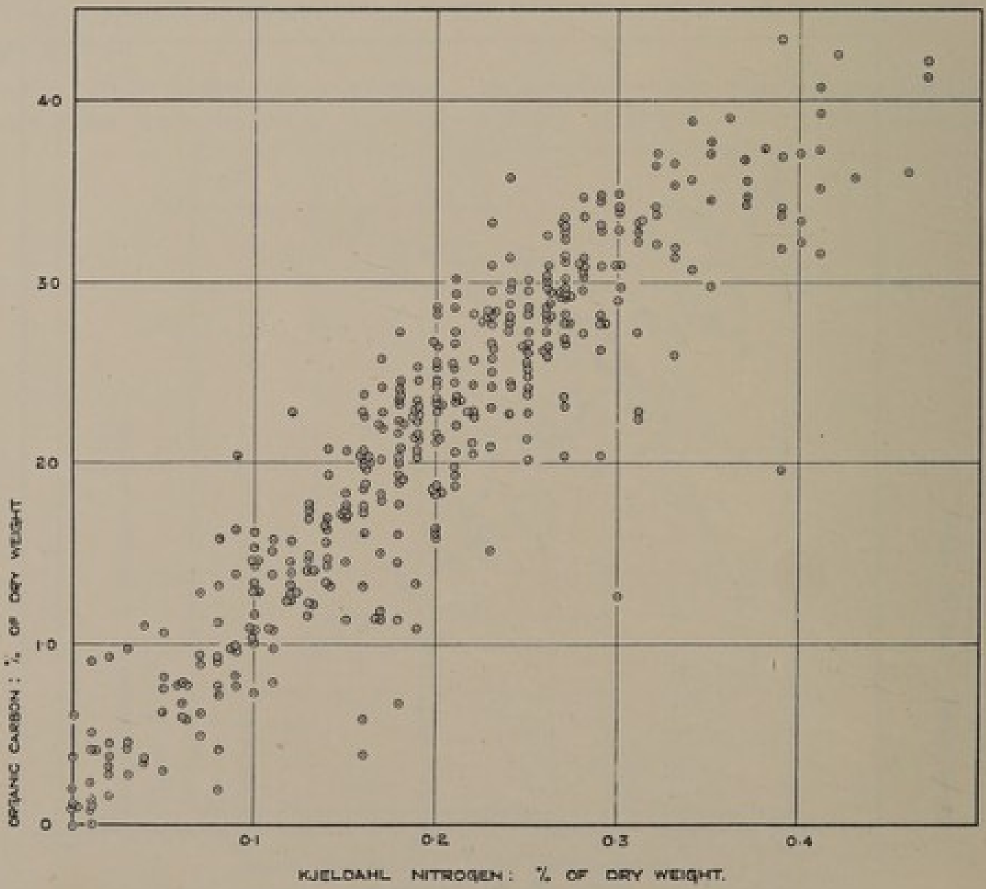
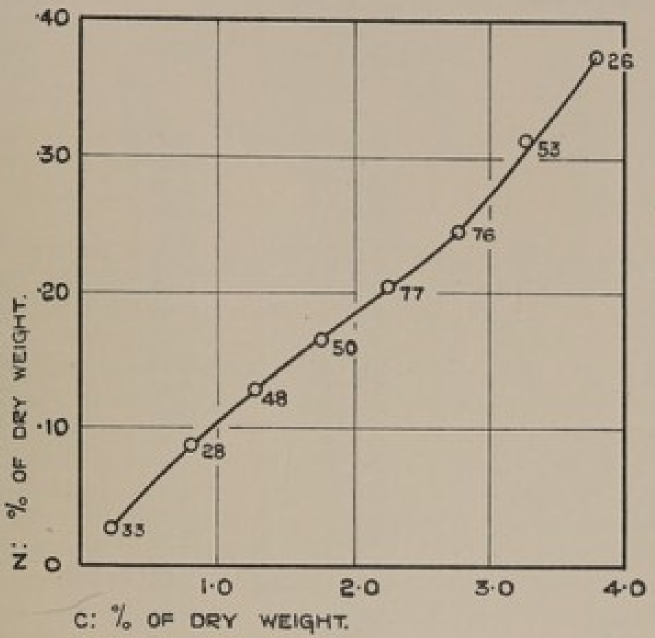


FIG. 23—*Relation between the Contents of Organic Carbon and Kjeldahl Nitrogen in Muds from the Upper Mersey Estuary*

higher for organic matter of vegetable origin than for organic matter of animal origin. The results in Fig. 23, however, indicate that, even in a mud bank which appears to be homogeneous, the ratio may vary within wide limits; large numbers of samples from a mud deposit should be examined before any conclusions on the origin of the organic matter present are drawn from a consideration of the carbon-nitrogen ratio.



The number of determinations is shown against each point

FIG. 24—*Relation between the Contents of Organic Carbon and Kjeldahl Nitrogen in Samples from the Inter-Tidal Deposits in the Upper Mersey Estuary*

MATERIAL EXTRACTED BY PETROLEUM ETHER

During this investigation several attempts were made to determine the nature of the organic matter in estuarine mud, particular attention being paid to constituents which might throw some light on the original source of the organic material. No reliable method was found for distinguishing between organic matter of vegetable and animal origin, but a promising method appeared to be the determination of the content of ether-soluble substances in the organic matter in the mud. The content of ether extractives of sewage and of sewage sludges is high; thus in seven samples of crude sewage the ether extractive varied between 3·3 and 24·4 per cent. of the total solids or between 16·2 and 56·0 per cent. of the suspended solids. Some of these sewages contained trade wastes, including tannery effluents and wool-scouring wastes[1]. The percentage of fat in crude sewage sludges has been put at 29·5 per cent. by Hoyle[2], and at 21·0 to 22·0 per cent. by Coste[3]; these workers gave the fat content of digested sludges as 12·2 per cent. and 7·0 to 8·0 per cent. The fat content of vegetable organic matter is usually much lower. In determining the fat content of a mud, diethyl ether is unsuitable as it dissolves iron salts. Extractions were therefore carried out with petroleum ether which dissolves fatty material and also a certain amount of elementary sulphur which is often present in mud; the sulphur must be removed by a second extraction of the fatty material, using only a small quantity of petroleum ether. It is probable that the material ultimately extracted contains substances other than fats. The content of petroleum ether extractives in samples from the Stanlow Bank is given in Table 27. The extraction was carried out in some cases on the sample as taken, but in a few samples the sand was first separated from the mud by fractional sedimentation in water. The quantity of extractive per unit weight of organic carbon in all the samples examined was reasonably constant at a value of about 1 per cent. by weight of the organic carbon present in the muds.

TABLE 27.—*Content of Material extracted by Petroleum Ether in Muds from the Stanlow Bank, Upper Mersey Estuary*

Sample No.	Percentage of dry weight.		Petroleum ether extract (gm. per 100 gm. of organic carbon).
	Petroleum ether extractives.	Organic carbon.	
S 314	0·026 0·045 0·030	2·28 2·28 2·28	1·5
S 310	0·020 0·023 0·016	3·01 3·01 3·01	0·6
S 112	0·013	1·62	0·8
S 105	0·082	2·63	3·1
S 222	0·041	3·06	1·3
S 209	0·032	2·73	1·2
S 165	0·013	1·42	0·9
S 180	0·023	1·93	1·2
S 304	0·013	—	—
S 302	0·027	—	—
S 303	0·015	—	—
S 301	0·014	—	—
S 344	0·029	2·25	1·3
S 343	0·042	4·25	1·0
S 339	0·018	1·84	1·0
S 345	0·022	2·26	1·0
Average values	0·027	2·49	1·2
Samples after removing sand by fractional sedimentation :—			
S 286	0·053	3·49	1·5
S 287	0·051	2·97	1·7
S 285	0·007	3·48	0·2
S 288	0·020	3·09	0·6
S 271	0·007	2·06	0·3
S 290	0·011	2·78	0·4
Average values	0·025	2·98	0·8

SULPHUR CONTENT

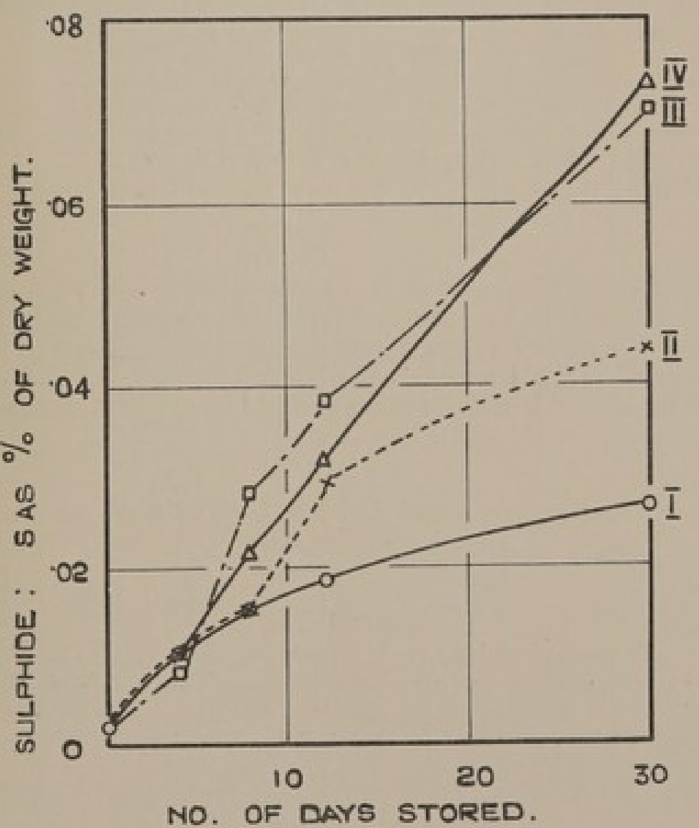
A general examination of the Stanlow Bank showed that the surface layer of the mud consists of light brown material, but that below the surface the mud is often black. When the black mud is exposed to the air, as, for example, after erosion of the edge of the bank by fretting, the black mud rapidly becomes light brown in colour. The black colour of sub-surface mud is due to the presence of ferrous sulphide. In determining the distribution of sulphide in different parts of the bank it is evident that the distribution of all forms of sulphur should be considered, since the sulphide in mud which has been maintained under anaerobic conditions can readily be changed to other forms of sulphur when the mud is exposed to the air. The presence of ferrous sulphide in mud has been ascribed to various causes. It may be produced by way of the bacterial decomposition of organic matter containing sulphur. On the other hand, it is known that certain bacteria in the presence of organic matter can reduce sulphates to sulphides; this reaction probably accounts for the presence of ferrous sulphide in marine muds in many parts of the world.

The changes in the distribution of sulphur which can occur in Mersey mud under different conditions were followed in some laboratory experiments. Samples of brown Mersey mud were allowed to stand in stoppered jars and sub-samples were removed at intervals for the determination of total sulphur and of sulphide, sulphate, and elementary sulphur; the results obtained in one experiment are given in Table 28.

TABLE 28.—*Changes in Distribution of Sulphur in Brown Mersey Mud incubated at 18·3° C. in Stoppered Jars*

Time (days).	Moisture (per cent.).	Sulphur (S as per cent. of dry weight).			
		Total sulphur.	Sulphate.	Elementary sulphur.	Sulphide.
0	73·2	0·44	0·17	0·24	0·029
3	68·0	0·44	0·14	0·23	0·053
4	66·9	0·44	0·14	0·22	0·059
5	66·0	0·43	0·12	0·23	0·067
6	66·0	0·44	0·11	0·23	0·076

During the six days on which determinations were made, the total sulphur found remained constant within the limits of analytical error; the concentration of elementary sulphur similarly showed no wide fluctuation. On the other hand, the concentration of sulphate fell steadily during the period of the experiment, while the concentration of sulphide rose by an amount which was approximately equivalent to the loss of sulphur from the sulphate. In a second experiment, samples of a black Mersey mud which had been taken from below the surface of the Stanlow Bank were set out in open Petri dishes and allowed to dry at air temperature; the changes in the distribution of sulphur during this process are shown in Table 29. In this case the concentration of total sulphur again remained unchanged during the experiment, as did also the concentration of sulphate sulphur. The concentration of sulphur present as sulphide, however, fell to zero by the sixth day and the figures show that the sulphide had been converted to elementary sulphur.



Curve I. No Na_2SO_4 added.
,, II. 1 ml. of 10 per cent. Na_2SO_4 solution added to 200 gm. wet mud.
,, III. 5 ml. ,, ,, ,, ,, ,, ,,
,, IV. 10 ml. ,, ,, ,, ,, ,, ,,

FIG. 25—*Effect of the Addition of Sodium Sulphate on the Production of Sulphide in a Mud stored Anaerobically*

TABLE 29—*Changes in Distribution of Sulphur in Black Mersey Mud allowed to dry in Petri Dishes at Room Temperature*

Time (days).	Moisture (per cent.).	Sulphur (S as per cent. of dry weight).			
		Total sulphur.	Sulphate.	Elementary sulphur.	Sulphide.
0	50·1	0·74	0·09	0·27	0·38
3	35·8	0·75	0·10	0·35	0·30
4	25·3	0·75	0·10	0·38	0·27
5	22·7	0·74	0·09	0·45	0·20
6	4·9	0·75	0·09	0·66	0

The conversion of sulphate to sulphide in muds kept under anaerobic conditions was shown in a third experiment in which samples of brown Mersey muds mixed with different amounts of sodium sulphate were allowed to stand in stoppered jars. The results obtained in this experiment are shown in Fig. 25. The addition of increasing concentrations of sodium sulphate caused the production of increasing amounts of sulphide.

It thus appears that the presence of sulphide in a mud bank depends mainly on the extent to which the mud comes into contact with the air or with water containing dissolved oxygen. Some determinations, however, were made of the concentration of sulphide sulphur in the Stanlow Bank and the results are shown in Table 30.

TABLE 30—*Distribution of Sulphides in Mud from the Stanlow Bank, Upper Mersey Estuary*

Sulphide content of mud (S as per cent. of dry weight)	0	0 to 0·03	0·03 to 0·06	0·06 to 0·09	0·09 to 0·12	0·12 to 0·15	0·15 to 0·18
No. of samples	56	12	19	17	6	3	2
Percentage of total number of samples examined	48·7	10·4	16·5	14·8	5·2	2·6	1·7

About half the samples examined contained no sulphide, while the highest value found was about 0·18 per cent. of sulphide expressed in terms of sulphur. Most of these samples, however, were taken from the top layer of the mud bank; the concentration of sulphide found would have been higher if sub-surface samples had been considered. The concentration of all forms of sulphur in a series of Stanlow muds is given in Table 31.

TABLE 31—*Distribution of Total Sulphur in Mud from the Stanlow Bank, Upper Mersey Estuary*

Total sulphur content (per cent. of dry weight)	0 to 0·07	0·07 to 0·13	0·13 to 0·19	0·19 to 0·25	0·25 to 0·31	0·31 to 0·37	0·37 to 0·43
No. of samples	12	6	9	5	4	2	2
Percentage of total number of samples examined	30·0	15·0	22·5	12·5	10·0	5·0	5·0

These values represent the maximum concentration of sulphide sulphur possible in the muds considered if all forms of sulphur had been converted to sulphide. Sea water however contains an appreciable amount of sulphate, and a mud bank may convert this sulphate to sulphide, as did samples of mud stored in the laboratory with solutions of sodium sulphate. The determination of sulphide may throw some light on the availability of the organic matter of mud for bacterial action, but it is not considered that the presence of sulphide gives any direct evidence of the presence or absence of sewage or other polluting material in a mud. It is well known that muds, in polluted or unpolluted localities, often contain black ferrous sulphide beneath the surface.

Biochemical Oxygen Demand

When organic matter is diluted with a large quantity of water containing dissolved air it is usually found that bacterial action begins and that part of the organic matter is oxidised, the oxygen used being taken from solution in the diluting water. This process is known to occur in the Mersey Estuary, and for this reason the dissolved oxygen content of the water is usually less than the saturation value. An attempt was made to determine the extent to which the organic matter of Mersey mud is capable of being oxidised biologically at the expense of the dissolved oxygen of the water in which it is suspended. The value was determined by measuring the weight of dissolved oxygen used per gm. of mud when a mud suspension in water was allowed to stand for 5 days at a temperature of 18·3° C. in completely full, stoppered bottles. It was found that the biochemical oxygen demand of mud depended largely on the efficiency with which the mud was kept in suspension during the determination. In all later experiments, therefore, the bottles were slowly rotated in a wheel to ensure that the mud did not settle to the bottom of the bottles during the 5-day period. The results of these determinations are given in Table 32. The values obtained range from 0 to 0·34 gm. of oxygen absorbed per 100 gm. (dry weight) of mud.

Table 32—*Biochemical Oxygen Demand of Mud from the Stanlow Bank, Upper Mersey Estuary*

Biochemical oxygen demand (gm. oxygen per 100 gm. dry wt. of mud).	No. of samples.	
	In tap water.	In sea water.
0 to 0·04	7	1
0·04 to 0·08	19	6
0·08 to 0·12	21	7
0·12 to 0·16	11	7
0·16 to 0·20	4	3
0·20 to 0·24	1	4
0·24 to 0·28	0	1
0·28 to 0·34	0	1

In Chapter III it was pointed out that the concentration of dissolved oxygen in the water of the Upper Estuary is in most parts well below saturation value. From the determinations made it cannot be said to what extent the mud carried in suspension in the Mersey, as distinct from the organic matter discharged in the form of sewage and industrial wastes, is responsible for this oxygen deficiency. It seems unlikely, however, that the presence of the mud is largely responsible for the deficiency since the examination of several estuaries, which are unpolluted by sewage or by industrial discharges but which contain large quantities of mud, gave concentrations of dissolved oxygen not significantly below the saturation value.

Sub-Surface Deposits

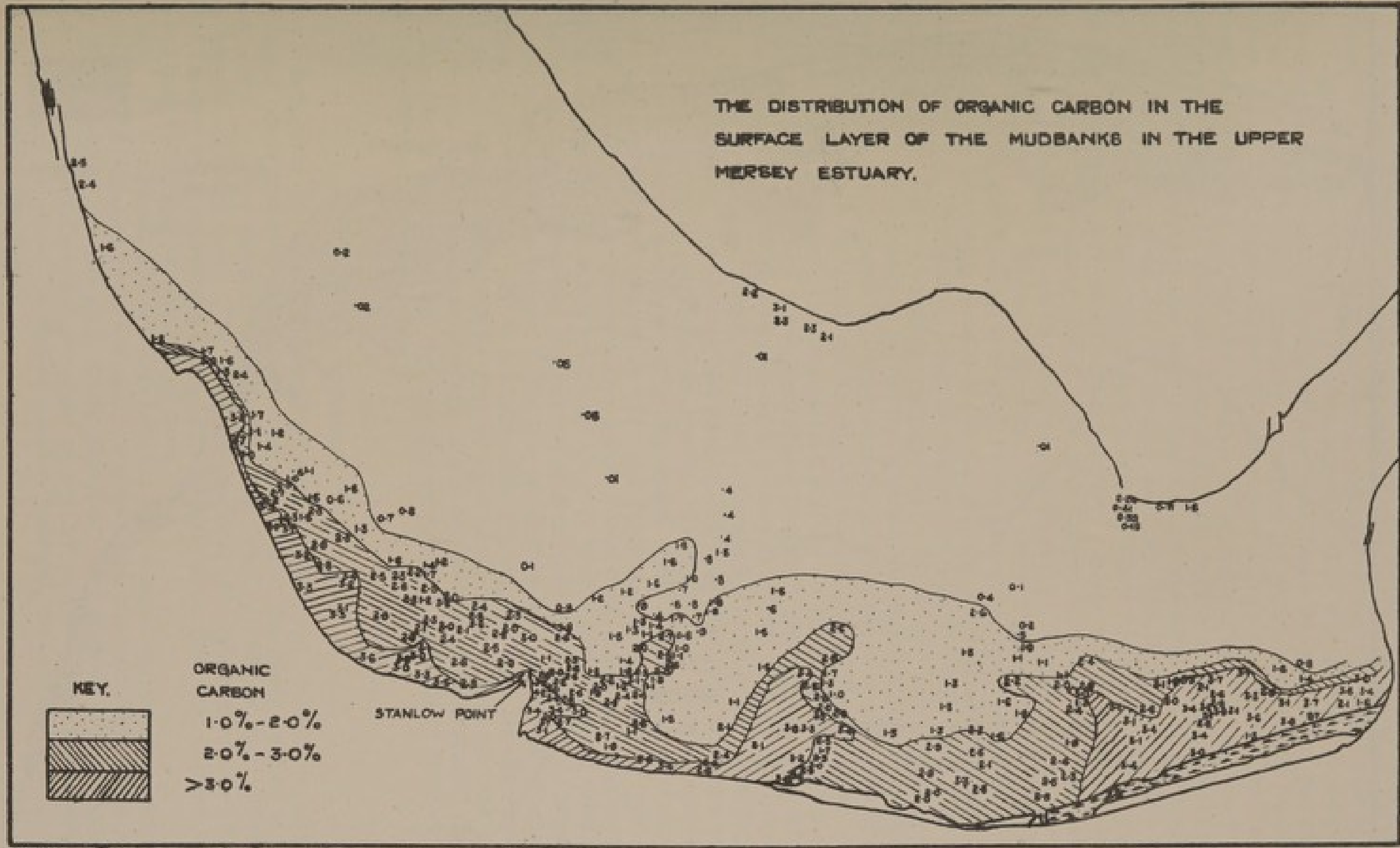
The majority of the samples of mud examined were taken from the surface of inter-tidal deposits in the Upper Estuary. Although the area of mud banks in the upper basin at the time of this investigation is known, little or no information is available on the amount of mud in the Estuary before the investigation was made. Moreover, owing to the continual changes which take place in the distribution of the mud, the period during which the deposits have remained in any position cannot generally be determined. An attempt was made, however, to obtain samples of old deposits by means of borings in the Stanlow Bank. A consideration of the charts of the quinquennial surveys of the Upper Estuary made by the Mersey Docks and Harbour Board shows that different parts of the Stanlow Bank, which now lie at a height of more than 20 feet above Datum, are of different ages. Over large areas, the bank, although it attained a height of 20 feet or more in earlier years, has subsequently been washed away and the material has been redeposited elsewhere; only in a few positions has it remained at this height for any length of time. By comparing successive charts, an estimate can be made of the period during which the surface material of different parts of the bank was laid down. In general, the part of the bank nearest to the shore is the most stable. In other places the old deposits now lie at some distance below the surface and over most of the area there has been alternating erosion and deposition of material. In some areas, however, it appears from the charts that the bank had a height of, for example, 10 feet above Liverpool Bay Datum in a certain year, but that other material was thereafter deposited on its surface until at this position the height is now approximately 20 feet. If a boring 10 feet deep is made at this position so as to reach a height of 10 feet above Datum, a sample taken at this level should consist of the material which was deposited when the surface of the bank was last at a height of 10 feet above Datum. There is a good deal of uncertainty in these estimates, since the charts from which they are made were prepared at 5-yearly intervals and no information is available of changes which may have occurred during these 5-yearly periods. For these reasons, no borings have been made near the River Gowy or Holpool Gutter, as these streams are known to change their course frequently and so cause rapid erosion and deposition in the areas through which they flow.

The composition of some sub-surface samples from the Stanlow Bank with an estimate of the date of their deposition is given in Table 33 (p. 246). In general it was found that the amount of sand in the mud increased at increasing distances from the surface of the bank, although, in one sample (S216), mud with comparatively little sand was found at a depth of 12·5 ft. below the surface of the bank where the deposit is estimated to have remained since the period 1861 to 1871. It would be expected that the material at the lower levels of the bank would be more sandy than that at the surface. At the present time most of the banks of a height of less than 20 ft. above Datum consist almost entirely of sand, and it appears that the deposition of mud does not occur extensively until a sand bank has reached this height, after which mud may be deposited to form a cap on the surface. The fact that there is now available only relatively sandy material which was laid down in earlier years and has not since been moved does not mean that in those years mud was not present in the Estuary. The high banks present in early years may have consisted partly of mud which has since been washed away and deposited in new positions. An examination of the figures in Table 33 shows that the amount of organic matter in the samples of material deposited in earlier years is approximately the same as in recent deposits containing the same amount of sand. There is thus no evidence that the mud mixed with these samples is significantly different in composition from the mud at present found on the surface of the Stanlow Bank.

Composition of Mud on the Stanlow Bank

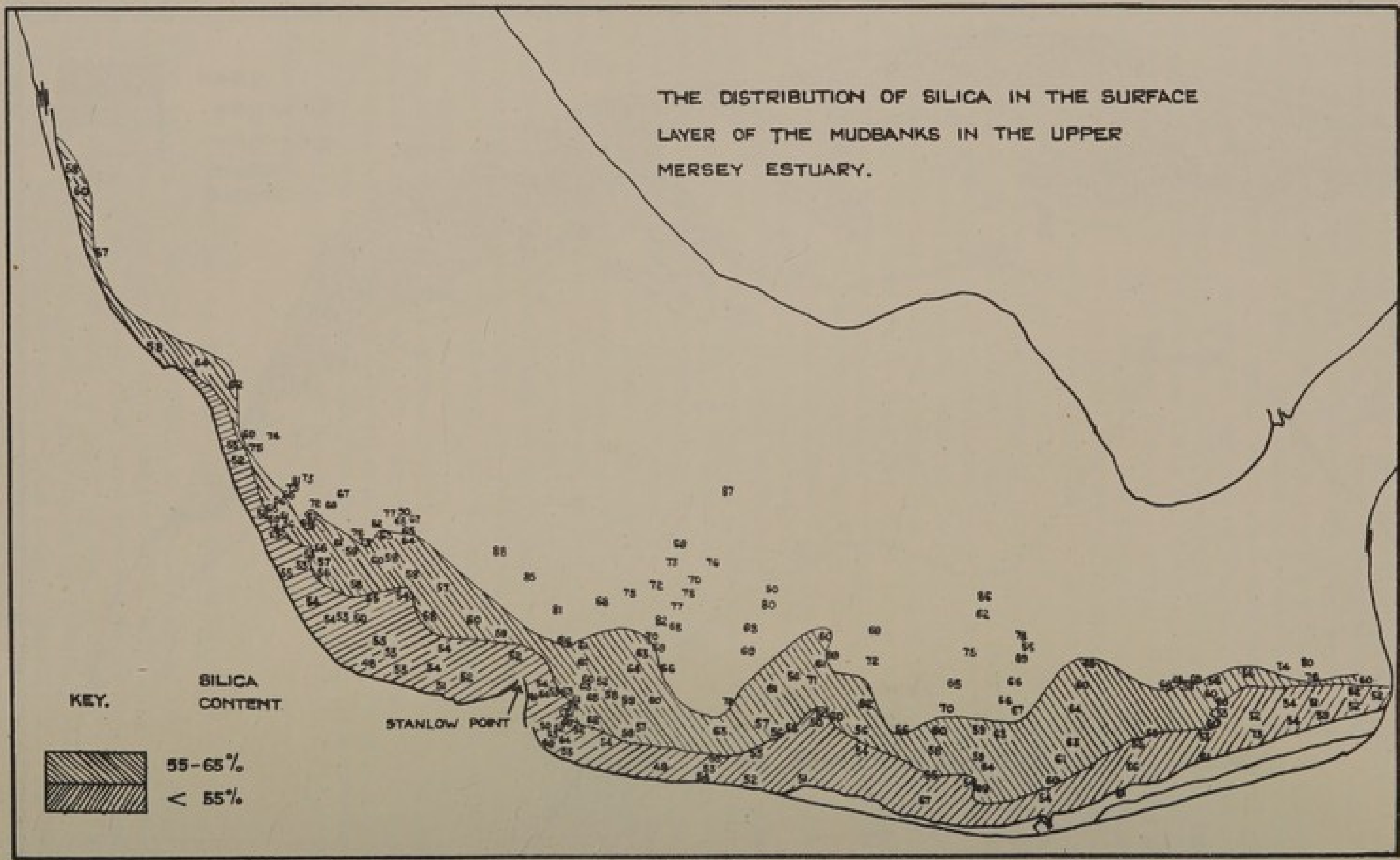
In Figs. 26 and 27 the concentrations of organic carbon and of silica in surface samples of inter-tidal deposits have been plotted in the positions from which the samples were taken, and contour lines have been drawn showing the general distribution of organic matter and of silica in the Stanlow Bank. These figures show that there is considerable regularity in the distribution of mud and sand in the bank. In general, the contours are roughly parallel with the shore of the Estuary, the less sandy samples occurring near the shore, and the more sandy samples in the off-shore part of the bank. The contours follow roughly the distribution of stream velocity shown in Fig. 13B (Chapter V), and it is evident that the mud has mainly been deposited in areas of low stream velocity near the shore of the Estuary. The occurrence of a few abnormally sandy muds

Fig. 26.


THE DISTRIBUTION OF ORGANIC CARBON IN THE SURFACE LAYER OF THE MUDBANKS IN THE UPPER MERSEY ESTUARY.
KEY.
ORGANIC CARBON
1·0%–2·0%
2·0%–3·0%
>3·0%
STANLOW POINT

(3296).

Fig. 27.


THE DISTRIBUTION OF SILICA IN THE SURFACE LAYER OF THE MUDBANKS IN THE UPPER MERSEY ESTUARY.
STANLOW POINT
KEY.
SILICA CONTENT
55-65%
< 55%

with low carbon and high silica contents shown in Figs. 26 and 27 is due to the fact that some samples were taken from drainage gulleys running through the mud bank; these gulleys often contain sand at the bottom where the mud has been washed away by the drainage water.

From the samples examined it appears that differences in the amount of organic matter in different samples are mainly due to the presence of varying proportions of sand. The muds with most organic matter are found chiefly in regions of low stream velocity. It thus appears that the deposits consist of mixtures of sand with varying amounts of mud which may be regarded as alumino-silicates in association with a reasonably constant proportion of organic matter. In the least sandy samples examined the amount of organic carbon was not more than about 4·5 per cent. of the dry weight. The organic matter contained on the average approximately 10 times as much organic carbon as Kjeldahl nitrogen. It is generally supposed that the association of large amounts of organic matter with clay is due to the small size of the clay particles, the surfaces of which are covered with organic matter. Sand grains, on the other hand, are too large to allow of the adsorption of so much organic matter. In no sample of Mersey mud examined was any indication found that the alumino-silicates are associated with a proportion of organic matter which is considerably higher than that found in the majority of the Mersey deposits. The concentration of sesquioxides in a sample has been taken as an indication of the amount of mud as distinct from sand; it is known that wide variations in the particle sizes of alumino-silicates can occur, and the amount of organic matter associated with this material probably increases with decreasing particle size. In a few cases mechanical analyses of muds were carried out by the method usually employed in soil analysis; these results are given in Table 34. In this method a sample of mud is first boiled with hydrogen peroxide to break up its organic matter, and is then treated with hydrochloric acid to destroy carbonates and washed to remove electrolytes; it is then dispersed in distilled water containing a small concentration of sodium hydroxide. The object of this treatment is to break up the clay or silt into its ultimate inorganic particles which are then separated into fractions of different sizes by sedimentation. In the method used in this work the finer fractions were separated by centrifuging at different speeds. It was found that, in general, the silica-sesquioxide ratio decreased in the order, sand, silt, clay, but that the ratio was approximately constant in the clay fractions irrespective of particle sizes. The greater part of the mud consisted of relatively coarse material which in a soil analysis would be called sand and silt. It is probable, however, that the clay fraction is of preponderating importance in determining the amount of organic matter associated with the sample. The loss on ignition increased in clay fractions of decreasing particle size, and it is reasonable to suppose that the amount of organic matter associated with the clay is also dependent on the particle size. The particle size distribution and the type of alumino-silicate present should therefore be considered in comparing the organic contents of samples of muds from different localities or of different origin.

Summary

Determinations of the chief inorganic constituents and of organic carbon and nitrogen were made on samples of mud taken over the whole surface of the Stanlow Bank. These samples consisted of clay and silt mixed with different proportions of siliceous sand. The moisture content, although it fluctuated from time to time as tidal conditions changed, was related to the sand content and decreased with increasing proportions of sand.

There was a well-marked relation between the organic carbon and nitrogen contents of mud samples and their silica content, the concentration of organic matter being highest in the least sandy samples. The highest organic carbon content found was less than 4·5 per cent. of the dry weight and in most samples was less than 4·0 per cent. A similar relation between the content of silica and the loss on ignition was found.

The ratio of organic carbon to nitrogen varied considerably in different samples, especially in those containing much sand, but the mean value was approximately 10.

The concentration of material soluble in petroleum ether was about 1 per cent. of the weight of organic carbon in any sample.

TABLE 34.—*Inorganic Composition of Different Fractions obtained by Centrifuging Mersey Muds*

Mud samples S 301, 302, 304 and 305 were dried and treated with H_2O_2 and HCl on the water-bath and thoroughly washed. They were then dispersed in distilled water with the addition of a small amount of NaOH. The following fractions were then separated by sedimentation or by centrifuging.

Fraction.	Approximate speed of centrifuge (r.p.m.). Period of centrifuging (min.).							
	1,000	1,220	1,440	1,670	1,900	2,140	2,400	3,000
1	Gravity sedimentation. Falling 30 cm. in 7 mins.							
2	5							
3	½	5						
4	½	½	10					
5	½	½	½	½	15			
6	½	½	½	½	½	½	15	
7	½	½	½	½	½	½	½	30
8	Left in suspension after No. 7. Obtained by drying.							

Sample No.	Fraction No.	Weight of fraction. (gm.)	Weight of fraction (per cent. of total weight).	Ultimate analyses (per cent. of dry weight). SiO₂	Al₂O₃	Fe₂O₃	Sesqui-oxides	Loss on ignition
S 301		50·55	100·0	55·7	11·0	7·0	18·0	12·3
	Sand 1	18·52	36·6	80·1	6·6	2·9	9·5	5·2
	Silt 2	18·17	36·0	60·7	15·5	6·9	22·4	9·0
	Clay 3	1·97	3·9	48·6	22·7	8·8	31·5	12·5
	Clay 4	2·48	4·9	43·7	23·6	9·2	32·8	16·9
	Clay 5	2·56	5·1	42·2	23·6	10·2	33·8	17·1
	Clay 6	1·91	3·8	40·1	22·2	10·2	32·4	20·3
	Clay 7	1·94	3·8	38·3	17·8	6·4	24·2	32·0
	Clay 8	3·00	5·9	39·8	19·7	10·2	29·9	19·1
S 302				57·3	—	—	16·6	12·9
	Sand 1	—	—	79·5	—	—	9·8	5·3
	Silt 2	—	—	61·7	—	—	20·5	10·3
	Clay 3	—	—	47·9	—	—	31·4	17·2
	Clay 4	—	—	44·7	—	—	32·6	15·1
	Clay 5	—	—	42·2	—	—	32·5	16·6
	Clay 6	—	—	38·9	—	—	29·5	24·0
	Clay 7	—	—	40·6	—	—	29·8	20·1
302 } 304 }	Clay 8	—	—	37·8	17·1	7·8	24·9	26·4
S 304				73·0	—	—	11·0	7·3
	Sand 1	—	—	79·0	5·5	2·4	7·9	3·5
	Silt 2	—	—	63·7	13·6	7·1	20·7	9·0
	Clay 3	—	—	48·7	22·4	9·8	32·2	13·1
	Clay 4	—	—	43·5	22·0	9·5	31·5	17·6
	Clay 5	—	—	41·0	21·9	10·4	33·3	19·7
	Clay 6	—	—	39·4	21·5	10·0	31·5	22·2
	Clay 7	—	—	38·7	20·7	9·9	30·6	25·2
304 } 302 }	Clay 8	—	—	37·8	17·1	7·8	24·9	26·4
S 305		59·86	100·0	57·1	11·5	5·9	17·4	13·0
	Sand 1	21·51	35·9	79·2	—	—	8·4	5·2
	Silt 2	22·87	38·2	64·6	—	—	18·4	7·8
	Clay 3	2·05	3·4	45·4	—	—	27·5	19·2
	Clay 4	2·67	4·5	48·2	—	—	31·0	13·2
	Clay 5	2·69	4·5	40·4	—	—	28·2	24·1
	Clay 6	2·59	4·3	37·7	—	—	26·4	29·0
	Clay 7	2·24	3·7	35·7	—	—	23·7	32·2
	Clay 8	3·24	5·4	31·9	—	—	22·1	38·3

The concentration of sulphide varied in different samples between 0 and 0·18 gm. S per 100 gm. of dry mud; the highest concentration of total sulphur found was 0·43 gm. S per 100 gm. The sulphide content was in all cases low in mud exposed to the air but was higher in the black mud below the surface and thus exposed to anaerobic conditions. It was shown by laboratory experiments that sulphide in mud allowed to dry in the air is converted to elementary sulphur, while under anaerobic conditions sulphate is reduced to sulphide. The sulphide content could be further increased by the addition of sodium sulphate to muds allowed to stand out of contact with air.

The biochemical oxygen demand in 5 days of mud maintained in suspension in sea water and in tap water varied between 0 and 0·34 gm. oxygen per 100 gm. dry weight of mud.

Samples of mud deposited on the Stanlow Bank at different periods, including some estimated to have been deposited between the years 1861 and 1871, were obtained by boring. In most cases the sand content increased with increasing depths below the surface. The organic content of the mud deposited in earlier years was approximately the same as that of recent deposits with about the same silica content.

The surface mud of the Stanlow Bank is least sandy and contains the highest concentrations of organic matter near the shore, the proportion of sand increasing towards the outer edge of the bank. These changes are correlated with the velocity of the tidal streams.

Mechanical analysis of some samples showed that the greater part of the mud consisted of relatively coarse material, but it is suggested that the capacity of the mud to adsorb organic matter may be largely dependent on the particle-size distribution in the finer clay fraction.

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CHAPTER VII

POSSIBLE SOURCES OF MERSEY MUD

The composition of the inter-tidal deposits in the Upper Estuary has now been discussed, and it has been shown that the composition of the muds found in different parts of the upper basin is approximately the same, due allowance being made for the sand mixed with the mud. Before it can be decided to what extent the composition of these deposits has been influenced by the presence of sewage in the Estuary water it is necessary to ascertain the source of the deposits in the Upper Estuary. It would appear that there are three sources from which material might enter the upper basin and be deposited on the inter-tidal banks. These sources are the fresh-water streams and discharges of sewage which may carry material in suspension, the water entering the Estuary from Liverpool Bay, which may carry material eroded from the sea bed, and the shores of the Estuary which may be eroded by the Estuary water. The deposition of suspended matter brought in by sewage, by fresh-water streams or from the sea would tend directly to decrease the capacity of the upper basin, but if erosion of the shores of the basin occurred the process would consist, at least in part, of a transference of material from one part of the Estuary to another.

Shores of the Estuary

An attempt has been made to estimate the extent to which the shores of Liverpool Bay and of the Upper Estuary are being eroded. It was found impossible from a consideration of the available charts of the Estuary to determine the volume of material removed and the estimate of the extent of the erosion in recent years is based only on visual observation of the shores.

On the Lancashire side of Liverpool Bay from Formby to the Narrows the material exposed to the action of the sea is mainly sand, the shores being formed of an almost continuous strip of sand dunes. These dunes have been much eroded during recent years, and at one point they have been faced with slag to prevent further erosion. In other places groynes have been constructed. In some places at the base of the sand dunes a peat bed is exposed with an under-clay which is thought to be an ancient estuarine mud. This comparatively small belt of clay is composed of material similar in composition to mud taken from the Upper Estuary. Thus a sample of the clay gave the following analysis :—

Silica	64·9 per cent. of dry weight.
Sesquioxides	18·0 ,, ,, ,, ,,
Loss on ignition	11·6 ,, ,, ,, ,,
Organic carbon	2·77 ,, ,, ,, ,,

From the entrance to the Narrows to Garston the shore is everywhere protected by stone-work, so that no erosion can take place in this section. From Garston for a distance up-stream of about 6 miles the shore consists of cliffs of boulder clay, the base of which for most of the distance is only reached at high water of high spring tides. This line of cliffs has in the past been subject to considerable erosion, but the erosion now appears to have ceased in most places since the face of the cliffs is mainly covered by small trees and bushes. Above Dungeon Point there is a belt of salt marshes in front of the cliffs, and above this point erosion of the cliffs does not now appear to be going on to any great extent. Above Widnes the river runs through old salt marshes which in places are being washed away.

On the Cheshire shore between Runcorn and Eastham the boundary of the Estuary is the outer bank of the Manchester Ship Canal. Between Runcorn and the River Weaver there are no old deposits in front of the canal bank; below the Weaver, however, there is a strip of marsh which originally formed part of the Frodsham marsh, the greater part of which is now cut off from tidal action by the canal. There is no evidence that the remaining strip of marsh is now being eroded. Below Eastham to the entrance of the Narrows the Cheshire bank is largely protected by stone-work. From the entrance of the Narrows to the Dee the shore consists mainly of sand dunes or stone-work, though there is a small patch of exposed clay which does not appear to be eroded to any great extent. It would appear, therefore, that the main materials capable of being eroded from the shores of the Estuary are sand, boulder clay, and material from old salt marshes.

The composition of some samples taken from marshes in positions where erosion was occurring is given in Table 35 (p. 247). The composition of these samples is similar to that of deposits from inter-tidal banks in the Upper Estuary, the highest organic carbon content found being 3·27 per cent. The composition of some samples of boulder clay is shown in Table 36 (p. 247), and the average composition is given in Table 37.

TABLE 37—*Average Composition of Samples of Boulder Clay from Cliffs on the Shores of the Mersey Estuary*

No. of samples.	Percentage of dry weight (mean).		No. of samples.	Percentage of dry weight (mean).	
	Organic carbon.	Kjeldahl nitrogen.		Silica.	Sesquioxides.
9	0·45	0·04	4	65·6	16·3

The composition of boulder clay is entirely different from that of mud, since, although it contains a high proportion of alumino-silicates, the content of organic matter is very much lower than in mud. It does not appear, however, that the erosion of boulder clay has proceeded to any great extent during recent years, and it is considered that the amount of boulder clay eroded must be very small compared with the changes which have occurred in the volume of the Upper Estuary. Thus it is calculated that if the whole line of boulder clay cliffs were cut back for a distance of 1 yard the volume of material which would be removed would be about 75,000 cubic yards. This is very small in comparison with the average annual change which has taken place in the volume of the Estuary since about 1900; it is certain that the cliffs are not at present being cut back at the rate of 1 yard per year.

FRESH-WATER STREAMS

The main fresh-water streams entering the Estuary have been largely altered in character by their conversion into canals. Thus the River Mersey with its tributaries and the River Weaver, the two largest streams entering the Estuary, have been deepened for a considerable part of their length and the speed of flow of the fresh water in them has consequently been reduced. Part of the suspended matter brought down from the catchment areas, which would normally be discharged into the Estuary, is now deposited upon the bed of the canals, whence it is removed by dredging. The quantity of suspended matter entering the Estuary from fresh-water sources is thus considerably lower than would be the case if the streams ran in their natural beds. In the River Mersey the concentration of the material in suspension at times of low fresh-water flow is as a rule small, but becomes much higher during fresh-water spates. Owing to the fact that the flow of the Mersey is in part artificially controlled by the operation of sluices, it has not been found possible to estimate the average amount of suspended material brought by it into the Estuary during a year. A few determinations of the flow of the river and of the corresponding concentrations of suspended matter have, however, been made (Table 38).

TABLE 38—*Flow of the River Mersey at Howley Weir and Concentration of Suspended Matter*

Date.	Flow of river (mil. gal. per day).	Concentration of suspended matter (parts per 100,000).
27.9.34	—	0·4
5.10.34	3·62	11·0
8.10.34	0·84	1·1
18.10.34	0·72	5·7
30.10.34	1·60	6·4
2.11.34	0·38	1·2

The highest concentrations occurred at times when the flow of the river was highest. The mean concentration of suspended matter observed was approximately 4·3 parts per 100,000. If this figure is taken as the mean for a year and the mean flow of the river is taken at the value given in Table 4 (Chapter II), the weight of suspended material coming in from the River Mersey to the Estuary is about 33,000 tons per year. It is probable that the actual amount in a year exceeds this figure, since the concentration of material in suspension increases considerably at times of high fresh-water flow. It appears, however, that the suspended matter discharged in fresh-water streams cannot now be one of the main sources of material available for the formation of extensive inter-tidal banks in the upper basin.

Some figures giving the composition of the suspended matter in the River Mersey and in Sankey Brook are shown in Table 39 (p. 248). This material is entirely different from that of the estuarine deposits; the silica content is low and the content of organic matter very high. Thus, in suspended matter carried by the River Mersey, a content of organic carbon of nearly 40 per cent. was found on one occasion. In most samples, however, the ratio of organic carbon to nitrogen was not greatly different from that found in estuarine muds. The composition of material dredged from the bed of the Manchester Ship Canal, through which the River Mersey flows, is shown in Table 40 (p. 248) and the average figures are given in Table 41.

TABLE 41—*Average Composition of Samples dredged from the Bed of the Manchester Ship Canal*

Distance above Eastham Locks (miles).	No. of samples.	Mean organic carbon (per cent. of dry weight).	Mean Kjeldahl nitrogen (per cent. of dry weight).
0 to 5	4	2·80	0·41
5 to 10	4	2·25	0·23
10 to 15	2	3·40	0·22
15 to 20	5	2·59	0·14
20 to 25	2	7·43	0·48
25 to 30	4	6·34	0·50
30 to 34	4	9·81	0·61

The bed of the tidal part of the canal immediately above Eastham is mainly composed of material similar to that which forms the inter-tidal banks in the Estuary, and it is probable that in this part the deposits on the bottom have been carried into the canal in suspension in Estuary water during spring tides. In the higher reaches of the canal, however, the bottom deposits contain very much more organic matter. The deposits in the upper reaches are semi-liquid, and are easily eroded by moving water; it is probable that some of this material is washed into the Estuary during fresh-water spates.

In general, it may be said that the greater part of the material entering the Upper Estuary in suspension in fresh-water rivers is likely to have a considerably higher content of organic matter than the inter-tidal deposits in the Estuary.

A small quantity of inorganic material enters the Estuary as a constituent of sewage. This material includes sand and silt washed from the streets into the sewers during storms. From published data giving the weight of inorganic material deposited in sludge at sewage purification works in large towns it is calculated that if the whole of the insoluble inorganic matter in sewage discharged direct into the Estuary were deposited, the annual volume would not exceed 25,000 cubic yards. The true value is probably less than this since part of the inorganic matter will be carried in suspension and out to sea. Even the estimated maximum quantity of 25,000 cubic yards per year is less than 0·25 per cent. of the average quantity of material removed annually by dredging in the Estuary, and is negligible in comparison with the changes observed in the capacity of the Estuary.

Bed of Liverpool Bay and the Irish Sea

The third possible source of the material of which the inter-tidal banks in the Estuary are composed is the bed of Liverpool Bay or of the Irish Sea outside it. It was not found possible to estimate directly the amount of material in suspension which comes into the Upper Estuary from the Irish Sea and is retained there. The concentration of suspended matter in the water passing in and out of the Narrows is often very high, especially during spring tides, but measurement of the amount which comes in from the sea and does not return would be a matter of great difficulty. It is certain, however, that a considerable amount of material

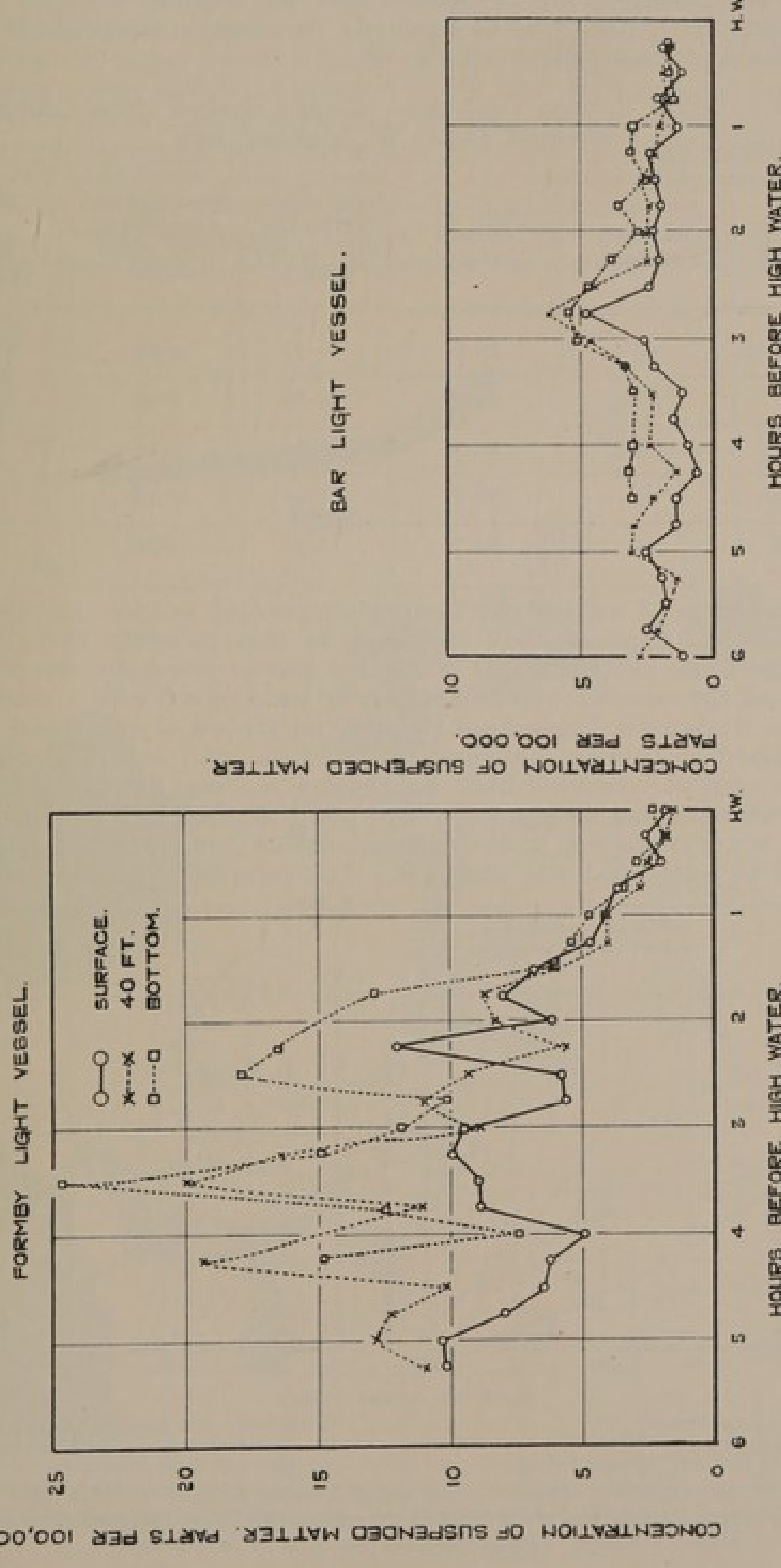


Fig. 28—*Concentration of Suspended Matter in Liverpool Bay during the Flood Tide on 11th November, 1935 Height of High Water 30 ft. 4 in.*

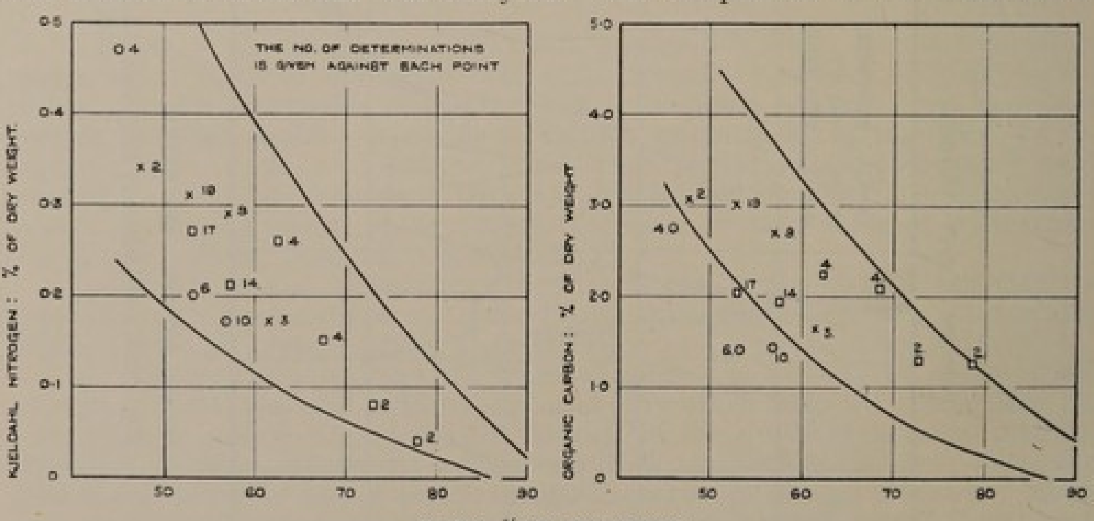
is transported in Liverpool Bay since large volumes of sand frequently change their position and have to be removed by dredging. Diagrams showing the concentration of suspended matter during the flood tide at the Bar Lightship and at Formby Lightship on 11th November, 1935, are given in Fig. 28. At the Bar the maximum concentration at about half flood was approximately 6 parts per 100,000 and at Formby Lightship 25 parts per 100,000. It is probable that the sea bed is the most important source of any large quantity of material coming into the upper basin. The daily inflow of water from the Bay through the Narrows is very large compared with the flow from fresh-water streams.

It was mentioned in Chapter V that, though the greater part of the bed of Liverpool Bay consists of sand, patches of mud or of muddy sand were found in some positions. Samples were collected from the Bay by dredging and their content of organic matter was determined; the figures are given in Table 42 (p. 249), and the average values in Table 43.

TABLE 43—*Average Organic Content of Samples dredged from Channels and Submerged Banks in Liverpool Bay*

Range of organic carbon (per cent. of dry weight).	No. of samples examined.	Moisture content (per cent.).	Mean organic carbon (per cent. of dry weight).	Mean Kjeldahl nitrogen (per cent. of dry weight).	Ratio: Carbon / Nitrogen.
0 to 0·5	46	19·9	0·27	0·03	9·0
0·5 to 1·0	25	27·3	0·69	0·06	11·5
1·0 to 1·5	5	37·3	1·31	0·11	11·9
1·5 to 2·0	6	36·5	1·69	0·13	13·0
2·0 to 2·5	3	50·7	2·16	0·23	9·4

In the majority of the samples the organic content was low and the carbon-nitrogen ratio was approximately the same as that in muds from the Upper Estuary. The small concentrations of organic matter found are due to the fact that almost all the samples consisted mainly of sand mixed with a small amount of mud. This mud can be washed out by a moving stream of water, and, to obtain a better comparison between the composition of the mud and that of inter-tidal deposits, the mud was removed from a number of samples dredged from the Bay by making a suspension in tap water and allowing the sand to fall out. The supernatant water containing mud in suspension was then poured off and the mud was allowed to settle and was analysed. The composition of the material so



○ Irish Sea—Average Values.
□ Liverpool Bay—Average Values.
× Upper Mersey Estuary—Average Values.

In all but a few cases the corresponding points for individual samples from the Upper Estuary fall within the lines shown (*see* Fig. 22)

FIG. 29—*Content of Organic Carbon and of Kjeldahl Nitrogen in Muds from Samples taken from the Bed of the Irish Sea, from Liverpool Bay, and from the Upper Mersey Estuary. Muds separated from Sand by Sedimentation.*

obtained is given in Table 44 (p. 250). The composition of the mud fraction in bottom deposits from the Bay appears to be almost the same as that of the inter-tidal muds from the Upper Estuary. The mean values for the silica, organic carbon and Kjeldahl nitrogen contents of the muds examined are shown in Fig. 29. In this figure lines have been drawn which would enclose the majority of the individual points in corresponding diagrams for the values obtained from all the samples examined of inter-tidal muds from the Upper Estuary. Most of the mean values for the muds separated from the samples from the Bay fall within these limits. It was not known whether there was any considerable loss in the organic matter of mud when the mud was separated by sedimentation from a large quantity of sand. Samples of surface mud from the Stanlow Bank were, therefore, similarly treated in order to compare their relationship of carbon to silica with that in the untreated muds. The composition of a number of muds separated from samples from the Upper Estuary (Stanlow Bank) in this way is given in Table 45 (p. 251) and the mean values have been included in Fig. 29. A certain amount of organic carbon appears to be lost in separating the mud from the sand by the method used. The mean points for the muds separated from the Stanlow samples, however, lie in approximately the same positions as the corresponding points for muds separated from dredged material from the bed of Liverpool Bay.

If the large-scale Admiralty charts of the British coast are examined, it will be found that large areas of the sea bed are covered with muddy deposits (Fig. 30).

FIG. 30—*Distribution of Mud on the Sea Bed round the Coasts of the British Isles*

Areas of Mud shown black

In the Admiralty surveys the bottom deposits are usually obtained by arming a sounding lead with tallow, and the deposits brought up are classified by inspection. There is little mud off the east coast of Great Britain but mud is wide-spread on the west coast and covers large areas of the bed of the Irish Sea. A tongue of this mud appears to connect the Mersey Estuary with a large area of mud extending northwards in shallow water to the Solway. A few samples of the bottom deposits from the Irish Sea were examined during the investigation; many of the samples contained mixtures of mud and sand similar to those dredged from the bed of Liverpool Bay. The content of organic matter in some of the samples as taken is given in Table 46 (p. 252) and the composition of the mud separated from sand by sedimentation is shown in Table 47 (p. 252). The organic matter of the Irish Sea muds had usually a carbon-nitrogen ratio which was rather smaller than that of muds from the Upper Estuary. The mean values of organic carbon and Kjeldahl nitrogen found in the Irish Sea muds have been inserted in Fig. 29. It will be seen that the relation between the silica and nitrogen contents was roughly the same as that for muds from the Upper Estuary or from Liverpool Bay, but for a given silica content the amount of organic carbon present was rather lower in the Irish Sea muds than in the muds from the other two areas.

It seemed possible that the material carried in suspension in the Estuary water might be different in nature from that found in inter-tidal banks and accordingly some samples of material found in suspension were examined (Table 48, p. 253). The relation between the silica content and the organic constituents is shown in Fig. 31, from which it is clear that the material carried in

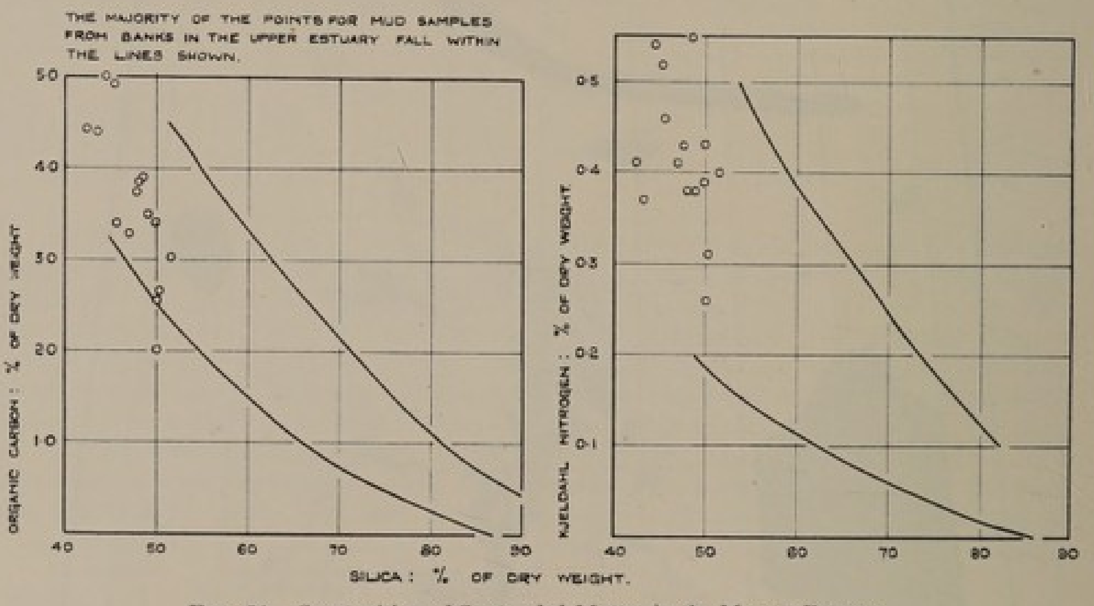


Fig. 31—*Composition of Suspended Matter in the Mersey Estuary*

suspension was essentially of the same nature as that taken from the mud banks of the Upper Estuary. In Fig. 31 the contents of nitrogen and organic carbon for different concentrations of silica are shown. It was found that the contents of organic matter and silica in the suspended material in the Estuary water were largely dependent on the concentration of the suspended matter; this variation is more fully discussed in Chapter XVI.

Summary

The most probable source of any large quantity of new mud which may be brought into the Mersey Estuary and assist in forming inter-tidal deposits is the bed of Liverpool Bay and the Irish Sea. The quantity of inorganic solid matter carried by sewage discharged direct into the Estuary is small. Suspended matter in the fresh-water streams contains on the whole a much higher proportion of organic matter than the deposits in the Upper Estuary. The boulder clay which forms cliffs on the Lancashire shore contains little organic matter, while the mud which is mixed with sand in the deposits in Liverpool Bay and in the Irish Sea has approximately the same general composition as the mud on the Stanlow Bank. No source has been found from which there has recently been eroded any appreciable quantity of clay with an organic content significantly lower than that of the existing deposits in the Estuary, nor has any such material been found in suspension in the Upper Estuary or in Liverpool Bay. It would appear, therefore, that mud coming into the upper basin is from the first associated with approximately the same amount of organic matter as is found in the mud forming the inter-tidal banks.

CHAPTER VIII

COMPARISON OF THE COMPOSITION OF THE DEPOSITS IN THE MERSEY WITH THAT OF DEPOSITS FROM OTHER LOCALITIES

Localities from which Samples were taken

It is well known that marine and estuarine deposits, which on inspection would be called "mud", are of widespread occurrence on the coasts of the British Isles and on the sea bed. It is of interest, therefore, to compare the composition of deposits which have been laid down in localities where pollution by sewage or industrial effluents is absent with the composition of the Mersey deposits which have settled out from water containing sewage and other polluting material. The composition of deposits from the bed of the open sea, where the influence of polluting substances may be considered to be negligible, is of special interest. It is well known that a considerable quantity of dissolved organic matter is present in sea water. Krogh[1] states that the organic matter in solution in sea water is in excess of that present as plankton. Raben[2] found about 3·0 mg. of organic carbon per litre in water from the Baltic Sea and 11 to 14 mg. in Baltic inshore waters. Task[3], in a report on an investigation of recent marine sediments, gives analyses for a large number of ocean deposits; those in the open sea contained up to 1 per cent. organic matter, while inshore deposits in the Pacific had an average of about 5 per cent. organic matter; approximately the same composition was found for deposits from the Black Sea and the Baltic. In recent deposits the carbon-nitrogen ratio was about 8·4, while in ancient deposits it was about 14·0. It was estimated that in muds of geological age about 20 per cent. of the original organic matter had been lost. Waksman[4], reporting on muds from the Cape Cod Bay area, found about 2 per cent. of organic carbon and a carbon-nitrogen ratio of approximately 8·0.

A general survey shows that the majority of the estuaries round the coasts of the British Isles contain mud. It is, however, difficult to find an estuary which is unpolluted, and samples have therefore been taken from estuaries most of which contain some sewage although in concentrations much less than the Mersey. The areas visited were the following :—

(1) *Salt marshes in Norfolk.*—Samples were collected on the north Norfolk coast between Blakeney and Wells-on-Sea. This coast has a belt of salt marshes in which there are numerous creeks. The small towns on the coast have no water-carriage sewerage systems, and the water covering the marshes is almost unpolluted.

(2) *Tamar Estuary, Devonshire.*—This estuary contains large areas of mud. It is polluted to some extent by sewage.

(3) *Dee Estuary, Cheshire.*—The Dee was visited as being the nearest estuary to the Mersey. It contains some polluting material from Chester and from works on the estuary banks, but is very much less polluted than the Mersey. Inter-tidal deposits consist mainly of sand, which in places is mixed with varying proportions of mud; the banks along the shores are much more muddy than those in the middle of the estuary.

(4) *Ribble Estuary, Lancashire.*—The fresh-water river contains polluting material but there are no towns comparable in size with those on the Mersey Estuary.

(5) *Morecambe Bay, Lancashire.*—This Bay contains a very large area of inter-tidal banks consisting mainly of sand or muddy sand, with mud banks along the shore in some places. Some sewage is discharged into the Bay but the concentration of polluting material must be small.

(6) *Tay Estuary, Perthshire.*—The estuary is fed by two large rivers, the Tay and the Earn; the sewage of Perth is discharged into the upper reaches of the Tay Estuary, and that from Dundee enters near the mouth. In connection with a survey of the River Tees[5], the water of the Tay Estuary was examined on several occasions in 1930, and was throughout found to be almost completely saturated with dissolved oxygen. The distribution of mud and sand in the Estuary of the Tay is very similar to that in the Mersey. The deposits on the south shore consist of clean sand and are subject to frequent movement, while in the bay on the north shore there is a large mud bank of about the same size and shape as the Stanlow Bank in the Mersey.

(7) *Lough Foyle, North of Ireland.*—The arrangement of mud and sand in this estuary is again similar to that in the Tay and the Mersey. A large mud bank occurs in a bay on the southern bank of the Lough. The River Foyle receives some sewage from Londonderry at the head of the estuary but there are no towns on the Lough itself. In view of the large volume of water in the Lough the concentration of sewage must be very small.

(8) *Estuaries in Suffolk and Essex.*—All the rivers between the Deben in Suffolk and the Roach in Essex were examined. Their estuaries are in general narrow and comparatively small. The greater part of the inter-tidal deposits consists of mud, and sand banks are uncommon; the mud, as a rule, covers the whole of both banks of each estuary and, in many cases, the bed of the low water channel. Most of the rivers contain some polluting matter but the concentration is much lower than in the Mersey. The least polluted locality visited was probably Hamford Water which is remote from any source of pollution; it consists of a large area of salt marshes intersected by creeks and is similar in appearance to the marshes in Norfolk.

(9) *The Wye Estuary, Monmouthshire.*—The Wye itself is little polluted, but is a tributary of the Severn which contains sewage and trade wastes. The Estuary of the Wye appears to be entirely covered with mud.

(10) *Estuaries of the Suir and Barrow, Irish Free State.*—These estuaries were visited to obtain information on the behaviour of mud in suspension. The estuary of the Suir receives sewage from the town of Waterford at its head, but has no towns on its lower part. The Barrow estuary, which enters the estuary of the Suir in its lower reaches, has no towns, and the amount of pollution it receives is negligible.

Determinations of the dissolved oxygen in some of the estuaries from which samples were obtained are given in Table 49 (p. 253). Except in the Ribble the dissolved oxygen contents indicate that the water in the estuaries examined was substantially unpolluted.

The estuaries examined were of three main types :—

(*a*) In the River Wye and in the Essex and Suffolk rivers, which are comparatively narrow and have shores which are almost parallel, the inter-tidal deposits on the banks and often those on the bed of the low water channel consist almost entirely of mud.

(*b*) In large estuaries, such as those of the Dee and the Ribble, which are widest at their mouth, the off-shore banks consist of sand mixed with mud, and there are comparatively narrow mud banks along the shores.

(*c*) The distribution of mud and sand in Lough Foyle and in the Estuaries of the Tay and Mersey is very similar. Each of these estuaries is comparatively narrow at the mouth and has a broader tidal lagoon above; in this lagoon the banks on the more concave side are composed of mud, and are sharply differentiated from banks of comparatively clean sand on the other side.

Inorganic and Organic Constituents

The composition of deposits from the various estuaries visited is given in Table 50 (p. 254). Where the deposits contained a considerable proportion of mud the composition of the samples as taken was determined; in samples of muddy sand, however, the sand was first removed by sedimentation and the mud was analysed (Table 51, p. 257). In general, the organic content of all the muds was of the same order as that of Mersey muds with the same silica content. The mean values for silica and organic carbon have been plotted in Fig. 32, and for silica and Kjeldahl nitrogen in Fig. 33. Lines have been drawn between which lie the majority of the corresponding points for all samples of Mersey mud examined; these lines were constructed from the data in Chapter VI. The organic content for a given silica value was in general highest in the muds from the Tay, the Wye, and the Severn, and the majority of the mean points for the other rivers fell within the limits found for the Mersey muds. A similar distribution was found for Kjeldahl nitrogen except that the nitrogen content of the Wye muds was low and the carbon-nitrogen ratio was, therefore, correspondingly high. The relation between the contents of silica and organic matter has not been shown for the muds from Lough Foyle, since in this Estuary the coarse material corresponding to sand in the Mersey is not entirely composed of silica, but contains a fair proportion of heavy minerals containing sesquioxides. The concentration of organic matter in the Foyle muds was higher than that in deposits from any other locality, an organic carbon content of 10·6 per cent. being found in one sample. The organic matter in the Foyle muds consisted largely of peat, which was found by microscopic examination to be present in different stages of decomposition. In general, the muds, such as those from the Essex rivers, which had approximately the same composition as the Mersey muds were found to be similar also in appearance and texture. They were usually black below the surface, had a characteristic smell, and were generally so soft as to make walking on them difficult. The deposits in the Foyle were semi-liquid in places and it was impossible to walk on them. The relation between the moisture and the organic content of all the samples examined was similar to that of the Mersey muds, the moisture content increasing with increasing amounts of organic carbon.

The relation between the silica and organic carbon content for all the muds included in Tables 50 and 51 is shown in Fig. 34, with the corresponding relation for the muds from the Upper Mersey. The two curves are approximately coincident. In this figure is also shown the mean carbon-nitrogen ratio for the two sets of muds. Up to a value of about 3 per cent. organic carbon the ratio is approximately the same for the Mersey and the other muds, but above this value the ratio is lower in the Mersey muds than in those from other localities. The difference is mainly caused by the inclusion of values given by the muds from Lough Foyle,

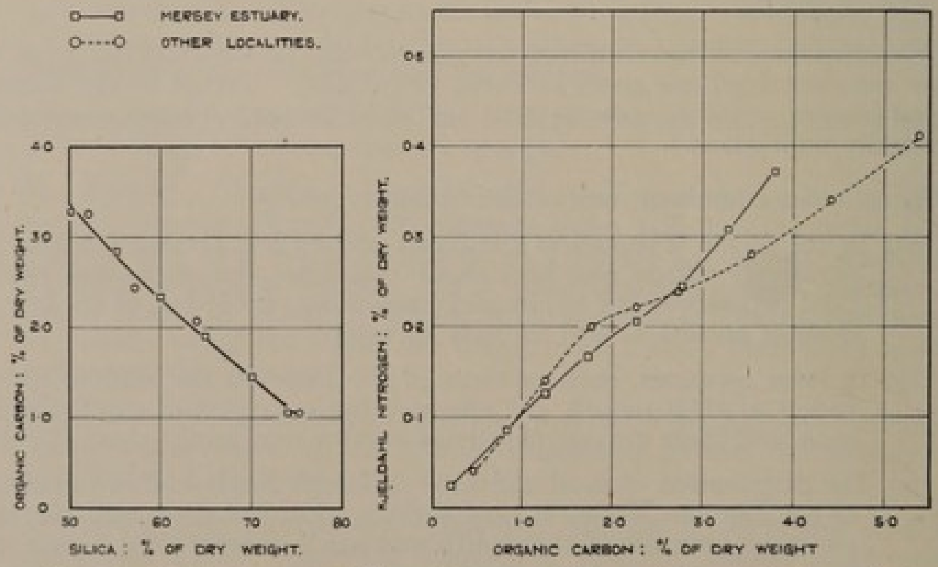


Fig. 34—*Relation between the Mean Contents of Silica and Organic Carbon and of Organic Carbon and Kjeldahl Nitrogen in Deposits from the Mersey Estuary and from other Localities*

Fig. 32.

THE RELATION BETWEEN THE SILICA & THE ORGANIC CARBON CONTENTS FOR DEPOSITS FROM VARIOUS LOCALITIES.

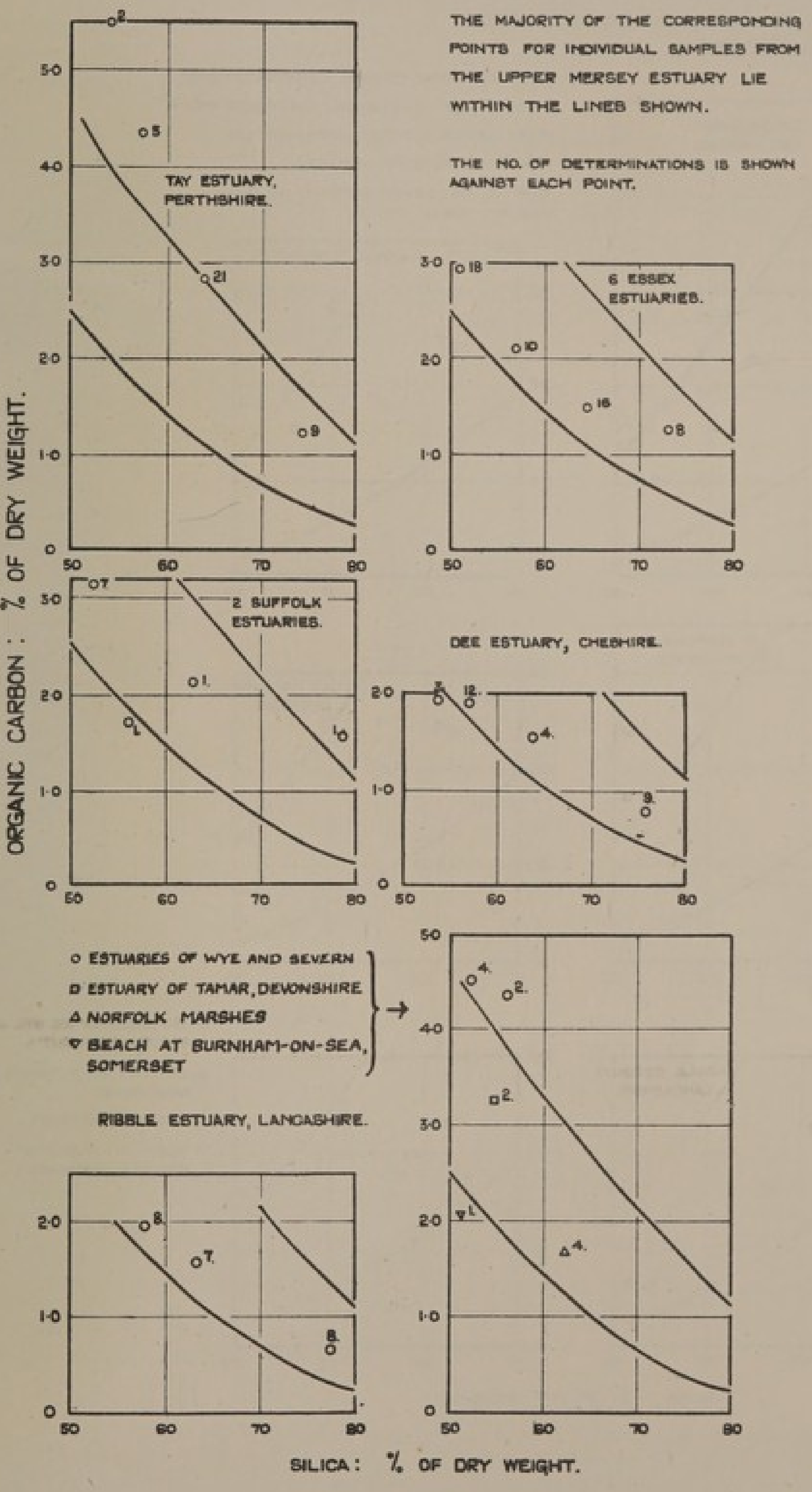
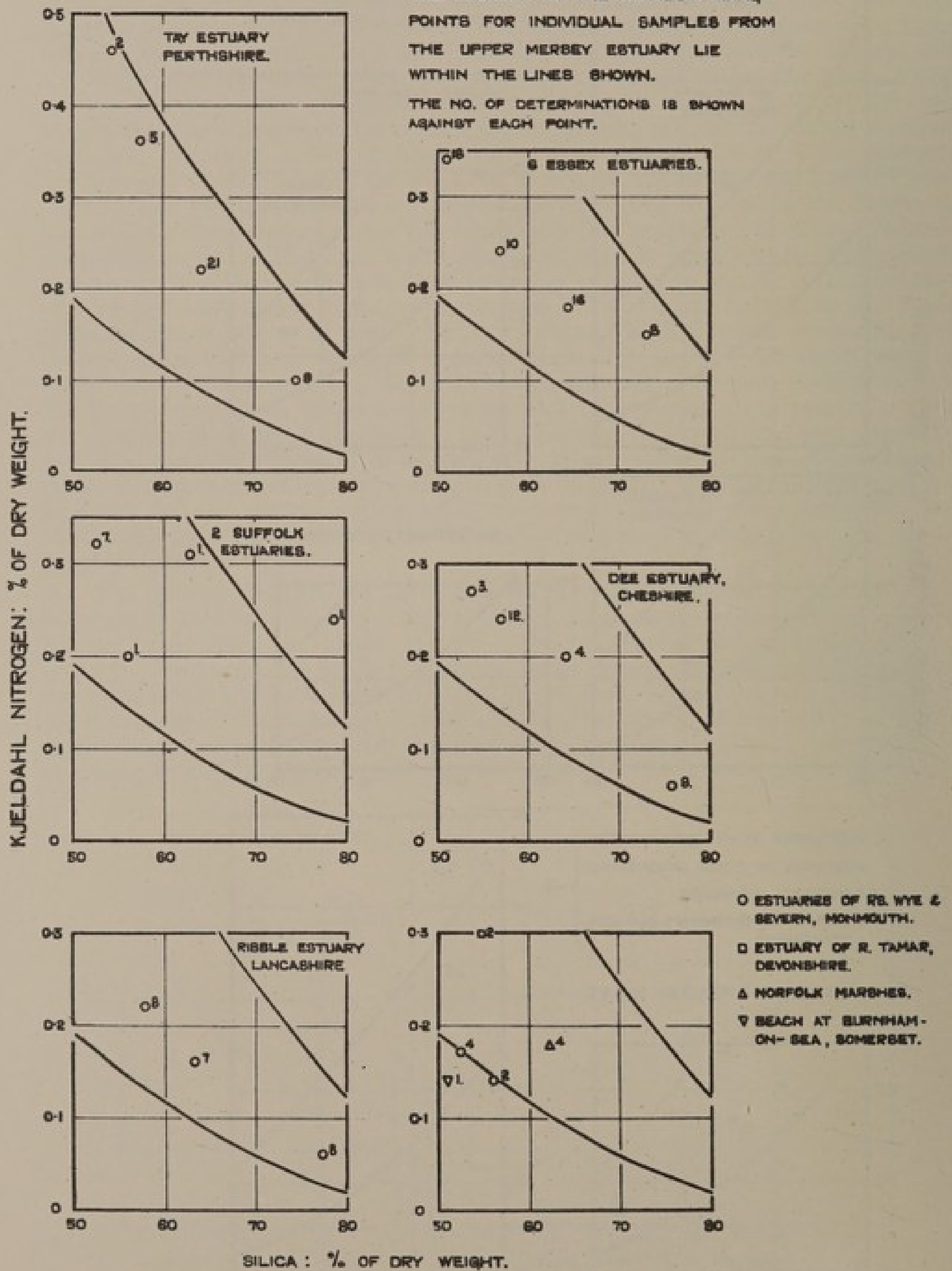


Fig. 33.

THE RELATION BETWEEN THE SILICA & THE KJELDAHL NITROGEN CONTENTS FOR DEPOSITS FROM VARIOUS LOCALITIES.

THE MAJORITY OF THE CORRESPONDING POINTS FOR INDIVIDUAL SAMPLES FROM THE UPPER MERSEY ESTUARY LIE WITHIN THE LINES SHOWN.

THE NO. OF DETERMINATIONS IS SHOWN AGAINST EACH POINT.



which contained a large amount of organic matter with a high carbon-nitrogen ratio.

A few experiments were carried out to determine the effect on the carbon-nitrogen ratio of stirring Mersey muds and boulder clay with various concentrations of sewage. The results are given in Table 52 (p. 259). Suspensions of the mud or boulder clay were stirred in large tanks with settled sewage liquor in concentrations up to 5 per cent. After stirring for some days the mud was allowed to settle, the supernatant water was siphoned off and the mud was collected and analysed. The addition of sewage under these conditions brought about an increase in the organic content of the muds, but the figures in Table 52 show that there was no considerable change in the carbon-nitrogen ratio.

Petroleum Ether Extractives

In Chapter VI some figures were given for the petroleum ether extractives of Mersey muds. Similar data for some of the muds from other localities are shown in Table 53 (p. 260). In this table figures for muds from the bed of the Irish Sea, from Liverpool Bay, and from the Manchester Ship Canal have been included for comparison. The contents of organic carbon and of petroleum ether extractives are also given for five digested sewage sludges, the earliest of which dates from 1913. The data are summarised in Table 54.

Table 54—*Average Content of Petroleum Ether Extractives in Mud from Various Localities*

Locality from which samples were taken.	No. of samples.	Percentage of dry weight.		Weight of ether extractives (gm. per 100 gm. of organic carbon).
		Petroleum ether extractives.	Organic carbon.	
Mersey Estuary	22	0·026	2·62	1·0
Liverpool Bay	6	0·025	1·89	1·3
Irish Sea	9	0·008	1·25	0·6
Dee Estuary, Cheshire.. ..	5	0·006	1·27	0·5
Ribble Estuary, Lancashire ..	5	0·007	1·58	0·4
Estuaries in Suffolk and Essex	6	0·011	3·90	0·3
Lough Foyle, North of Ireland	5	0·016	3·06	0·5
Manchester Ship Canal ..	5	0·274	1·76	15·6
Birmingham sewage sludges ..	5	2·049	21·56	9·5

In the samples from Liverpool Bay and the Upper Mersey Estuary, about 1 per cent. of the organic carbon consisted of material soluble in petroleum ether. In muds from the other estuaries and from the Irish Sea the proportion of extractives was rather lower. The amount of ether extractives found in individual samples varied considerably, and it is not certain that the figures shown in Tables 53 and 54 indicate any real difference between the content of petroleum ether extractives in Mersey mud and in other muds. There is, however, a distinct difference between estuarine muds and the samples of mud from the Manchester Ship Canal and of digested sewage sludges. In the two latter groups of samples the content of petroleum ether extractives is much too high to be due to uncertainty in sampling and in the analytical method used.

Summary

The concentration of organic carbon in muds from the polluted Upper Mersey Estuary is not appreciably different from that of muds of a similar silica content taken from estuaries and marshes in the British Isles which are not heavily polluted. Most of the localities from which the samples were taken are polluted by some sewage but the concentration of sewage in the water must in most cases be negligible when compared with that in the Mersey. In the few samples taken from localities such as the Norfolk marshes and Hamford Water, which as far as is known are unpolluted by sewage, there is no indication that the mud has a different composition from that found in the Mersey. The carbon-nitrogen ratio is, on the whole, similar in the Mersey and other muds, and it has been shown for Mersey muds that the ratio does not change significantly if the organic content is increased by the addition of sewage. There is an indication from average results that the Mersey Estuary mud contained rather more ether-soluble material than did the muds from other localities. It should be emphasised, however, that these average results were obtained from individual figures which differed considerably from one another. Both the Mersey and the unpolluted muds differ in a marked degree from the digested sewage sludges examined and from bottom deposits from the Manchester Ship Canal; these contained a high proportion of ether-soluble material.

In general the amount of organic matter in muds from the localities examined did not exceed the equivalent of about 4 per cent. of organic carbon in the dried mud, although higher values occurred in such estuaries as Lough Foyle, where the mud contains decomposing peat. This concentration of organic carbon is of a different order from that found in digested sewage sludges which contained up to 30 per cent. of the dry weight (Table 55, p. 261). As determined by analyses of the kind used in this investigation, the chemical composition of the muds from polluted and from unpolluted estuaries was approximately the same and by these methods it would seem to be impossible to determine whether a given mud was deposited in a polluted or unpolluted estuary.

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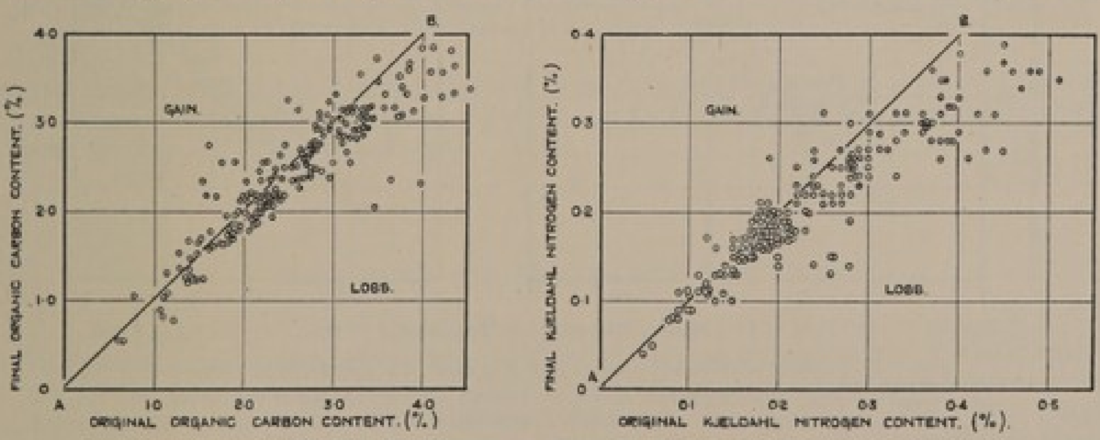
CHAPTER IX

CHANGES IN THE COMPOSITION OF MUDS AS A RESULT OF STORAGE

In an uncultivated soil the concentration of organic matter tends to remain at a constant level. Green plants produce organic matter, the carbon content of which is obtained from the carbon dioxide of the air, and when they die part of this organic matter remains in the soil. Here the organic matter is transformed into simpler substances, including carbon dioxide, by the action of bacteria, and the content of organic carbon at any time in the soil is the result of the equilibrium between these two processes. It is known that if an excess of organic matter is added to a soil the excess is rapidly decomposed until the content of organic matter falls to a value which depends on the type of soil and on other conditions. When this value has been reached the decomposition of further organic matter becomes a relatively slow process. The mud banks in the Mersey Estuary, which in many respects resemble soil, are at times covered with green algae, and it was thought that the organic carbon content of the mud might thus be increased by photosynthetic activity. Samples of mud were therefore allowed to stand, exposed to the light, and covered with sea water, for a period of about six months in shallow vessels, in order to determine whether a gain or loss of organic matter occurred. Under these conditions, however, the algae did not thrive. In some samples where growths occurred felted masses were formed on the surface of the mud and were difficult to mix with the mud for the purpose of analysis; before analysis, therefore, the algae were scraped away and discarded. A second series of samples was later allowed to stand in the dark for about a year. In all the samples the main changes in the organic content were due to decomposition only.

Mersey Muds

The contents of organic carbon and of Kjeldahl nitrogen in each sample before and after storage for six to twelve months are given in Table 56 (p. 262) and are shown graphically in Fig. 35. In some samples there was an observed gain in



The line AB represents no change in carbon or nitrogen

Fig. 35—*Contents of Organic Carbon and Kjeldahl Nitrogen in Mersey Muds before and after Storage for 6 to 12 Months at Laboratory Temperature*

carbon or nitrogen; this may be due, at least in part, to the uncertainty introduced by taking sub-samples from the samples stored, since mud contains a certain amount of adventitious organic matter which appreciably affects the organic content if included in a sub-sample. In general, the samples lost both organic carbon and nitrogen, the relative loss of nitrogen being somewhat greater than that of carbon. This is shown more clearly in Fig. 36, in which is plotted the percentage of the total number of samples examined which contained, after storage, a given proportion of their original organic content.

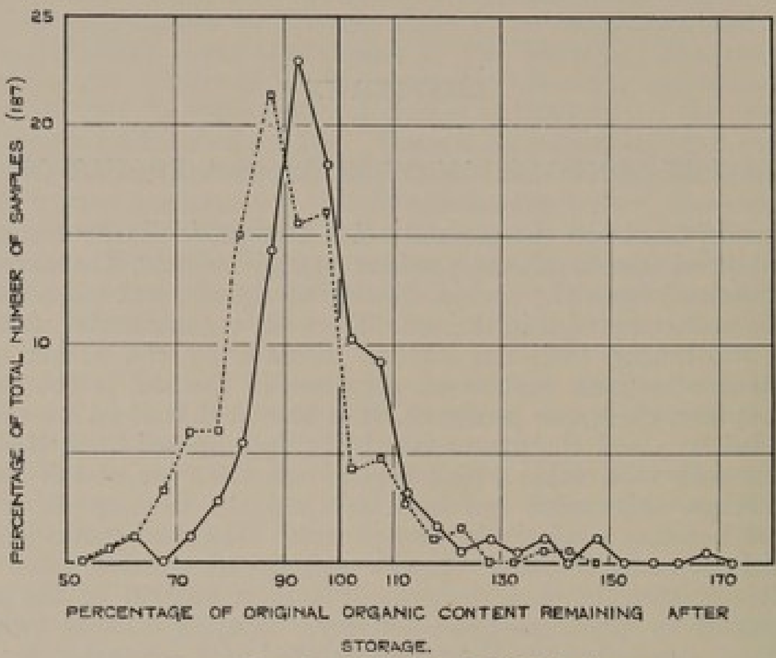


Fig. 36—*Percentage of the Original Contents of Organic Carbon and Kjeldahl Nitrogen remaining in Mersey Mud after Storage for Periods up to 1 Year at Laboratory Temperature*

The data from which Fig. 35 was drawn are shown in another way in Fig. 37, where the organic carbon is plotted against the Kjeldahl nitrogen of each sample before and after storage. The effect of storing the muds was twofold; both carbon

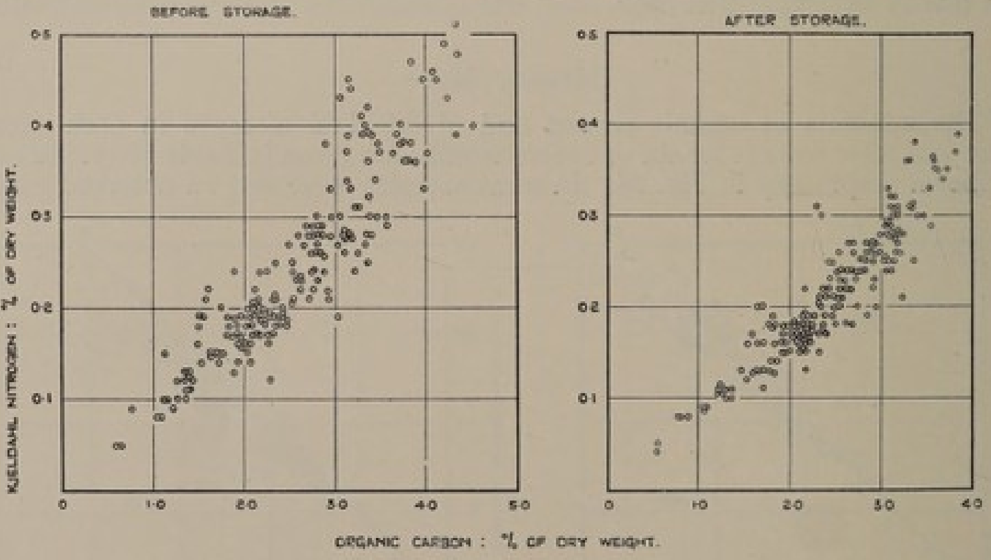


Fig. 37—*Content of Organic Carbon and Kjeldahl Nitrogen in Mud from the Upper Mersey Estuary before and after Storage for Periods up to 1 Year at Laboratory Temperature*

and nitrogen were lost and the points expressing the relation between the contents of carbon and nitrogen moved so as to lie more nearly on a smooth curve. It would appear that the composition of the organic matter before storage, while approximately constant, was in part fortuitous; when the mud was kept for a time and no further organic matter was added to it, organic carbon or nitrogen was lost in such a way as to bring the organic matter to a more constant composition. It was found also that before storage the points expressing the relationship between either the organic carbon or the Kjeldahl nitrogen and the silica content of the muds lay in a broad band. After storage this band became narrower, indicating that the relation between the content of organic matter and the silica had become more exactly defined.

A second series of samples of muds from the Stanlow Bank was maintained for about a year covered with sea water in a thermostatically controlled incubator at a temperature of 37° C.; distilled water was added from time to time to prevent the samples from drying out. Duplicate samples were stored under the same conditions at laboratory temperature. The contents of organic carbon and Kjeldahl nitrogen for the samples stored at 37° C. are given in Table 57 (p. 264), and the corresponding figures for the duplicate samples stored at laboratory temperature are given in Table 56. The majority of the samples stored at 37° C. lost both carbon and nitrogen, but at a rate which was not appreciably different from that of the samples stored under similar conditions at laboratory temperature; the percentage of the organic matter originally present remaining after storage at 37° C. and at laboratory temperature is shown in Table 60 (p. 84).

In Table 59 (p. 265) and in Fig. 38 is shown the composition, before and after storage for different periods, of samples of estuarine suspended matter which had

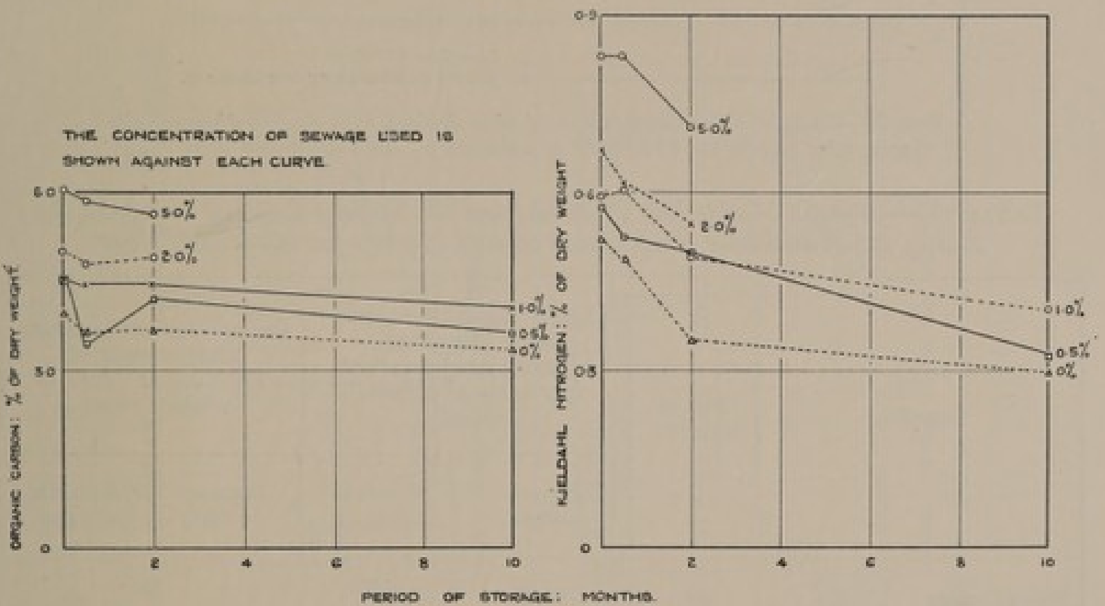


Fig. 38—*Changes in the Contents of Organic Carbon and Kjeldahl Nitrogen in Estuarine Suspended Matter previously stirred with Sewage, after Storage for Various Periods at 37° C.*

previously been stirred with different concentrations of settled sewage. During storage for ten months there was a loss of organic carbon from all the samples and a greater loss of Kjeldahl nitrogen.

Muds from the Manchester Ship Canal

In Table 58 (p. 265) is shown the composition before and after storage of a few samples of mud dredged from the bed of the Manchester Ship Canal. These samples are in two groups, one stored at 37° C., and one at laboratory temperature; the changes in composition after storage are shown graphically in Fig. 39. Large losses of organic matter occurred in some of these samples, especially those incubated at 37° C. Before storage the samples differed entirely in appearance from Mersey muds, the more organic of them being semi-liquid and containing as much as 10 per cent. of organic carbon on the basis of dry solid matter. After storage for ten months at 37° C. their composition was in most cases similar to that of muds from the Stanlow Bank.

The percentages of organic matter lost during storage by Mersey muds and by samples from the bed of the Manchester Ship Canal are compared in Table 60.

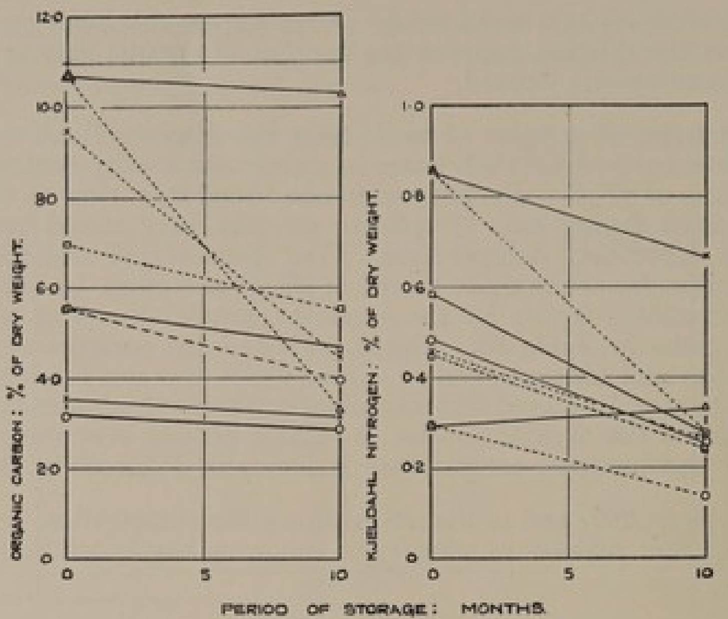


Fig. 39—*Changes in the Composition of Mud dredged from the Manchester Ship Canal, after Storage for 10 Months at Laboratory Temperature and at 37° C.*

Table 60—*Organic Matter lost by Mud from the Mersey Estuary and from the Bed of the Manchester Ship Canal during Storage for about One Year*

Samples.	No. of samples.	Organic matter remaining after storage at laboratory temperature (per cent. of original value).		Organic matter remaining after storage at 37° C. (per cent. of original value).	
		Organic carbon.	Kjeldahl nitrogen.	Organic carbon.	Kjeldahl nitrogen.
Mersey muds	187	95·5	88·2	—	—
Mersey muds	32	96·4	79·4	94·8	81·4
Manchester Ship Canal muds	4	91·2	69·9	—	—
Manchester Ship Canal muds	4	—	—	53·0	45·3

The percentage of the original organic matter lost by Mersey muds during storage either at laboratory temperature or at 37° C. was relatively small. The percentage lost by the more organic Manchester Ship Canal samples was much greater at 37° C. than at laboratory temperature.

Significance of Changes

It seems probable that mud loses by fermentation excess organic matter deposited with it until the concentration of organic matter in the mud falls to a value depending on the proportion of alumino-silicates present, after which further fermentation proceeds only slowly. That there is a concentration of organic matter which is only relatively slowly destroyed would appear to follow from the fact that muds have not been found in any locality, whether polluted or unpolluted, in which there was not a fairly definite relationship between the amount of silica and the amount of organic matter present. Since, however, the relation between the content of organic carbon and of Kjeldahl nitrogen has been found to vary more widely in Mersey muds before storage than after storage, it might be expected that this relation would be found to be especially variable in muds to which large amounts of organic matter were continuously added. In Fig. 40 is shown the

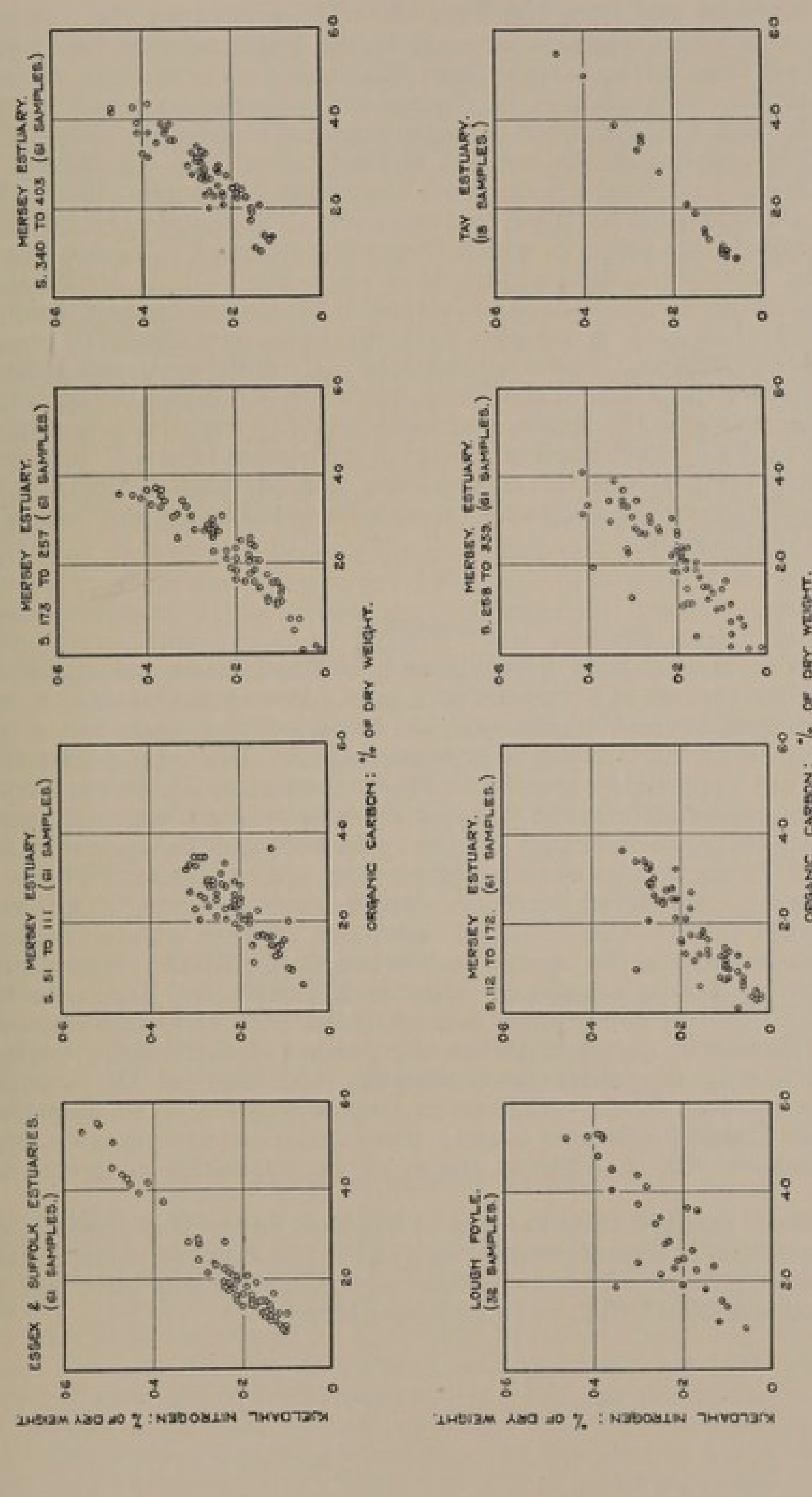


FIG. 40—*Relation between the Contents of Organic Carbon and Kjeldahl Nitrogen in Mersey and other Muds*

relation between the contents of organic carbon and Kjeldahl nitrogen in 61 samples of muds taken in Suffolk and Essex from various estuaries which are believed to be polluted only to a small extent. In the figure there is also shown the similar relation for 32 samples of mud from the comparatively unpolluted Lough Foyle in the north of Ireland, and for 18 samples from the Tay Estuary in Scotland, which also contains only a small concentration of polluting matter. There seems to be a pronounced difference between the samples from the Foyle and those from the Essex estuaries and from the Tay, the relation between the concentrations of organic carbon and Kjeldahl nitrogen in the Foyle samples being much less clearly defined than in the samples from the other two localities. It is thought that the irregular composition of the organic matter in the samples from the Foyle is due to the high concentrations of peaty material in different stages of decomposition. For comparison, the samples of mud taken from the Mersey Estuary have been divided into five groups, each containing 61 samples, that is the same number as were available for the Essex estuaries. The samples were divided into the five groups in the order in which they were collected. The carbon-nitrogen ratio for the samples in these groups is given in Fig. 40. It is difficult to say whether the composition of the organic matter in the Mersey samples is significantly more variable than that in samples from the Essex estuaries. In some of the groups of Mersey samples the variation in the carbon-nitrogen ratio appears to be somewhat greater than that in the Essex muds; in other groups the composition of the organic matter in the Mersey and Essex muds appears to be equally variable. Before it could be decided whether the small differences between the composition of the Mersey samples and the composition of muds from unpolluted estuaries are significant it would be necessary to examine much larger numbers of samples from unpolluted localities.

Summary

Samples of Mersey mud were allowed to stand under sea water at room temperature for periods of 6 months or 1 year. During this time the content of Kjeldahl nitrogen in most of the samples decreased and there was a relatively smaller decrease in the content of organic carbon. The rate of loss of organic matter was not appreciably greater at 37° C. than at room temperature. After storage the organic matter in the different muds had a more constant composition than before storage, as indicated by the ratio between the organic carbon and the Kjeldahl nitrogen. It was suggested that the composition of the organic matter of mud in unpolluted localities might be more constant than that of mud from polluted localities where frequent additions of fresh organic matter might occur. The ratio between the organic carbon and the Kjeldahl nitrogen contents in 61 samples of mud from unpolluted estuaries in Suffolk and Essex was therefore compared with that in five groups, each of 61 samples, of mud from the Mersey Estuary. The results suggest that the composition of the organic matter in the Mersey muds may be rather more variable than that of the samples from unpolluted estuaries. Wide variations in the composition of the organic matter of muds from Lough Foyle were found; these variations are probably due to the large amounts of peat in different stages of decomposition contained in these muds.

When muds dredged from the bed of the Manchester Ship Canal, containing high concentrations of organic matter, were allowed to stand for 10 months covered with sea water, a large porportion of the organic matter was lost; the amount lost was greater at 37° C. than at room temperature.

CHAPTER X

METHODS AND CONDITIONS OF MEASUREMENT OF RATE OF SEDIMENTATION OF MUD

Material used

In Chapter VII the sources from which mud-forming material might enter the Upper Estuary were discussed, and it was concluded that the bed of the Bay and the Irish Sea was probably the principal source of the mud in the Estuary.

Numerous experiments have been made on the effect of various factors on the rate of sedimentation of mud. Before laboratory experiments were begun an estimate was made of the concentration of sewage in the water of the Upper Estuary; this was discussed in Chapter IV, where it was shown that organic matter was present in concentrations which did not in general exceed the equivalent of 5 per cent. of sewage. In the bulk of the Estuary water the concentration was considerably less than this amount. The suspended matter carried in the Estuary water was also examined and it was found that for an average tide the concentration was usually about 20 parts per 100,000. In some parts of the Estuary where the stream velocity is high, especially during spring tides, the concentration may considerably exceed this value, but it does not as a rule anywhere exceed about 100 parts per 100,000. It was found that during the period of slack water (about two hours) almost the whole of the suspended matter settled to the bottom. The salinity of the water in the Upper Estuary was determined under different tidal conditions, and it was shown that the salinity of a large proportion of the water lay between 20 and 25 gm. per 1000 gm. The general conditions under which determinations of the settling rate of suspended matter should be made in the laboratory, therefore, were known. The material carried in suspension by the Estuary water was found to consist of mud of composition indistinguishable from that of mud taken from the inter-tidal banks.

Material forming the bed of the Irish Sea and Liverpool Bay also consists partly of mud, as does the suspended matter brought in from fresh-water streams. The composition of the deposits in Liverpool Bay and the Irish Sea was shown to be similar to that of the material forming inter-tidal banks in the Upper Estuary, their organic content being mainly dependent on the proportion of alumino-silicates present. Clay containing a much smaller quantity of organic matter was not found in any position from which appreciable quantities of material could be eroded and brought into the Upper Estuary. In the laboratory experiments on the effect of sewage and other factors on the rate of sedimentation of suspended matter the material used was mud taken from the bed of Liverpool Bay and from the inter-tidal banks in the Upper Estuary and material carried in suspension in the Estuary water. The settling rate of these samples has been compared with the settling rate under similar conditions of muds taken from estuaries containing little or no polluting matter.

Preparation of Sample

In determining the rate of sedimentation of suspensions of muds in the laboratory it was found that the settling rate depended very largely on the extent to which the mud was broken up in making the suspension. In all experiments wet muds were collected and the evaporation of water from them in the laboratory was prevented as far as possible. A quantity of the wet mud was then mixed to a cream with a small quantity of water of salinity 25 gm. per 1,000 gm. and was later diluted to give the required concentration. In a few preliminary experiments the sand present in the mud was not separated, but this was done in later work in order to obtain more comparable samples. In the method finally adopted the mud was stirred vigorously with a small quantity of saline water and the resulting slurry was diluted to half the final volume required. The suspension was stirred and allowed to stand for 5 minutes, and the suspension of mud was poured off from the sand which had settled; this procedure was repeated, after which a sample of the suspension was taken and the concentration of mud determined. The requisite volume of saline water was then added to bring the concentration of mud to the value required.

Methods

Several methods have been used by other workers in determining the rate of sedimentation of soil particles and other materials. In selecting a method for use in this investigation it was desirable to choose one in which the material settling from suspension or remaining in suspension after given time intervals could be collected for analysis. Since it was essential to compare the effect of different concentrations of sewage on the settling rate of the mud under different conditions, it was necessary also that the method should be simple so that a number of determinations could be made at one time. In determining the settling rate of mud through shallow columns, suspensions were made up in beakers about 30 cm. in depth and of a capacity of about 5 litres. At given time-intervals a pipette was inserted vertically into the liquid until the tip was 10 cm. below the surface and 100 ml. of the suspension were withdrawn. The weight of mud in the sample gave the concentration remaining in suspension at a depth of 10 cm. at intervals during the sedimentation period. This method is frequently used in soil analysis. Since the initial concentration of mud was usually of the order of 20 parts per 100,000 it was necessary to withdraw at least 100 ml. for each sample in order to obtain sufficient material for analysis. The total volume withdrawn in each experiment was thus considerable in relation to the total volume of liquid, so that the depth of liquid was appreciably decreased during the sedimentation. The chief objections to this method are that the sample is not withdrawn only from the level of the tip of the pipette, and in taking the sample turbulence is set up which affects the sedimentation of the mud. Most of the determinations, however, were made by another method, in which a suspension was allowed to settle in glass tubes about 1½ inches in diameter and 9 feet in length, each holding about 3 litres of water. The bottom of each tube was closed with a rubber bung through which projected a small glass funnel closed with a pinch-cock; the funnel was made of thin glass and at the upper wide end had an outside diameter of 2·15 cm. A sketch of the apparatus is shown in Fig. 141 (p. 207). The suspension of mud to be examined was poured into the tube and at intervals during a period, usually of 1½ hours, the mud which had collected in the glass funnel at the bottom was withdrawn. It was found that all the mud could be removed in a volume as small as 10 to 15 ml. of water. The weight and composition of the mud removed in each fraction was determined. Similar methods, in which the weight of material falling to the bottom is observed, have been used by other workers who have reported that the method is in general subject to considerable errors, as indeed are most methods for determining rates of sedimentation. It is essential that the long tube should be exactly vertical, and in the present work the tubes were set up and clamped in a vertical position, determined by means of a plumb line. It is also important to obtain glass tubes which are quite straight. In a tube 9 feet in length it is difficult to avoid the setting up of convection currents which may alter considerably the observed rate of sedimentation. The chief disadvantage, which has been pointed out by other workers, is that at the bottom of the tube conditions are not uniform owing to the presence of the collecting funnel or other device. The maximum amount of suspended matter capable of falling into the funnel should be that contained in a column of water of the length of the tube and with the same diameter as the funnel, but owing to the disturbed conditions at the bottom of the tube the amount of mud collected is occasionally greater than this amount. It was observed that mud tended to collect in a ridge on the edge of the funnel and was sucked into it when the samples were withdrawn; the error introduced in this way was minimised by having the upper edge of the funnel ground to a knife edge. The chief advantages of the method are that a relatively large weight of mud can be collected so that the error in washing, drying and weighing it is not high and methods of analysis requiring a relatively large weight of material can be used. Moreover, the volume of liquid withdrawn from the tube during a sedimentation is small compared with the total volume. It was found that the accuracy of the method was smaller with material of a high settling rate than with that of a lower settling rate; with rapidly settling material the amount of suspended matter collected often considerably exceeded the theoretical amount. It appeared that the method was reliable for the determination of the comparative settling rates of different materials, though it might not give accurately the absolute rate for any one of them. Rates of sedimentation of mud through other depths were similarly determined. For a depth of 40 feet the apparatus consisted of a tube made from a number of steel pipes, each 5·2 inches in diameter, bolted together.

The tube was erected on the outer wall of the laboratory and was carefully plumbed so as to be vertical; it held about 180 litres when full. The bottom was closed by a heavy rubber plug, held in place by a steel plate attached by bolts to a flange on the bottom of the tube. The mud falling to the bottom was caught in a glass funnel passing through the rubber plug (Appendix II).

In all methods in which a small amount of mud was collected, the weight of mud in each sample taken was determined by filtering the sample through an asbestos filter in a Gooch crucible. The asbestos filtering pad consisted of a thin layer of fine asbestos sandwiched between two layers of rather coarser material; the pad was thoroughly washed with distilled water before the crucible was dried and weighed. After a sample had been filtered the crucible was dried at 105° C., the mud was thoroughly washed with distilled water and the crucible was again dried and weighed. It was found to be impossible to wash all the salt from the mud unless it had previously been dried. In determinations in which the material remaining in suspension at a depth of 10 cm. was collected, the organic content of the filtered mud was determined after it had been dried and weighed. The method used for the determination of comparative amounts of organic matter was that of Adeney[1]. In this method the mud is heated with a standard solution of potassium dichromate containing sulphuric acid, and the quantity of dichromate used in the oxidation of the organic matter is determined. In the present work this was done by determining the unused dichromate iodimetrically. When the 9-ft. tubes were used a second series of samples was collected from duplicate suspensions of mud and the organic carbon in these samples was determined.

Before determining the rates of sedimentation of mud from different localities, some conditions governing the settling rate of mud from suspension were examined. The most important variable factors in the Estuary which might affect the settling rate include the depth of water through which the mud is allowed to settle, the initial concentration of suspended matter, the salinity of the water and its temperature.

Depth of Suspension

When finely-divided mud is allowed to settle in a glass tube 9 ft. in length, it can be seen that the rate of sedimentation of a particle increases as it falls. If a suspension consisting of mud in sea water was introduced into the tube, after a short time it was observed that the suspended matter began to form aggregates, which increased in size as they fell, so that the largest clots were found at the bottom of the tube. In a few experiments (Table 61, p. 266) the rate of fall of the mud particles at different levels was directly observed. It was found that the particles which were visible at any level tended to be of about the same size and to fall at approximately the same rate. The mean velocity was estimated by timing groups of particles over a distance of 5 cm.; the results of one typical experiment are shown in Fig. 41. The figure shows that particles with a high rate of fall first appeared near the bottom of the tube. The speed of fall of particles in the top 4 ft. never became as great as that of particles in the bottom 5 ft., and the period during which the fall of particles could be observed was much longer in the bottom half than in the top half of the tube. The maximum velocity observed in these experiments was nearly 1 ft. per minute. Mud particles which fall at this rate are of considerable size, their diameter being estimated at between 1 and 2 mm. In falling they elongate in the direction of travel and often have the appearance of comets with filamentous tails. Their growth may be observed directly when two large particles collide. From these observations it was clear that the size of the particles falling from a mud suspension was different from that of the mud particles when the suspension was first made up and that the rate of sedimentation of the mud might well be dependent on the speed with which the larger aggregates were formed. The occurrence of the most swiftly moving aggregates at the bottom of the tube is explained if it is considered that their formation is governed by the frequency with which the initially smaller mud particles come into contact with each other. Thus when the suspension is first introduced into a vertical tube the mud particles with the greatest settling rate begin to fall, and in doing so pass through water containing less rapidly moving particles with which they collide and form aggregates. After a time those aggregates near the bottom which have travelled the

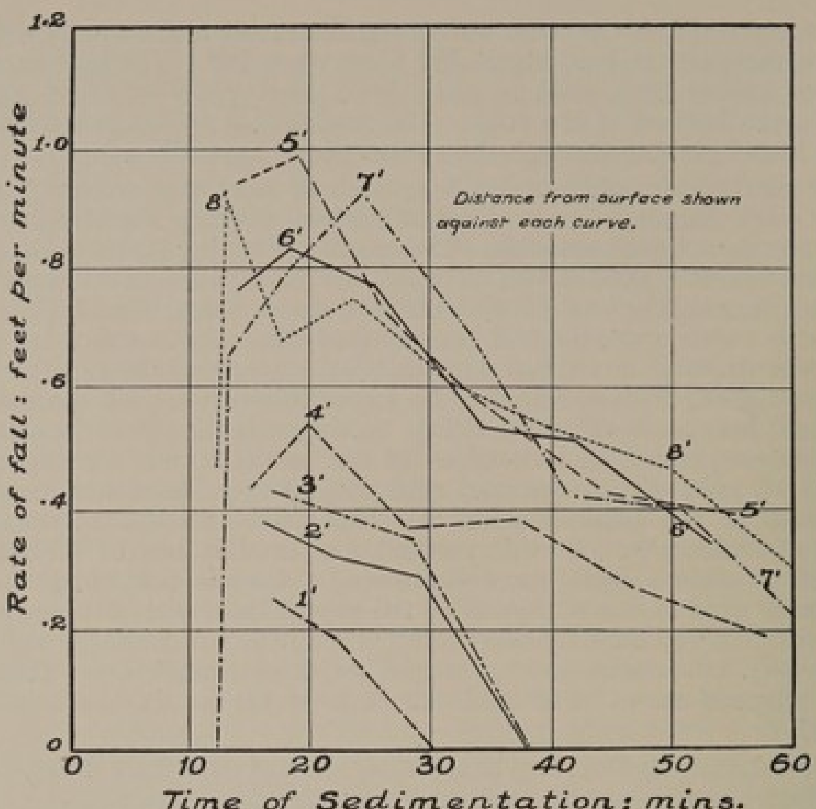


Fig. 41—*Rate of Falling of Mud Particles in Saline Water at Different Levels in a Tube* 9 *ft. long during a Sedimentation Period of* 1 *Hour*

longest distances and have suffered the greatest number of collisions are the largest and most swiftly moving. The conditions governing the sedimentation of mud are, therefore, quite different from those which govern the rate of settling of particles which do not clot, the sedimentation of which is defined by Stokes's law.

The rates of sedimentation of mud suspensions through columns of different lengths are shown in Fig. 42, where the weights of mud falling on unit area after different time intervals are plotted. The observed rate of sedimentation increased with increasing length of the column through which the mud fell. In carrying out comparative experiments, therefore, it is essential that the rate of sedimentation should be observed in columns of the same length.

Initial Concentration of Mud Suspensions

In Fig. 43 are shown the observed rates of sedimentation of muds made up in suspensions of different concentrations in saline water. In this figure the percentage of the mud originally present which settled out after different periods of sedimentation is shown. The first series of determinations was made by the method in which the change in the concentration of mud remaining at a depth of 10 cm. is found. In the other three series the mud suspensions were allowed to settle for 1½ hours in columns 9 ft. in length, and the mud falling to the bottom during this period was collected at intervals and weighed. The rate of sedimentation markedly increased with increasing initial concentration of the mud suspensions. The three series of curves showing the rate of sedimentation through 9-ft. columns indicate the extent to which the mud had formed aggregates during the sedimentation period. The mud is initially present in the form of a turbid suspension of particles too small to be seen; in this condition their settling rate is low. In the more concentrated suspensions the aggregation of the particles soon begins and the settling rate increases as larger clots are formed. When the greater part of the mud has settled, leaving a dilute suspension, large clots are no longer formed, and the settling rate consequently falls off. The sedimentation curves for the stronger suspensions therefore have an " S " shape. In the least concentrated suspensions the rate of sedimentation is reasonably constant throughout the period of 1½ hours. It is thought that the failure of weak suspensions to form large aggregates is due to the smaller number of collisions which take place, on account of the low initial particle concentration of the suspensions.

Fig. 42.

RATE OF SEDIMENTATION OF MERSEY MUDS IN COLUMNS OF DIFFERENT LENGTHS.

S.M. = SUSPENDED MATTER FROM MERSEY ESTUARY.
S. = MERSEY MUD.

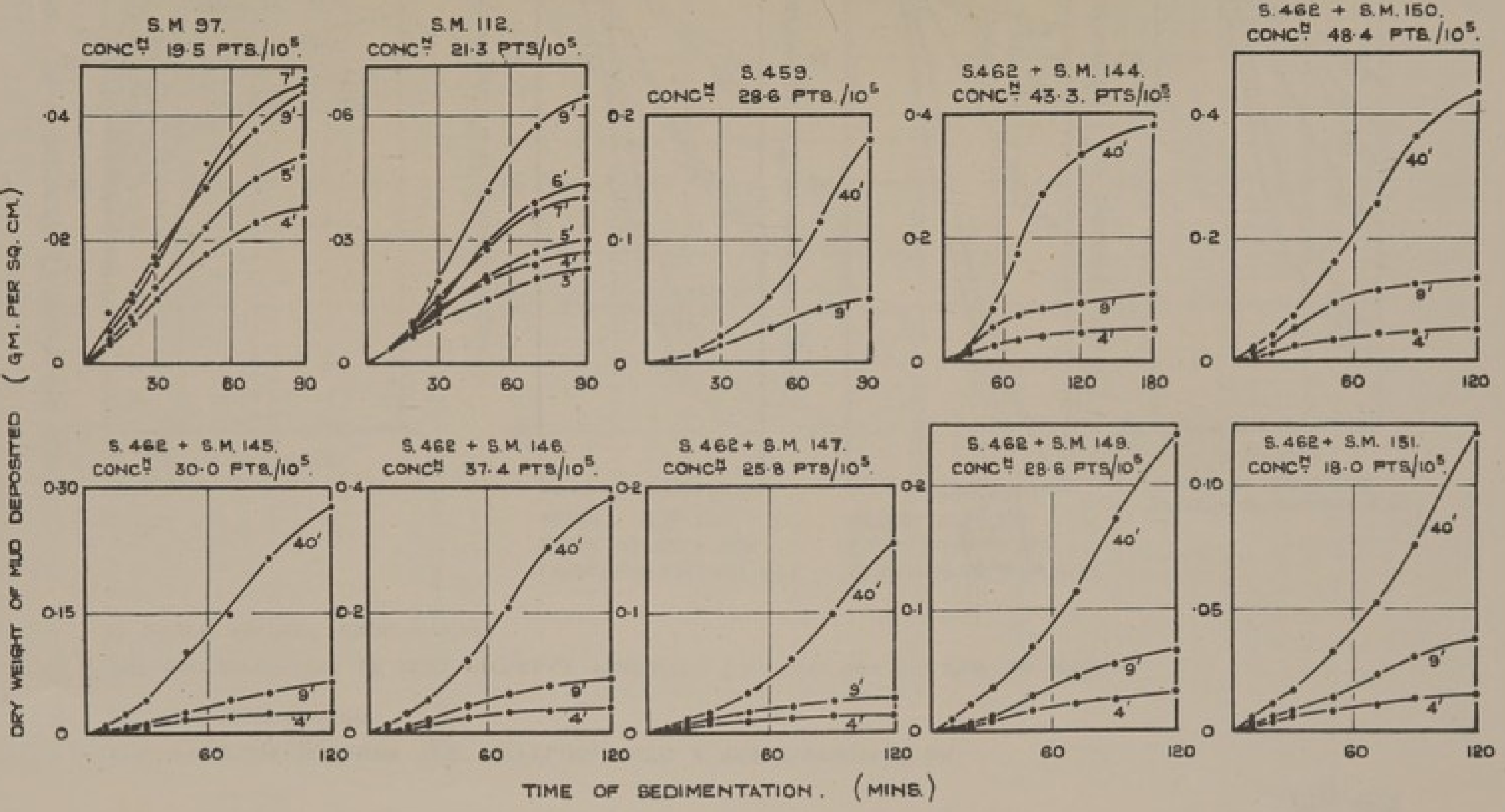
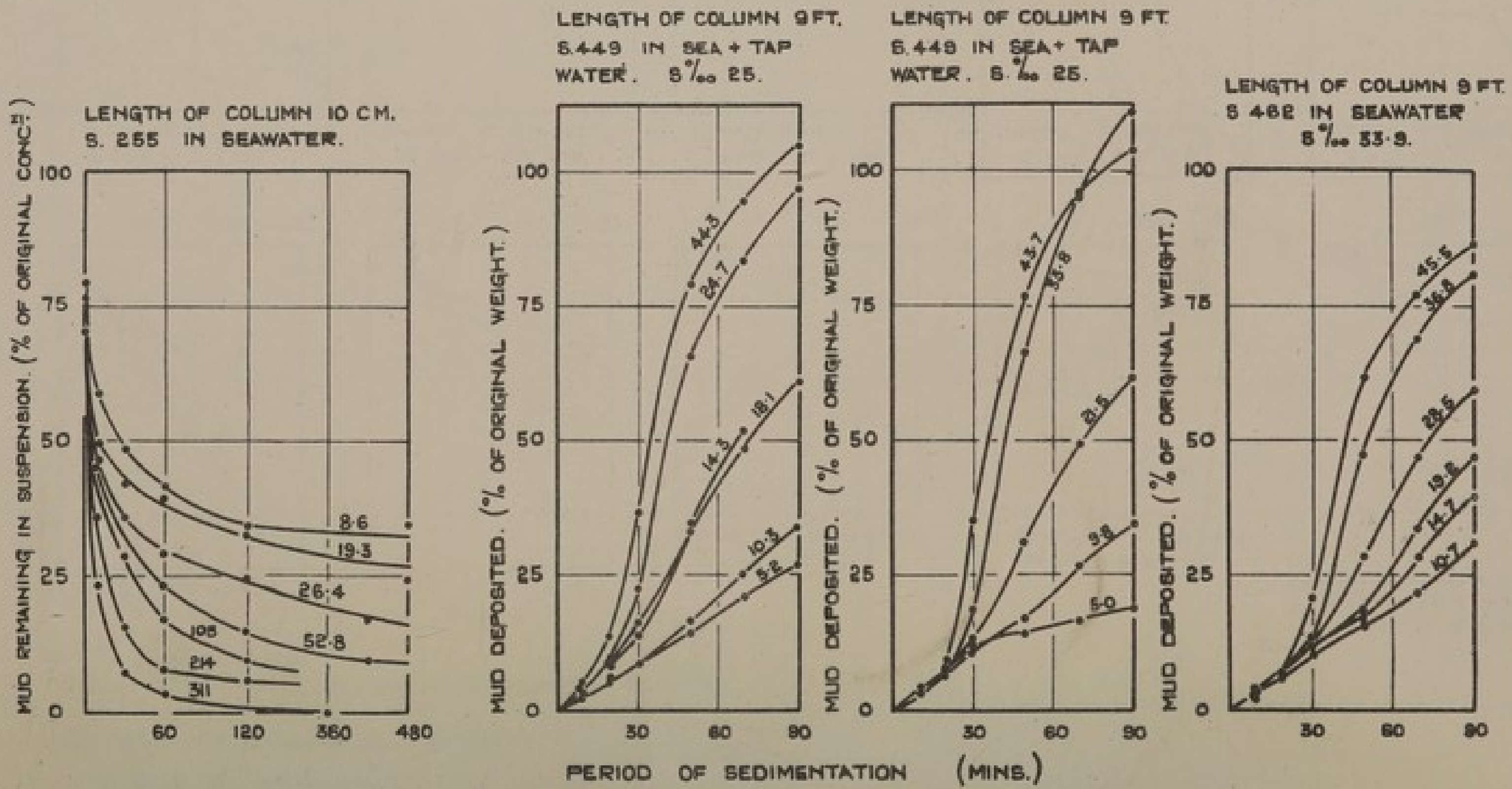


Fig. 43.

THE RELATION BETWEEN THE SETTLING RATE & THE CONCENTRATION OF MUD SUSPENSIONS.

THE CONCENTRATION OF MUD INITIALLY PRESENT (IN GM. DRY WT. PER 100 LITRES) IS SHOWN AGAINST EACH CURVE.



Effect of Salinity

The salinity of the water in the Upper Estuary changes from a value approaching that of sea water at the mouth of the Narrows to a value approaching that of fresh water at the head of the Estuary. It is of importance, therefore, to determine the effect of the salinity of water on the rate of sedimentation of mud suspended in it. The results of some experiments are given in Table 62 (p. 268). The effect of salinity was found to be very variable; the results of one experiment which is most nearly typical of the series are given in Fig. 44. The mean relation, obtained from 9 experiments, between the salinity and the percentage of the mud which settled from suspensions in columns 9 feet in length after 1½ hours is also shown in Fig. 44. There was a distinct rise in the rate of sedimentation between a salinity of 0·4 and a salinity of 10·0 but no appreciable change in the rate occurred between salinities of 10·0 and 30·0 gm. per 1,000 gm. In some experiments, the maximum rate of sedimentation was found at a salinity value between 10·0 and 20·0, but the effect of this in the average curve is counterbalanced by some other experiments in which a considerable rise occurred between salinity 20·0 and 30·0. The point in Fig. 44 at a salinity of 0·4 gm. per 1,000 gm. gives the

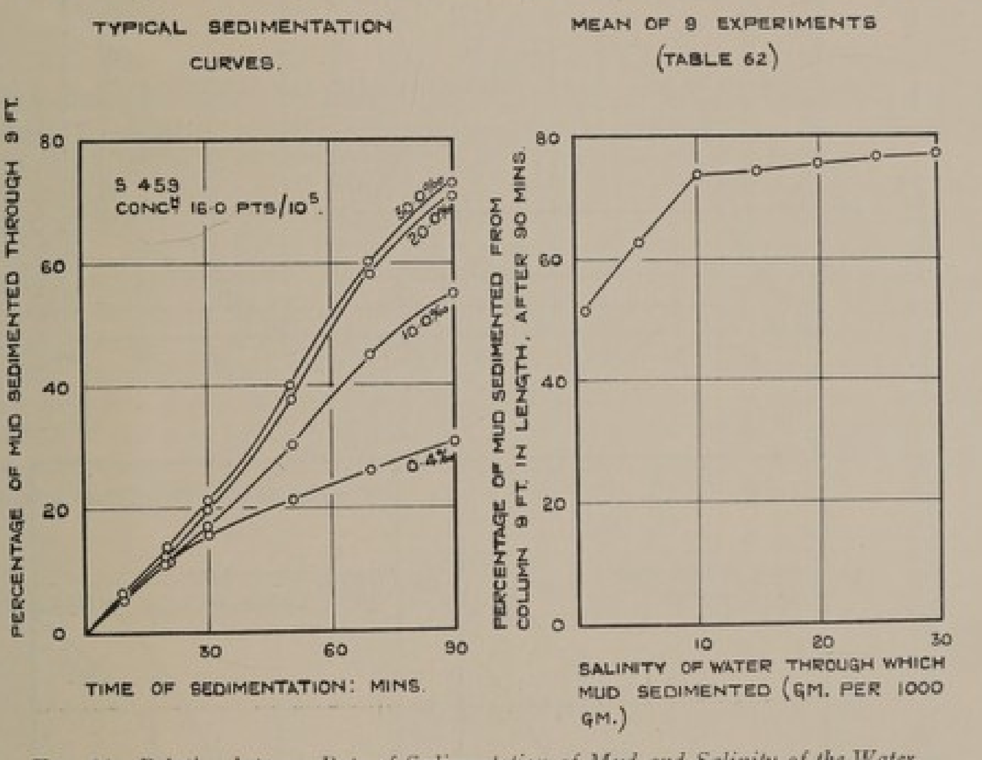


Fig. 44—*Relation between Rate of Sedimentation of Mud and Salinity of the Water in which it is suspended*

rate of sedimentation of a wet saline mud made up in tap water. In these circumstances comparatively large concentrations of salts are present, derived from the tap water and the water associated with the mud. If all electrolytes were removed from the mud by thorough washing following treatment by acid to dissolve carbonates, and if this mud was then suspended in electrolyte-free water, it is known that the rate of sedimentation would be much smaller than that shown in Fig. 44. In comparing the rates of sedimentation of different muds or in determining the effect of sewage or other material on the settling rate of a mud, the suspensions were always made up in water of the same salinity. In most cases the water consisted of a mixture of sea water and tap water, the salinity being 25 gm. per 1,000 gm. This value was chosen as representative of that of a large proportion of the water in the Upper Estuary. The sea water was usually obtained from the Northwest Buoy at a distance of about 7½ miles seaward of the Bar Lightship where, except during rough weather, the surface water contains very little suspended matter and is not appreciably contaminated by polluting material.

Effect of Temperature

A series of five sets of experiments was carried out to determine the effect of temperature on the rate of sedimentation of muds in suspension in saline water. For this purpose 6 sedimentation tubes, each 9 feet in length and insulated by thick layers of cotton wool, were used. The tubes were first brought to the temperature required by filling them with water at a suitable temperature. The experimental suspensions were heated or cooled to the required temperature by standing the vessels containing them in warm water or in a mixture of ice and salt. It was found that the temperature of the suspensions of mud did not change by more than 2° C. to 3° C. during a sedimentation period of 1½ hours. The results obtained are shown in Fig. 45; in every case the rate of sedimentation increased with a rise in temperature.

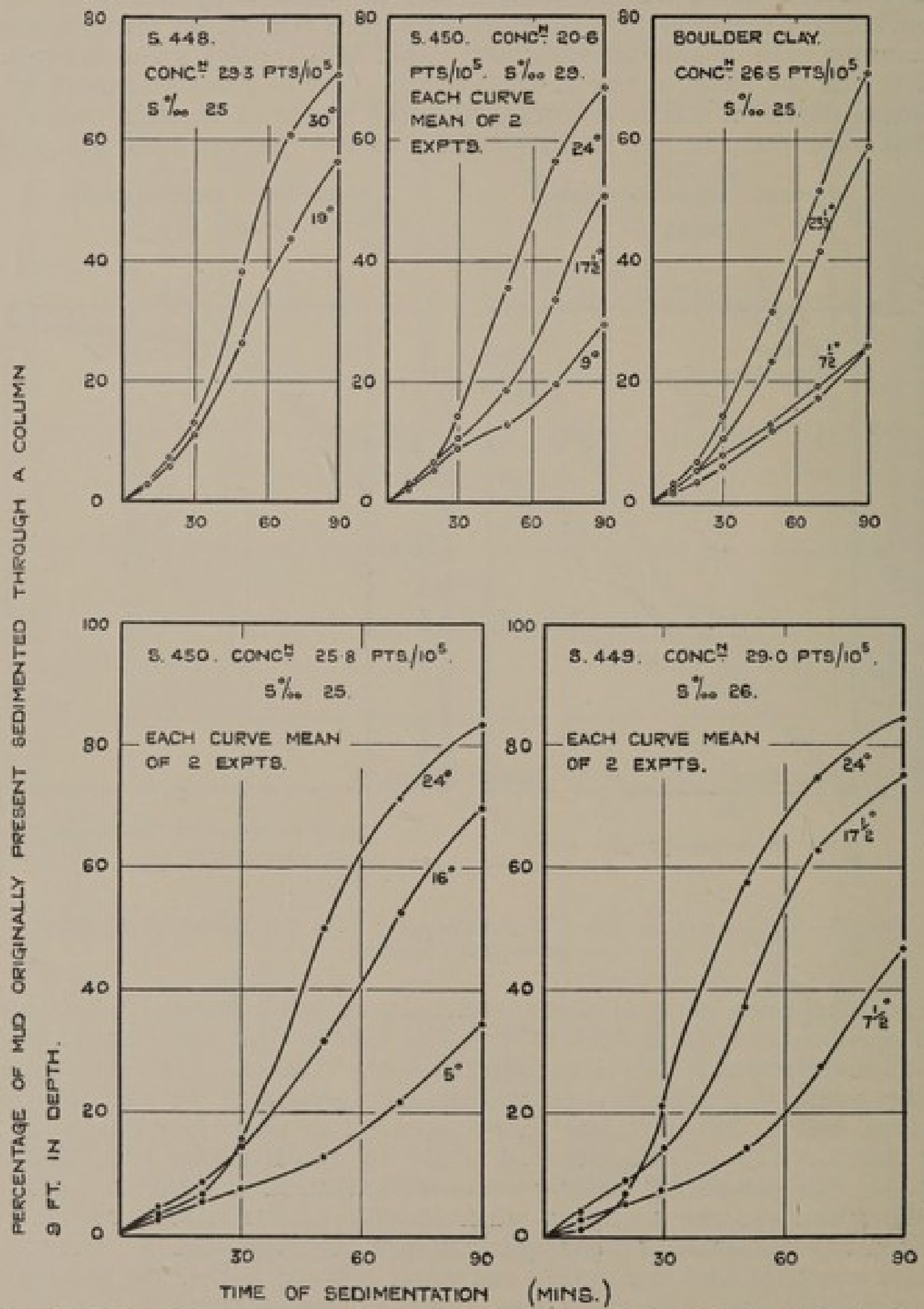


Fig. 45—*Effect of Temperature on Rates of Sedimentation of Mersey Mud and Boulder Clay from Suspensions in Saline Water*

The mechanism by which a rise in temperature increases the rate of sedimentation of mud is not known; it is probable that the increase is due, at least in part, to the decrease in viscosity of the water in which the mud is suspended, since the rate of fall of particles increases with decreasing viscosity of the medium.

It is evident from the shape of the curves that aggregation occurred to a much greater extent in the warm than in the cold suspensions. An increased rate of aggregation might be expected to follow a decrease in the viscosity of the water, since the differential movement between relatively fast and slow moving particles would then be increased. It is improbable that the large increase in the rate of sedimentation brought about by increasing temperature is due to the acceleration of any bacterial changes. In one diagram in Fig. 45 is shown the rate of sedimentation of a sample of boulder clay at two temperatures. The boulder clay contained little or no organic matter and the sample used was dug from a considerable distance below the surface of a clay cliff; the numbers of bacteria in this clay would be much smaller than in estuarine mud. The increase in the rate of sedimentation brought about by raising the temperature from 7½° C. to 23½° C. was, however, of the same order as that observed in mud, the bacterial content of which is known to be high.

In most comparable series of determinations, the rate of sedimentation of muds was carried out in glass tubes erected side by side in the laboratory so that the temperature of each tube was approximately the same. In later experiments the tubes were contained in large thermostats in which the temperature could be controlled to within about 1° C.

Summary

The methods used in determining the rate of sedimentation of mud are described. To obtain comparable results with different samples, the sand initially present must be removed before the rate of sedimentation is measured.

In settling though saline water, small particles of mud increase in size through collision with other mud particles and their settling rate in consequence increases as they fall. In comparing the rate of sedimentation of different muds it is thus essential that they should be allowed to settle through columns of the same depth. The extent to which mud in a finely divided condition forms larger aggregates by collision increases as the initial concentration is increased. The settling rate is in general increased by increasing the salinity of the water in which mud is suspended between the limits 0·4 and 30 gm. per 1,000 gm. In comparable determinations of the rate of sedimentation it is necessary to maintain mud suspensions at the same temperature since the settling rate is increased by a rise in temperature between the limits 5° C. and 30° C.

Reference

(1) Adeney, W. E., and Dawson, B. B. *Sci. Proc. R. Dublin Soc.*, 1926, **18**, 199.

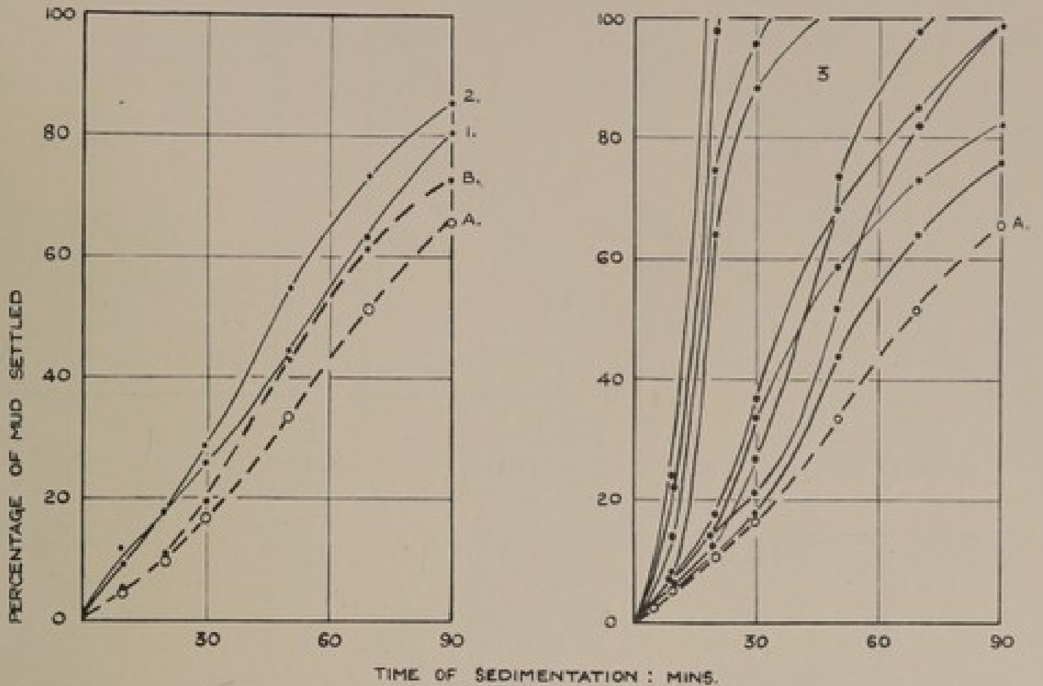
CHAPTER XI

RATE OF SEDIMENTATION OF MERSEY AND OTHER MUDS

In some early experiments, not here reported, it was found that the rate of sedimentation of samples of mud from the Upper Estuary depended mainly on the sand content of the samples. If a series of samples is taken from the Mersey or from other estuaries it is usually found that the samples consist of mud of approximately constant composition mixed with various proportions of sand. In order to compare the rates of sedimentation of different muds it is therefore necessary first to remove the sand. In all cases this was done by making up a suspension of mud in a concentration of about 100 gm. per 100 litres in a mixture of sea water and tap water with a salinity of about 25 gm. per 1,000 gm. This suspension was allowed to stand for five minutes in beakers about 1 ft. deep, and the mud suspension was then poured off from the sand which had settled to the bottom. The concentration of mud remaining in suspension was then determined, and the same mixture of sea and tap water was added so as to give a concentration of mud of approximately 20 or 30 gm. per 100 litres. In some cases the material used consisted of mud already in suspension in water taken from the Estuary; the amount of sand present was then usually low, but it was sometimes necessary to concentrate the mud to 20 or 30 gm. per 100 litres. This was done by allowing the suspended matter to settle, and then siphoning off the appropriate volume of water. If necessary, the salinity of the estuary water was adjusted to a value of 25 gm. per 1,000 gm. by the addition of sea water or tap water. In all cases sedimentation was carried out in tubes 9 ft. in length. It has been shown that the rate of sedimentation of a mud increases as the depth through which it settles is increased. In many parts of the Estuary sedimentation of material in suspension takes place in water of a depth much greater than 9 ft., but this is the approximate depth of water at high water of spring tides over the Stanlow Bank.

Mersey Muds

The rates of sedimentation of 96 samples of mud from the Upper Estuary are given in Table 63 (p. 269). These samples were taken from widely spaced positions on the Stanlow Bank. They fall into two groups in which the initial concentrations of mud were approximately 20 and 30 gm. per 100 litres; the average rate of sedimentation of each group is shown in Fig. 46. In general the individual muds in each group settled at similar rates and no very abnormal samples were found. In all cases the formation of clots was observed in the deeper parts of the sedimentation tubes. The average rate of settling was higher for the group of muds which had an initial concentration of approximately 30 gm. per 100 litres than for the group with a concentration of 20 gm. per 100 litres; this result was to be expected from the work described in Chapter X where it was shown that the settling rate of mud increases with increasing concentration. In the first diagram in Fig. 46 is shown also the average rate of sedimentation of 5 muds from the bed of Liverpool Bay and of 11 samples of suspended matter from the Estuary water. The material from Liverpool Bay was dredged from positions between the Crosby Light Vessel and the Bar Light Vessel; it consisted of mud mixed with a large amount of sand which was removed by repeated sedimentation before the settling rate of the mud was determined. The samples of Estuary water containing suspended matter were taken from different positions between the Narrows and Widnes. The proportion of the material which settled from the Liverpool Bay muds after $1\frac{1}{2}$ hours was, on the whole, higher than the proportion which settled from the Upper Estuary muds; it is probable that a small amount of fine sand remained in the Bay muds, which when taken contained a much higher proportion of sand than did the samples from the Upper Estuary. The shape of the curves suggests that a small quantity of sand settled out from the suspensions of Bay muds before effective clotting began. After the first 30 minutes of the sedimentation period, when the formation of large clots had begun, the rate of sedimentation of the samples from the Upper Estuary and from the Bay was approximately the same. The rate of sedimentation of suspended matter obtained from Estuary water was rather higher than that of Mersey muds made up in a mixture of sea water and tap water.



Curves :

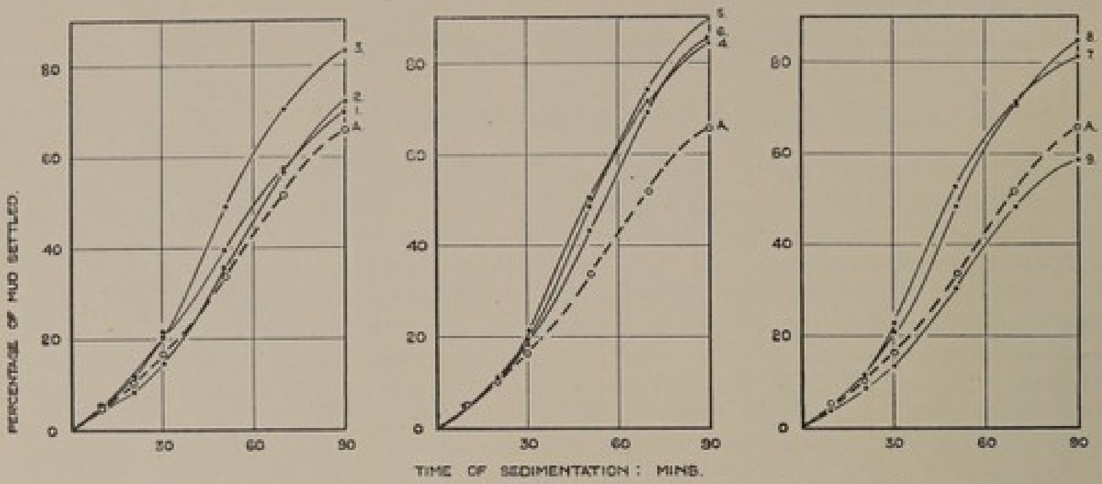
		Mean concentration
A.	Mean for 44 samples from Mersey Estuary	20·2 p.p. 100,000
B.	,, ,, 52 ,, ,, ...	29·0 ,,
1.	,, ,, 5 ,, ,, Liverpool Bay	21·2 ,,
2.	,, ,, 11 ,, of suspended matter from Mersey Estuary ..	19·3 ,,
3.	Nine samples from bed of Manchester Ship Canal	20·2 ,,

FIG. 46—*Rate of Sedimentation through a Distance of 9 ft. of Mud in Suspension in Mixtures of Sea and Tap Water of Salinity approximately* 25 *gm. per* 1,000 *gm.*

In Fig. 46 are also shown the rates of sedimentation of 9 samples of mud dredged from the bed of the Manchester Ship Canal at positions between Eastham and Manchester. The composition of this mud was described in Chapter VII, where it was shown that the mud in the upper reaches of the Manchester Ship Canal is very rich in organic matter, and is different in nature from the estuarine muds of the Mersey. The rate of sedimentation of muds dredged in the tidal reaches of the Ship Canal immediately above Eastham was found to be similar to that of estuarine muds. The semi-liquid material from the higher reaches of the Canal, however, when allowed to settle almost immediately formed very large clots, and the whole of the suspended material settled in a few minutes. Owing to the disturbed conditions in the sedimentation tube brought about by this rapid settling the method used was found to be no longer reliable for the determination of the rate of sedimentation of the mud. It is evident that the mud collected in the funnel had not fallen vertically from the column of water lying above it, but that the funnel had also collected mud which had fallen from positions nearer the side of the sedimentation tube.

MUDS FROM OTHER ESTUARIES

In Table 63 (p. 269) the rates of sedimentation of samples of mud from other estuaries are also given. The majority of the samples were taken from estuaries in south-east England between the Deben in Suffolk and the Roach in Essex. The composition of these muds was described in Chapter VIII, where it was shown that they had essentially the same constitution as muds from the Upper Mersey Estuary. So far as is known none of the estuaries from which samples were taken is substantially polluted and most of them are almost unpolluted. The samples taken were representative of large quantities of material, since the foreshores of the Essex rivers consist almost entirely of mud. The average rates of sedimentation of the Suffolk, Essex and Mersey muds are compared in Fig. 47. The rate of settling of the Suffolk and Essex material was in all cases rather higher than that of Mersey mud. In all the samples examined the formation of clots similar to those produced by Mersey muds was observed. In Fig. 47 are also shown the average rates of sedimentation of two samples from the Tamar Estuary in Devonshire, and of 14 samples from the shores of the Firth of Forth. The latter

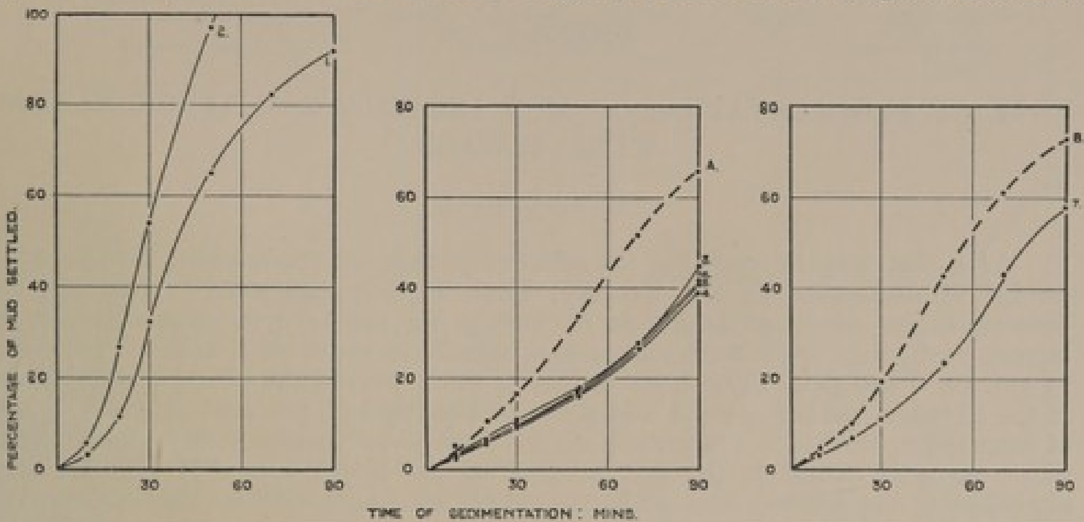


Curves : A.	Mean for	44	Samples from	Mersey Estuary :	mean conc'n.	20·2	p.p. 100,000	
1.	,,	13	,,	Deben ,,	,,	21·1	,,	Suffolk and Essex Estuaries.
2.	,,	9	,,	Blackwater ,,	,,	20·8	,,	
3.	,,	6	,,	Crouch ,,	,,	20·3	,,	
4.	,,	11	,,	Stour ,,	,,	20·6	,,	
5.	,,	4	,,	Colne ,,	,,	19·4	,,	
6.	,,	11	,,	Hamford Water :	,,	21·2	,,	
7.	,,	2	,,	Tamar Estuary :	,,	20·1	,,	
8.	,,	14	,,	Firth of Forth :	,,	20·4	,,	
9.	,,	2	,,	Dee Estuary :	,,	18·0	,,	

FIG. 47—*Rate of Sedimentation through a Distance of 9 ft. of Mud in Suspension in Mixtures of Sea and Tap Water of Salinity approximately 25 gm. per 1,000 gm.*

estuary was visited in order to measure the rate of sedimentation of suspended matter in the estuary itself; the Firth receives some polluting material, but is probably less polluted than the Mersey. In Fig. 47 the average settling rate of two samples of suspended matter from the Estuary of the River Dee in Cheshire is also shown; the initial concentration of mud in these samples was rather lower than the average concentration in the suspension of Mersey mud (18·0 instead of 20·2 gm. per 100 litres), but the rates of settling of the Dee and Mersey muds were substantially the same.

It was learned during the investigation that high concentrations of suspended matter were carried by the water in the estuaries of the Rivers Severn and Wye at the head of the Bristol Channel, and the rate of settling of this material in these estuaries was determined. The rates of sedimentation of muds from the foreshores of the two estuaries and of suspended matter in samples of the water were also measured in the laboratory; the results are given in Table 64 (p. 272), and are shown graphically in Fig. 48. The estuaries of both the Wye and the Severn are polluted to some extent but the concentration of sewage and trade effluents is considerably lower than in the Mersey. It was found that the concentration of suspended matter carried by the water in the estuary of the Wye was very much greater than that in the Mersey, concentrations of the order of 200 gm. per 100 litres being observed in the Wye as against values of about 20 to 60 gm. per 100 litres, which are normally present during spring tides in the Mersey. In the first diagram in Fig. 48 the rate of sedimentation of the mud in two samples of water as taken from the Wye is shown. The samples contained initially 95 and 159 gm. of mud per 100 litres respectively, and at these concentrations the proportion of the suspended matter which settled out in a given period was considerably higher than that found for Mersey muds in the concentrations at which they occur in the Mersey Estuary. When, however, the samples of Wye estuary water were diluted with sea water so as to give a concentration of approximately 20 gm. of mud per 100 litres, the rate of sedimentation was lower than that of Mersey mud at the same concentration. In Fig. 48 is shown also the average rate of settling of two muds from the Severn estuary at a concentration of approximately 30 gm. per 100 litres; the rate was again lower than that of Mersey muds at the same concentration. From the shape of the curves it is evident that clotting of the Severn and Wye muds occurred when they were allowed to settle from the concentrated suspensions in which they were found. Sedimentation curves of a shape typical of that given by muds which clot during sedimentation were also given by the Severn and Wye muds in a concentration of about 30 gm. per 100 litres, but at a concentration of 20 gm. per 100 litres the shape of the curves



Curve.	Samples.	No. of Samples.	Concentration Parts per 100,000.	Salinity of Water, gm. per 1,000 gm.
A.	Mersey Muds	44	20·2	25·0 approx.
B.	" "	52	29·0	25·0 approx.
1.	Suspended Matter, Wye Estuary	4	94·5	11·4
2.	" " " "	4	158·6	14·0
3.	" " " "	4	19·3	25·3
4.	" " " "	4	19·6	25·1
5.	Severn Muds	4	18·7	25·0
6.	Muds, Wye Estuary	4	20·0	25·0
7.	Severn Muds	2	29·7	25·0

FIG. 48.—*Rate of Sedimentation of Muds and Suspended Matter from the Estuaries of the Rivers Severn and Wye*

shows that clotting did not begin until comparatively late in the sedimentation period. The explanation of the relatively low settling rate of muds from the Wye and Severn is not known, but it is not due to a deficiency of organic matter since they have approximately the same composition as Mersey muds. The abnormal behaviour of the Severn and Wye muds is also not due to the fact that their estuaries are particularly unpolluted, since the Severn is probably more polluted than the estuaries in Essex, in which the mud has a settling rate of the same order as that of Mersey mud. In the estuary of the Wye the foreshore and bed appeared to be entirely covered with mud and no sandy deposits were seen.

SUMMARY

The rate of sedimentation of Mersey mud is not significantly different from that of mud in Liverpool Bay as far seaward as the Bar Lightship. As already mentioned it is probable that material eroded by the tide from Liverpool Bay and from the bed of the Irish Sea beyond it is the main source of any considerable quantity of new mud brought into the Upper Estuary. If this is so it appears that no significant change in the rate of sedimentation of the mud is brought about during its transport from the Bay to the Upper Estuary. Comparison with muds from other localities suggests that the rate of sedimentation of mud from the Mersey Estuary has not been affected by the pollution of the Estuary by sewage and trade effluents. For example, the rates of sedimentation of mud from relatively unpolluted estuaries in Suffolk and Essex were found to be higher than the rate for Mersey mud, whereas the rates of sedimentation of muds from the Severn and the Wye, which are not so heavily polluted as the Mersey, were lower. It may be that the differences in rate of sedimentation are due to differences in natural inorganic constituents. The most abnormal muds examined were those from the fresh-water part of the Manchester Ship Canal. These samples contained high concentrations of organic matter and had very high rates of settling. They cannot, however, be directly compared with muds from the estuary of the Mersey and from other estuaries, as they were deposited under vastly different conditions from relatively stagnant polluted fresh water instead of from saline water subject to tidal movement.

CHAPTER XII

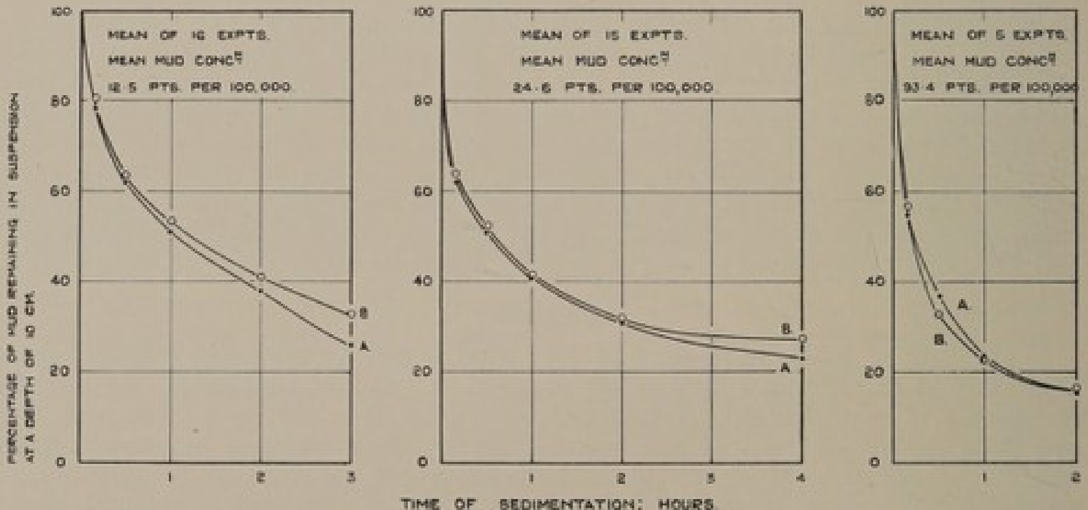
RATE OF SEDIMENTATION OF MUD IMMEDIATELY AFTER MIXING WITH SEWAGE

Mersey Muds

As a first step in studying the effect of sewage on the settling rate of mud carried in suspension in the Estuary, some experiments were carried out to determine the effect of additions of sewage on the rate of sedimentation of Mersey and other muds from suspension, usually in water of a salinity of about 25 gm. per 1,000 gm. The concentrations of mud covered the range usually found in the Estuary and sewage was added in amounts up to 5 per cent. of the volume of suspension, that is in concentrations over the same range as, and higher than, those normally found in the greater part of the Upper Estuary. In the first experiments the settling rate of Mersey mud with and without the addition of sewage was determined by measuring the concentration of mud remaining in suspension in a 5-litre beaker at a depth of 10 cm. after various time intervals; these results are given in Table 65 (p. 273). In the later work sedimentation was carried out in columns 4 ft., 9 ft. and 40 ft. in depth and the mud which settled to the bottom was collected at intervals (Table 66, p. 275).

In the experiments reported in Table 65 unsettled sewage was allowed to settle for about 1 hour; the settled sewage liquor was then siphoned off and added to the suspensions of mud. In some experiments reported in Table 66 similarly settled sewage was used, but unsettled sewage was used in other experiments; the type of sewage employed is indicated in the tables.

The experiments in Table 65, in which 5 per cent. of settled sewage liquor was added to mud suspensions, have been divided into 3 groups in which the



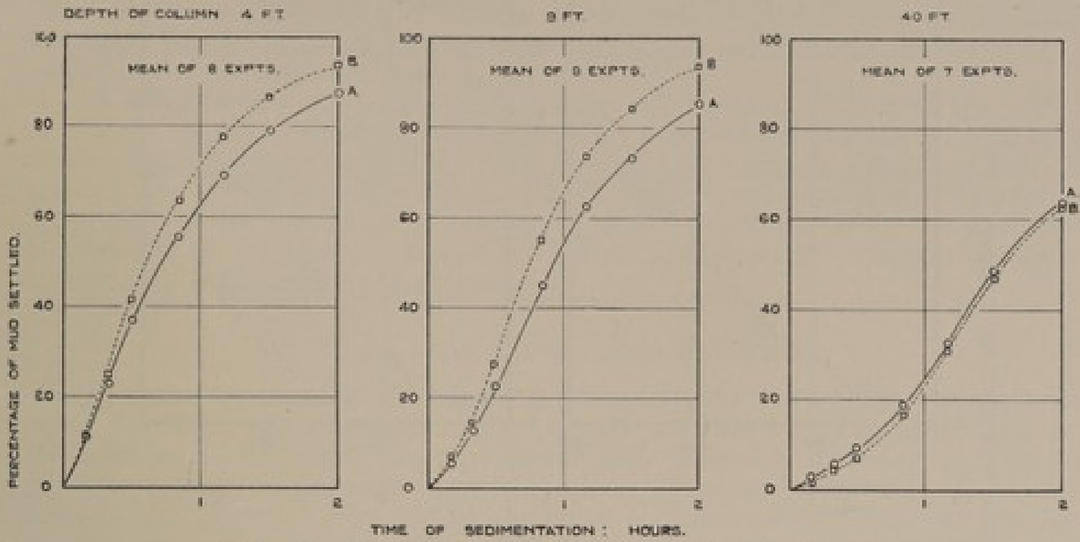
● A. No sewage. ○ B. 5 per cent. settled sewage.

Fig. 49—*Effect of Settled Sewage on Rate of Sedimentation of Mersey Mud through a Depth of* 10 *cm.*

Salinity of Water approximately 25 *gm. per* 1,000 *gm.*

original concentration of mud was between 10 and 20, between 20 and 30, and greater than 30 gm. dry weight per 100 litres. The settling rates of the muds in each group through a depth of 10 cm. with and without the addition of 5 per cent. of settled sewage have been averaged and the mean curves are shown in Fig. 49. In all three groups the average rate of settling of the mud through 10 cm. was not substantially changed by the addition of the sewage, though with the two lowest ranges of concentration of mud the presence of sewage appeared slightly to diminish the rate of settling. The curves in this figure show the percentage of the original concentration of mud which remained at a depth of 10 cm. after different time intervals.

In Fig. 50 is shown the change in the settling rate of Mersey mud, through columns 4 ft., 9 ft., and 40 ft. in depth, due to the addition of 5 per cent. of

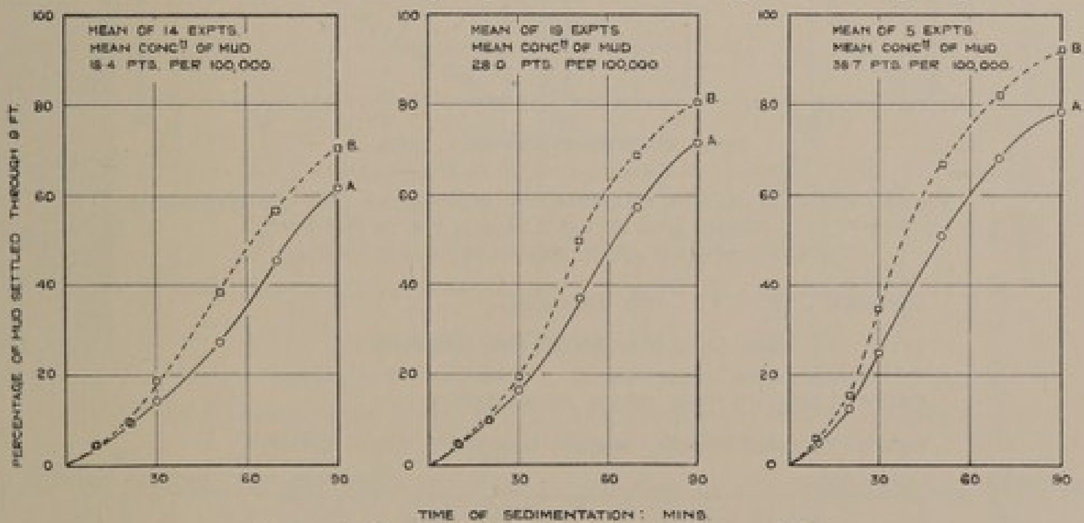


Curves: A. No sewage added. B. 5 per cent. unsettled sewage added.

Fig. 50—*Effect of Addition of 5 per cent. of Unsettled Sewage on Rate of Sedimentation of Mersey Mud through Columns of Various Depths*

Salinity of Water approximately 25 gm. per 1,000 gm.

unsettled sewage. In columns 4 ft. in depth the presence of the sewage somewhat increased the rate of sedimentation; there was a rather greater increase in columns 9 ft. in length, but the sewage had no effect on the rate of sedimentation of the mud through depths of 40 ft. The experiments in which 5 per cent. of unsettled sewage was added to mud settling through 9-ft. columns have been divided into three groups in which the initial concentrations of mud were from 15 to 25, from 25 to 30, and greater than 35 gm. dry weight per 100 litres. The mean sedimentation curves for the three groups are shown in Fig. 51. The groups contain



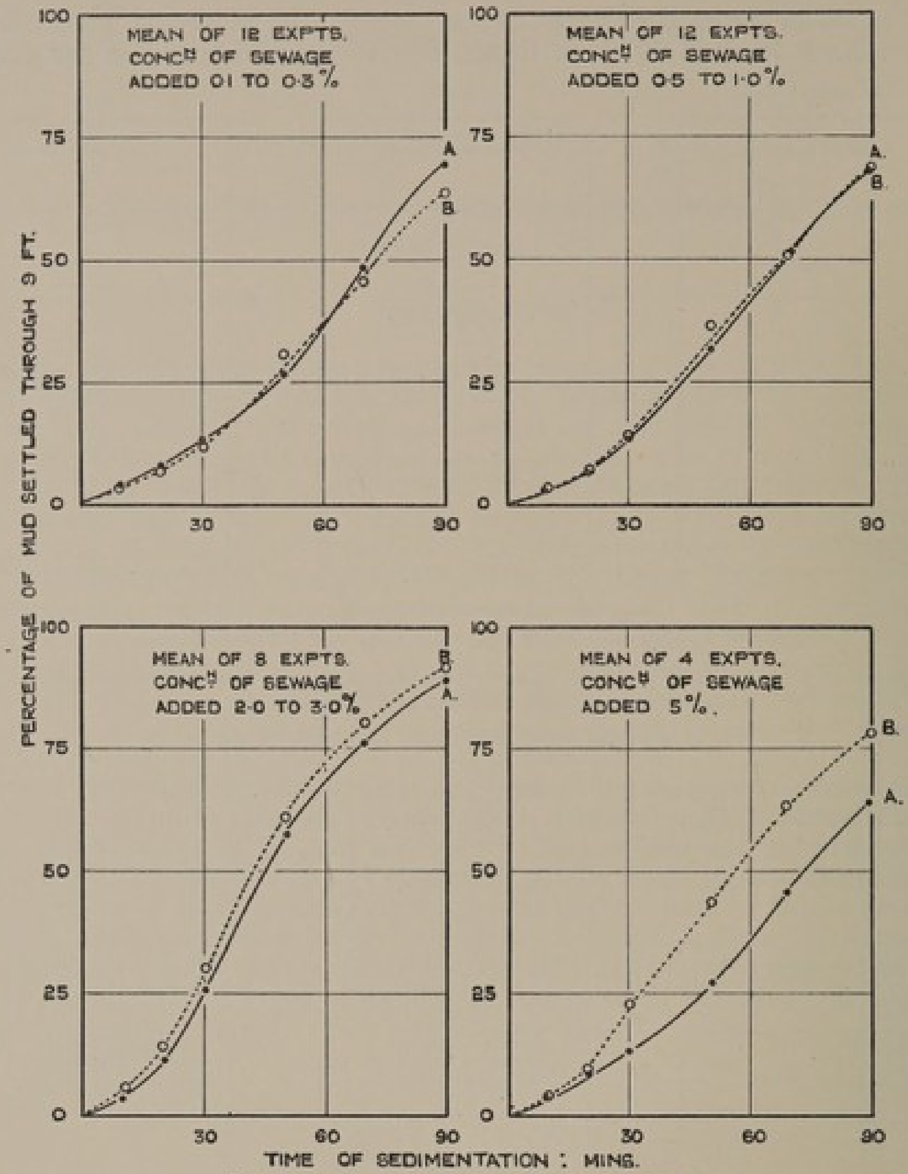
Curves: A. No sewage added. B. 5 per cent. sewage added.

Fig. 51—*Effect of Sewage on Rate of Sedimentation of Mersey Mud*

Salinity of Water approximately 25 gm. per 1,000 gm.

some experiments in which settled sewage was used and others in which unsettled sewage was added. In all cases the addition of the sewage increased the rate of sedimentation of the mud.

In almost all experiments carried out it has been found that a significant increase in the settling rate of mud through columns 4 ft. and 9 ft. in depth is brought about by the addition of 5 per cent. of unsettled or of settled sewage. It appears, however, that no significant increase in the settling rate is caused by the addition of sewage in concentrations up to 3 per cent. of the volume of the suspension. The results of some experiments showing the effect of different concentrations of



Curves: A. No sewage. B. Sewage added.

FIG. 52—*Effect of Different Concentrations of Sewage on Rate of Sedimentation of Mersey Mud through Columns 9 ft. in Depth*
Salinity of Water approximately 25 *gm. per* 1,000 *gm.*

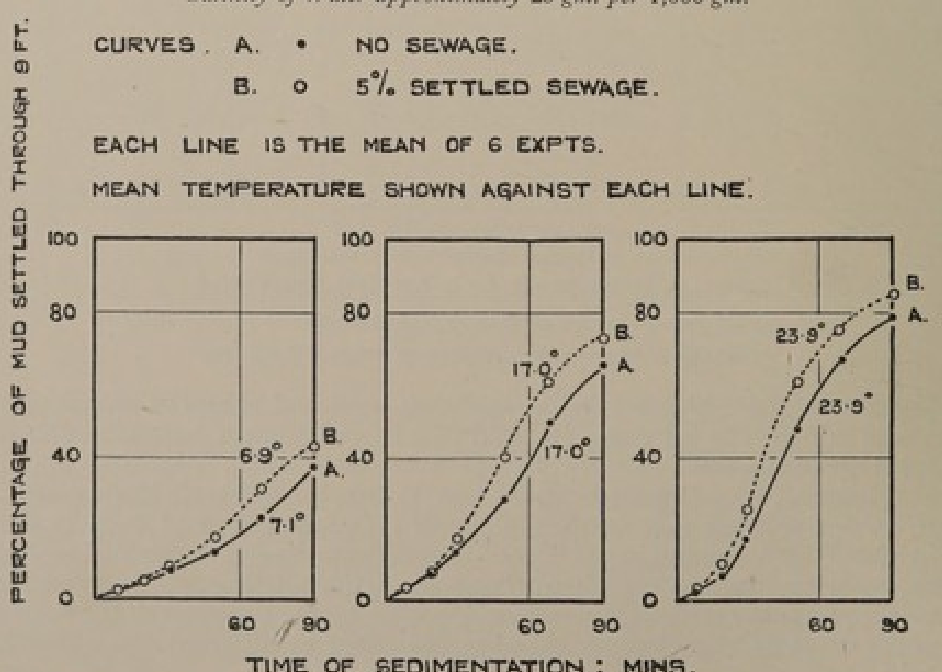


FIG. 53—*Effect of Addition of 5 per cent. of Settled Sewage on Rate of Sedimentation of Mersey Mud at Different Temperatures*
Salinity of Water approximately 25 *gm. per* 1,000 *gm.*

sewage are given in Fig. 52, which has been drawn from data presented in Table 66. In concentrations up to 1 per cent. the addition of sewage had no significant effect on the settling rate of Mersey muds; the settling rate was very slightly increased by the addition of 3 per cent. and was significantly increased by the addition of 5 per cent. of sewage.

A few experiments were carried out to determine the effect of the addition of sewage to suspensions of Mersey mud at different temperatures; the results obtained are given in Table 67 (p. 278), and are shown graphically in Fig. 53. The settling rate of mud through columns 9 ft. in depth was increased by the addition of 5 per cent. of settled sewage at temperatures of approximately 7°, 17° and 24° C., but insufficient data were obtained to determine whether the effect of sewage was appreciably influenced by temperature.

Muds from Unpolluted Estuaries

In some experiments the effect of sewage on the settling rate of muds from other estuaries was observed. Most of the samples of mud used came from estuaries in Essex which are not appreciably polluted, and one sample came from the estuary of the river Severn, in which the extent of pollution is much less than in the Mersey. The results are given in Table 68 (p. 279), and are shown graphically in Fig. 54. Addition of 5 per cent. of settled sewage increased the

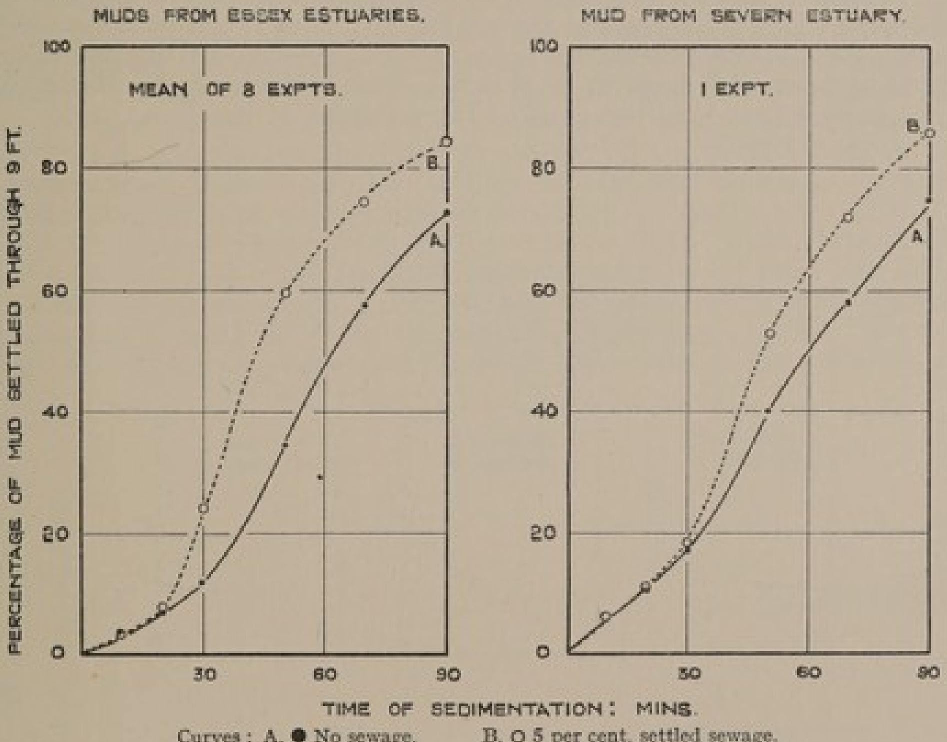


FIG. 54—*Effect of Settled Sewage on Rate of Sedimentation of Muds from the Estuary of the River Severn (Monmouthshire) and from Estuaries in Essex*

rate of settling through columns 9 ft. in depth of all the muds used, the increase being of the same order as that observed for Mersey muds.

Effect of Bacteria

The mechanism by which the addition of sewage in a sufficient concentration may bring about a considerable immediate increase in the rate of sedimentation of mud has not been investigated. Two experiments, however, were carried out to determine whether the observed effect might be due to the addition of bacteria to mud. The settling rate of suspensions of Mersey mud was determined in columns 9 ft. in depth; to a similar series of suspensions were added suspensions of a culture of living bacteria isolated from sewage. The numbers of bacteria in the suspension supplied were not known, but the liquid was milky in appearance and the concentration of bacteria in the suspension was much greater than in sewage. The results obtained are given in Table 69 (p. 279); in no case was the rate of settling of the mud significantly changed by the addition of the bacteria.

Summary

The effect of sewage on the settling rate of mud depends on the conditions under which the sedimentation takes place. In shallow depths the settling rate is not significantly affected by the presence of sewage. In columns 4 and 9 ft. in depth the addition of settled or unsettled sewage in amounts equivalent to 5 per cent. of the volume of the suspension significantly increases the rate of sedimentation of the mud, though no appreciable change in the settling rate is brought about by the addition of sewage in amounts up to 3 per cent. of the volume of the suspension. Through depths of 40 ft., however, the settling rate of Mersey mud is unaffected by the presence even of 5 per cent. of unsettled or settled sewage. It appears, therefore, that there is a depth of column in which the effect of sewage on the settling rate of mud has a maximum value. It seems that the observed differences in the effect of sewage depend on the extent to which clotting occurs in the muds to which the sewage is added. In shallow columns of a depth of about 4 in. (10 cm.) the rate of settling of mud is low since large clots are not formed, and under these conditions the effect of sewage on the settling rate is negligible. In columns 4 and 9 ft. in depth clots of mud of considerable size are formed as the mud settles, and the process of clot formation is accelerated by the presence of more than about 3 per cent. of sewage. In depths of 40 ft., however, the clots formed by the mud itself are so large and the rate of settling is so high that any change brought about by the presence of sewage again becomes negligible. Under conditions in which an increase in the settling rate of mud can be measured by the methods used, the effect of the sewage appears to be similar when added to muds which have been laid down in a polluted estuary such as the Mersey and in relatively unpolluted localities such as the estuaries of the Essex rivers.

CHAPTER XIII

EFFECT OF STIRRING ON THE STATE OF AGGREGATION OF MUD IN SUSPENSION

In the Mersey Estuary during each flood and ebb period mud is carried in suspension in water polluted by sewage. Experiments have therefore been carried out to determine the effect on the settling rate of mud of stirring mixtures of mud and sewage in concentrations of the same order as those found in the Estuary. In the first place experiments were undertaken to determine the effect on the settling rate of mud of stirring it in suspension without the addition of sewage; these results are reported in this Chapter.

Vigorous Stirring

In the earlier experiments mud suspensions were stirred sometimes for periods of several weeks, by paddles revolving at speeds sufficient to cause considerable turbulence. In some cases stirring was carried out in a battery of six large tanks, each with a capacity of about 70 gallons. The contents of each tank were stirred by three large paddles driven by a 2-h.p. electric motor; the paddles were designed to cause considerable turbulence. With this apparatus it was possible to stir a suspension of mud for some weeks, and to take 5-litre samples at frequent intervals for the determination of the settling rate of the mud without materially altering the conditions of stirring. In other experiments suspensions were stirred vigorously in 5-litre beakers by glass paddles driven by small electric motors. When a sample was taken the concentration of mud in suspension was first determined, and the sample was then poured into a 5-litre beaker or into a 9-ft. sedimentation tube, where the settling rate of the mud was determined. The results obtained for experiments in which mud suspensions were stirred vigorously are given in Tables 70 (p. 280) and 71 (p. 281). Table 70 contains the results of experiments in which the rate of sedimentation of the mud after different periods of stirring was measured by determining the concentration of mud remaining in suspension at a depth of 10 cm. during the sedimentation period. The results have been divided into 5 groups, and the mean curves are given in Fig. 55, which

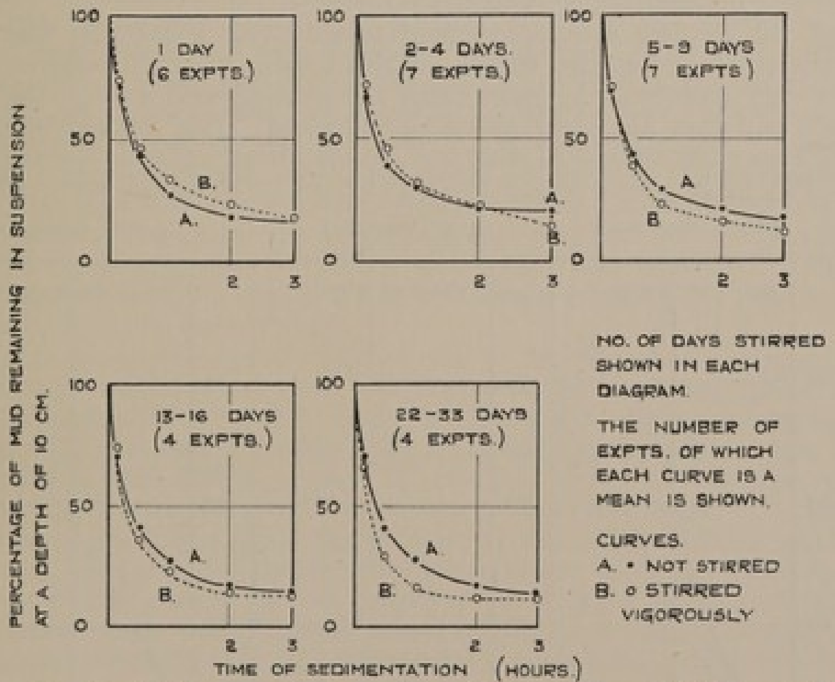
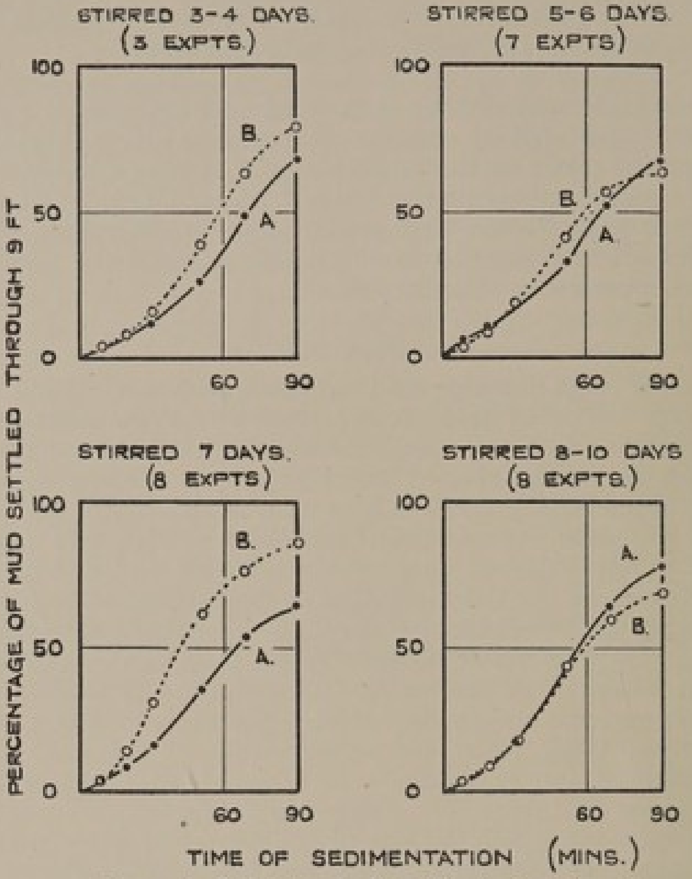


Fig. 55—*Effect of Vigorous Stirring on Rate of Sedimentation of Mud through 10 cm. Salinity of Water approximately 25 gm. per 1,000 gm.*

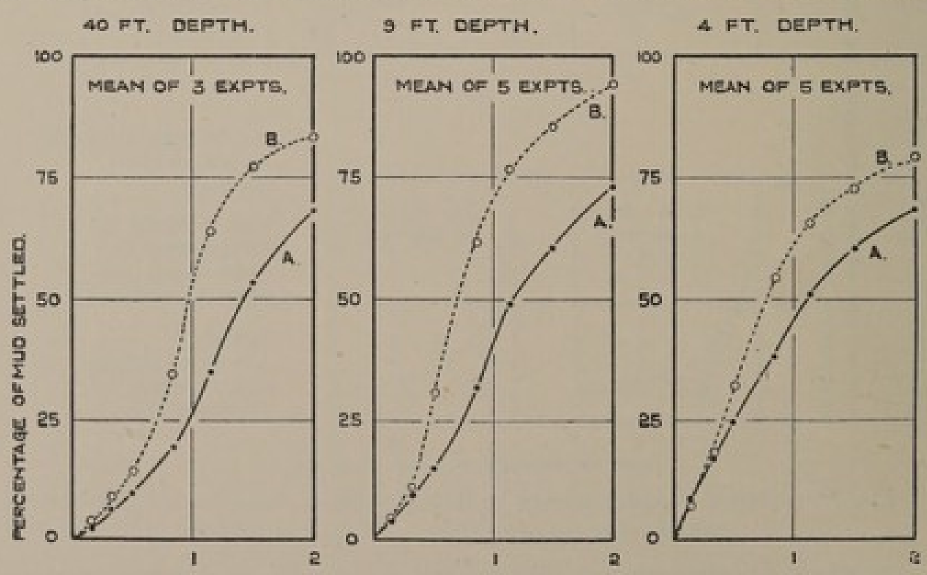
shows the effect of stirring mud suspensions vigorously for different periods on the rate of settling through a depth of 10 cm. In general, the change brought about by this treatment was not large, the average rate of settling being little greater after the suspensions had been stirred for 5 to 16 days, though significantly greater after stirring for 3 to 4 weeks. The effect on the rate of sedimentation of muds through a depth of 9 ft. caused by stirring them vigorously for periods up to 10 days is shown in Fig. 56 which has been prepared from the results in Table 71.



Curves: A. ● Not stirred. B. O Stirred vigorously.

FIG. 56—*Effect of Vigorous Stirring for Various Periods on Rate of Sedimentation of Mud*
Salinity of Water approximately 25 gm. per 1,000 gm.

In general, the settling rate determined under these conditions was increased by vigorous stirring, but the results obtained with different samples of Mersey mud were very variable. In some cases the settling rate was greatly increased by stirring, and in a few cases no change resulted. This variability is reflected in Fig. 56, where the individual diagrams do not always refer to the same samples of mud. Fig. 57 has been drawn from Table 71 to show the mean results for a



Curves: A. ● Not stirred. B. O Stirred 6 to 7 days.

FIG. 57—*Effect of Vigorous Stirring on Rate of Sedimentation of Mersey Mud through Various Depths*
Salinity of Water approximately 25 gm. per 1,000 gm.

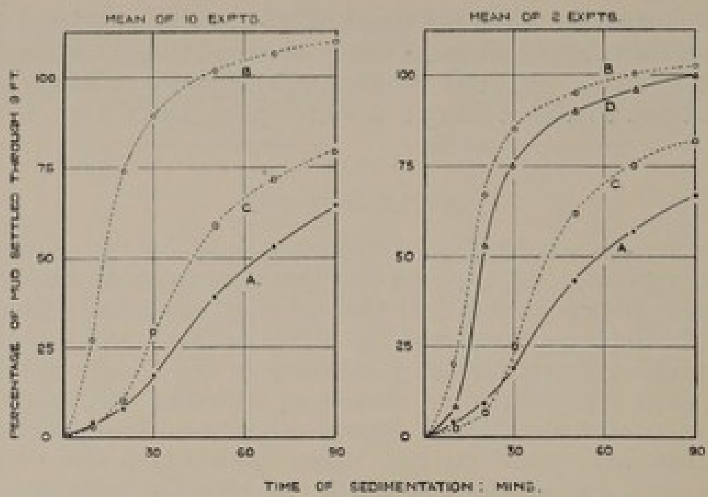
number of experiments in which suspensions of mud were stirred for about one week, after which the rate of sedimentation of the mud through columns of different depths was determined. In these experiments vigorous stirring brought about a significant increase in the settling rate through columns 4 ft., 9 ft., and 40 ft. in depth.

Gentle Stirring

It has been mentioned that the results obtained by the vigorous stirring of mud were often variable; an attempt was therefore made to discover the causes of the variations. It was known that the degree of turbulence brought about by stirring differed in the large tanks and the 5-litre beakers, and it was thought that the difference might account for the variability of the results obtained. Similar suspensions of mud were therefore stirred at different known speeds. It was found that the changes in the state of aggregation of mud brought about by stirring depended to a marked extent on the vigour with which the suspensions were stirred. In the early experiments, in which considerable turbulence was induced, the mud did not form large aggregates while being stirred, though large aggregates were rapidly formed during subsequent settling. The formation of large aggregates after stirring did not usually occur until a mud had been stirred for some days. When however a suspension of mud was stirred gently, very large clots were formed during the course of about a quarter of an hour, and when stirring was stopped the clots settled to the bottom of the vessel after a few seconds. The aggregates formed under these conditions became smaller as the speed of stirring, and thus the degree of turbulence, was increased.

When the properties of the mud which had clotted as the result of gentle stirring were examined, it was at once found that the clots formed in this way differed in their nature from those resulting from long periods of vigorous stirring. The clots formed after gentle stirring were very fragile and were broken up immediately when the mud suspension was stirred vigorously or poured from one vessel to another. In determining the settling rate of mud in the form of fragile clots it was necessary to introduce the suspension very carefully into the sedimentation tube. In the method adopted a mud suspension was stirred in a 5-litre beaker by means of a paddle attached by a thumb screw to a vertical rotating shaft; the paddle was removed by loosening the thumb screw while the shaft was still rotating, and the beaker was carried quickly to a 9-ft. sedimentation tube into which the mud suspension was carefully introduced. This was done by submerging the lower open end of the sedimentation tube in the mud suspension; a filter pump was connected to the upper end of the tube and suction was applied until the suspension had risen in the tube to the required height. The lower end of the tube was then closed, while still under the surface of the remaining mud suspension, by means of a rubber bung through which passed the collecting funnel. The sedimentation tube was then fixed vertically in a rack and samples were taken while the mud was settling. The filling of the tube had to be carried out quickly in order to ensure that the mud did not meanwhile settle out of suspension in the beaker in which it had been stirred.

The changes in the sedimentation rate of Mersey mud brought about by stirring it for periods between 1 and 4 days at slow and moderate speeds are shown in Table 72 (p. 283) and in Fig. 58. In these experiments all suspensions were stirred in beakers of the same shape and size and by paddles of the same design, one group of samples being stirred at a speed of 28 revs. per minute and another at 85 revs. per minute. At the higher speed a moderate increase in the rate of sedimentation resulted, but at the lower speed the increase in the sedimentation rate was very much greater. The shape of the sedimentation curves in the two cases is different. The S-shape of the sedimentation curves given by mud which had been stirred at a relatively high speed shows that aggregation was proceeding in the sedimentation tube during the first 30 minutes. A mud suspension which had been stirred slowly was already in the form of large clots when the tube was first filled; the clots immediately began to fall and the greater part of the mud settled through a depth of 9 ft. in the first 20 minutes. Under these conditions the shape of the sedimentation curve is more nearly the same as that which would be given by a suspension of particles which settled freely without mutual interference. In the second diagram in Fig. 58 is shown the result of two experiments in which different samples of similar mud suspensions were stirred for 1 day at 28 revs. per minute,



Curves: A. ● Not stirred.
B. ○ Stirred 1 to 4 days at 28 r.p.m.
C. □ ,, ,, ,, 85 r.p.m.

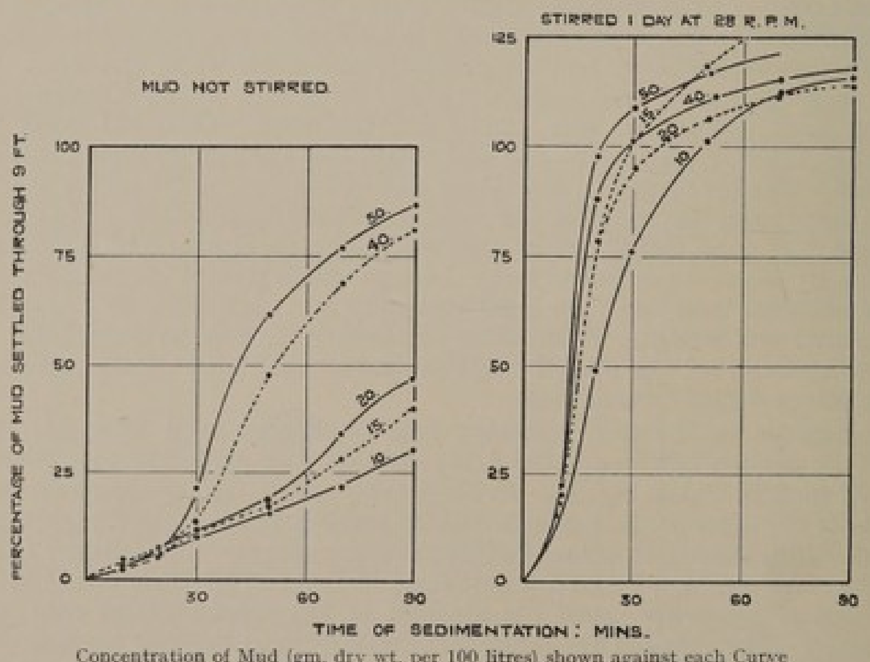
Curves: A. ● Not stirred.
B. ○ Stirred 1 day at 28 r.p.m.
C. □ ,, ,, 85 r.p.m.
D. △ ,, ,, 85 r.p.m. and 2 hrs. at 28 r.p.m.

FIG. 58—*Change in Rate of Sedimentation of Mersey Mud brought about by Stirring Suspensions at Different Speeds*

Salinity of Water approximately 25 gm. per 1,000 gm.

for 1 day at 85 revs., and for 1 day at 85 revs. followed by stirring for two hours at 28 revs. per minute. The rate of settling in the suspensions stirred for 1 day at 28 revs. was greater than in the suspensions stirred at 85 revs., but was approximately the same as in the samples stirred for 1 day at the higher speed, and then stirred for 2 hours at the lower speed.

When the settling rate of a mud is determined without previous stirring it is found that the rate of sedimentation increases with increasing concentration of the mud. In Fig. 59 is shown a series of sedimentation curves of a sample of Mersey



Concentration of Mud (gm. dry wt. per 100 litres) shown against each Curve

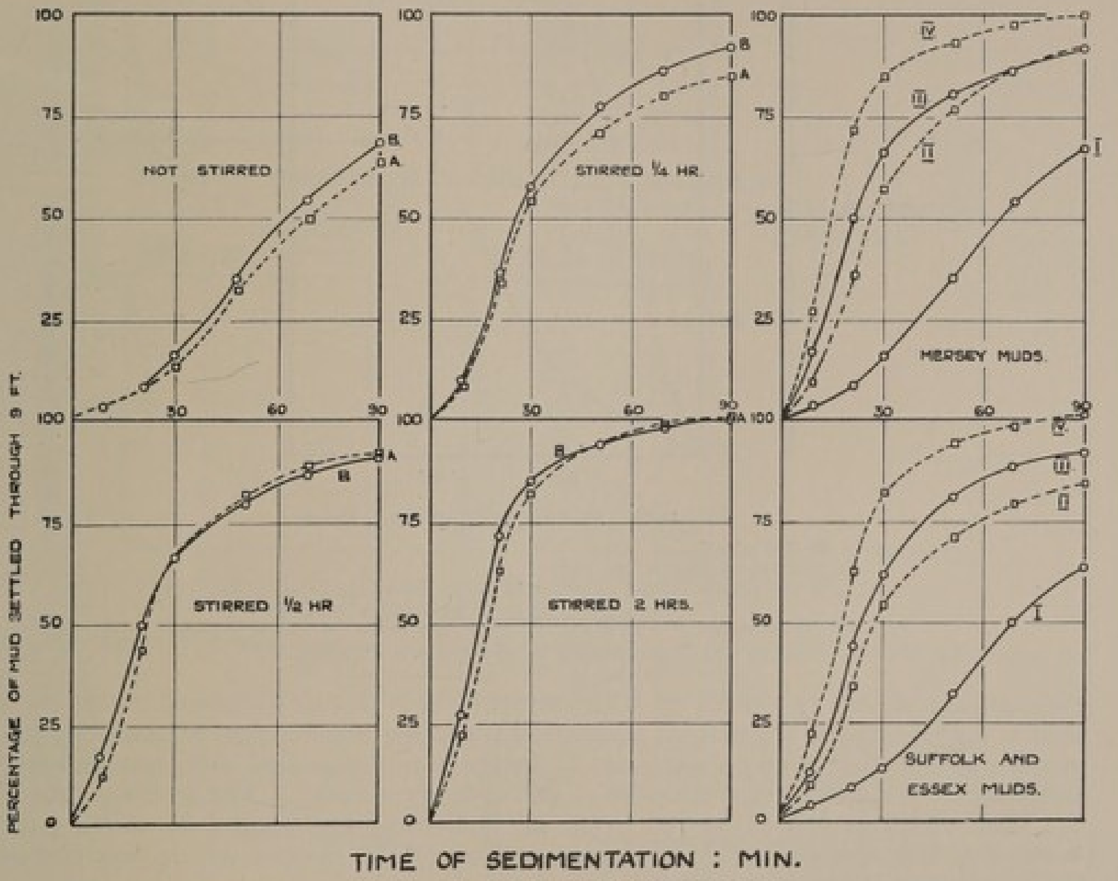
FIG. 59—*Rate of Sedimentation of Mersey Mud in Various Concentrations, either not stirred or slowly stirred*

Salinity of Water approximately 25 gm. per 1,000 gm.

mud in concentrations between 10 and 50 gm. per 100 litres; these suspensions were poured into 9 ft. sedimentation tubes. During a period of 1½ hours about 30 per cent. of the mud settled out from the most dilute suspension, while approximately 90 per cent. of the mud settled from the most concentrated suspension. When a similar series of suspensions was stirred slowly for 1 day and the rate of sedimentation of the mud was determined without breaking up the aggregates formed during stirring, the mud from all the suspensions settled out at approximately the same speed, and the rate of sedimentation in each case was mnch higher than for the unstirred samples.

Comparison of Mersey Mud with Muds from Estuaries in Suffolk and Essex

In Table 73 (p. 284) are given the rates of sedimentation of two series of muds, one series from the Mersey Estuary and one from various estuaries in Suffolk and Essex which are not appreciably polluted. Suspensions of these muds were stirred slowly under similar conditions for periods up to 2 hours by means of paddles rotating at a speed of 28 revs. per minute. In general the rate of sedimentation increased as the period of stirring was increased. The averaged results are shown in Fig. 60. It will be seen that the curves for the Suffolk and Essex samples, both



Curves: A = Suffolk and Essex Muds. B = Mersey Muds.
I. Not stirred. II. Stirred ¼ hour. III. Stirred ½ hour. IV. Stirred 2 hours.
Curves are the means given by 10 Suffolk and Essex Muds and by 8 Mersey Muds.

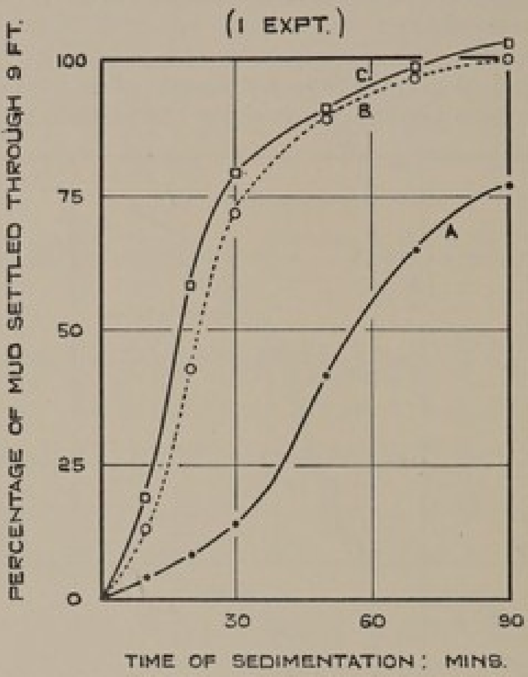
Fig. 60—*Rate of Sedimentation of Mersey, Suffolk and Essex Muds after stirring slowly* (28 *r.p.m.*) *for Different Periods*

Salinity of Water approximately 25 *gm. per* 1,000 *gm.*

before stirring and after stirring for periods of 15, 30 and 120 minutes, are almost identical with the corresponding curves given by the Mersey muds, so that the property of forming large clots during short periods of gentle stirring is common to muds taken from polluted and unpolluted localities.

Settling Rate of Mersey Mud Eroded from the Bottom and Stirred Gently

In the Estuary, mud settles out during each slack water period and is again brought into suspension by the moving water during the succeeding tide. The eroding action of the water in the Estuary on the mud at the bottom of the channels does not appear to be very vigorous, and during neaps the amount of mud eroded by the low stream velocities is small. Some experiments were therefore carried out in the laboratory to determine the settling rate of mud eroded from the bottom of a vessel by stirring the water above the mud. A sample of mud was first broken up with a small quantity of saline water and a dilute suspension was made by adding a further quantity of water of the same salinity. When such a suspension was allowed to stand in a beaker the finely divided mud slowly settled to the bottom and the sedimentation was usually found to be complete if the suspension was allowed to stand overnight. When the water was stirred gently until the mud was eroded the mud was broken off from the layer on the bottom of the beaker in large pieces which broke up into clots as the pieces came into suspension. The clots, however, did not break up into small particles unless the suspension was stirred vigorously. The results of one experiment are given in Fig. 61. In this



Curves : A. ● Not stirred.
B. ○ Stirred ½ hour at 28 r.p.m.
C. □ Not stirred, settled in beaker 18 hours, stirred for 4 min. at 28 r.p.m.

FIG. 61—*Formation of Aggregates in Mud suspended in Saline Water* (*Stour* 11, *Concentration* 22·0 *parts per* 100,000)

diagram are shown the rates of sedimentation of : (*a*) an unstirred mud, (*b*) a similar sample stirred for half an hour at 28 revs. per minute, and (*c*) a suspension of the same mud allowed to settle for 18 hours in a beaker and then brought into suspension by stirring for 4 minutes at 28 revs. per minute. The settling rate of the mud which had been eroded from the bottom of the beaker by stirring for 4 minutes was approximately the same as that of the sample which was stirred for 30 minutes at the same speed.

Properties of the Aggregates Formed by Stirring

The changes which take place in suspensions of mud stirred vigorously appear to be quite different from those occurring when the suspensions are stirred gently. If a mud suspension is stirred so as to set up violent turbulence the mud does not appear to be aggregated to any great extent while stirring continues, though visible clots may appear if stirring is continued for long periods. On allowing a suspension to come to rest, however, the mud forms clots more quickly than it did before stirring was begun. The main result of vigorous stirring, therefore, appears to be to increase the tendency for the mud particles to adhere when the mud is allowed to settle. The process by which this change takes place is a relatively slow one, and often no considerable change in the properties of the mud occurs until it has been stirred for some days. The behaviour of different samples of mud is however variable, the tendency to form clots being greatly increased by vigorous stirring of some samples while in other muds no appreciable change takes place.

It may be that the changes which occur in the properties of the mud particles are due, at least in part, to bacterial action. For example, experiments described in the next chapter have shown that the formation of clots after vigorous stirring is accelerated if the mud suspension is stirred with sewage. It has also been found that this effect can be reduced by the addition of chlorine, borax or formaldehyde, which are sterilising agents; it is realised that results of this kind are not conclusive as such sterilising agents may also cause chemical and physical changes. The results of some experiments illustrating this point are given in Fig. 62. The formation of clots after vigorous stirring was retarded by the presence of chlorine water,

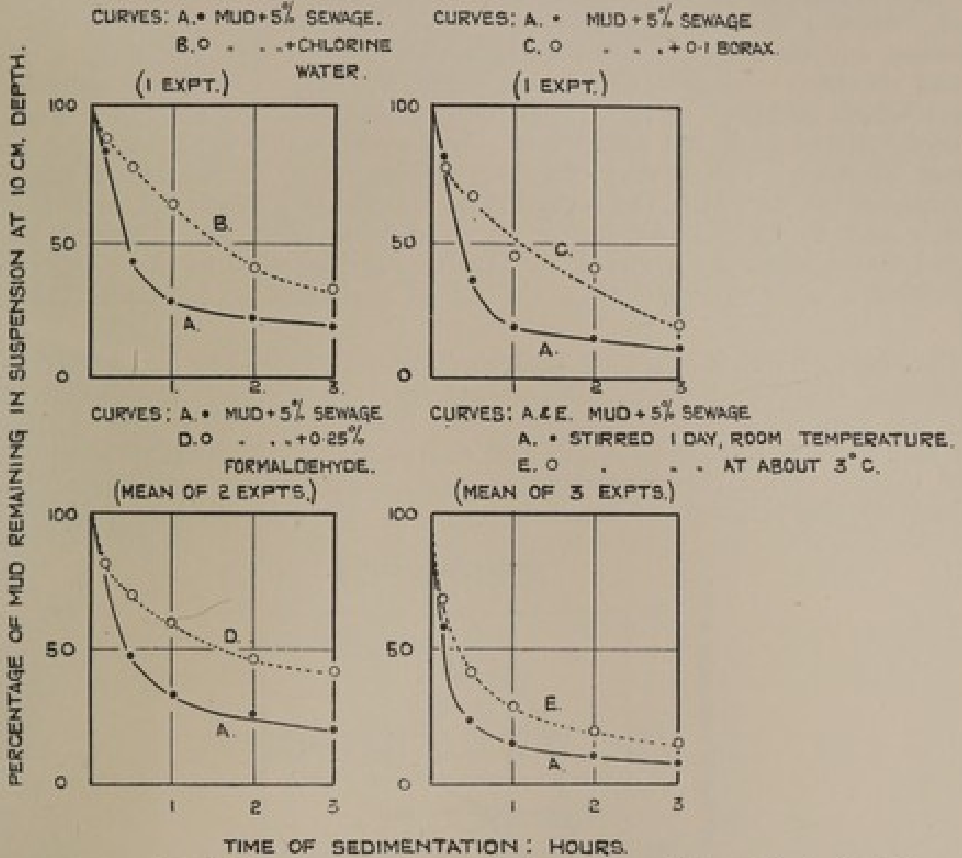
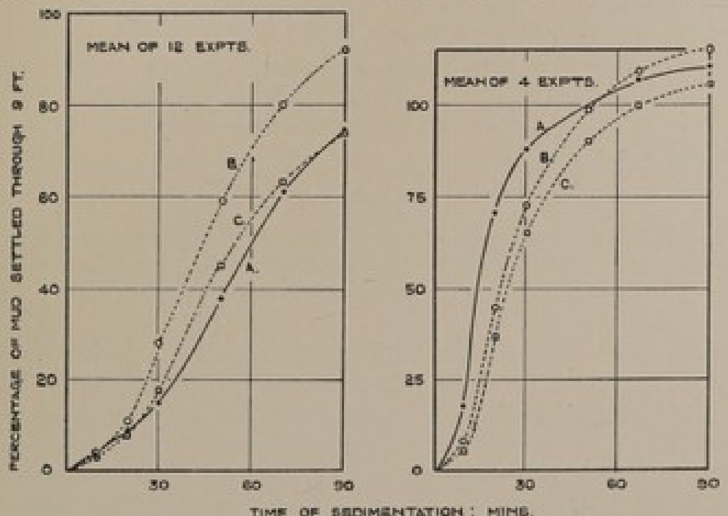


FIG. 62—*Effect of Sterilising Agents on Rate of Sedimentation of Mersey Mud, stirred vigorously for 1 Day with 5 per cent. of Settled Sewage*
Salinity of Water approximately 25 gm. per 1,000 gm.

borax or formaldehyde. The tendency of the mud to form clots was also less when it was stirred vigorously at 3° C. than when stirred at room temperature.



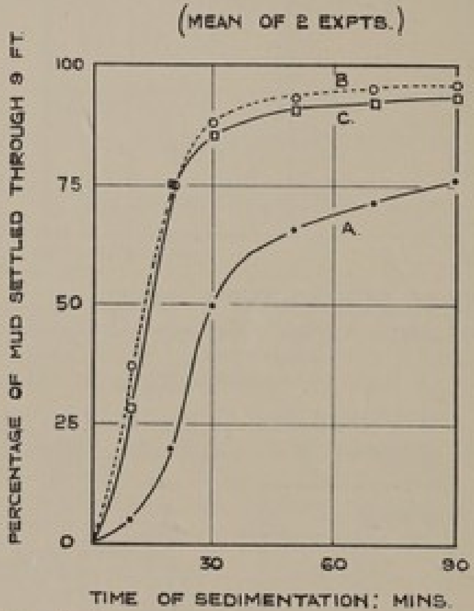
Curves: A. ● Mud not stirred.
B. ○ Stirred 5 to 8 days.
C. □ Stirred and allowed to stand 7 to 8 days.

Curves: A. ● Stirred 7 days.
B. ○ Stirred, allowed to stand 7 days.
C. □ Stirred, allowed to stand 14 days.

FIG. 63—*Change in Rate of Sedimentation of Mud which has been vigorously stirred, brought about by allowing the Mud to stand under Water. Sewage added in some Experiments*
Salinity of Water approximately 25 gm. per 1,000 gm.

The property of rapid clot formation which is induced in mud by vigorous stirring partly disappears if the stirred mud is allowed to stand under water for some time. The averaged results of some experiments are shown in Fig. 63. The first diagram in Fig. 63 shows the mean settling rate for 12 mud samples before stirring and after vigorous stirring for about a week. Similar suspensions were stirred for a week and were then allowed to stand, when the mud settled out and remained as a layer on the bottom of the beaker covered by the water in which it had been stirred. After a further period of one week the mud was again brought into suspension and its rate of sedimentation was determined; the settling rate of the mud was then similar to that found before the suspensions were stirred. The changes which occurred in the clot-forming properties of muds which were first vigorously stirred and then allowed to stand under water were found to vary in different samples. The second diagram in Fig. 63 gives the mean results for four experiments in which the reversion of the muds to their original condition was slow and no appreciable change occurred until the muds had been allowed to stand under water for a fortnight. In the samples used in these experiments the formation of aggregates after the initial period of stirring was unusually rapid.

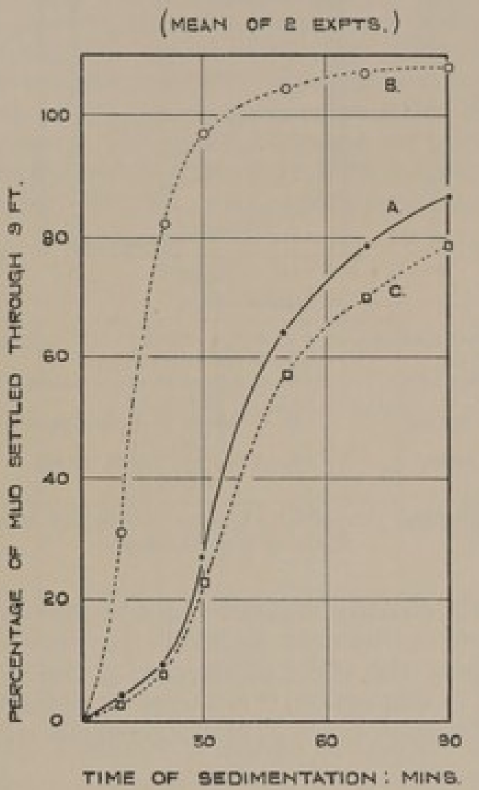
The changes which occur in mud suspensions when they are stirred gently are strongly contrasted with those caused by vigorous stirring. When stirred gently the formation of clots began almost immediately, and after stirring for about half an hour the mud appeared to consist of large aggregates suspended in almost clear water. The formation of clots under these conditions was not inhibited by the presence of sterilising agents. This is illustrated in Fig. 64,



Curves: A. ● Not stirred.
B. ○ Stirred 1 hour at 28 r.p.m. No formaldehyde.
C. □ Stirred 1 hour at 28 r.p.m. 0·25 per cent. formaldehyde.

FIG. 64—*Effect of Formaldehyde on the Formation of Aggregates in Suspensions of Mersey Mud stirred slowly* (S541, *Concentration* 42·0 *parts per* 100,000)
Salinity of Water approximately 25 *gm. per* 1,000 *gm.*

where the settling rate of mud suspensions after gentle stirring for one hour was unaffected by the presence of 0·25 per cent. of formaldehyde. The mechanism by which mud clots are formed during gentle stirring may be similar to that which governs the formation of aggregates when mud settles through deep columns of water. In deep columns and especially with concentrated suspensions the more rapidly settling mud particles fall through water containing more slowly falling particles with which they collide and form aggregates. It is thought that the main effect of gentle stirring is to increase the number of collisions between the particles in suspension, and that the maximum clotting effect is obtained when the stirring is sufficiently vigorous to bring about the greatest degree of mixing in a mud suspension but yet is not so vigorous as to break up the aggregates formed. The fragility of the clots formed in this way is the factor limiting the speed of stirring which can be used. The aggregates formed after slow stirring are so fragile that they are easily broken up if the mud suspension is stirred vigorously for a few seconds, and they are almost completely broken up by pouring the suspension from one vessel to another, as for example from a stirring beaker into a sedimentation tube. The rate of sedimentation of a sample of Mersey mud before stirring and after stirring slowly for four hours is given in Table 74 (p. 285) and in Fig. 65. In one case the stirred suspension was carefully introduced into a 9-ft.

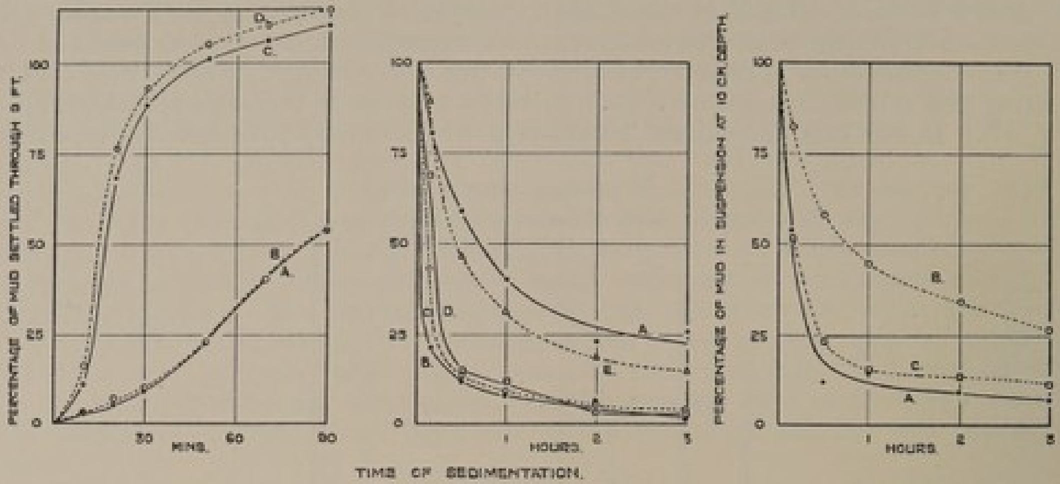


Curves : A. ● Not stirred, poured into sedimentation tube.
B. ○ Stirred 4 hours, sucked ,, ,, ,,
C. □ Stirred 4 hours, poured ,, ,, ,,

Fig. 65—*Stability of Aggregates formed by Stirring Mersey Mud slowly. Mud stirred 4 hours at 28 r.p.m.*

sedimentation tube by sucking it from the stirring beaker into the open end of the tube; in the other case a similarly stirred suspension was poured into the tube. The result of pouring the suspension was that the large aggregates which had been formed were broken up so that the mud had a settling rate approximately the same as it had before stirring.

While the aggregates formed by gentle stirring are very fragile, the settling rate of mud after vigorous stirring is altered only with difficulty. The results of some experiments on the properties of the aggregates formed after violent stirring are shown in Fig. 66. The first diagram refers to three experiments in which similar unstirred mud suspensions were poured or gently sucked into sedimentation tubes; their settling rates were identical. Further suspensions were then stirred vigorously for 19 days, and the settling rate of the mud was determined after pouring or sucking the stirred material into 9-ft. tubes. The rate of sedimentation, which had been greatly increased by stirring, was approximately the same in both cases. The second diagram refers to experiments in which vigorously stirred suspensions were shaken for different periods in a mechanical reciprocating shaker before their settling rate was determined. The curves show that the settling rate was not greatly altered after a suspension had been shaken violently for one minute, but that the rate was decreased after shaking for 15 minutes. This change was, however, not permanent. In the third diagram is shown the settling rate of a mud suspension after vigorous stirring for 11 days before and after being shaken for 25 minutes. As a result of shaking, the rate of sedimentation was decreased; when the shaken material was allowed to stand overnight and its rate of sedimentation was again determined, it was found that the mud then settled at a rate similar to that found before it had been shaken.



Curves: A. ● Not stirred, poured into tube.
B. ○ Not stirred, sucked into tube.
C. ● Stirred 19 days, poured into tube.
D. ○ Stirred 19 days, sucked into tube.

Curves: A. ● Not stirred.
B. ● Stirred 13 days.
C. ○ Stirred 13 days, shaken 15 secs.
D. □ Stirred 13 days, shaken 1 min.
E. △ Stirred 13 days, shaken 15 min.

Curves: A. ● Stirred 11 days.
B. ○ Stirred 11 days, shaken 25 min.
C. □ Stirred 11 days, shaken 25 min., stood overnight, stirred 5 min. and settled.

FIG. 66—*Stability of Aggregates formed by Vigorous Stirring of Mersey Mud. Each Curve the Mean of 3 Experiments.*

It is evident that the changes brought about by maintaining mud in suspension depend very largely on the manner in which the water containing the mud is agitated. In determining the effect of sewage on the settling rate of mud with which it is maintained in suspension, it is therefore necessary to consider the effect of the sewage on the different types of mud aggregates which can be formed.

SUMMARY

When suspensions of Mersey mud were stirred vigorously for periods of several weeks and then allowed to settle, the original rate of sedimentation of the mud was generally increased. During stirring the size of the mud particles was not usually appreciably altered, but the effect of stirring was to increase the rate of aggregation of the mud particles when the suspensions were allowed to settle. When mud was stirred slowly an almost immediate flocculation occurred and fragile clots were formed which had a high rate of sedimentation. The size of the aggregates formed increased gradually during gentle stirring for a period of two hours; the settling rate of these aggregates was approximately the same for Mersey muds and for muds from unpolluted localities.

Large fragile mud aggregates, similar to those produced by gentle stirring, were formed when mud was allowed to settle as a layer on the bottom of a beaker and was then brought into suspension by stirring the water above it.

Some experiments carried out suggest that the alteration in the properties of mud, which occurs when it is stirred vigorously and results in an increase in the rate at which it subsequently forms aggregates on standing, may be due in part to bacterial activity. The formation of large aggregates by gentle stirring, however, appears to be mainly a physical process, and is believed to be encouraged by the increased number of collisions between mud particles caused by gentle agitation of the suspension.

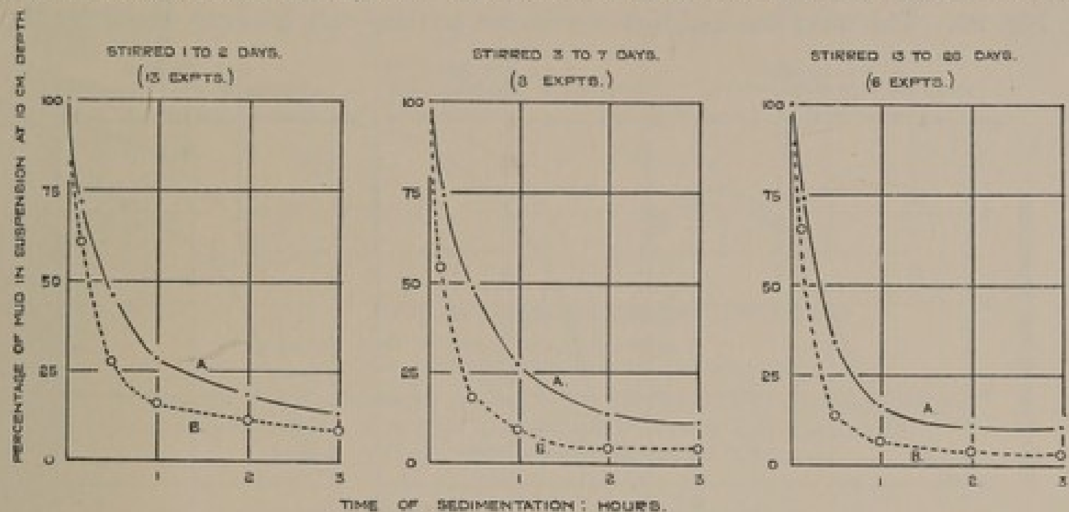
The mud aggregates formed by gentle stirring are very fragile and can be broken up by vigorous agitation.

CHAPTER XIV

EFFECT OF STIRRING WITH SEWAGE ON THE RATE OF SEDIMENTATION OF MUD IN DIFFERENT STATES OF AGGREGATION

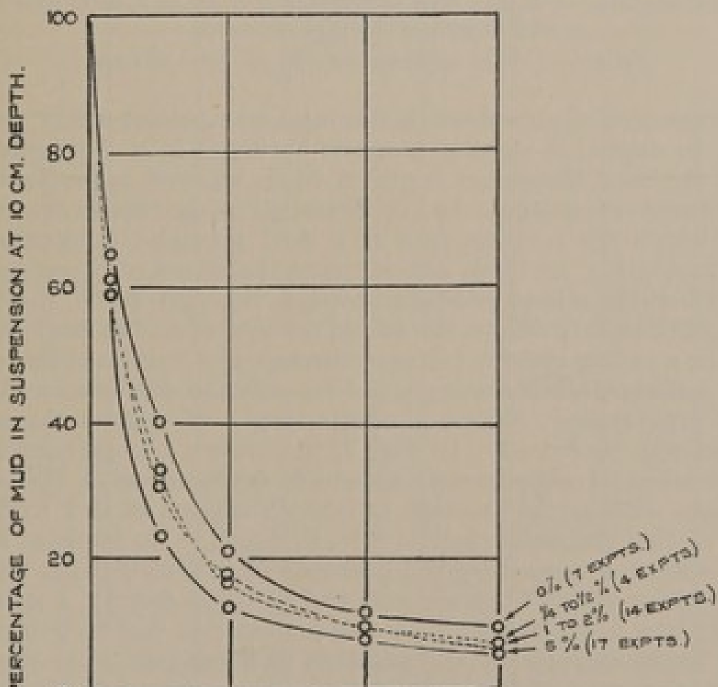
Vigorous Stirring

In a first series of experiments, suspensions of Mersey mud were stirred vigorously for different periods, settled sewage being added either before stirring or in small quantities during the period of stirring. The stirred suspensions were then poured into 5-litre beakers, and the concentrations of mud which remained in suspension at a depth of 10 cm. were determined at intervals during a sedimentation period of 3 hours. The results obtained are given in Table 75 (p. 286), and the average results for those experiments in which 5 per cent. of settled sewage was added are shown in Fig. 67. The rate of sedimentation of the mud in control



Curves: A. ● Stirred vigorously, no sewage. B. ○ Stirred vigorously with 5 per cent. of settled sewage.

Fig. 67—*Effect of Vigorous Stirring with Sewage on Rate of Sedimentation of Mersey Mud*
Salinity of Water approximately 25 gm. per 1,000 gm.



Muds stirred from 1 to 4 days.
Percentage of sewage shown against each curve.

Fig. 68—*Effect of Vigorous Stirring with Different Concentrations of Settled Sewage on Rate of Sedimentation of Mersey Mud*
Salinity of Water approximately 25 gm. per 1,000 gm.

experiments in which no sewage was added increased as a result of stirring for various periods up to 3 weeks. A further increase in the settling rate of the mud was brought about by the addition during stirring of 5 per cent. of settled sewage. In Fig. 68 are shown the average results of other experiments in which mud suspensions were stirred vigorously with settled sewage in concentrations of 0·25 to 5·0 per cent. Some increase in the rate of sedimentation was brought about by the addition of the smaller amounts of sewage and a larger increase by the addition of 5 per cent. of sewage. In these experiments the effect of sewage on the settling rate of mud with which it was stirred varied considerably with different samples of Mersey mud.

The change in the settling rate of Mersey muds resulting from stirring them vigorously with sewage was also determined by measuring the rate of sedimentation of the stirred material in tubes 4 ft., 9 ft., 20 ft. and 40 ft. in length (Table 76, p. 288). The mean sedimentation curves for a number of muds stirred vigorously with 5 per cent. of sewage, and then settled through columns 4, 9 and 40 ft. in length are shown in Fig. 69. The most marked increase in the settling rate brought about by the

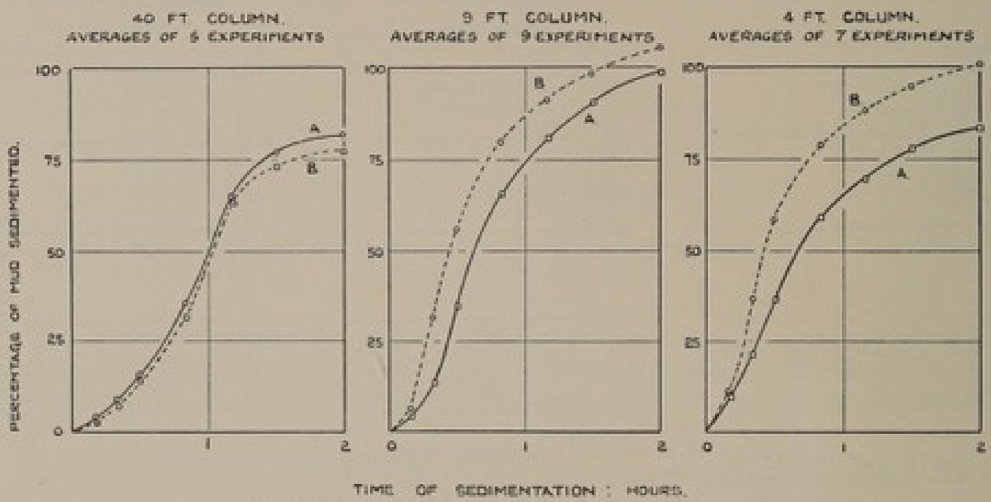
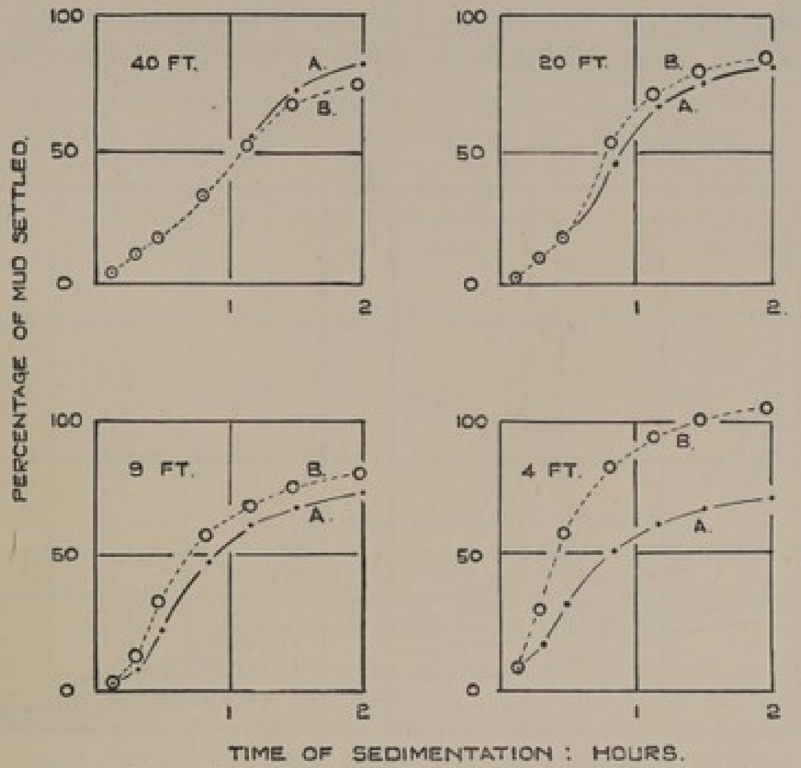


FIG. 69—*Rate of Sedimentation of Mersey Mud in Columns of Different Lengths after Vigorous Stirring with or without Addition of Sewage*

Salinity of Water approximately 25 *gm. per* 1,000 *gm.*

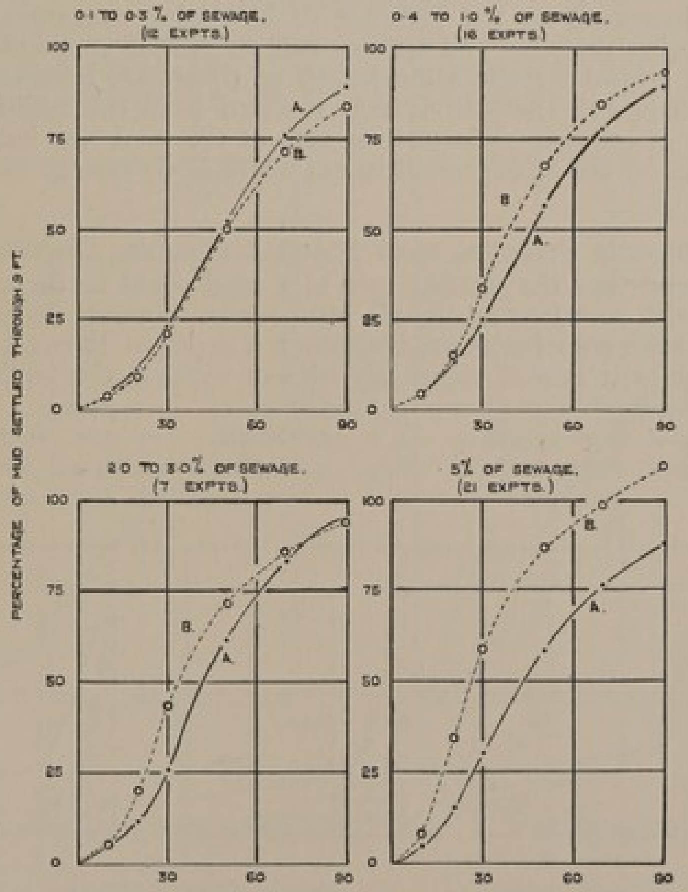
presence of sewage was observed when the mud was subsequently settled through a column 4 ft. in depth; a smaller increase occurred in a 9-ft. column, but the settling rate of the mud through a depth of 40 ft. was not appreciably affected by addition of 5 per cent. of sewage. In Fig. 70 are given the results of a more complete experiment in which the settling rate of a mud was also determined through a column 20 ft. in depth. In these experiments the effect of 5 per cent. of sewage was negligible when the stirred mud was settled through 40 ft., there was a slight increase in the settling rate due to the added sewage when the mud settled through a depth of 20 ft., a rather greater increase through 9 ft., and a considerably greater increase when sedimentation through a 4-ft. column was observed. The effect of sewage thus progressively increased as the length of column through which the mud was settled was decreased. In Fig. 71 are shown the average sedimentation curves for a number of experiments in which suspensions of Mersey mud were stirred vigorously with settled sewage in concentrations of 0·1 to 5·0 per cent., and were then settled through columns 9 ft. in depth. No increase in the settling rate of these muds was caused by the presence of 0·1 to 0·3 per cent. of sewage during the period for which they were stirred (3 to 15 days); a small increase in the settling rate was brought about by the presence of 0·4 to 3·0 per cent., and a considerably larger increase by the addition of 5 per cent. of sewage. Increases in the sedimentation rate of the same order as those found in Mersey muds were also obtained when two samples of mud, one from the Estuary of the River Blackwater in Essex, and one from the Estuary of the River Severn, were stirred with 5 per cent. of sewage (Table 77, p. 290).

The effect of sewage on the settling rate of mud with which it was stirred was found to be greater when the suspensions were made up in Liverpool tap water



Curves: A ● Stirred 6 days, no sewage.
B. ○ Stirred 6 days, 5 per cent. settled sewage.

FIG. 70—*Effect of Vigorous Stirring with 5 per cent. of Settled Sewage on Rate of Sedimentation of Mersey Mud through Columns of Different Lengths Salinity of Water approximately 25 gm. per 1,000 gm.*



Curves: A. ● Stirred vigorously without sewage. B. ○ Stirred vigorously with sewage.

FIG. 71—*Effect of Vigorous Stirring with Different Concentrations of Sewage on Rate of Sedimentation of Mersey Mud*
Salinity of Water approximately 25 gm. per 1,000 gm.

instead of in sea water. The averaged results of two series of experiments are shown in Fig. 72. After stirring in tap water without the addition of sewage the

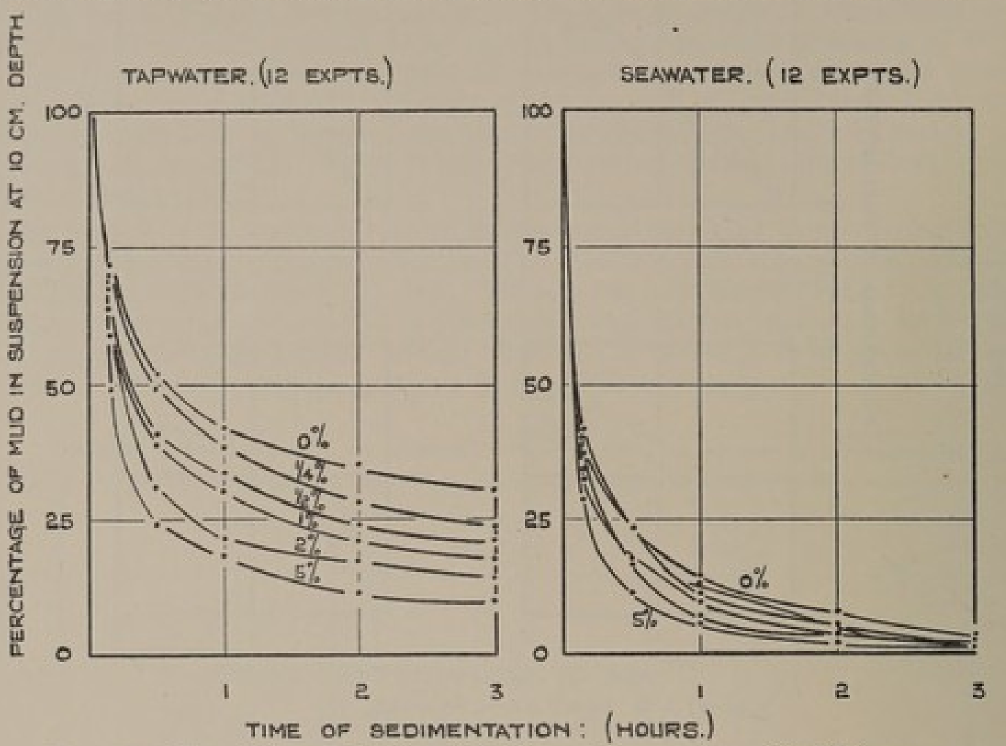


Fig. 72—*Effect of Vigorous Stirring with Different Concentrations of Settled Sewage on Rate of Sedimentation of Mersey Mud in Tap Water and Sea Water. Concentration of Sewage shown against each Curve*

settling rate of Mersey mud through 10 cm. was comparatively low, but it was progressively increased by the presence of increasing concentrations of sewage during the stirring period. The settling rate of similar suspensions made up in sea water and stirred for the same length of time was, however, high, and no considerable change in the settling rate resulted from the addition of the same concentrations of sewage. The settling rate of the mud was increased to about the same extent by the salts present in sea water as by sewage in a concentration of 5 per cent.

Vigorous Stirring with Soluble Organic Compounds

It was found that the settling rate of a mud could be increased by stirring it vigorously with solutions of organic compounds. In Fig. 73 are shown curves of the rate of sedimentation of muds through a depth of 10 cm.; the suspensions had previously been stirred vigorously with or without the addition of glucose,

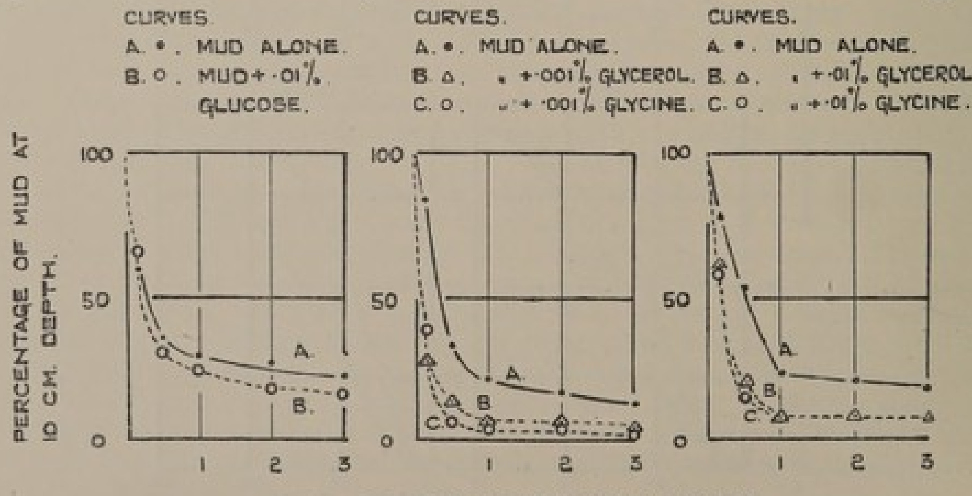
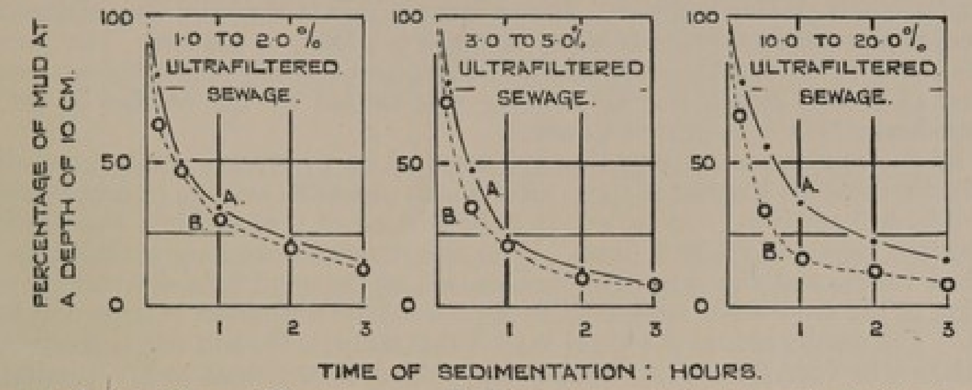


Fig. 73—*Effect of Vigorous Stirring with Soluble Organic Compounds on Rate of Sedimentation of Mersey Mud*

Suspensions stirred from 1 to 3 Days in Different Experiments
Salinity of Water approximately 25 gm. per 1,000 gm.

glycerol or glycine in concentrations of 1·0 and 10·0 parts per 100,000. The increase in the rate of settling caused by the presence of the organic compounds was of the same order as that brought about by the addition of 3 to 5 per cent. of sewage. In Table 78 (p. 290) and in Fig. 74 are also given the results of similar experiments in which the added material consisted of the ultrafiltrate from sewage;



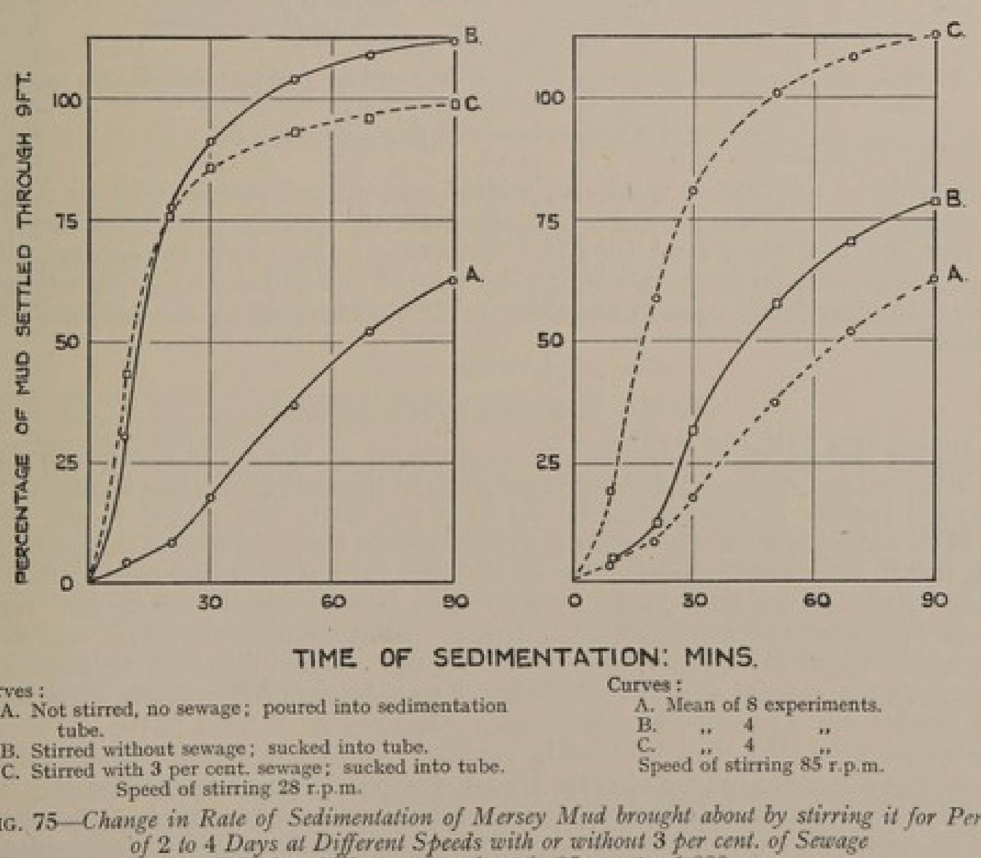
Curves: A. ● Stirred vigorously 2 to 4 days. B. ○ Stirred vigorously 2 to 4 days with ultrafiltered sewage. Each curve is the mean from 3 experiments.

FIG. 74—*Effect of Vigorous Stirring with Ultrafiltered Sewage on Rate of Sedimentation of Mersey Mud Salinity of Water approximately 25 gm. per 1,000 gm.*

a significant increase in the settling rate of the mud was caused by the addition of 20 per cent. of the ultrafiltrate to a mud suspension which was vigorously stirred. Addition of 5 per cent. or less of sewage ultrafiltrate had no significant effect. It had previously been found that the addition of ultrafiltered sewage without stirring had no immediate effect on the settling rate of Mersey mud. It may be that the changes which take place during the vigorous stirring of mud are partly due to bacterial activity which would be increased by the additional food supply provided by the soluble organic matter added.

GENTLE STIRRING

The effect of the addition of sewage to suspensions of mud stirred slowly has also been investigated; the results of some experiments are given in Table 79 (p. 291), and the average curves are given in Fig. 75. In this figure the rates of sedimentation



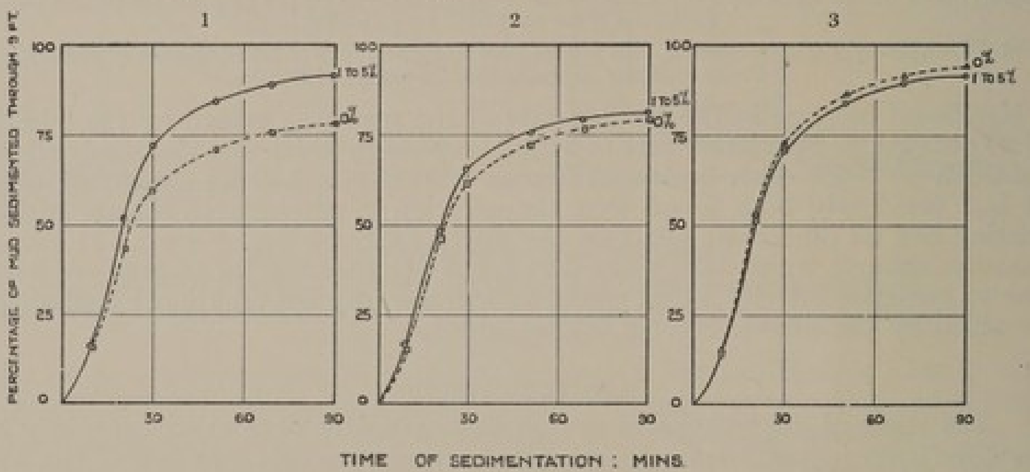
Curves:
A. Not stirred, no sewage; poured into sedimentation tube.
B. Stirred without sewage; sucked into tube.
C. Stirred with 3 per cent. sewage; sucked into tube.
Speed of stirring 28 r.p.m.

Curves:
A. Mean of 8 experiments.
B. " 4 "
C. " 4 "
Speed of stirring 85 r.p.m.

FIG. 75—*Change in Rate of Sedimentation of Mersey Mud brought about by stirring it for Periods of 2 to 4 Days at Different Speeds with or without 3 per cent. of Sewage Salinity of Water approximately 25 gm. per 1,000 gm.*

through a depth of 9 ft. of suspensions of mud poured into sedimentation tubes are shown. When the suspensions were stirred for a period of 2 to 4 days by a paddle revolving at 85 revs. per minute, and were then sucked carefully into a sedimentation tube, the rate of settling of the mud was somewhat increased by the preliminary stirring; stirring at only 28 revs. per minute for the same period caused a much greater increase. In other experiments the mud suspensions were stirred at the same two speeds after adding 3 per cent. of sewage. The presence of the sewage considerably increased the subsequent settling rate of the suspensions stirred at a high speed, but no increase was caused by the sewage in the mud suspensions which were stirred slowly.

In the next series of experiments suspensions of Mersey muds were stirred slowly for different lengths of time, after which unsettled sewage in concentrations of 1·0 to 5·0 per cent. was added, and the stirring of the mixtures was continued for further periods of 1 or 2 hours. The suspensions were then sucked into 9-ft. vertical tubes, and the rate of sedimentation of the mud was determined. The stirring of the mud under these conditions caused the formation of large and fragile clots. The results obtained are given in Table 80 (p. 292), and the average curves are shown in Fig. 76. When sewage was added to the mud before stirring was



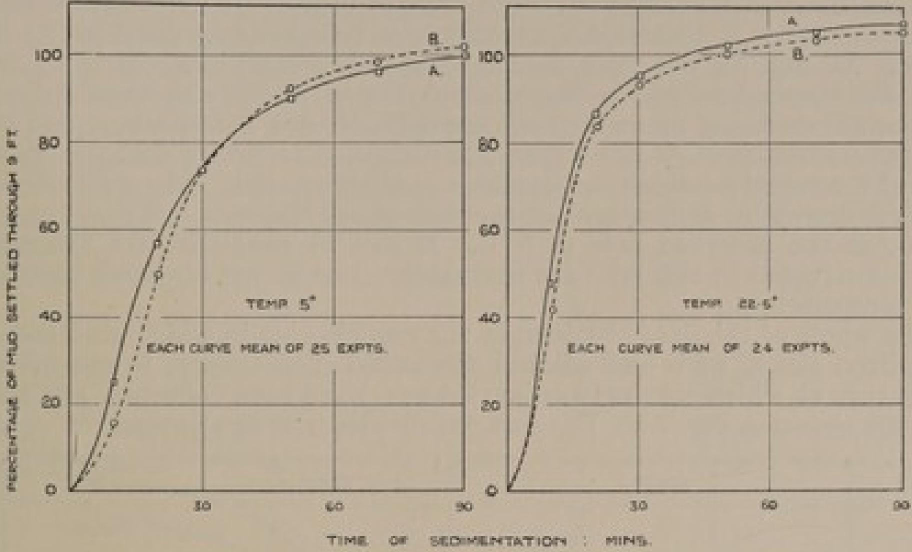
Curves: 1. Not stirred. Average of 14 experiments.
2. Stirred 30 min. before addition of sewage. Average of 10 experiments.
3. Stirred 1 hour before addition of sewage. Average of 14 experiments.
Concentration of unsettled sewage added: 1 to 5 per cent.

FIG. 76—*Rate of Sedimentation of Mersey Mud, stirred gently for Different Periods, then mixed with Water or Sewage and stirred gently for a Further Period*
Salinity of Water approximately 25 gm. per 1,000 gm.

begun and the mixture of mud and sewage was stirred slowly for 1 or 2 hours, the settling rate of the mud was increased by the presence of the sewage. If, however, the mud was stirred slowly for 30 minutes or for 1 hour before the addition of the sewage, so as to form clots before the sewage was added, no significant change in the rate of sedimentation of the mud was brought about by the presence of the sewage.

Gentle Stirring after Erosion

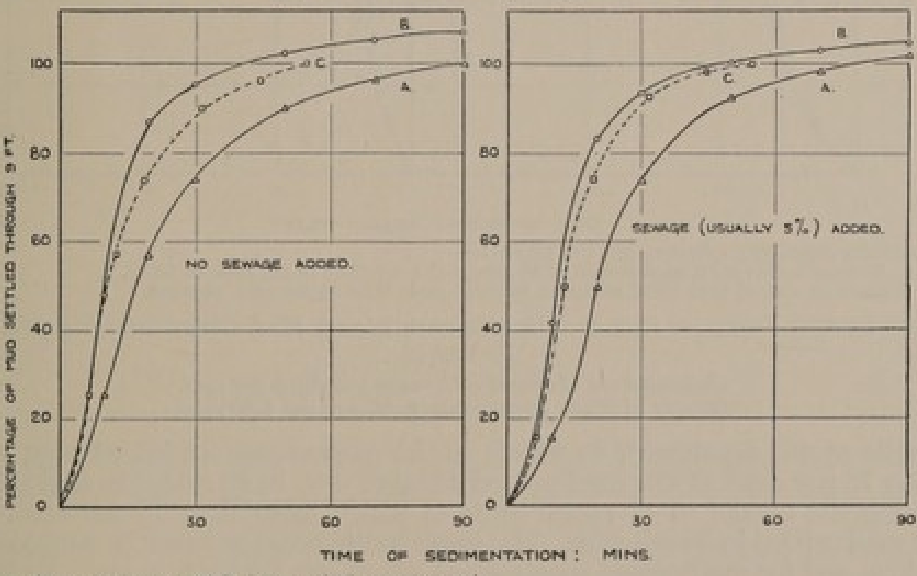
In the last series of experiments suspensions of Mersey mud were made up in 5-litre beakers, and were allowed to settle until the mud had fallen to the bottom. Unsettled sewage in concentrations up to 5 per cent. was added to the supernatant water, which was then stirred so as to erode the mud from the bottom and bring it into suspension mixed with the sewage. The mud was eroded in the form of large pieces which later broke up into clots though the clots were not further broken up under the conditions of stirring. After erosion the mud was stirred for periods up to 3 hours, the suspensions were sucked into 9-ft. sedimentation tubes, and the rate of settling of the mud was determined. These experiments were carried out at temperatures of approximately 5° C. and 23° C. The mud suspensions were stirred in beakers in two large insulated boxes, one cooled with ice and the other heated by electric lamps, temperatures of approximately 5° C. and 22·5° C. being maintained by thermo-regulators. After stirring, the suspensions were quickly transferred to sedimentation tubes in insulated boxes maintained at the same temperatures. The results obtained are given in Table 81 (p. 294), and the average results for 25 experiments at 5° C. and for 24 experiments at 22·5° C. are shown in Fig. 77. Under the conditions of these experiments the presence of



Curves: A. No sewage. B. With sewage (usually 5 per cent., unsettled).

FIG. 77—*Rate of Sedimentation of Mersey Mud eroded from the Bottom of a Beaker into Saline Water or Saline Water containing Sewage, stirred and settled at a Temperature of 5° or 22·5° C.*

sewage had no appreciable effect, either at 5° C. or at 22·5° C. on the settling rate of the muds. The relation between the sedimentation rates at 5° C. and at 22·5° C. of the mud stirred both with and without sewage can more easily be seen from Fig. 78; the rate of settling was considerably higher when the muds were stirred



Curves: A. Observed rate at 5° C. (mean of 25 experiments).
B. Observed rate at 22·5° C. (mean of 24 experiments).
C. Curve calculated from Curve A, allowing for effect of temperature on viscosity of water.

FIG. 78—*Rate of Sedimentation of Mersey Mud eroded from the Bottom of a Beaker into Saline Water or Saline Water containing Sewage, stirred and settled at a Temperature of 5° or 22·5° C.*

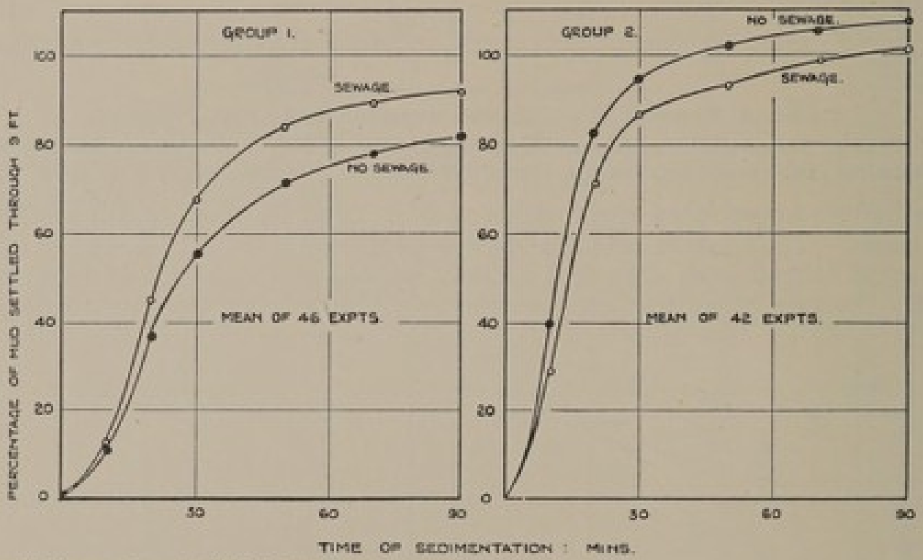
at the higher temperature than at the lower. It seems probable that the difference in the settling rate of the muds at the two temperatures is largely due to the effect of temperature on the viscosity of the water. After slow stirring the mud is in the form of large aggregates which begin to settle at once, and which do not apparently increase very much in size as they fall. Their rate of sedimentation should therefore be governed by the law of Stokes :—

$$V = \frac{2}{9} g r^2 \frac{(s - s')}{c}$$

where V is the rate of fall, g is the acceleration due to gravity, r is the radius of the particles, s is the specific gravity of the particles, s′ is the specific gravity of the liquid, and c is the coefficient of viscosity of the liquid.

The main effect of the increase in temperature on the settling rate of mud is due to the decrease in the coefficient of viscosity of the water through which the particles fall. At 5° C. the value of the coefficient of viscosity is approximately 1·6 times the value at 22·5° C. The rate of sedimentation of particles which obey Stokes's law is therefore approximately 1·6 times as great at 22·5° C. as at 5° C. In Fig. 78 the calculated rate of sedimentation at 22·5° C. has been drawn for suspensions the sedimentation rate of which was observed at 5° C., the assumptions being made that the particles obeyed Stokes's law, and that the only appreciable effect of the increase in temperature was a decrease in the viscosity of the water in which the particles were suspended. The calculated curves were thus drawn by assuming that the rate of settling was 1·6 times as great at 22·5° C. as the observed rate at 5° C. It will be seen that the sedimentation curves constructed in this way are reasonably close to the observed curves at the higher temperature.

The whole of the data obtained in the experiments in which mud suspensions were stirred slowly with and without the addition of sewage, irrespective of the temperature at which stirring was carried out, have been collected, and the mean results are shown in Fig. 79. The data are divided into two groups, one containing



All available experiments divided into two groups :—
1. Weakly clotted mud (mud settled in 30 mins. not more than 75 per cent. of total).
2. Strongly clotted mud (mud settled in 30 mins. more than 75 per cent. of total).

FIG. 79—*Effect of Sewage on Rate of Sedimentation of Mersey Mud, Clotted before the Addition of the Sewage*

Concentration of Unsettled Sewage usually 5 *per cent.*
Salinity of Water approximately 25 *gm. per* 1,000 *gm.*

the results of 46 experiments in which, in the suspensions stirred without sewage, less than 75 per cent. of the mud settled through 9 ft. in 30 minutes, and the other containing the results of 42 experiments in which more than 75 per cent. of the stirred mud settled in 30 minutes. The mean sedimentation rates for suspensions of mud alone and for mud mixed with sewage are shown for each group. In the first group, which consisted of muds not well flocculated, the addition of unsettled sewage somewhat increased the rate of sedimentation. The typical " S " shape of the sedimentation curves for Group 1 shows that the mud was not at first in the form of large clots, but that it formed larger aggregates as sedimentation proceeded. In the second group of experiments, in which the mud had been well flocculated by stirring, the addition of sewage did not increase the rate of sedimentation but slightly decreased it. A similar small decrease in the settling rate of mud was observed when sewage was added to mud suspensions allowed to settle through columns 40 ft. in depth, where again the mud reached the bottom of the tube in the form of large aggregates.

SUMMARY

The effect of the addition of sewage to mud in suspension depends on the size of the aggregates of mud. If a mud suspension is vigorously stirred so as to prevent the formation of clots while stirring proceeds, the presence of sewage increases the subsequent settling rate of the mud. It may be that this increase is due partly to increased bacterial activity since similar changes result when soluble organic matter is added instead of sewage and the extent of the changes which occur with sewage can be decreased by the addition of sterilising agents. If, however, sewage is added and is stirred gently with mud which has been caused to form large fragile clots either by previous stirring or gentle erosion from the bottom, the presence of the sewage does not significantly affect the rate of sedimentation of the mud. Sewage has no appreciable effect on suspensions containing large mud aggregates. In assessing the importance of sewage in its effect on the rate of sedimentation of mud carried in suspension in the Estuary water, it is therefore important to determine the size and nature of the aggregates of mud which exist under natural conditions.

CHAPTER XV

STATE OF AGGREGATION OF SUSPENDED MATTER IN THE MERSEY AND IN OTHER ESTUARIES

During the present investigation it was observed that the mud carried in suspension in the Mersey Estuary was in the form of large clots. When viewed from a boat or from the banks, the suspended matter in the moving water had a granular appearance and the individual aggregates could be easily seen. Where the water was shallow and flowing over an uneven bed, the mud could be seen rising to the surface in " boils " and being distributed in the water without the large particles being broken up. When, however, water samples were taken in the ordinary way and poured into a bottle the mud was broken up into particles too small to be distinguishable by the naked eye. A series of determinations was therefore carried out in which an attempt was made to measure the rate of sedimentation of estuarine suspended matter obtained in its natural state. The determinations were made during both spring and neap tides and at all states of the tide except during periods of slack water.

Method Used

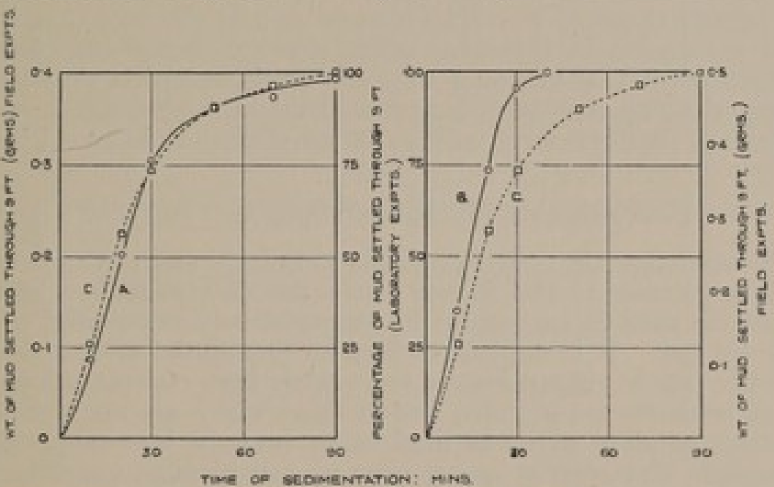
In these determinations a 9-ft. sedimentation tube, open at both ends, was lowered slowly and vertically into the water from a boat drifting with the stream. When the tube had been lowered to a depth of 9 feet the top was closed by a bung and the tube was withdrawn vertically with the water inside it. When the bottom of the tube was a few inches from the surface of the water the lower end was closed with a rubber bung through which passed a small funnel of known diameter. The period of sedimentation was taken as having begun at this point. The tube was then carried ashore in a vertical position and was placed in a portable rack which held 6 tubes and which was set up above the high water mark at a convenient place on the shore of the Estuary. The solid bung was then removed from the top of the tube, the mud was allowed to settle, and samples were taken from the funnel at the bottom as in laboratory determinations. By this method the breaking up of the mud clots carried in the Estuary water was minimised. In some cases the rate of sedimentation of the suspended matter after the clots had been broken was also observed. This was done by taking a second sample, which was run out from the collecting tube into a beaker and was stirred and poured into the top of a second sedimentation tube in the rack. This treatment was found to break up the clots of mud originally present.

Difficulties were encountered in observing accurately the rate of sedimentation of the unbroken clots of mud. It was necessary to lower the collecting tube to a depth of 9 feet from a boat moving at exactly the same speed as the stream since otherwise the aggregates might be broken by the relative motion between the tube and the water. It was necessary also to lower the tube slowly in order that the clots should not be broken up by the turbulence set up as the water entered the tube. The only places in which the work could be carried out were those in which a deep channel ran near the shore of the Estuary. In most places the tube had to be carried, after sedimentation had begun, to a position above the high water mark over a belt of soft mud and it was difficult to carry the tubes vertically while crossing this belt. It was also found difficult to keep the six tubes vertical during the sedimentation of the mud, especially when the wind was strong, since the gear used had to be light enough to be transported easily. The uneven temperatures set up by wind or sun often caused marked convection currents and it was usually found that the mud did not settle evenly at the base of the tube but tended to settle more on one side than on the other. The result of this was that a smaller quantity of mud was collected in the funnel in the centre of the tube than would have been the case if sedimentation had proceeded uniformly over the whole cross-section.

In laboratory experiments the amount of mud settling out after different time intervals has been expressed as a percentage of the weight of mud originally present in the suspension. The initial concentration of mud was obtained by taking a sample from the suspension, stirred so as to give a uniform distribution of mud, before the suspension was introduced into the sedimentation tube. In field experiments it was impossible to determine accurately the initial mean concentration of mud in those suspensions which were introduced into tubes without breaking the mud clots. When a tube was filled by lowering the open end vertically into the water, the sample obtained represented a vertical section from the surface to a depth of 9 feet and the concentration of the mud might vary between these levels. The only method available for taking a duplicate sample which could be uniformly mixed and in which the mean concentration of mud could be determined was to lower a second 9 ft. tube alongside the first. It was found, however, that owing to the frequent distribution of mud in patches in the Estuary the mean concentration of mud was often different in tubes lowered as nearly as possible at the same time. In the field experiments, therefore, the actual weight of mud settling after different periods of sedimentation has been plotted.

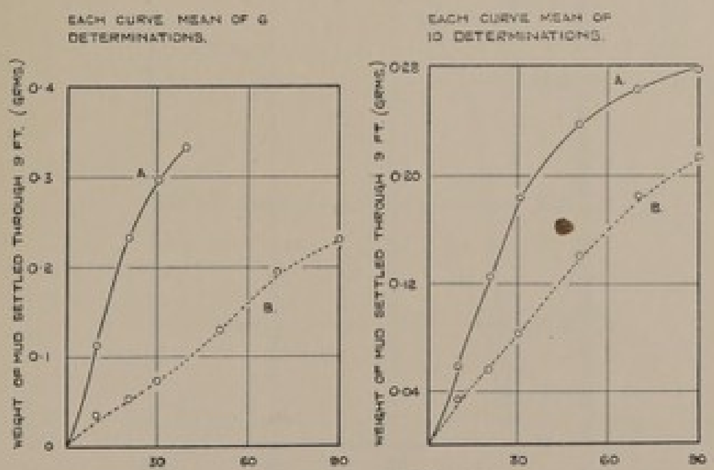
Mersey Estuary

The results obtained in the Mersey Estuary are given in Table 82 (p. 296). The experiments in which unbroken clots of mud were allowed to settle have been divided into two groups, one containing 29 experiments in which the sedimentation was continued for 90 minutes, and the other containing 27 experiments in which the mud was allowed to settle for 40 minutes. The mean settling curves from the two groups are shown in Fig. 80. In Fig. 81 are given the mean curves from two



Curves: A. O Field determinations (average of 29). Mud clots not broken.
B. O ,, ,, (,, 27). Mud clots not broken.
C. □ Laboratory expts., sedimentation rate of Mersey Mud after slow stirring at 5° C. (Fig. 77, Chapter XIV).

Fig. 80—*Rate of Sedimentation of Suspended Matter from Mersey Estuary Water. Field Experiments*



Curves: A. Sample taken without breaking clots. B. Sample poured into tube; clots broken.

Fig. 81—*Rate of Sedimentation of Suspended Matter from Mersey Estuary Water. Field Experiments*

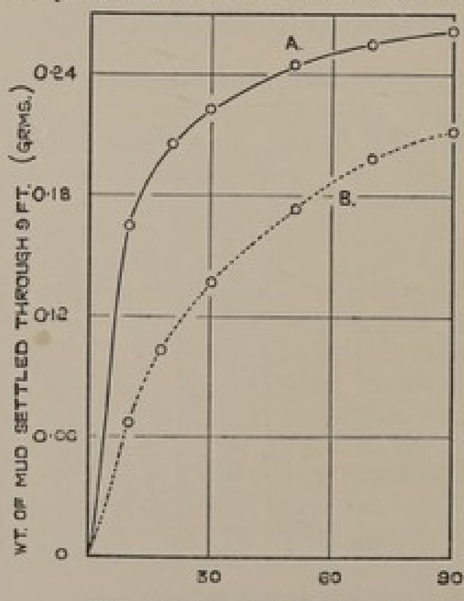
similar groups of experiments in which the settling rate of the estuarine suspended matter both before and after breaking up the mud aggregates was observed.

The curves given by the suspended matter in its natural state are similar to those given by suspensions of mud which have been stirred slowly and in which large aggregates are present. After pouring from one vessel to another the clots present in the Estuary water were broken up and the settling rate of the mud was then much lower. It appears therefore that the aggregates present in the Estuary water are fragile and are similar in nature to those resulting from slow stirring of mud suspensions or from the erosion of mud into water in which there is no violently turbulent movement. There was no indication that the mud aggregates in the Estuary water are broken up by the movement of the water even at the times of maximum stream velocity which occur during the highest spring tides.

In Fig. 80 two curves (C) drawn on a similar scale are also shown. These curves are identical and are copied from Fig. 77 (Chapter XIV). They represent the mean settling rate of 25 mud suspensions which were eroded from the bottom of beakers, stirred slowly for various periods, and then allowed to settle; the stirring was carried out at a temperature of 5° C. and the sedimentation at a temperature of 6·5° C. The rate of sedimentation of the estuarine mud in one group of determinations was almost the same as that of the muds eroded in the laboratory and in the other group the settling rate of the estuarine material was the higher. It was shown in Chapter XIV that the mean rate of settling of the group of muds treated in the laboratory was not significantly altered when the muds were brought into suspension and stirred with water containing unsettled sewage in concentrations up to 5 per cent. The failure of the sewage to increase the settling rate of the mud was shown to be due to the fact that the mud was brought into suspension in the form of large clots. Since the clots present in the Estuary are at least as big as or bigger than those which were present in the laboratory experiments, it is very improbable that the presence of sewage in the Estuary water affects the rate of sedimentation of the mud carried in suspension.

Estuaries of the Rivers Suir and Barrow

It was thought that the occurrence of mud in large aggregates in the estuarine water might be peculiar to the Mersey and some determinations of the state of aggregation of the mud in suspension in comparatively unpolluted estuaries were therefore carried out. It is difficult to find an unpolluted estuary in which mud is carried by the tide in suspensions of reasonably high concentration, since many of the English estuaries are polluted and in those which are not the tidal range is often insufficient to allow of much mud being brought into suspension. It was found for example that even at spring tides no considerable quantity of mud was carried in suspension in any of the estuaries examined in Essex, though patches



Curves: A. Clots unbroken. Mean of 9 determinations.
B. Sample poured into tube and clots broken. Mean of 9 determinations.

FIG. 82—*Rate of Sedimentation of the Suspended Matter in Water from the Estuaries of the Rivers Suir and Barrow, Irish Free State. Field Experiments*

of water with mud in suspension were occasionally seen. Where these patches occurred the mud had the same clotted appearance as in the Mersey. The large quantities of mud carried in the Mersey Estuary are probably due to the high range of the tide, which is one of the largest in England and is more than 30 feet during springs. A visit was paid to the River Suir and Barrow in the Irish Free State where it was reported that mud is carried in suspension. The estuaries of these rivers, though not completely unpolluted, are comparatively clean since the estuaries are large and the only large quantity of polluting material they receive is the domestic sewage from the town of Waterford at the head of the Suir Estuary. There are extensive salmon and herring fisheries in both estuaries. Determinations of the settling rate of the mud in the Suir and Barrow were made by the same method as that used in the Mersey; the results are reported in Table 83 (p. 297) and the mean curves are shown in Fig. 82. The mud carried in the two Irish estuaries was found to be in a well clotted condition, as in the Mersey Estuary; the clots were fragile and easily broken up by pouring the suspension from one vessel to another.

Summary

It has been shown that when Mersey or other estuarine muds are eroded from a layer on the bottom of a vessel by the movement of water in which turbulence is not too violent, the mud comes into suspension in the form of large fragile clots with a high rate of settling. The settling rate of the mud under these conditions is not appreciably affected by the presence of sewage in concentrations up to 5 per cent. The mud carried in suspension in the Mersey and in the comparatively unpolluted estuaries of the Rivers Suir and Barrow has been found to be present in the form of large fragile clots similar to those which were formed in laboratory experiments by erosion or by gentle stirring. It is concluded that the rate of sedimentation of mud in the Mersey Estuary is not appreciably affected by sewage which, in the greater part of the Estuary, is present in concentrations considerably smaller than 5 per cent.

CHAPTER XVI

RATE OF SEDIMENTATION OF SUSPENDED MATTER IN THE MERSEY AND IN OTHER ESTUARIES

In the previous Chapter the settling rate of Mersey mud in the form in which it is carried in suspension in the Estuary was discussed and it was shown that its accurate determination by laboratory methods presented several difficulties. At different times during the investigation attempts were made to measure the rate of settling of suspended matter in the moving water in the Estuary itself. A float, consisting of large crossed canvas vanes attached to a vertical pole, was put in the water, usually at high or at low tide, and was allowed to drift freely during the succeeding ebb or flood. Since only a short length of the pole carrying a small marking flag was above water, the float was little affected by wind and had little motion relative to the Estuary water. At intervals during the drift samples were taken at different depths at the position occupied by the float and the concentration of suspended matter was determined. The position of the float was determined at short intervals by sextant angles and the speed of the stream with which the float was moving was thus measured. In other cases samples were taken from a boat anchored in a fixed position, the stream velocity being determined by observations taken with current meters. The results of the determinations made by both methods are given in Table 84 (p. 298). In this Table are also given some results for the content of volatile matter and the oxygen consuming capacity of the suspended matter; these results will be discussed in Chapter XVIII.

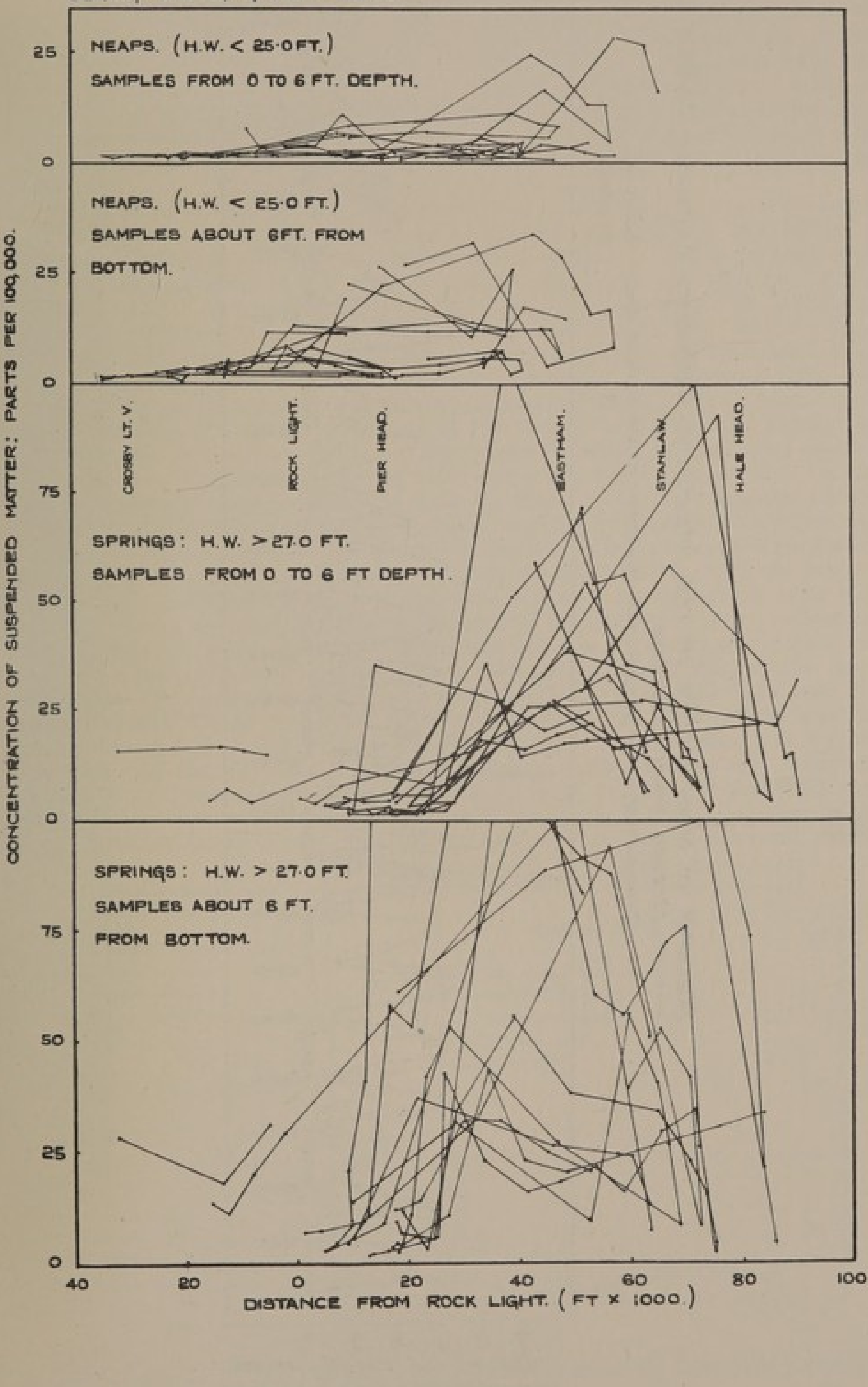
Mersey Estuary

The concentrations of material found in suspension during float drifts are shown graphically in Fig. 83. The data have been divided into two groups, one showing conditions in the Upper Estuary during neap tides and the other during spring tides, and for each group the concentration of suspended matter near the surface and near the bottom is separately plotted. In most cases the floats were put in the water in the Narrows at low tide and were followed during the flood, observations often being continued during the succeeding ebb. This was done in order to obtain information on the conditions affecting sewage discharged in the Narrows at low water and carried up the Estuary during the flood tide. A series of float runs, the results of which are included in Fig. 83, was also carried out in order to obtain information on the residual seaward rate of travel of water in the Narrows over complete periods of ebb and flood; this series was discussed in Chapter IV. Most of the information obtained shows the conditions which exist above the Narrows during the run of the tide but comparatively little information is available on the conditions in the Narrows and in Liverpool Bay during the time of maximum stream velocity. It will be seen from Fig. 83 that the concentration of suspended matter in the Estuary water differs considerably during springs and neaps. During neaps the concentration of material in suspension either near the surface or near the bottom was never much greater than 30 parts per 100,000 and for the greater part of the tidal period did not exceed 20 parts per 100,000. When a float was started in the Narrows at low water of a neap tide the amount of material in suspension remained at a low level until the float had reached the shallow part of the upper basin. During springs however the quantity of material in suspension was much higher and high concentrations of suspended matter were found after the float had travelled only a short distance upstream from the Narrows.

It was found that the concentration of material in suspension was subject to rapid fluctuation; this was particularly noticeable in the shallow reaches of the Upper Estuary where sudden increases in the concentration of suspended matter were often observed when the float drifted over an uneven part of the Estuary bed. In general the suspended matter, though present in high concentrations during the run of the tide, settled almost entirely out of suspension at slack water both in the Narrows and in the upper basin. The rate at which the suspended matter settled, however, was found to vary considerably since the greater part of the settling occurred while the water was still moving. Under these conditions the settling of suspended matter was often affected by turbulence set up in the slowly

Fig. 83.

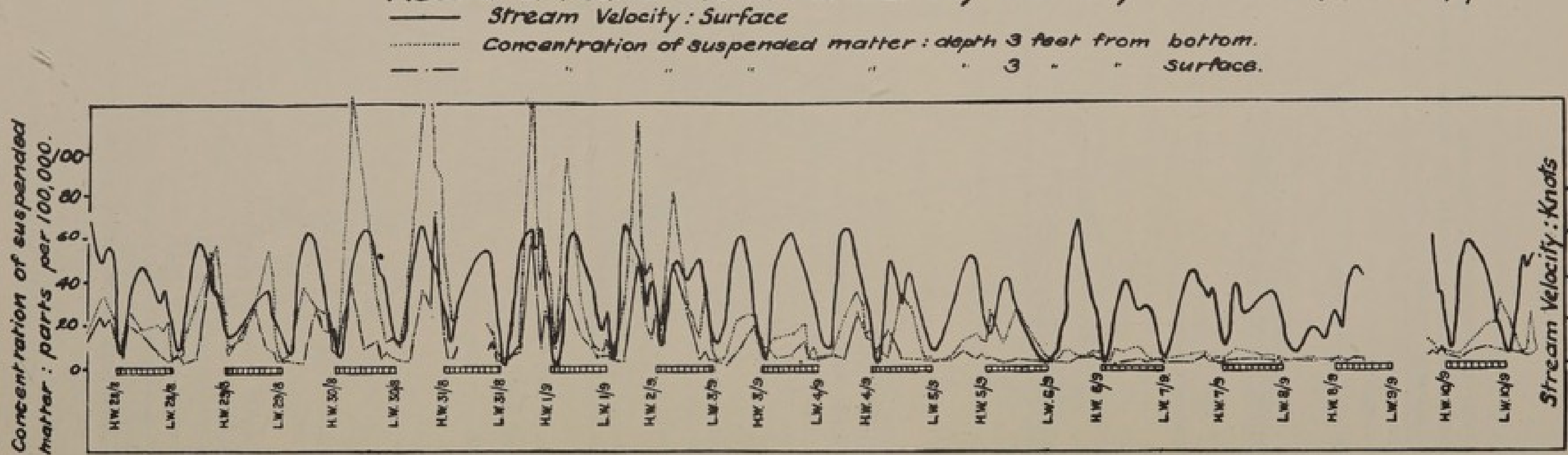
THE CONCENTRATION OF SUSPENDED MATTER IN THE MERSEY ESTUARY OBSERVED DURING A SERIES OF FLOAT DRIFTS DURING SPRING & NEAP TIDES.



(3256).

Fig. 84.

Record of float drifts in the Mersey Estuary between 28/8/35 & 10/9/35.



moving water as it passed over banks on the bed of the Estuary. Although the settling rate of estuarine suspended matter cannot for this reason be determined so exactly in the Estuary itself as in laboratory experiments, the results show that the settling rate was in all cases very high, so that both at spring and at neap tides only a small concentration of material remained in suspension at any depth at slack water. At low tide in the Narrows the depth of water is between 40 and 70 ft., and almost the whole of the material in suspension settles out through this depth at slack water. The rate of sedimentation is greater than was observed through a 40-ft. column in the laboratory; the difference is no doubt due to the fact that in the laboratory experiments in which a 40-ft. column was used the mud in suspension was initially present in a finely divided condition, while in the Estuary it is present in the form of large clots throughout the run of the tide. High rates of sedimentation similar to those in the Estuary were obtained with suspensions of flocculated aggregates in the experiments with 9-ft. tubes in the laboratory.

In the series of float drifts described in Chapter IV, floats were put in the water near the entrance to the Narrows at the same time on successive days during a period of a fortnight, and a float was followed continuously for 12 hours on each day. At the beginning of the period the float was started at about the time of low water so that during the next 12 hours it travelled upstream and afterwards, on the ebb, returned to a position not far from its starting point. The first float drift was carried out during a spring tide. On successive days the float was started at the same time of day, but, as the time of high water becomes later daily, the age of the tide when the float was started became successively less. After about a week the float was put in the water at the time of high tide, and during the succeeding ebb it travelled seaward of the Narrows and returned on the following flood. By this time, however, spring tides had given way to neap tides. On the whole, therefore, the results obtained show the concentration of suspended matter in the Upper Estuary during spring tides and in the channels seaward of the Narrows during neap tides. In Fig. 84 are shown the observed concentrations of suspended matter at a depth of 3 ft. below the surface and at a depth of 3 ft. from the bottom, together with the stream velocities near the surface. During spring tides high concentrations of suspended matter were found in the Upper Estuary, particularly near the bottom; during neap tides when the float was for the greater part of the time seaward of the Narrows the concentration of suspended matter was never very high either near the surface or near the bottom. It is noticeable that the stream velocity during neaps under the conditions of the observations was not greatly different from that observed during springs. The data shown in Fig. 84 were obtained mainly from the Upper Estuary during springs and from the Narrows or sea channels during neaps, and it might be thought that high concentrations of mud would have been found if observations had been taken in the Upper Estuary during neaps. In Fig. 85, however, are shown the mean results

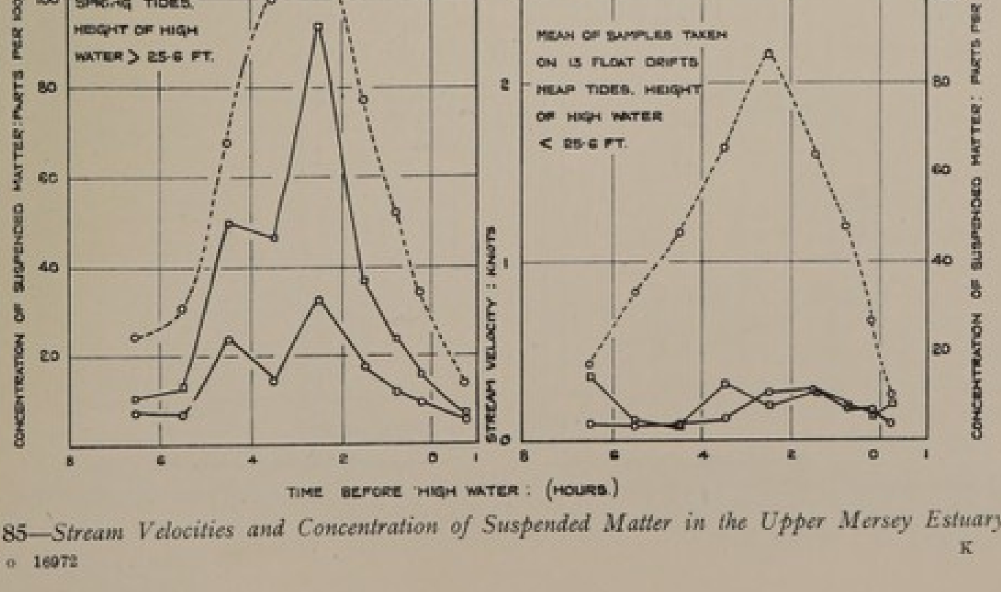


Fig. 85—*Stream Velocities and Concentration of Suspended Matter in the Upper Mersey Estuary*

of all the float observations taken in the Upper Estuary above Rock Light. This figure shows the average amount of material in suspension at different states of the tide in the surface layers and at depths greater than 4 ft. with the corresponding average stream velocity. The data have been divided into two groups, one taken during spring tides and the other during neaps. The concentration of suspended matter was much greater during springs than during neaps, although the mean maximum stream velocity during springs was less than 1 knot greater than the corresponding maximum during neaps. It is evident, therefore, that the comparatively high concentration of material in suspension during springs and the comparatively low concentration during neaps occur in all parts of the Upper Estuary since mud is not found in high concentrations even near the bottom during neaps. It seems probable that a certain critical stream velocity is necessary to erode mud from the bottom of the channels, but that when the mud has been eroded a smaller velocity is sufficient to keep it in suspension. This point is further discussed in Chapter XIX, where laboratory experiments on the erosion of mud are described.

During springs a much greater area of mud banks is covered by the tide than during neaps, and some erosion of the surface of the banks during springs doubtless occurs. This cannot be the main factor responsible for the high concentration of mud carried in the Estuary water during springs since the mud banks are covered only when the speed of the tidal streams is low and little erosion seems to occur.

The first diagram in Fig. 85 illustrates the changes in the quantity of mud carried in suspension in the Estuary during spring tides. At slack water little suspended matter is found. As the stream velocity increases, mud is continuously eroded from the bed of the Estuary into the bottom layer of water, but the turbulence is insufficient to lift more than about one-third of the eroded mud to the surface. In the latter half of the flood or ebb the greater part of the suspended matter settles from the surface to the bottom layers through water which is moving fairly rapidly. As soon as the stream velocity begins to slacken more mud settles than is eroded. The sedimentation period extends from this point until the following slack water, when little material remains in suspension.

Other Estuaries

From time to time during the investigation visits were made to estuaries which were only slightly polluted, with the intention of carrying out float drifts similar to those in the Mersey, in order to determine the rate of sedimentation of mud carried in suspension. It was found that in the estuaries of the Rivers Tay and South Esk in Scotland, in Lough Foyle in the north of Ireland and in all the rivers in the south-east of England between the Deben and the Roach, little or no mud is carried in suspension except possibly during rough weather. The tidal range and velocity of the tidal streams in these estuaries are small. Float drifts were however carried out in the Estuary of the River Wye (Monmouthshire), in the River Suir (Irish Free State) and in the Firth of Forth. All these estuaries are to some extent polluted but the amount of the pollution compared with the size of the estuary is in each case much smaller than it is in the Mersey. Float drifts were followed in each of the three estuaries on the flood tide, the float being started at the seaward end of the estuary. In Fig. 86 the mean rate of sedimentation

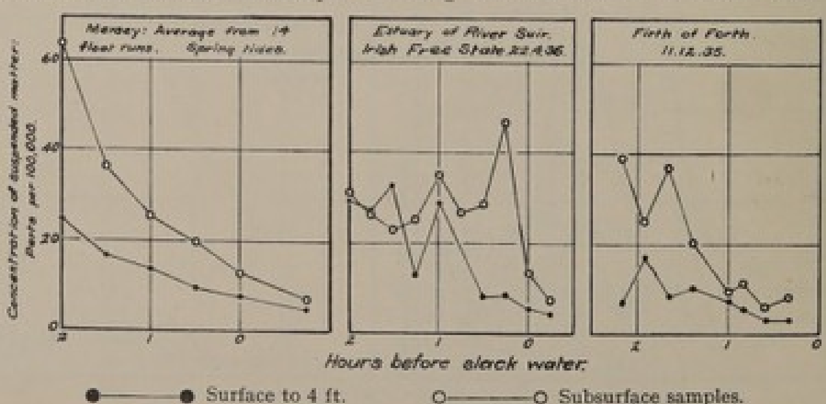


Fig. 86—*Rate of Settling of Suspended Matter in the Mersey and Two Other Estuaries (Suir and Forth)*

of suspended matter during spring tides in the Upper Mersey, taken from the results of 14 float drifts, is compared with the rate of sedimentation of mud in the Firth of Forth and in the estuary of the River Suir; the rate of settling is of the same order in the three estuaries. In Fig. 87 are shown the results obtained during a float

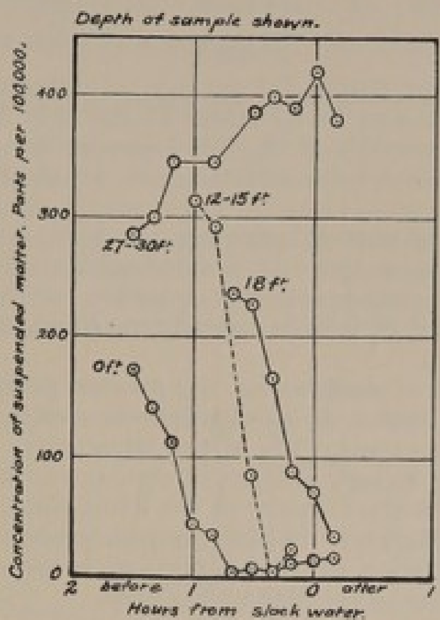


Fig. 87—*Sedimentation of Suspended Matter in the Estuary of the River Wye (Monmouthshire), 30th October, 1935*

drift in the River Wye. It was shown in Chapter XI that the settling rate of mud from this river, as determined in the laboratory, is lower than that of any other mud which has been examined. The conditions found by field determinations in the Wye also differed considerably from those in the Mersey, Forth and Suir; in the Wye the concentration of mud in suspension during the run of the tide was very high; near the bottom it approached a value of 400 parts per 100,000, while at the surface it was nearly 200 parts per 100,000. These concentrations are much higher than those found in the Mersey. During slack water the greater part of the mud between the surface and a depth of 18 ft. settled from suspension, but at a depth of 27 feet, which was only a few feet from the bottom of the estuary, the concentration of mud rose steadily during the sedimentation period. It is believed that the mud at the bottom was prevented from settling by a current running near the bottom when the water was slack near the surface. The estuary of the Wye is small compared with the size of the upper river, which was in spate at the time when the observations were taken. The current system in the Wye is thus subject to much greater disturbance from the incoming fresh water than is that of the Estuary of the Mersey. In the Wye the weight of mud transported by the tide and settling out at each slack water period must be very much greater than it is in a corresponding volume of water in the Mersey Estuary.

It was thought that it might be possible to obtain from field observations an indication of the source in Liverpool Bay from which mud might be carried into the Mersey Estuary. It is now believed however that no reliable information on this point can be obtained by the methods used. The quantity of mud moving to and fro in the Estuary is very large and it is difficult to detect the presence of a small quantity of additional mud entering the Estuary. It has been found that during spring tides comparatively high concentrations of mud are carried in the Narrows and in the sea channels. The results of one series of determinations made under these conditions is shown in Fig. 83. In Chapter VII the concentration of suspended matter found during the spring flood tide at the Formby and Bar Light Vessels was given; these results were taken from Table 84 (p. 298). At the Formby Light Vessel comparatively high concentrations of suspended matter were observed during the run of the tide and at the Bar Light Vessel some suspended matter was present at all depths. It seems evident that in the estuarine system of the Mersey the highest concentrations of mud are carried by the tide in the Upper Estuary where the water is comparatively shallow and the bed is uneven. Further seaward, where the water is on the whole less turbulent than in the Upper Estuary, the concentration of suspended matter is lower but the amount of mud and sand transported is nevertheless very high. It does not seem likely that under these conditions any small residual drift of mud either into or out of the Upper Estuary could be detected by the methods available.

Summary

The concentration of suspended matter at different depths in the Mersey Estuary has been determined at all states of the tide during springs and neaps. At the same time the velocity of the tidal stream was determined, either from observation of a float allowed to drift freely or by the use of a current meter at fixed positions.

The concentration of material in suspension was considerably higher during spring tides than during neaps. It is concluded that mud is eroded from the bottom only when the stream velocity exceeds a critical value, but that when material has been eroded it is subsequently maintained in suspension by water moving at a lower speed.

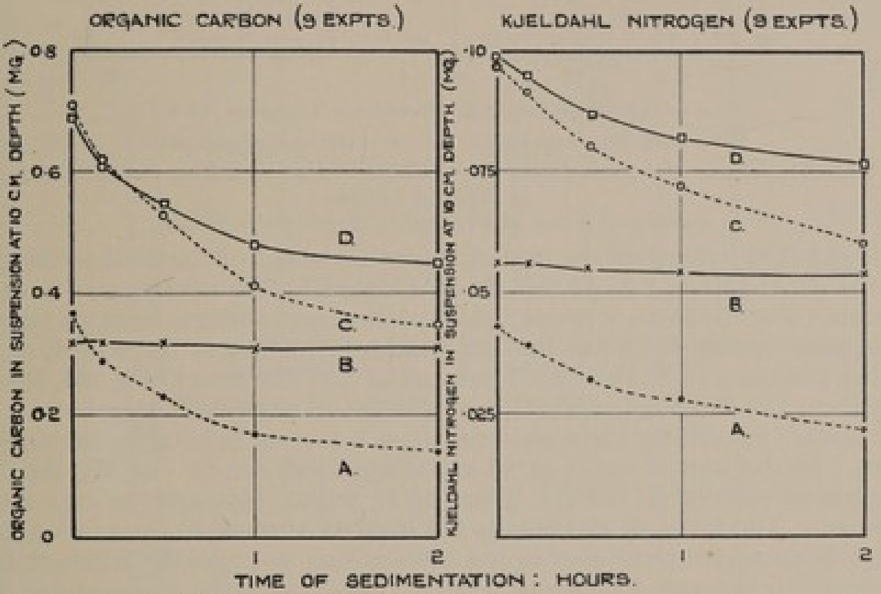
During each period of slack water the greater part of the suspended matter in the Estuary rapidly settles to the bottom at a rate similar to that observed with flocculated mud in experiments in the laboratory. The settling rate of the suspended matter in the Mersey Estuary is similar to that of suspended matter in the Firth of Forth and in the Estuary of the River Suir; these estuaries are much less polluted than the Mersey. In the comparatively unpolluted estuary of the River Wye the concentration of mud carried in suspension and settling at slack water is much greater than in the Mersey Estuary.

CHAPTER XVII

CONCENTRATION OF ORGANIC MATTER IN MUD SETTLED FROM SUSPENSIONS IMMEDIATELY AFTER MIXING WITH SEWAGE

Sedimentation through Different Depths

In the first experiments in which the rate of sedimentation of mixtures of mud and sewage was measured, the mixed suspensions were allowed to settle in 5-litre beakers and samples were taken at intervals at a depth of 10 cm. The concentration of mud remaining in suspension at this depth was thus measured. In some cases the weights of insoluble organic carbon and Kjeldahl nitrogen remaining in suspension as sedimentation proceeded were also determined; the results of some experiments are shown in Fig. 88. In a suspension of mud



Curves : ● A. Mud alone in saline water.
× B. 5 per cent. settled sewage in saline water.
○ C. Mud + 5 per cent. settled sewage in saline water.
□ D. Sum of curves A. + B.

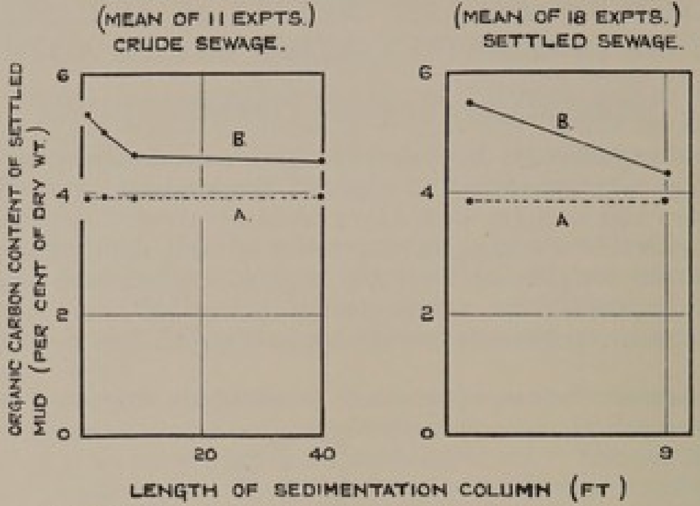
Fig. 88—*Rate of Sedimentation of Organic Constituents of Suspended Matter of Settled Sewage, with and without Addition of Mersey Mud*

Salinity of water approximately 25 *gm. per* 1,000 *gm.*

in saline water (salinity 25 gm. per 1,000 gm.) containing no sewage the concentration of insoluble organic matter at a depth of 10 cm. gradually decreased during a sedimentation period of two hours. With 5 per cent. of settled sewage in saline water but without mud the rate at which insoluble organic matter settled during the same period was inappreciable. In a mixture of mud and settled sewage with water of salinity 25 gm. per 1,000 gm., if the rate of settling of the insoluble organic matter of each component is unchanged, the rate of settling of the insoluble organic material in the mixture can be calculated. This has been done in Fig. 88 where the two curves marked " D " are the sum of the curves " B " and " A ". The observed rate of settling of the insoluble organic matter in the mixture is given by the curves " C ". The figure shows that the measured rate of sedimentation of the suspended organic matter in suspensions of Mersey mud in mixtures of saline water and settled sewage is greater than the sum of the measured rates for mud and for sewage separately in saline water. From these results it appeared probable that part of the organic matter of settled sewage was carried down by mud with which the sewage was mixed.

In experiments in which mud was allowed to settle through long tubes the material reaching the bottom was collected and its organic content was directly determined. Many determinations of this kind were made during the investigation. Mixtures of mud with varying amounts of sewage in saline water were allowed to settle in tubes 4, 9 and 40 feet in length, and in 5-litre beakers about 1 foot in depth.

In the tubes the mud reaching the bottom was collected in a funnel and examined for organic carbon and Kjeldahl nitrogen; in the beakers mud suspensions were allowed to settle for the same length of time, after which the supernatant water was siphoned off and the mud on the bottom was collected and analysed (Fig. 89).



Curves: A. No sewage added. B. 5 per cent. sewage added.

FIG. 89—*Uptake of Organic Matter from Sewage by Mud in settling through Columns of Different Lengths*
Salinity of Water approximately 25 gm. per 1,000 gm.

It was found that in general the organic carbon content of the mud settling through any of the depths from 1 to 40 feet was increased by the presence of sewage in the suspension. For the same concentrations of mud and sewage, however, the increase in the organic matter in the settled mud became smaller as the length of the sedimentation column was increased. Thus, in the first diagram in Fig. 89, Mersey mud took up from the same concentration of sewage (5 per cent.) about twice as much organic matter in settling through a depth of 1 foot as in settling through a depth of 9 feet. In the second series of 18 experiments shown in Fig. 89, the difference in the amount of organic matter taken up in falling through the two depths was still greater. The increase in the organic content of mud settling through a depth of 40 feet from suspensions containing sewage was not greatly different from that caused by a fall through a depth of 9 feet. In all cases the composition of Mersey mud settling from suspensions containing no sewage was unchanged whatever the depth of water through which it settled.

It was found that the amount of organic carbon taken up by mud from suspensions containing sewage increased steadily as the concentration of sewage was raised from 0·1 to 5·0 per cent. The mean results from 24 experiments in which suspensions of mud mixed with different concentrations of sewage were allowed to settle through a depth of 1 foot and from 16 experiments in which similar mixtures were allowed to settle through 9 feet are shown in Fig. 90.

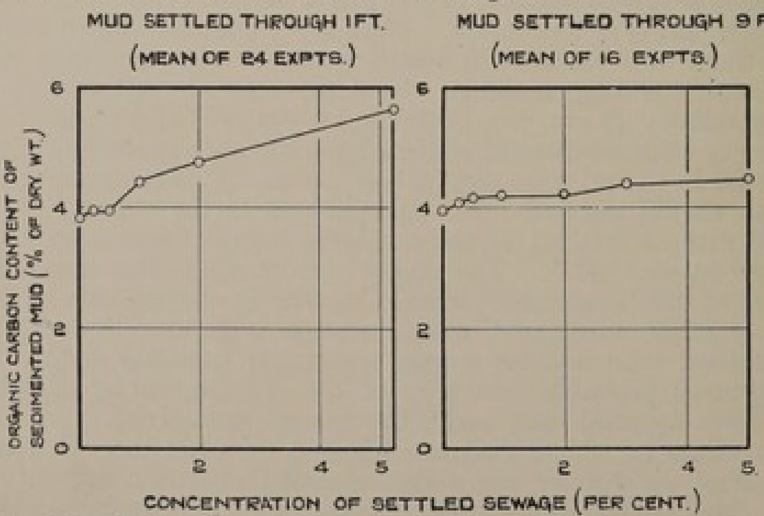


FIG. 90—*Uptake of Organic Matter by Mud from Settled Sewage in Different Concentrations in Water of Salinity 25 gm. per 1,000 gm.*

In falling through either depth the mud carried down increasing amounts of organic matter as the concentration of sewage was increased. For the same concentration of sewage, however, the amount of organic carbon taken up by the mud in falling through 9 feet was considerably less than the amount taken up in falling through 1 foot.

RATE OF SEDIMENTATION OF ORGANIC MATTER

When this work was begun it was thought that the composition of mud settling from suspension might vary during a sedimentation period since it seemed possible that coarser and less organic fractions would settle first. In a number of experiments, therefore, the mud falling to the bottom of a 9-ft. column after different time intervals was collected and examined. The quantity of mud collected was not usually sufficient to allow of the determination of the organic carbon content; the comparative amount of organic matter was therefore estimated by determining the weight of oxygen consumed from acid potassium dichromate by the method of Adeney (Fig. 91). It was found that the composition of the material reaching

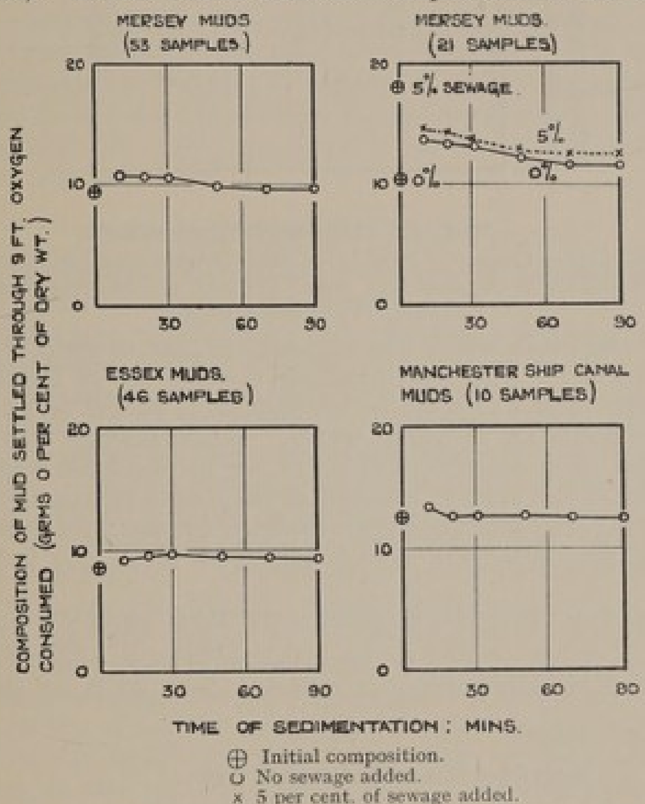


FIG. 91—*Composition of Mud settled after Different Time Intervals from Suspensions of Mud or of Mud and 5 per cent. Settled Sewage in Water of Salinity 25 gm. per 1,000 gm.*

the bottom remained substantially unchanged during a settling period of 1½ hours. In Fig. 91 are shown the mean curves for 53 samples of Mersey muds and for 46 samples of Essex and Suffolk muds, all allowed to settle from suspensions in saline water of salinity 25 gm. per 1,000 gm. The mean organic content in the two groups was, initially, approximately the same and the composition of the mud settling from suspension during the period of 1½ hours did not alter appreciably and was roughly the same as that of the muds before sedimentation. A similar mean curve for 10 samples of more organic muds dredged from the bed of the Manchester Ship Canal is also shown; here again the composition of the material settling throughout the sedimentation period was nearly constant. In a fourth group of 21 samples of Mersey muds the organic content of the material settling during a period of 1½ hours from suspensions in saline water and from suspensions containing 5 per cent. of settled sewage was determined. With these muds in saline water without sewage, the settled material became rather less organic towards the end of the settling period. When sewage in a concentration of 5 per cent. was added, the organic content of each fraction was higher than without sewage, but the relative organic content of successive fractions was not appreciably altered. In one series of five experiments, suspensions of mud with and without the addition of 5 per cent. of sewage were allowed to settle through a depth of 40 feet and the mud reaching the bottom after different time intervals was collected. With these samples sufficient material was collected to allow of the determination of the organic carbon content (Fig. 92), and the results obtained may be used for comparison

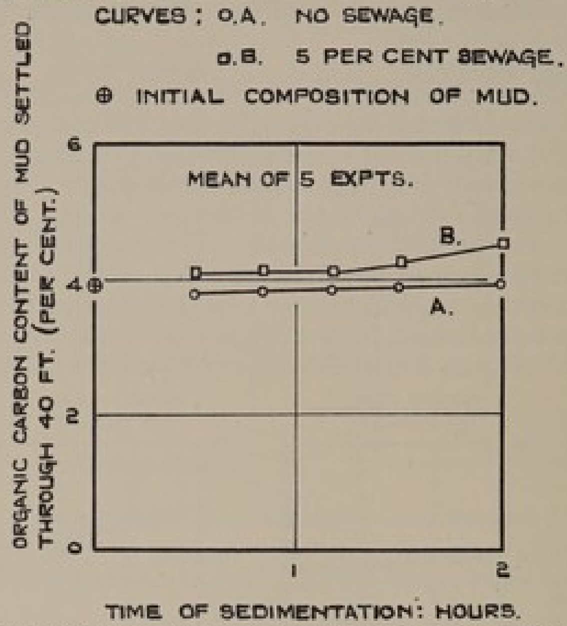


FIG. 92—*Organic Carbon Content of Mud settled between Successive Time Intervals during the Sedimentation of Mud or Mud plus 5 per cent. of Sewage in Water of Salinity 25 gm. per 1,000 gm.*

with the similar results in which the organic content of mud was determined by the method of Adeney. The mud reaching the bottom of the 40-ft. column had approximately the same composition throughout a period of two hours when the suspensions were made up in saline water. When sewage was added in a concentration of 5 per cent. the composition of the settled mud was at first constant, but after 70 minutes the organic content of successive fractions slightly increased. In some of these experiments unsettled sewage was used, and it is possible that the coarse suspended matter of the sewage began to settle out independently.

Organic Matter Removed by Mud from Sewage

In general, if either settled or unsettled sewage is added to a suspension of finely divided mud in saline water in columns 1 to 40 ft. in depth some of the

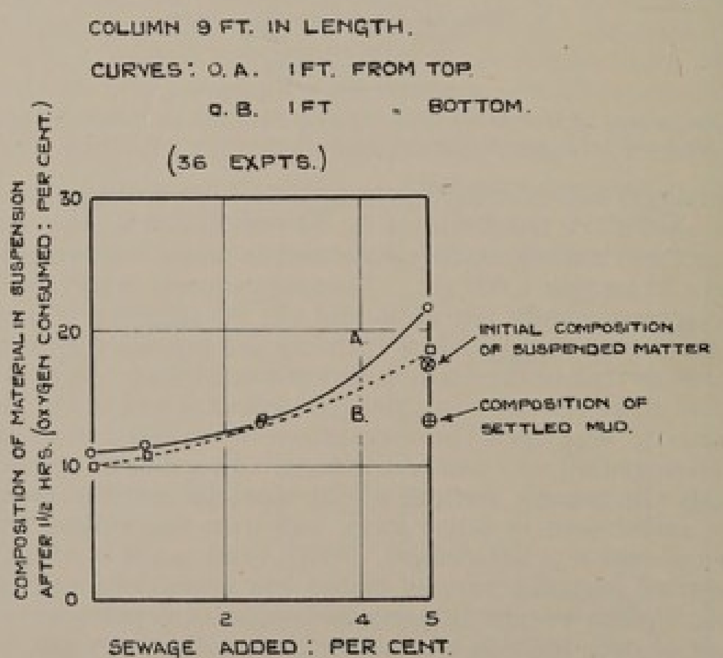
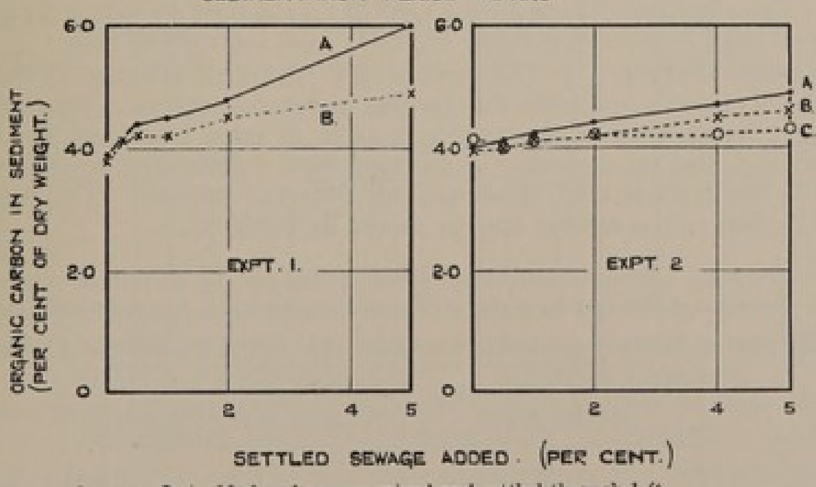


FIG. 93—*Composition of Material remaining in Suspension after 1½ hours when Mud and Sewage were allowed to settle through a Depth of 9 ft. in Water of Salinity 25 gm. per 1,000 gm.*

organic matter of the sewage is carried down with the mud. A few experiments were made to determine whether all or only a part of the insoluble organic matter of the sewage was taken out of suspension under these conditions. Sedimentation tubes 9 ft. in length were made, each with two side tubes, one at a distance of 1 ft. from the bottom and another at 1 ft. from the top, so that after the sedimentation of the mud, samples of supernatant liquid could be withdrawn for analysis. The mean results of 36 determinations are shown in Fig. 93. When increasing concentrations of sewage were added to similar mud suspensions and the mixtures were allowed to settle for 1½ hours, the organic content of the material remaining in suspension at the end of this period progressively increased. It is evident, therefore, that only a part of the insoluble organic matter of the sewage had been carried down by the mud. For those experiments in which the concentration of sewage used was 5 per cent. the compositions of the mixture of mud and sewage initially in suspension and of the mud which settled out in 1½ hours are also shown. The organic content of the mud which settled was increased by the presence of the sewage, but the settled material had a smaller organic content than the original mixture of suspended matter. From the mixed suspension most of the mud but only part of the insoluble organic matter of the sewage settled, so that the organic content of the material remaining in suspension after the mud had settled was greater than that of the original mixture of mud and sewage. These results are of interest in explaining the conditions found in the Estuary, and will be referred to again in the next chapter.

Effect of Size of Mud Particles

It has been shown that the amount of organic matter taken up by mud from sewage in saline water becomes less as the depth through which the mud settles is increased. It has also been shown that the size of the mud aggregates formed increases with increasing depth. It seemed probable, therefore, that the amount of organic matter extracted from sewage by a mud suspension would be dependent on the size of the mud clots, since it was to be expected that large mud aggregates having a relatively small surface area would take up less organic matter than finely divided mud. In two experiments the uptake of organic carbon by mud when a suspension of mud in saline water and sewage was allowed to settle through a depth of 1 ft. was measured. Similar mud suspensions without added sewage were put into 5-litre beakers. A sedimentation tube 9 ft. in length and open at the bottom was then placed vertically with its lower end dipping under the surface of the liquid and reaching nearly to the bottom of the beaker. The mud suspension was stirred for a few minutes, and was drawn into the sedimentation tube by applying suction to its upper end. The whole of the suspension could be drawn into the tube with the exception of a layer about a quarter of an inch in depth, which remained in the beaker as a seal. The mud was then allowed to settle for about 15 minutes in the vertical tube until clots had formed. When this had



Curves: ● A. Mud and sewage mixed and settled through 1 ft.
× B. Mud clotted, sewage added, mixture settled through 1 ft.
○ C. Mud and sewage mixed and settled through 9 ft.

Fig. 94—*Organic Content of Mud settled from Suspensions in Saline Water (Salinity 25 gm. per 1,000 gm.) containing Sewage. Mud clotted before Addition of Sewage in Some Cases*

occurred the appropriate amount of sewage was added to the beaker, and the mud suspension was run gently from the tube to the beaker by opening a valve at the top. The mixture of clotted mud and sewage was then allowed to stand for a further period of 1½ hours in the beaker. The results of two experiments are shown in Fig. 94. In both cases the amount of organic matter taken up from similar concentrations of the same sewage was less when the mud had been clotted before the addition of the sewage than when the mud was finely divided. In one experiment a third series of mixtures of mud and sewage was allowed to settle through a 9-ft. tube; the amount of organic matter extracted by the mud was then rather less than that taken up by clotted mud falling through a depth of 1 ft. in a beaker. It is probable that the clots formed in the 9-ft. tube were larger than those transferred to the beaker, since the aggregates are fragile and may have been partly broken up during transference from the tube to the beaker.

In some further experiments a suspension of mud was stirred vigorously in saline water for different periods up to 4 days. On each day a quantity of this material was mixed with 5 per cent. of fresh settled sewage and the organic content of the material settling through 9 ft. from the mixture was determined. The results are shown in Fig. 95. The amount of organic carbon taken up by the mud

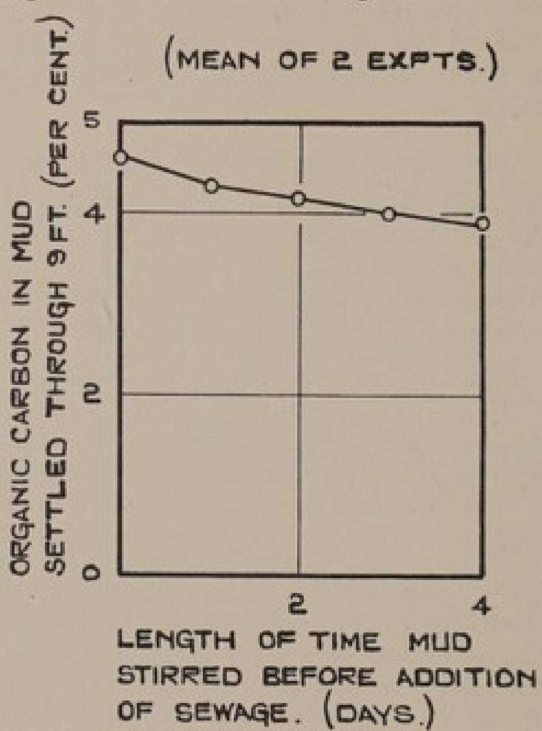


Fig. 95—*Organic Carbon in Mud settled through 9 ft. in 1½ hours from Suspensions in Saline Water (Salinity 25 gm. per 1,000 gm.) containing 5 per cent. of Sewage. Mud Suspensions stirred for Different Periods before adding Sewage*

from the sewage decreased as the preliminary period of stirring of the mud was lengthened. This was probably due to the increased rate of clotting induced by the stirring. In another experiment a sample of mud was kept for three days without stirring, and on each day was mixed with mixtures of sewage with saline water which had been stirred vigorously for different periods. The concentration of organic carbon in the settled mud is shown in Table 85.

Table 85—*Organic Carbon Content of Mud settled for 1½ Hours through a Depth of 9 ft. from Suspensions in Saline Water containing 5 per cent. of Sewage*

Mixtures of Saline Water and Sewage previously stirred for Different Periods

Period of preliminary stirring (days).	Organic carbon in sediment (per cent. of dry weight).
0	4·4
1	4·3
2	3·9
3	3·9

The amount of organic matter taken up by the mud from the sewage was smallest where the sewage had been stirred for the longest periods. The results of an experiment in which both mud and sewage in saline water were vigorously stirred separately and together are shown in Table 86.

TABLE 86—*Organic Carbon Content of Mud settled for 1½ Hours through a Depth of 9 ft. from Suspensions in Saline Water containing 5 per cent. of Sewage*

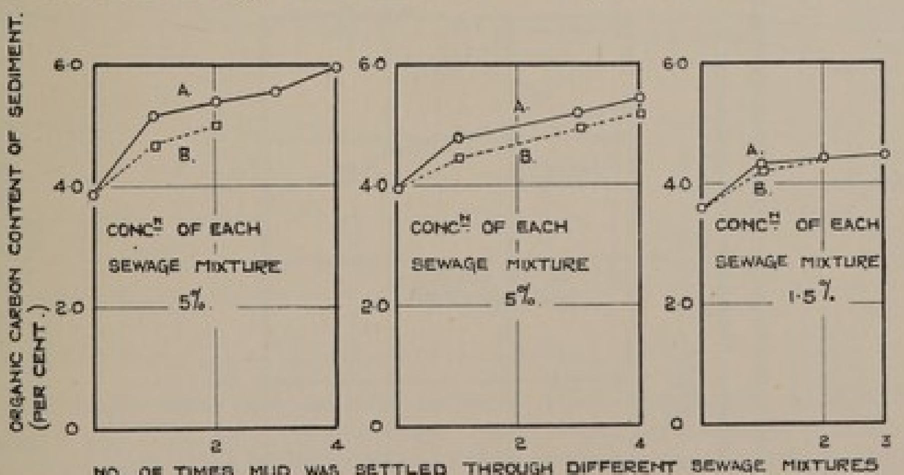
Mud and Sewage previously treated in Different Ways

Treatment of mud and sewage before mixing.	Organic carbon in sediment (per cent. of dry weight).
Mud not stirred; sewage not stirred	4·7
Mud stirred 1 day; sewage not stirred	4·5
Mud not stirred; sewage stirred 1 day	4·4
Mud stirred 1 day; sewage stirred 1 day	4·3
Mud and sewage stirred together 1 day	4·8

The organic content of the material settling from the mixture of mud and sewage was decreased when either the mud or the sewage had previously been stirred alone for one day and a further decrease occurred when both components had been stirred before mixing. When the mud and the sewage were stirred together, the organic content of the sediment was greater than that settling from a mixture in which neither component had been stirred.

Relation between Concentration of Organic Matter in Suspension and Amount Removed by Mud

It has been shown that in general the organic content of mud settling from suspension in saline water containing sewage increased as the concentration of sewage in the suspension was increased. In some further experiments muds were allowed to settle from suspensions in saline water containing sewage and were then collected and settled from similar mixtures of sewage and saline water, this procedure being repeated several times (Fig. 96). It was found that as the sedimentation of the mud through fresh mixtures was repeated, the mud continued to

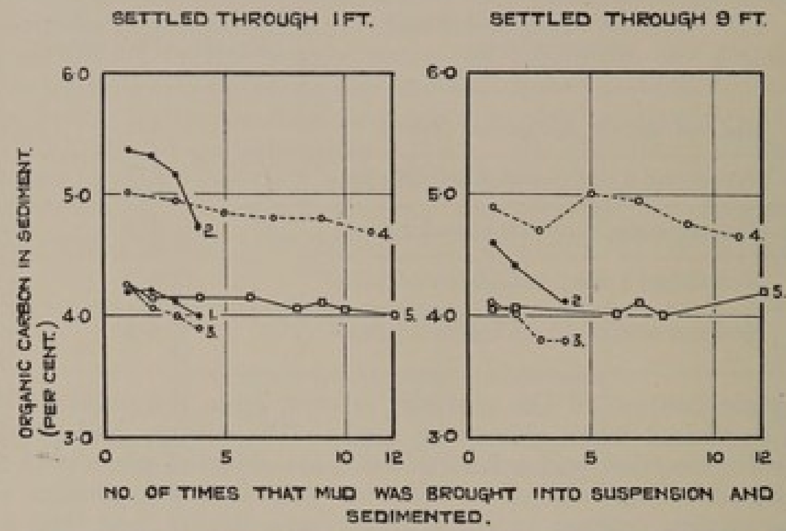


Curves: ○ A. Settled through 1 ft. □ B. Settled through 9 ft.

FIG. 96—*Uptake of Organic Carbon by Mud settled Several Times from Successive Mixtures of Sewage and Saline Water (Salinity 25 gm. per 1,000 gm.)*

gain organic matter. As in the previous experiments the increase was smaller when the mud settled through a depth of 9 ft. than through a depth of 1 ft.

It was shown in Fig. 93 that the whole of the insoluble organic matter of sewage mixed with a mud suspension was not carried down by the mud. A mud continued however to gain organic matter when mixed with successive quantities of diluted sewage. It was thought therefore that a mud which had carried down part of the sewage with which it was mixed might carry down a further quantity of organic matter if it were again brought into suspension and re-settled. Some experiments were carried out in which a mixture of mud and sewage in saline water was allowed to settle either in a 9-ft. tube or in a beaker and the organic content of the material reaching the bottom was determined. Similar suspensions were allowed to settle under the same conditions and afterwards the mud and the supernatant liquid were again mixed and allowed to settle for a further period. This procedure was repeated several times. The results are shown in Fig. 97.



Corresponding numbers against the curves refer to corresponding experiments

FIG. 97—*Uptake of Organic Carbon by Mud settled a Number of Times through the Same Mixture of 5 per cent. Settled Sewage in Saline Water (Salinity 25 gm. per 1,000 gm.)*

In general the organic content of the mud did not increase after successive sedimentations from the same liquid but tended to decrease. This may be due to the fact that after each sedimentation the mud aggregates containing some sewage material were broken up when the mud was again brought into suspension, so that the conditions during each successive sedimentation were similar. The proportion of the total quantity of sewage matter which the mud was capable of carrying down did not therefore increase during successive sedimentations. The

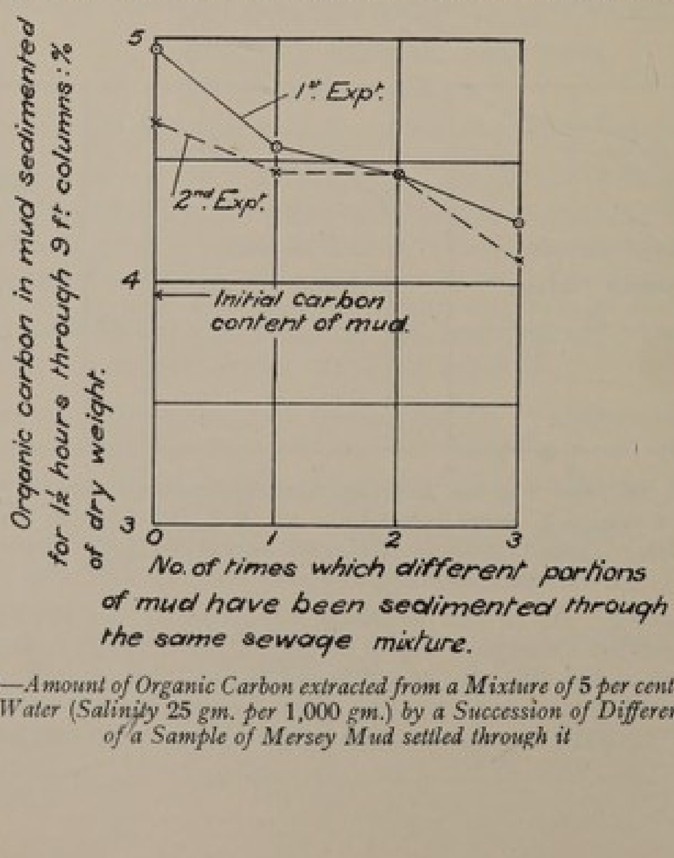


FIG. 98—*Amount of Organic Carbon extracted from a Mixture of 5 per cent. Sewage in Saline Water (Salinity 25 gm. per 1,000 gm.) by a Succession of Different Portions of a Sample of Mersey Mud settled through it*

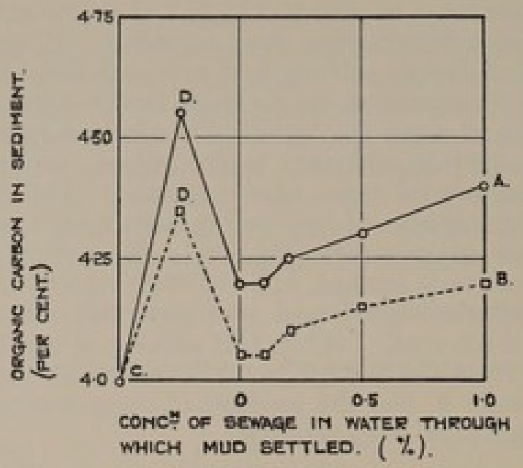
observed small decrease may be due to the fact that the extent of clotting of the mud increased as the sedimentation was repeated. If mud to which organic matter had been added during settling had retained this organic matter when it was again brought into suspension, no decrease in the organic content of the mud would have occurred and since the liquid still contained some organic matter of sewage in suspension, further additions to the organic content of the mud during repeated sedimentation would have been expected. The fact that under these conditions some sewage capable of associating with mud does remain in the liquid is shown by two other experiments (Fig. 98). Here mud was allowed to settle from a suspension containing sewage, and the mud which had reached the bottom was removed. The supernatant liquid was then run off and was mixed with a further quantity of fresh mud. When this procedure was repeated some organic matter was taken up from the sewage by each of four successive amounts of mud allowed to settle through it, but the amount of organic matter extracted became smaller as the sedimentation was repeated.

It has now been shown that the amount of organic matter extracted from a mixture of saline water and sewage by a given sample of mud increases with increasing concentration of sewage. After the mud has settled the liquid still contains organic matter, some of which can be removed by a fresh sample of mud but not by the mud which was first settled through the sewage. These results suggest that the amount of organic matter taken up by a mud reaches an equilibrium with the concentration of organic matter in the liquid through which it settles. If this is the case it is to be expected that when the organic content of a mud has been increased by allowing it to settle from a mixture containing sewage, the additional organic matter will be partly removed if the mud is mixed with clean water or with water containing a smaller concentration of sewage than that which caused the initial addition of organic matter to the mud. The results of some experiments in which this point was examined are shown in Table 87.

TABLE 87—*Removal of Organic Matter from Mud previously mixed with Saline Water and Sewage, by Sedimentation through Water of Salinity* 25 *gm. per* 1,000 *gm.*

No. of experiments.	Length of column through which mud settled (ft.).	Number of times settled through saline water.	Organic carbon in sediment (per cent. of dry weight).		
			Before addition of sewage.	After addition of 5 per cent. sewage.	After addition of sewage followed by settling through saline water.
8	1	1	3·93	5·09	4·41
8	9	1	3·93	4·70	4·29
1	1	2	4·00	4·55	4·20
1	9	2	4·00	4·35	4·05
2	9	3	—	4·50	4·13

Mersey muds were first allowed to settle from suspensions in saline water containing 5 per cent. of settled sewage; as a result the organic content of the mud was increased. The settled mud was then removed and was mixed with clean saline water, and again allowed to settle through columns 1 and 9 ft. in depth. It was found that a considerable part of the organic matter which had been extracted from the sewage was removed from the mud while settling through clean water. In another series of experiments, the results of which are shown in Fig. 99, this procedure was repeated except that the second sedimentation of the mud was carried out both in clean saline water and in water containing relatively small concentrations of sewage. The most complete removal of the added organic matter occurred when the mud was settled through clean water, but partial removal also



Curves: ○ A. Settled through 1 ft.
□ B. „ „ 9 ft.
Points: C. Initial composition of mud.
D. Composition after settling from suspensions containing 5 per cent. of sewage.

FIG. 99—*Removal of Organic Matter from Mud, recently settled from a Suspension containing 5 per cent. of Sewage, brought about by Further Sedimentation from Suspension in Saline Water containing Sewage in Concentrations between 0 and 1 per cent.*

occurred in water containing 1 per cent. of settled sewage; the amount of organic matter removed increased as the concentration of sewage was decreased below 1 per cent.

Although organic matter recently added to mud by allowing it to settle from suspensions containing sewage could readily be removed, the organic matter present in muds as taken from the Estuary cannot similarly be separated. In Table 88 are shown the original organic carbon contents of 69 samples of Mersey muds before and after sedimentation through 9-ft. columns of saline water without sewage. The samples have been divided into three groups according to their initial organic content and the averages of the three groups appear in the Table. In no case was the organic content of these muds appreciably affected by sedimentation. It would appear, therefore, that Mersey mud contains firmly attached organic matter which cannot be readily removed by washing with clean saline water. If the mud is brought into contact with sewage it can become associated with further quantities of organic matter, the amount taken up depending on the concentration of sewage in the suspension. The organic matter taken up in this way is not firmly attached and can be relatively easily removed. It is possible that this may in part be responsible for the comparative constancy of the organic content of different muds with the same inorganic composition, whether they occur in polluted or unpolluted localities. In sediments containing very high concentrations of organic matter, part of the organic matter is not firmly attached, and can be washed off by allowing the mud to settle through clean water. This occurs with mud dredged from the bed of the Manchester Ship Canal; it was found that increasing amounts of organic matter were washed off from a sample of this mud during successive sedimentations through saline water (Table 89).

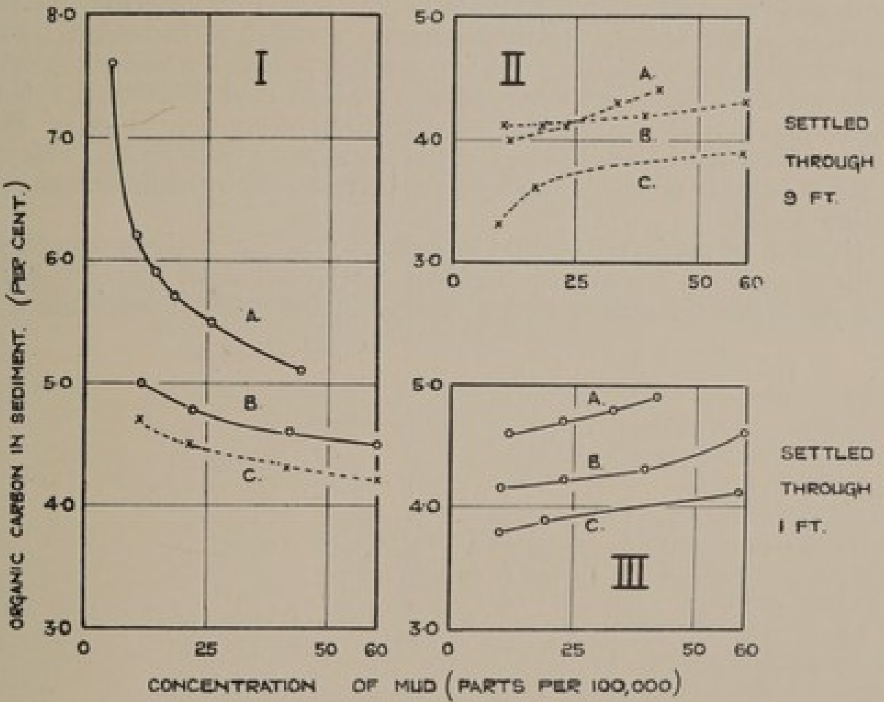
TABLE 88—*Composition of Mersey Mud before and after Sedimentation through a Column of Saline Water 9 ft. in Depth*

No. of experiments.	Organic carbon content of mud (per cent. of dry weight).	
	Before sedimentation.	After sedimentation through saline water.
15	3·58	3·67
38	3·88	3·82
16	3·98	3·98

TABLE 89—*Loss of Organic Carbon from a Sample of Mud dredged from the Manchester Ship Canal, when allowed to settle through Saline Water*

Number of times settled through saline water.	Length of column through which mud settled (ft.).	Organic carbon content of sediment (per cent. of dry weight).
1	1	18·3
1	9	16·8
2	1	16·6
2	9	16·0
4	1	15·7
4	9	15·8

It has been shown that for a given concentration of mud the amount of organic matter taken up from a suspension in saline water containing sewage increases with increasing concentration of sewage. The amount of organic matter extracted also depends on the concentration of the mud. In the first diagram in Fig. 100



Curves I: A. Settled through 1 ft., 3 per cent. of sewage.
B. Settled through 1 ft., 5 per cent. of sewage.
C. Settled through 9 ft., 5 per cent. of sewage.

Curves II and III: A. Mud ·041 per cent., sewage 2·5 per cent.; diluted.
B. Mud ·060 per cent., sewage 5·0 per cent.; diluted.
C. Mud ·059 per cent., sewage 5·0 per cent.; diluted.

FIG. 100—*Uptake of Organic Carbon by Mud from Suspensions in Saline Water (Salinity 25 gm. per 1,000 gm.) containing Sewage. Mud and Sewage in Different Relative Concentrations*

is shown the increase in the organic content of muds allowed to settle in different concentrations (5 to 60 parts per 100,000) from suspensions containing sewage; the highest increases in the organic content occurred with the lowest concentrations of mud. The second diagram in Fig. 100 refers to experiments in which a strong suspension of mud in saline water containing sewage was diluted to different extents with clean saline water. In these experiments the concentration of sewage decreased at the same rate as that of the mud, the ratio of mud to sewage being the same in each case; in these circumstances the largest increase in the organic content of the settled mud occurred with the most concentrated suspensions.

Summary

When settled or unsettled sewage is added to suspensions of fine particles of mud in saline water, the mud in settling carries down with it some of the sewage material. The amount of sewage which settles with the mud decreases as the depth of water through which the mud falls is increased. The quantity of sewage brought down with the mud also decreases if the mud has previously been treated in such a way that the rate at which it forms clots while settling is increased.

The organic content of the suspended matter falling to the bottom of a 9-ft. or 40-ft. column from a mixture of mud and sewage in saline water does not alter appreciably during a settling period of 1½ hours.

The organic content of fine particles of mud settling from mixtures of saline water and sewage increases when the concentration of sewage in the mixture is increased. When the material which has settled to the bottom is again allowed to settle from water containing sewage there is a further gain in organic matter in the sediment; further increase in the organic content of the sediment occurs when this treatment is repeated.

When mixtures of fine particles of mud and sewage in saline water are allowed to settle, most of the mud but only part of the insoluble organic matter of the sewage settles. The remainder of the insoluble matter of the sewage is not removed by the mud when it is again brought into suspension in the same liquid and re-settled. Part of the remaining sewage can, however, be caused to settle by bringing fresh mud into suspension in contact with it.

The organic content of Mersey muds is not altered by allowing them to settle through clean saline water. If their organic content is increased by allowing them to settle from suspensions containing sewage, part of the added organic matter is removed when the muds are subsequently allowed to settle through clean water or through water containing smaller concentrations of sewage. Part of the organic matter of muds dredged from the bed of the Manchester Ship Canal, which initially contain much organic matter, can similarly be removed by sedimentation through clean saline water.

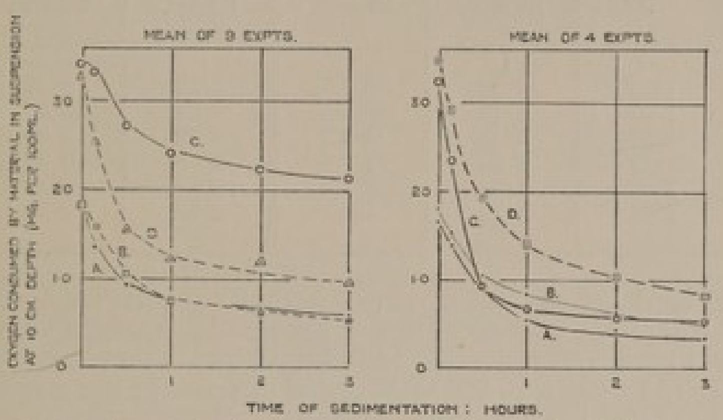
In mixtures of mud and sewage in saline water, for a given concentration of sewage the increase in the organic content of the sediment reaching the bottom is greater the lower the concentration of mud in the original suspension.

CHAPTER XVIII

COMPOSITION OF MUD SETTLED FROM PREVIOUSLY STIRRED SUSPENSIONS CONTAINING SEWAGE

Vigorous Stirring

It has been shown that the settling rate of the suspended matter in suspensions of mud in saline water and in sewage and saline water is increased if the suspensions are first vigorously stirred. The increase in the ability of mud to form quickly-settling flocs induced by vigorous stirring in water containing sewage is accompanied by an increased transference of organic matter from the sewage to the mud during settling. In the first diagram in Fig. 101 are shown the mean results from



Curves: ● A. Mud; 0 per cent. sewage; not stirred.
□ B. „ 0 per cent. sewage; stirred 1-4 days.
○ C. „ + 5 per cent. sewage; not stirred.
△ D. „ + 5 per cent. sewage; stirred 1-4 days.

Curves: ● A. Mud stirred alone.
● B. 5 per cent. sewage stirred alone.
○ C. Mud + 5 per cent. sewage stirred together.
□ D. Sum of A and B.

Fig. 101—*Rate of Sedimentation through a Depth of 10 cm. of Insoluble Organic Matter from Suspensions of Mersey Mud in Water of Salinity 25 gm. per 1,000 gm., with or without 5 per cent. of Settled Sewage. Suspensions previously stirred vigorously 1 to 4 days*

9 experiments in which suspensions of fine particles of mud in saline water and in saline water containing 5 per cent. of settled sewage were allowed to settle in beakers before and after vigorous stirring. At intervals during the settling period samples were taken at a depth of 10 cm. below the surface and the relative weight of insoluble organic matter in each sample, as measured by the oxygen consumed from potassium dichromate, was determined. In these experiments the rate at which insoluble organic matter settled from suspensions of mud in saline water (salinity 25 gm. per 1,000 gm.) was not significantly altered by stirring. When mixtures of mud, sewage, and saline water were stirred, however, the rate at which the insoluble organic matter settled was considerably increased. Experiments of this kind show that part of the insoluble organic matter of sewage is caused to settle at an increased rate when the sewage is stirred vigorously with a suspension of mud, but they do not indicate whether the sewage material settles independently of the mud or whether the mud and sewage fall out of suspension in an associated form. Some further information is given by the second diagram in Fig. 101. In this diagram, which was prepared from the mean results of 4 experiments, are shown the settling rates of suspended organic matter in suspensions of mud, of sewage, and of mixtures of mud and sewage in saline water, all after vigorous stirring. The fourth curve "D" in the diagram shows the calculated settling rate of the insoluble organic matter in a mixture of mud and sewage, on the assumption that the settling rate of each component of the mixture was the same as when the two components were stirred and settled separately. It will be seen that the rate of sedimentation of the insoluble organic matter in the mixture of mud and sewage was greater than would have been the case if there had been no interaction between the two constituents. It seems reasonable to suppose, therefore, that when a mixture of mud and sewage in saline water is stirred vigorously and allowed to settle, some of the organic matter of the sewage is carried down attached to the mud.

Similar results were obtained when smaller concentrations of sewage were used (Table 90).

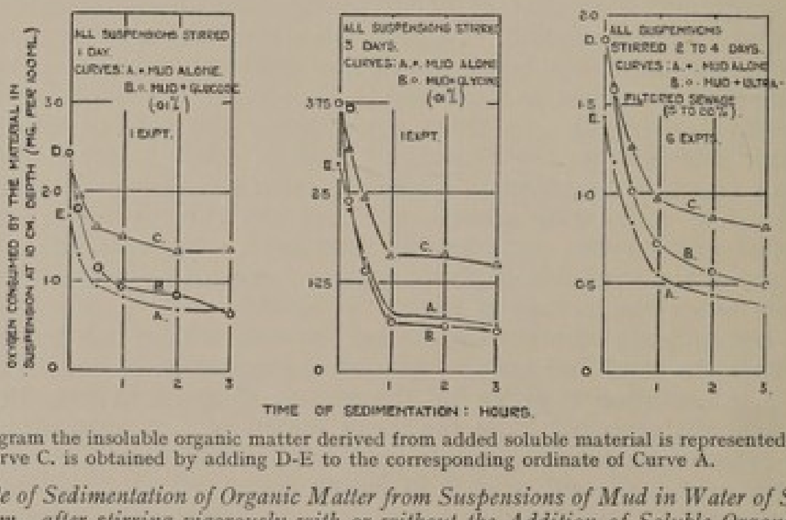
TABLE 90—*Rate of Sedimentation through a Depth of* 10 *cm. of the Insoluble Organic Matter from Suspensions of Mersey Mud in Water of Salinity* 25 *gm. per* 1,000 *gm. containing Different Amounts of Sewage*

Suspensions previously stirred vigorously 1 to 4 Days
Mean of 10 Experiments

Sewage added (per cent.).	Oxygen consumed by material remaining in suspension at a depth of 10 cm. (mg. O per 100 ml.) after :					
	0	10 min.	30 min.	1 hour.	2 hours.	3 hours.
0	1·59	1·14	0·77	0·53	0·39	0·34
0·25	1·61	1·12	0·76	0·54	0·37	0·33
0·5	1·71	1·15	0·72	0·52	0·39	0·24
1·0	1·77	1·26	0·73	0·55	0·37	0·30
2·0	2·06	1·34	0·77	0·57	0·42	0·35
5·0	2·91	1·77	1·00	0·69	0·65	0·47

The Table contains the mean results from 10 experiments in which settled sewage in concentrations from 0·25 to 5·0 per cent. was mixed with mud suspensions and stirred vigorously. The addition of increasing amounts of sewage increased the initial weight of insoluble organic matter in the mixtures. After a settling period of about 1 hour, however, the concentration of organic matter remaining in suspension at a depth of 10 cm. was substantially the same in every case, indicating that the increasing amounts of organic matter added with the sewage had by this time fallen out of suspension.

Suspensions of mud when stirred vigorously with organic matter in solution are also capable of causing part of the soluble material to become insoluble. In Fig. 102 are shown in curves " A " the rate of settling of insoluble organic matter



In each diagram the insoluble organic matter derived from added soluble material is represented by D-E. Each point on the Curve C. is obtained by adding D-E to the corresponding ordinate of Curve A.

FIG. 102—*Rate of Sedimentation of Organic Matter from Suspensions of Mud in Water of Salinity* 25 *gm. per* 1,000 *gm., after stirring vigorously with or without the Addition of Soluble Organic Materials*

from suspensions of mud in saline water after vigorous stirring. Curves " B " give the corresponding rates of settling after similar mud suspensions had been stirred vigorously with glucose or glycine in concentrations of 0·01 per cent. or with ultrafiltered sewage in concentrations of from 5·0 to 20·0 per cent. After stirring, the weight of insoluble organic matter in the mud suspensions had increased as part of the soluble organic matter had become insoluble. When the mixed suspensions were allowed to settle, the greater part of the newly-formed insoluble organic matter settled out with the mud.

There does not appear to be any appreciable difference between the amount of organic matter taken up by mud from sewage whether stirred in fresh or in salt water. The results of one experiment are shown in Table 91.

TABLE 91—*Uptake of Organic Carbon by Mud stirred vigorously with Sewage in Sea Water or Tap Water*

Mean of 2 Experiments

Concentration of sewage with which mud was stirred (per cent.).	Organic carbon (per cent. of dry wt.) in mud settling in 3 hours through 1 ft., after stirring vigorously for 1 to 3 days.	
	Sea water.	Tap water.
0	4·5	4·5
0·25	4·5	4·6
0·5	4·6	4·8
1·0	4·8	4·9
2·0	5·1	5·1
5·0	6·1	6·3

Mersey mud was stirred for 3 days with various concentrations of settled sewage, the diluent in one case being sea water and in the other tap water; after stirring, the suspensions were allowed to settle through a distance of 1 foot for 3 hours, the supernatant water was siphoned off and the organic carbon content of the mud which had fallen to the bottom was determined. The gain of carbon by the mud was roughly proportional to the concentration of sewage and was approximately the same in sea water and in tap water.

The extraction of organic matter from sewage by mud when the two are stirred vigorously together in saline water appears to be a relatively slow process. In Fig. 103 is shown the organic carbon content of mud settled through

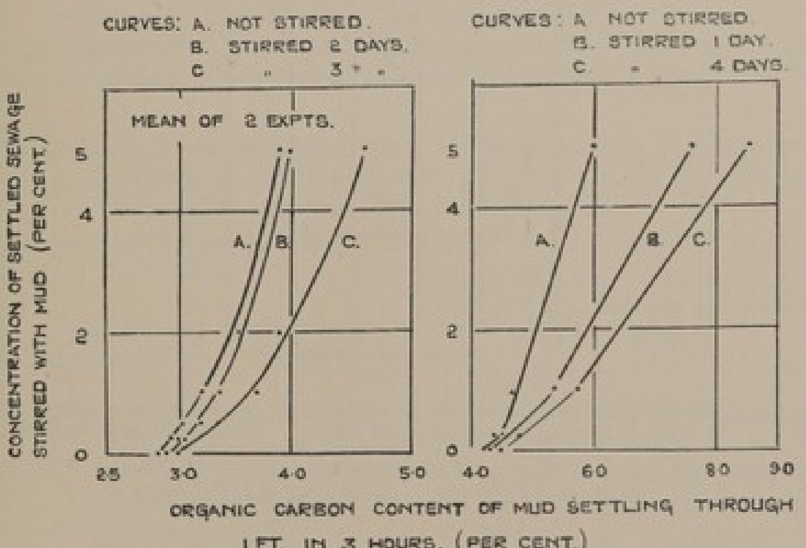
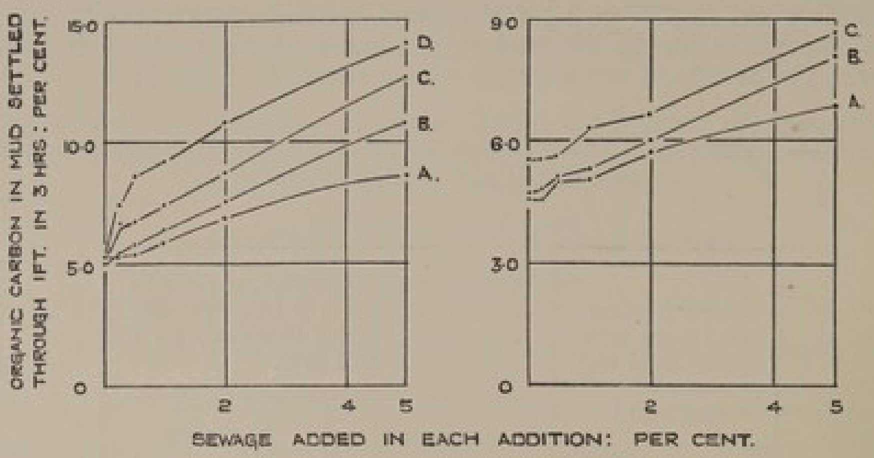


FIG. 103—*Uptake of Organic Carbon by Mud with which Sewage is stirred vigorously for Different Periods. Suspensions in Water of Salinity 25 gm. per 1,000 gm.*

a distance of 1 foot during three hours from suspensions containing sewage which had been stirred previously for different periods; the organic content of the mud settling under these conditions increased daily as stirring was continued for a period of 4 days. In Fig. 104 are shown the results of experiments in which Estuary water containing suspended mud was stirred with various concentrations of settled sewage from 0·25 to 5 per cent. At intervals stirring was stopped, the suspended matter was allowed to settle for three hours, the supernatant liquid was siphoned off and replaced by saline water containing the same concentration of sewage as

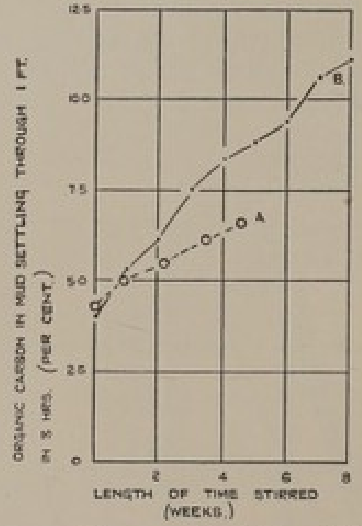


Curves: A. Mud + Sewage.
B. Mud + Sewage, stirred 1 day.
C. Mud + Sewage. Sewage replaced, stirred 2 days.
D. Mud + Sewage. Sewage replaced twice, stirred 3 days.

Curves: A. Mud + Sewage.
B. Mud + Sewage. Sewage replaced, stirred 2 days.
C. Mud + Sewage. Sewage replaced twice, stirred 3 days.

FIG. 104—*Uptake of Organic Carbon by Mud stirred vigorously with Successive Quantities of Sewage in Water of Salinity 25 gm. per 1,000 gm.*

before; vigorous stirring of the mixture was then continued. Under these conditions very large increases in the carbon content of the mud occurred. Thus after three additions of 5 per cent. of sewage the carbon content of one sample of mud rose from 5·0 per cent. to 14·0 per cent. Mud under these conditions of vigorous stirring is also capable of extracting relatively large amounts of organic matter from concentrations of sewage less than 0·25 per cent. This is shown in Fig. 105



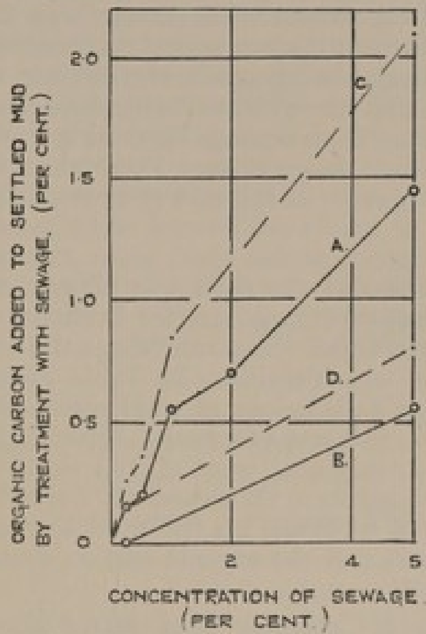
Curves: A. 0·025 per cent. unsettled sewage added daily. Total addition 0·575 per cent.
B. 0·10 per cent. settled sewage added daily. Total addition 4·3 per cent.

FIG. 105—*Uptake of Organic Carbon by Mud stirred vigorously with Sewage in Water of Salinity 25 gm. per 1,000 gm. Fresh Sewage added daily*

which gives the results of two experiments in which small concentrations of sewage were added every day to a suspension of mud; on each day during the period of the experiment the mud was stirred vigorously and allowed to settle, part of the supernatant water was siphoned off and replaced by saline water containing settled sewage and stirring was continued. In one experiment the organic carbon content of the mud rose during a period of 8 weeks from 4·0 per cent. to approximately 11·0 per cent. as the result of the daily addition of 0·1 per cent. of settled sewage.

As in the case of unstirred mixtures of mud and sewage in water the organic content of the mud settling from vigorously stirred mixed suspensions becomes lower as the depth of water through which the mud settles is increased. This has been found in a number of experiments the mean results of which are shown in

Fig. 106. The organic carbon content of mud settling from suspensions containing sewage was in every case higher after the suspensions had been vigorously stirred



Curves: ○ A. Settled through 1 ft. (18 expts.)
○ B. " " 9 ft. (13 ")
● C. " " 1 ft. after stirring (18 ")
● D. " " 9 " " " (13 ")

Fig. 106—*Uptake of Organic Carbon from Sewage by Mersey Mud when Suspensions of Mud and Sewage are mixed or are stirred vigorously together in Water of Salinity 25 gm. per 1,000 gm.*

than it was before stirring, but under the same conditions the organic carbon content of mud settling both from unstirred and from stirred suspensions was smaller when the mud was settled through a distance of 9 feet than through a distance of 1 foot. The results of further experiments in which stirred and unstirred mixtures of mud and sewage were allowed to settle through a distance of 9 feet are given in Table 92. In these 16 experiments the mud was allowed to settle both before and after vigorous stirring from suspensions containing different concentrations of sewage, and the weight of oxygen consumed by the settled mud was determined.

Table 92—*Organic Matter taken up by Mud from Sewage in Water of Salinity 25 gm. per 1,000 gm. in settling through 9 ft., before and after Vigorous Stirring of the Mixed Suspensions*

No. of experiments.	Sewage added (per cent.)	Oxygen consumed by mud settled through 9 ft. in 1½ hours (per cent. of dry weight).	
		Before stirring.	After stirring.
5	0	10·2	10·2
	0·25	10·3	10·2
3	0	10·8	10·3
	1·0	10·7	10·7
8	0	11·2	11·1
	5·0	11·8	12·4

Some increase in the organic content of the mud was brought about by the presence of sewage and a further increase occurred after the suspensions containing 5 per cent. of sewage had been stirred but the gain in organic matter was by no means as high as in the experiments in which similar suspensions were allowed to settle through a depth of 1 foot. This suggests that while some change in the nature of the mud and sewage is brought about by stirring, the effective association of the mud and sewage occurs when the mixture is allowed to settle.

Gentle Stirring

In Chapter XIV the change in the settling rate of mud brought about by stirring it under different conditions with sewage was described. It was found that the settling rate was increased when mixed suspensions were stirred vigorously together, but that no appreciable change in the settling rate occurred when mud in the form of fragile clots was stirred slowly with sewage. It was also shown that the uptake of organic matter from sewage by mud is reduced by any treatment which causes the mud to form large clots. These clots were formed by allowing the mixture of mud and sewage in saline water to settle through deep columns in which large aggregates of mud were formed or by previous stirring of the mud suspension. It was therefore expected that, when mixtures of mud and sewage were stirred slowly together and the mud was allowed to settle in the form of large aggregates, the uptake of organic matter from the sewage would be small. It was found, however, that under these conditions the amount of organic matter settling with the mud was considerable. In Table 93 are shown the results of some experiments in which suspensions of mud were stirred slowly for different periods during which large clots were formed. Unsettled sewage was then added to the suspensions and the mixtures were stirred slowly for a further period of 1 to 2 hours. The suspensions were then carefully sucked into 9-ft. sedimentation tubes, care being taken not to break up the mud aggregates; the material was allowed to settle for 1½ hours and the organic carbon content of the mud reaching the bottom was determined.

Table 93—*Uptake of Organic Carbon by Mud stirred slowly with Unsettled Sewage in Water of Salinity* 25 *gm. per* 1,000 *gm. for Periods of* 1 *to* 2 *Hours*

Mud previously stirred for Different Periods before Addition of Sewage

No. of experiments.	Concentration of unsettled sewage (per cent.).	Organic carbon (per cent. of dry weight) in mud settling through 9 ft. in 1½ hours. Mud stirred slowly for following times before addition of sewage.				
		0	15 min.	30 min.	60 min.	120 min.
13	0	3·95	3·97	3·97	4·02	4·00
7	1·0 to 2·0	4·51	4·30	4·53	4·53	4·50
6	5·0	5·08	4·95	5·13	4·98	—

In the same group of experiments it had previously been shown that the effect of the sewage on the rate of settling of the mud decreased as the preliminary period of stirring was lengthened and that in those suspensions which had been stirred for long periods before the addition of sewage the presence of the sewage brought about no change in the rate of settling of the mud. It will be seen, however, that the organic content of the settled mud, for any one concentration of added sewage, was approximately the same and was independent of the state of aggregation of the mud when the sewage was added. In the second series of experiments mud was eroded from the bottom of a beaker and was brought into suspension in saline water containing unsettled sewage; the mixture was then stirred slowly for 1 to 3½ hours. Under these conditions, the mud came into suspension in the form of large aggregates, and it was shown in Chapter XIV that its settling rate was not affected by the presence of sewage in concentrations as high as 5·0 per cent. The organic carbon content of mud treated in this way and allowed to settle through a distance of 9 ft. is shown in Table 94. Large increases in the organic content of the mud were brought about by the presence of the sewage.

Table 94—*Uptake of Organic Matter by Mud from Sewage. Mud eroded into Water of Salinity* 25 *gm. per* 1,000 *gm. containing Different Concentrations of Sewage; Mixture stirred slowly and Mud settled through* 9 *ft.*

No. of experiments.	Concentration of unsettled sewage (per cent.).	Organic carbon content of mud settled through 9 ft. in 1½ hours (per cent. of dry weight). Temperature during stirring and sedimentation:	
		3° to 7° C.	21° to 23·5° C.
9	0	3·97	3·98
3	2·0 to 3·0	4·87	4·88
6	5·0	5·21	5·39

Some experiments were carried out to determine whether unsettled sewage in saline water after stirring slowly would settle through a distance of 9 ft. at a rate comparable with that of mud treated in a similar manner. In the first experiments a mud suspension in saline water was stirred slowly for one hour, after which the mud was found to have formed large aggregates. Unsettled sewage was then added in a concentration of 5 per cent., and stirring of the mixture was continued for a further period of one hour. The suspension was then sucked into a sedimentation tube and the organic carbon in the material settling to the bottom after different time intervals was determined (Table 95).

TABLE 95—*Organic Carbon in Mud settled from Suspensions in Water of Salinity 25 gm. per 1,000 gm. containing 5 per cent. of Unsettled Sewage. Mud stirred slowly for 1 Hour, Sewage added and Mixture stirred slowly for 1 Hour*

Sedimentation period (min.).	Organic carbon content of mud settled through 9 ft. (per cent. of dry weight).		
	Experiment 1.	Experiment 2.	Experiment 3.
10	5·50	5·50	5·50
20	5·75	5·75	5·75
90	6·58	6·45	6·70

The organic content of the material reaching the bottom of the tube markedly increased during the later part of the sedimentation period though the bulk of the mud had settled from suspension during the first 20 minutes. The results shown in Table 95 indicate that the mud which had been stirred slowly with sewage quickly settled from suspension and was followed by the more slowly settling organic matter of the sewage which had formed aggregates as the result of the slow stirring. The behaviour of sewage and mud under these conditions is different from the behaviour of mixtures of mud and sewage when stirred vigorously together. In the latter case the organic content of the material settling through a distance of 9 ft. is substantially the same throughout a sedimentation period of 1½ hours (Table 96).

TABLE 96—*Organic Content of Mud settling through 9 ft. after Different Time Intervals from Suspensions of Mud or of Mud and Unsettled Sewage in Saline Water previously stirred vigorously for 3 to 6 Days*

Oxygen Consumed from Dichromate (per cent. of dry weight)
(Mean of 16 experiments)

Sedimentation period (min.).	No sewage added.	5 per cent. of sewage added.
10	12·2	14·9
20	12·9	13·3
30	12·4	12·4
50	11·4	12·1
70	11·1	12·3
90	11·1	12·4

In some further experiments Mersey mud previously stirred slowly for 1 hour in saline water was mixed with 5 per cent. of unsettled sewage, and the mixture was stirred gently for a further period of 1 hour. The suspension was then sucked into 9-ft. sedimentation tubes and the material reaching the bottom during a period of 1½ hours was collected for the determination of organic carbon; this material is called Sediment No. 1. A second sample of the same mud was similarly treated except that no sewage was added to it. A mixture of 5 per cent. of unsettled sewage in sea water was also stirred for 1 hour and was then allowed to settle through a 9-ft. tube; the material reaching the bottom from the sewage and sea water was mixed with the mud which had been settled without sewage and the organic content of the mixture was determined (Sediment No. 2). The carbon content of mud stirred and settled under the same conditions, but without sewage, was also found (Sediment No. 3). If the sewage did not settle out when not mixed with mud the composition of Sediment No. 2 should be the same as that of Sediment No. 3. If the sewage settled out at the same rate whether mixed with mud or not the composition of Sediment No. 2 should be the same as that of Sediment No. 1. The mean results for four experiments are given in Table 97.

TABLE 97—*Sedimentation of Insoluble Organic Matter of Sewage in Saline Water after stirring for* 1 *Hour, with and without the Addition of Mersey Mud*

Average of 4 experiments

Concentration of mud (parts per 100,000).	Type and concentration of sewage.	Organic carbon content of sediment from 9-ft. column after 90 min. (per cent. of dry weight).
30	Unsettled 5 per cent.	6·48 (No. 1)
0 30	Unsettled 5 per cent. 0 ,, ,, }	6·28 (No. 2)
30	Settled 5 per cent.	4·97
0 30	Settled 5 per cent. 0 ,, ,, }	4·85
30	Sediment from a volume of unsettled sewage equal to 5 per cent. of the suspension.. ..	5·67
0 30	Ditto ditto No sewage }	5·45
30	,, ,, ...	4·15 (No. 3)

It will be seen that the sewage settled at approximately the same rate after stirring slowly in saline water as after stirring under the same conditions with mud and saline water. It appears, therefore, that when a mixture of mud and unsettled sewage is stirred slowly the clotted mud first falls from suspension, and is followed by the insoluble material of the sewage, the rate of sedimentation of which has been increased by gentle stirring. In Table 97 are also shown the results of similar experiments in which instead of unsettled sewage the material used was either settled sewage or the sediment which separated from crude sewage when allowed to stand for about 2 hours. It is evident that the settled sewage had clotted to a large extent when stirred slowly in admixture with saline water for 1 hour. The sewages probably settled more completely than is indicated by the results in Table 97, since it was difficult to draw off without loss the small amount of sediment reaching the bottom of a 9-ft. tube when sewage was allowed to settle from saline water.

CONDITIONS IN THE ESTUARY

In the Estuary the state of aggregation of the mud in suspension is similar to that brought about by slow stirring in the laboratory. It is probable that the crude sewage transported in the Estuary water forms aggregates which during slack water settle independently of the mud and at a lower speed. Laboratory experiments indicate that the rate of settling of the sewage would be substantially the same if mud were not present. These conclusions are supported by observations in the field. In Fig. 107 is shown the mean relation, taken from a large number of determinations, between the concentration and the composition of material in suspension in the Upper Estuary. As a measure of the organic content of the suspended matter, loss on ignition, oxygen consumed from dichromate, and organic carbon content have been determined; the detailed results showing the relation between the organic carbon content and the concentration of suspended matter are given in Table 98 (p. 311). In all cases the organic content of the suspended matter increased as the concentration of suspended matter decreased.

As the mud in the Estuary settles at slack water it leaves in suspension material with a relatively high organic content. It seems that the mud, which has been eroded from the bottom and has remained in the form of large aggregates, settles

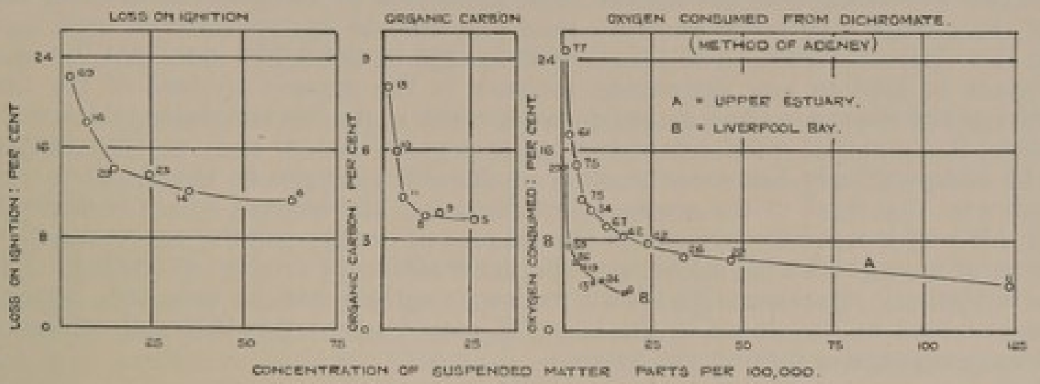


FIG. 107—*Relation between Concentration and Composition of Suspended Matter in the Mersey Estuary. Number of Determinations shown against each Point*

quickly from suspension, leaving more slowly settling sewage material. In the third diagram in Fig. 107 two curves expressing the relation between the organic content and the concentration of suspended matter are shown; one of these refers to samples taken in the Upper Estuary and the other to samples taken in Liverpool Bay. The curves are of similar shape, but the organic content of suspensions of a given concentration is lower in the Bay than it is in the Upper Estuary. The greater part of the material carried in suspension in the surface waters in the Upper Estuary consists of mud, while in the Bay the mud transported is mixed with a higher proportion of sand. When the concentration of suspended matter during slack water has fallen to a low value the organic content of the remaining material is higher in the Upper Estuary than it is in Liverpool Bay, and this would seem to be due to the greater concentration of sewage and trade waste remaining in suspension in the Upper Estuary. In Fig. 108 is shown the relation between the

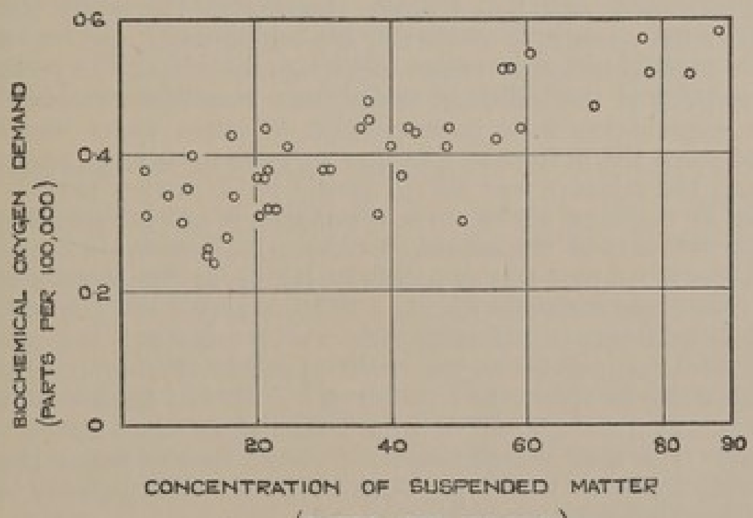


FIG. 108—*Relation between Concentration of Suspended Matter and Biochemical Oxygen Demand of Samples of Water taken in the Upper Mersey Estuary during a Float Drift, 25th March, 1936*

biochemical oxygen demand in five days of samples of Estuary water and the concentration of suspended matter; the samples were taken at the position occupied by a float allowed to drift freely in the Upper Estuary for a period of about six hours. These results show that when the suspended matter has settled during slack water until the concentration remaining in suspension is 5 to 10 parts per 100,000, the B.O.D. of the water is about one-half of the value when the water contains approximately 80 parts of suspended matter per 100,000. The B.O.D. of samples taken at slack water is due partly to dissolved material and partly to the remaining small amount of suspended matter.

As a result of the work described in this chapter it is concluded that the organic matter of the sewage carried in suspension in the Estuary is present in a clotted condition, and may settle from suspension during slack water. Although its rate of settling does not appear to be influenced by the presence of mud, some of the sewage may settle out with mud and may be incorporated in mud banks in the Upper Estuary. The presence of sewage in the banks does not, however, appear to lead to any permanent increase in the organic content of the mud. Part of the sewage in the Estuary does not settle to the bottom during slack water, since the material then remaining in suspension has a high organic content. The comparatively low concentration of dissolved oxygen in the Estuary water indicates that part of the sewage is oxidised but the amount which is destroyed in this way is not known, nor can the amount of sewage passing out to sea in the form of aggregates with a low rate of sedimentation be readily estimated. Flocs of a feathery appearance and with an imperceptible settling rate can, however, be observed in the water of the Bay; it may be that this material consists of sewage aggregates passing out to sea.

Summary

When mixtures of mud and sewage in saline water are stirred vigorously and then allowed to settle, part of the organic matter of the sewage is carried down by the mud. The amount of sewage which settles with the mud is greater than in similar unstirred mixtures of mud and sewage in saline water. The organic content of mud settling from suspension is not increased by the addition, immediately before the mud settles, of glucose, glycine, or the ultrafiltrate of sewage, but is increased when mud suspensions are stirred vigorously with these substances before sedimentation.

The increase in the organic content of mud settling from suspension after vigorous stirring in water containing sewage is approximately the same with tap water as with sea water.

The gain in organic matter by mud settled from suspension after vigorous stirring in water containing a fixed concentration of sewage increases as the period of stirring is increased from 1 to 4 days. In similar vigorously stirred mixtures to which additional quantities of sewage are added daily, the organic content of the mud after sedimentation increases more rapidly during the period of stirring; the organic content of the sediment under these conditions reaches a high value.

In some experiments mud in suspension in saline water was stirred gently or was eroded from the bottom of a beaker so as to form large aggregates, sewage was added and the mixture was stirred gently for a further period. The rate of sedimentation of the mud under these conditions is not affected by the presence of the sewage but part of the organic matter of the sewage settles out with the mud. The organic content of the sediment falling to the bottom of a 9-ft. tube under these conditions increases during a settling period of $1\frac{1}{2}$ hours. Since most of the mud falls from suspension during the first 20 minutes it is concluded that the sewage itself forms aggregates as the result of gentle stirring and settles independently and at a slower speed than the mud. This has been confirmed by some experiments in which sewage mixed with saline water was allowed to settle after gentle stirring. The rate of sedimentation of the sewage under these conditions is approximately the same with 5 per cent. of sewage stirred gently in saline water with and without mud in suspension.

In the Estuary, mixtures of mud and sewage are carried in suspension in the moving water and the mud occurs in the form of large fragile flocs. The laboratory experiments indicate that at each slack water period the clotted mud rapidly falls from suspension, while the sewage, also in the form of flocs, settles independently at a slower rate. This is supported by observations in the Estuary, where the material remaining in suspension becomes progressively more organic as the sedimentation of the mud proceeds.

CHAPTER XIX

RATE OF EROSION OF MERSEY AND OTHER MUDS

Some experiments and observations were made to obtain information on the conditions which affect the resistance of mud to erosion and to compare the relative rates of erosion of muds from the Mersey with those from estuaries which are comparatively unpolluted by sewage or by trade wastes.

In the Mersey the erosion of mud can occur under two different sets of conditions. During the run of the tide, especially during spring tides, a considerable quantity of mud is carried in suspension in the Estuary water; this settles to the bottom at high and at low water when the velocity of the tidal stream decreases until it is insufficient to keep the mud in suspension. During a succeeding tide, this material is eroded from the bottom where it has remained covered during slack water. In addition, the erosion of mud which has remained in one position as a tidal bank for a long period has been observed in the Estuary. On the main mud bank between the River Weaver and Eastham it appears from visual observation that the erosion of mud from the surface does not occur to any great extent; in general the speed of the tidal stream over the surface of this bank is not very high. The edge of the mud bank, which in places consists of a nearly vertical fret, is, however, exposed to a much stronger stream running past it and large quantities of mud are frequently eroded from the edge. Erosion does not appear to proceed by the gradual washing away of the mud but by the detachment of large pieces, sometimes weighing several hundredweights. The face of the fret is first softened and cracks appear in it at right angles to the line of the fret; finally the mud gives way at these cracks and large pieces, often of a generally cubical shape, are torn off. These pieces fall to the base of the fret where they are gradually broken up and frequently form a bank of soft slurry; when this slurry has been washed away by the stream further erosion of the fret begins. The water below the point where erosion is proceeding is heavily charged with mud in suspension and the greater part of the material washed from the fret is carried away in this form, though pieces of mud are occasionally rolled along the bottom of the channel and may be found embedded in sand banks in the Upper Estuary.

Method of Measuring Erodibility of Solid Muds

A quantitative method was developed for examining the erodibility of mud. This method had to be suitable for use with small quantities of mud since in some cases experiments were carried out with material which had been stirred in dilute suspension with sewage and saline water. It was desirable also that the method should cause erosion of mud in the laboratory in a manner approximating as nearly as possible to that in which mud is eroded from a fret in the Estuary. A sketch of the apparatus used is shown in Fig. 109. The mud was contained in a brass "boat," 28 cm. long, 0·5 cm. deep, and 1 cm. wide, with vertical sides and ends. This boat was filled with mud, the surface of which was smoothed so as to prevent the formation of violent eddies when water was passed over it. One charge of mud weighed about 20 gm. The boat fitted into a rectangular channel deeper at one end than at the other; the channel was cut in a brass plug of about the same length as the boat. The plug containing the boat fitted tightly into one end of a long glass tube with an internal diameter of 3·5 cm. Tap water was allowed to flow through the glass tube and so over the boat containing a charge of mud, which was at the exit end of the glass tube. The water was taken from a tank fitted with a constant level valve; the head between the tank and the boat was about 8 ft. In each determination, water was allowed to flow over the mud in the boat for ten minutes. Since the area of the cross-section of the channel over the surface of the mud was greater at the inlet than at the outlet, the current speed increased towards the exit end of the tube and erosion of the mud began at this end. It was found that erosion did not occur over the whole surface of the mud but that fairly large pieces were torn out of the boat, beginning at the exit end. The method of erosion thus appeared to be of a type generally similar to that which occurs from mud frets in the Estuary. When the flow of water was stopped after ten minutes, it was usually found that a strip of mud had been washed out from the exit end of the boat, leaving a mud face which was almost vertical and

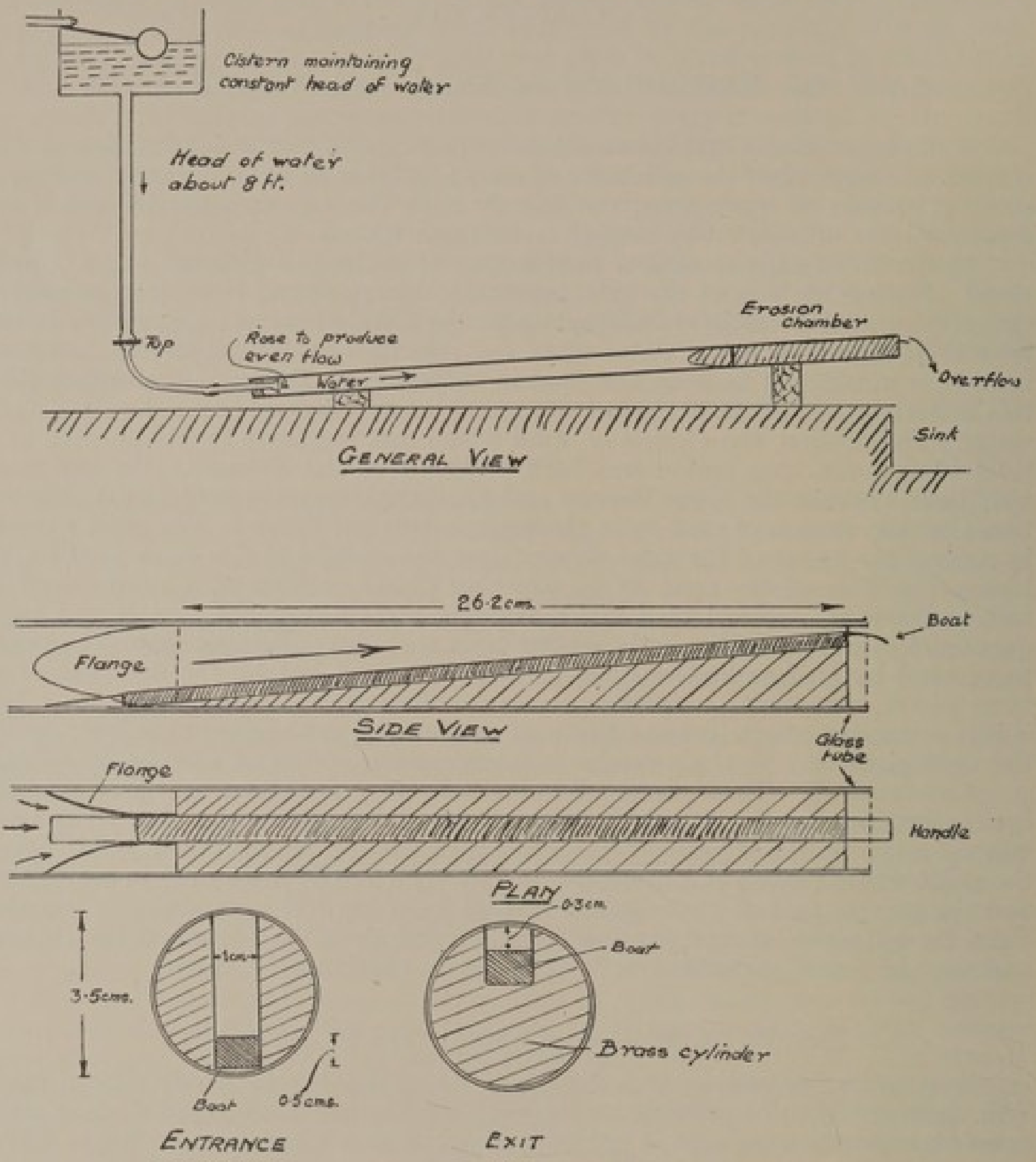
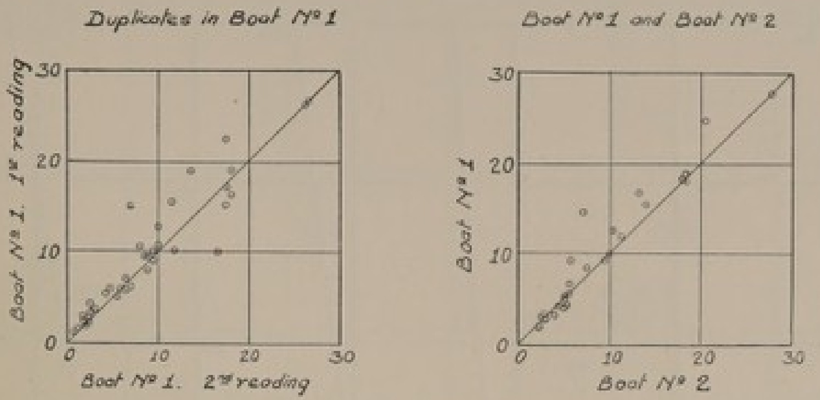


FIG. 109—*Erosion Apparatus*

approximately at right angles to the long axis of the boat. The length of the strip of mud which had been eroded was measured and was expressed as a percentage of the total length of the boat.

FACTORS AFFECTING ERODIBILITY

The resistance to erosion of portions of any particular sample of mud as measured by the method just described appeared to be reasonably constant; the agreement between duplicate determinations on a series of samples of Mersey muds is shown in Fig. 110. In the first diagram in this figure two determinations of the erodibility of each sample were carried out in the same boat; in the second diagram the first determination of each pair was done in boat No. 1, and the second in boat No. 2, which was constructed as nearly as possible with the same dimensions as boat No. 1. These two boats were used alternately in the work described later, and since the results obtained with the two boats agreed reasonably well, no correction of the results was made. The erodibility of a series of muds taken from the Stanlow Bank is shown in Table 99 (p. 312). With a number of these samples the erodibility was first determined on portions and the rest of the sample was allowed to dry in the laboratory at air temperature; a series of determinations of erodibility was then carried out on portions taken at intervals during the drying. It was found that the resistance to erosion increased as the moisture content decreased. The points giving the relation between the moisture content and the erodibility



Points show Percentage of Mud eroded

FIG. 110—*Agreement between Duplicate Determinations of Erodibility of Muds*

usually lay on smooth curves, examples of which are given in Fig. 111. Muds containing a large proportion of clay finally lost so much water that they became hard and could not be eroded. Sandy muds on the other hand passed through

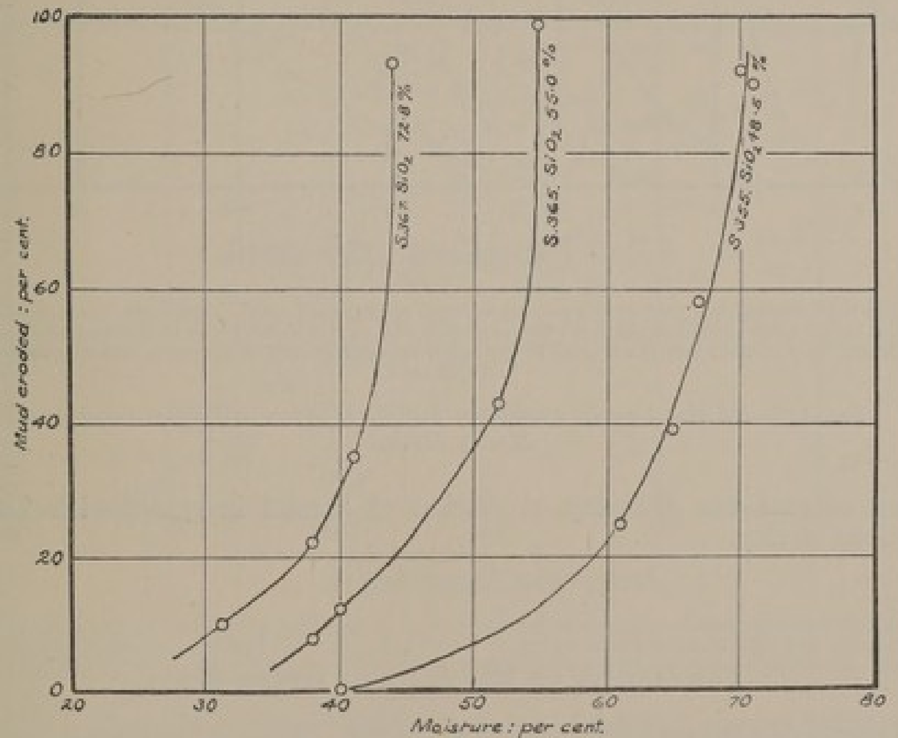
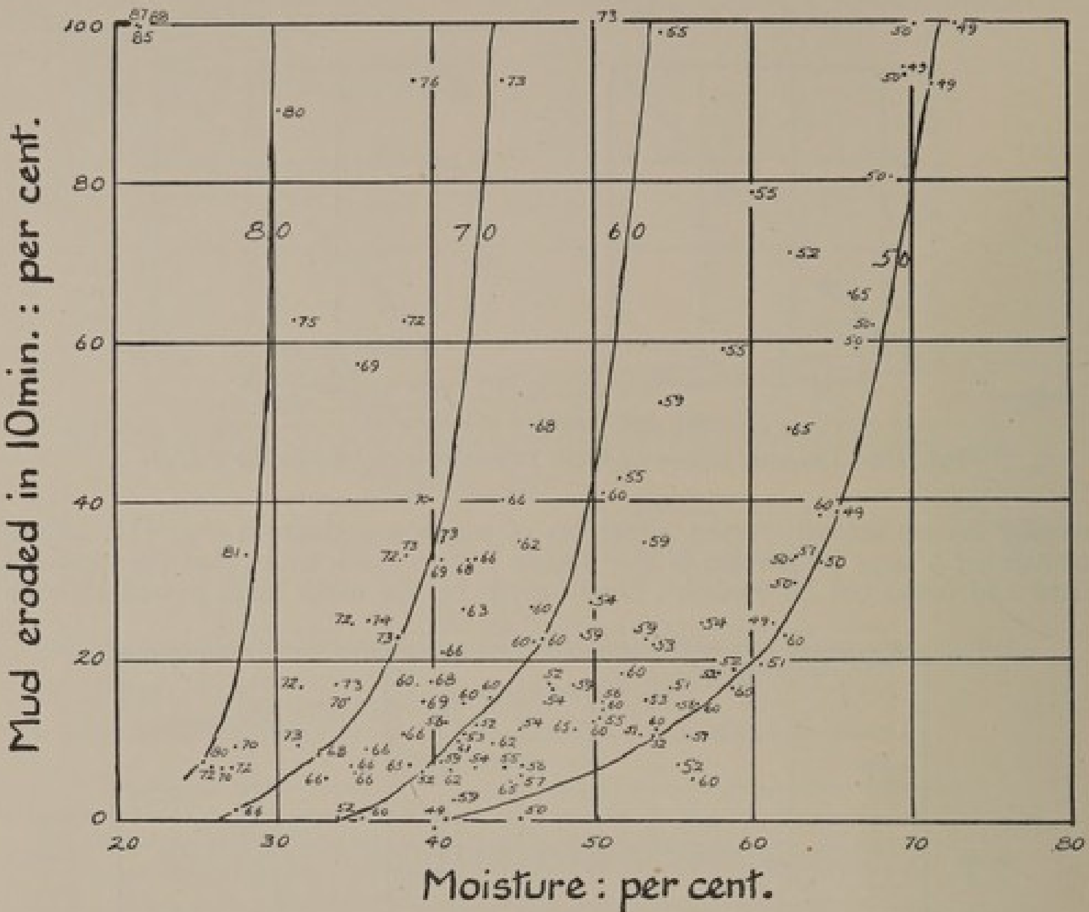


FIG. 111—*Relation between Erodibility and Water Content of 3 Samples of Mersey Mud*

a stage of minimum erodibility and then dried, forming a collection of loose particles which were easily eroded. In the samples referred to in Table 99 the determination of erodibility was discontinued before this stage was reached.

Besides being affected by the moisture content it was found that the erodibility of a mud was affected by the amount of sand in the sample. In Fig. 112 the percentage of mud eroded from a series of samples (Table 99) from the Stanlow Bank is plotted against the corresponding moisture content; lines have been drawn dividing these points into areas containing results from samples of approximately the same silica content. For a given moisture value the percentage of mud eroded increased with increasing silica content. A similar diagram can be drawn dividing the points into groups of samples in which the loss on ignition was approximately the same. The loss on ignition is a good index of the amount of clay present, since a considerable part of the loss consists of water associated with clay and not volatile at 105° C. This relation again indicates that for a given



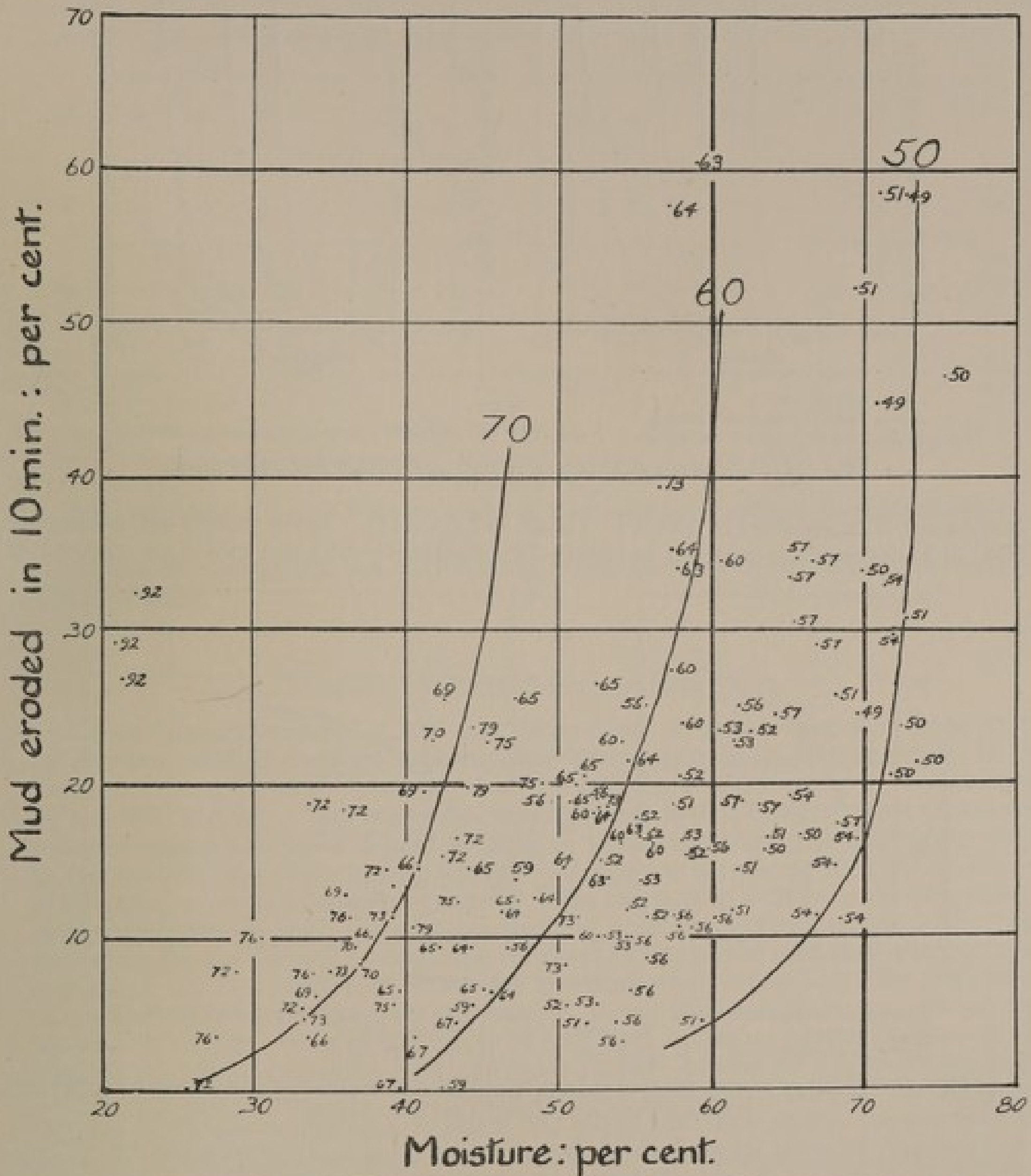
The silica content (per cent. of dry weight) is shown against each point. Lines are drawn dividing the samples into groups in which the silica contents are, on the whole, below 50 per cent., between 50 and 60 per cent., between 60 and 70 per cent., between 70 and 80 per cent., and greater than 80 per cent.

FIG. 112—*Relation between Erodibility and the Moisture and Silica Contents of Mersey Muds.*

moisture content the difficulty of erosion of a mud increases with increasing proportions of clay.

COMPARISON OF MERSEY AND OTHER MUDS

In comparing the rate of erosion of muds from different localities it is necessary to take into account both the silica content and the moisture content of the samples. This can best be done by allowing the mud to dry at room temperature, determinations of erodibility being carried out from time to time, after which the moisture-erodibility curves for different samples can be compared. In Table 100 (p. 313) are shown the results of determinations of erodibility on a series of samples from a number of rivers in Suffolk and Essex, and from the estuaries of the River Wye and the River Severn, Monmouthshire. The composition of muds from these localities was discussed in Chapter VIII, and it was pointed out that the rivers from which they were taken are comparatively unpolluted or less polluted than the Mersey. The relation between the moisture content and the erodibility of the samples from the Suffolk and Essex rivers is shown in Fig. 113; as with the Mersey muds the erodibility for a given moisture content increases with an increasing content of silica. In Fig. 114 the moisture-erodibility curves for the Mersey and Essex muds, taken from Figs. 112 and 113, are compared; a comparison has also been made by drawing lines separating samples with the same range of loss on ignition.

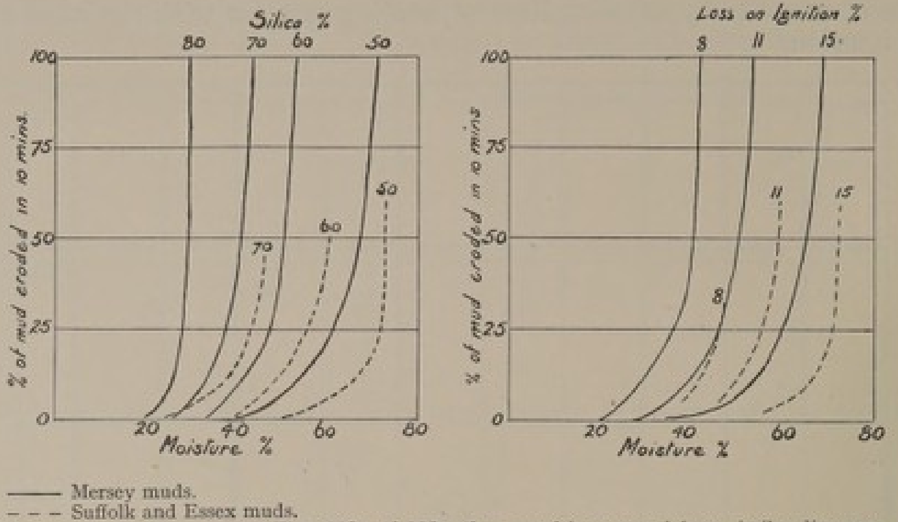


The silica content (per cent. of dry weight) is shown against each point. Lines are drawn dividing the samples into groups in which the silica contents are, on the whole, below 50 per cent., between 50 and 60 per cent., between 60 and 70 per cent., between 70 and 80 per cent., and greater than 80 per cent.

FIG. 113—*Relation between Erodibility and the Moisture and Silica Contents of Suffolk and Essex Muds.*

For a given loss on ignition or silica content and for a given moisture content the Essex muds are more resistant to erosion than are the Mersey muds. The extent of erosion of a mud under natural conditions must depend on its water content under those conditions. The water content varies according to the period which has elapsed since the mud was last covered by the sea, and the water content of inter-tidal muds should in general increase with an increase in their distance below the high-water mark.

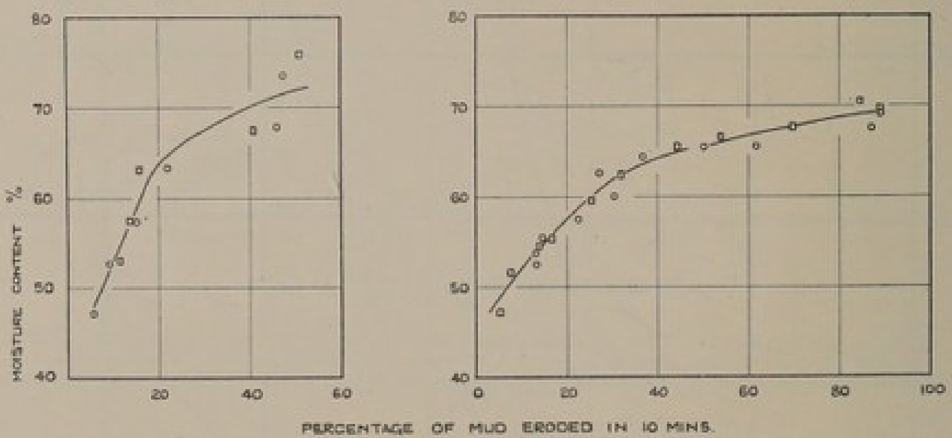
In a further series of experiments, mud and suspended matter from the Mersey Estuary were stirred in tanks with saline water (salinity 25 gm. per 1,000 gm.) containing various concentrations of sewage. After some days the mud was allowed to settle to the bottom, the water was siphoned off, and the sludge was transferred to dishes and allowed to dry slowly at air temperature. Series of determinations of the erodibility of the mud were carried out at intervals during drying, and the values obtained were compared with the corresponding moisture



The first diagram is prepared from Figs. 112 and 113; the second is prepared from similar diagrams.

FIG. 114—*Relative Erodibility of Mersey and Suffolk and Essex Muds*

contents. The results are given in Table 101 (p. 315). Mean values are plotted in Fig. 115 to show the relation between the erodibility and the moisture content of



Average of all determinations.
O—No sewage .. .. 48 expts.
□—With sewage .. .. 50 expts.

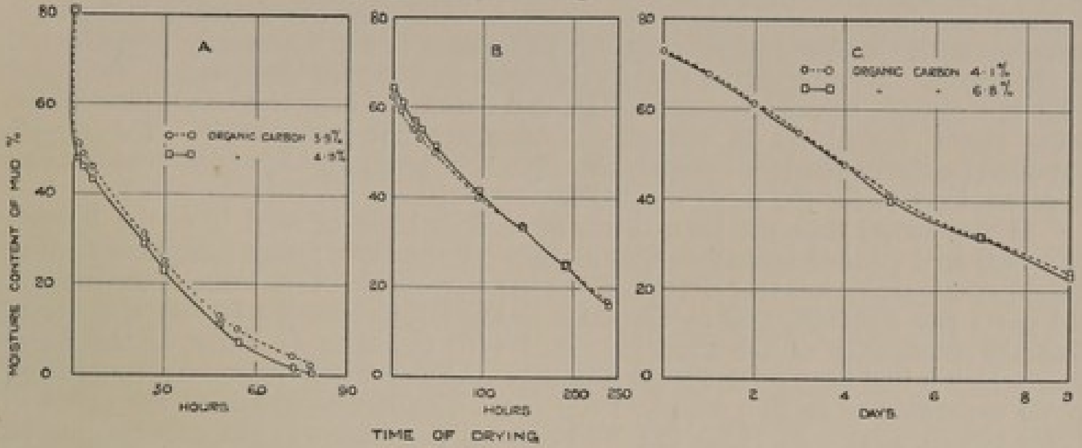
Complete results of one experiment (T.150–155).
O—No sewage.
□—With sewage.

FIG. 115—*Erodibility of Mersey Mud after Stirring with Saline Water (Salinity 25 gm. per 1,000 gm.) with or without Addition of 5 per cent. Sewage*

muds treated with saline water containing 0 to 5 per cent. of sewage. A diagram is also included to show the complete results of one typical experiment. Addition of sewage in concentrations up to 5 per cent. had no significant effect on the erodibility of the muds.

RATE OF DRYING OF MUDS

In view of the importance of the moisture content in affecting the ease of erosion of muds, some experiments were carried out to determine the effect of the addition of sewage on the rate of drying of mud at air temperature. Two methods of drying were employed. In the first, mud mixed with water to form a slurry, after treatment in various ways as indicated in Table 102 (p. 319), was poured into a Soxhlet thimble supported by a thin wire cage and the thimble was weighed at intervals. During the first few hours about half the water originally present drained from the thimble, which acted as a filter; further loss of water then occurred by evaporation from the surfaces. It seems probable that a similar initial loss of water, though not necessarily to the same extent, occurs when mud is freshly deposited on a mud bank. In the second method, suspensions of mud were placed in large open crucibles or in Petri dishes, and the mud was allowed to lose water by evaporation from the surface at air temperature. In each experiment unsettled sewage was added to one series of muds before drying, a second similar series without sewage being used as controls. The results are given in Table 102 (p. 319), and are shown graphically in Fig. 116. The addition of considerable



A. Dried in Soxhlet thimbles. B. Dried in crucibles. C. Dried in Petri dishes.
O- - -O No sewage. □—□ Sewage added

FIG. 116—*Rate of Loss of Water by Mud and Mud containing Sewage at Room Temperature*

quantities of sewage did not appreciably affect the rate of drying of the mud by either method.

EROSION OF RECENTLY SETTLED MUDS

Some determinations of the rate of erosion of muds have also been made by another method designed to reproduce as far as possible the conditions in the Estuary when mud which has settled to the bottom at slack water is eroded again by the tidal stream. Suspensions of mud in saline water, in some cases containing sewage, were made up in 5-litre beakers in which the mud was allowed to settle to the bottom, and there form a sludge. An apparatus was constructed consisting of a number of vertical spindles geared so as to rotate at speeds between 24 and 44·5 revolutions per minute. The water standing over the sludge in each beaker was stirred under the surface by a paddle clamped to one of the spindles, stirring being continued for five minutes. If all the material was eroded from the bottom of the beaker during this period, the time at which the last piece was eroded was noted. After five minutes if there was still mud adhering to the bottom of the beaker, the water was stirred by the same paddle, driven by a spindle revolving at the next higher speed. This treatment was continued until all the mud had been brought into suspension or until the water had been stirred for five minutes at the highest speed used. It was found that a large part of the mud was usually removed during the first few minutes of stirring, but that a much longer time was required to remove the last trace from the bottom of the beaker. Erosion did not appear to take place from the surface of the mud, but was usually brought about by the tearing off of pieces from the edge. After a time there usually remained several patches of mud, while the remainder of the bottom of the beaker was quite clean. The mud appeared, in fact, to be eroded by fretting in much the same way as occurred in the boat used in earlier experiments. In the Estuary the concentration of mud in suspension is much higher at spring than at neap tides, since some of the mud stays on the bottom of the channels and on the banks and foreshore during the whole period of neaps, that is, usually for about a week. In some of the laboratory experiments the mud, after settling from suspension, was therefore allowed to remain on the bottom for a period of about a week before its erodibility was determined. It was observed that during this time the mud layer became more compact, and its resistance to erosion increased. In comparing the rate of erosion of comparable series of muds each sample was first stirred at the same speed, and then at successively higher speeds, and the number of the speed at which all the mud was brought into suspension was taken as a measure of its erodibility. The driving shafts were numbered from 1 to 10 in order of increasing speed, and there was approximately the same increase in speed in revolutions per minute between successive shafts. In the method used the linear speed of the water was not the same at different distances from the centre of the beaker. It was found that erosion of the mud always began at the centre of the beaker, and it is evident that the main factor which brings about erosion is turbulence in the water induced by stirring. Although the degree of turbulence increases with the speed of stirring, the turbulence is not necessarily proportional to the speed. No attempt was made therefore to compare the speed of the water with the stream velocities observed in the Estuary, since the conditions which bring about turbulence in the two systems are not comparable. The results obtained by the method are comparable only when the erodibility of different samples is determined under the same conditions.

It was found that the time taken to erode a layer of mud from the bottom of a beaker depended largely on the thickness of the layer; each sample of mud in a comparable series was therefore made up in a suspension of the same concentration (30 parts per 100,000), and in the same volume (3·5 litres). It was also found that the erodibility of the mud increased with increasing salinity of the water from which it had been settled; the salinity of the water was therefore standardized in all experiments at 25 gm. per 1,000 gm. The results obtained are given in Table 103 (p. 321). In Table 104 are collected the results of the experiments on the effect of unsettled sewage on the rate of erosion of Mersey mud. In all cases the value given for the erodibility of any sample is taken from the mean of a number of determinations since the results by this method varied appreciably in replicate measurements on the same mud. The time during which the mud was allowed to remain on the bottom of a beaker before its erodibility was determined varied from 19 hours to 9 days. During this period sewage in concentrations up to 5 per cent. appeared to have little effect on the erodibility of mud; if anything, the sewage tended to reduce the difficulty of erosion of the mud.

TABLE 104—*Effect of Unsettled Sewage on the Erodibility of Mersey Mud*

No. of determinations.	Concentration of sewage added to suspension (per cent.).	Length of time after suspension was made up.	Speed of stirring at which all mud was eroded (average speed No.).
6	0	19 hrs.	4·3
6	5·0	" "	4·0
6	0	20 "	5·5
6	1·0	" "	5·1
6	0	" "	6·3
5	0·25	" "	5·4
6	1·0	" "	4·0
6	5·0	" "	4·0
6	0	3 days	8·5
6	5·0	" "	9·1
5	0	" "	6·6
6	5·0	" "	4·4
6	0	9 "	8·3
6	5·0	" "	8·3

Some experiments were also carried out in which the erodibility of a series of muds from the Stanlow Bank in the Mersey was compared with a series of muds taken from the estuaries of comparatively unpolluted rivers in south-east England and from the Estuary of the River Severn (Table 105).

TABLE 105—*Comparison of the Erodibility of Muds from the Mersey Estuary, from Estuaries in Suffolk and Essex, and from the Severn Estuary*

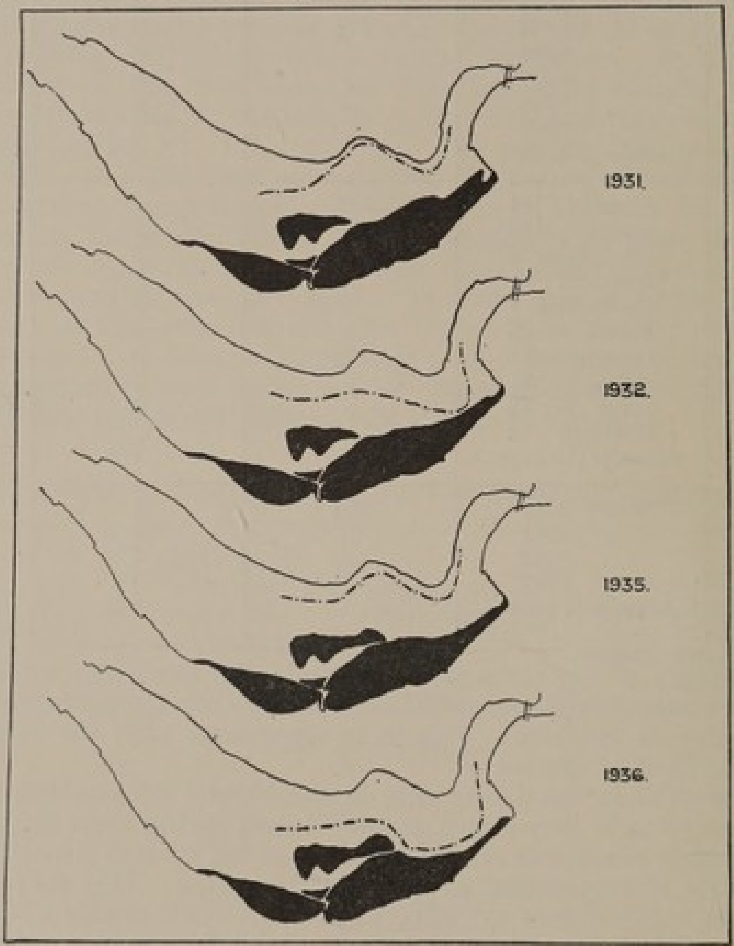
Sample of mud.	Length of time after suspension was made up (hours).	Speed of stirring at which all mud was eroded (speed No.).
Mersey S528	22½	4
" S525	"	3
" S529	"	3
" S526	"	3
" S524	17½	3
" S525	"	4
" S527	"	3
" S528	"	4
" S529	"	3
Average (9 expts.)		3·3
Stour 11	22½	5
Crouch 12	"	5
Blackwater 6	"	5
Hamford 11	"	4
Blackwater 7	"	5
Roach 3	"	5
Crouch 11	17½	3
Deben 21	"	4
Stour 12	"	4
Hamford 12	"	5
Average (10 expts.)		4·5
Severn SM1	20½	4
" SM1	"	4
" SM2	"	5
" SM2	"	5
Average (4 expts.)		4·5

The erodibility of the three series of muds was much the same, though the Mersey samples were eroded somewhat more easily than the muds from the Severn and from south-east England. This is in agreement with the results obtained by the boat method of erosion.

In Chapter XVI it was shown that in the Mersey Estuary the concentration of mud in suspension is very much greater during spring than during neap tides though the average maximum stream velocity during springs is less than one knot greater than the corresponding average during neaps. This may be explained by observations made during the experiments described in this Chapter. It was noticed that a critical velocity must be exceeded before mud covered with water could be brought into suspension, but that when this occurred a smaller velocity was sufficient to maintain the material in suspension. Although the stream velocities during neaps are not much lower than those during springs, the turbulence at neaps is evidently below the critical value required to bring much mud into suspension, whereas at springs this value is exceeded. A somewhat similar observation has been made by Lüders[1] on the transport of sand from the sea into the estuaries of rivers in Germany, where it was found that the stream velocity during the flood tide, though not greatly higher than during the ebb, exceeded the critical velocity necessary to transport sand on the sea bottom whereas the ebb velocity did not. In consequence there is an influx of sand on flood tides into the estuaries.

EROSION IN THE ESTUARY

It has been mentioned that the erosion of mud in the Mersey Estuary can take place by fretting at the edges of mud banks exposed to a sufficiently fast tidal stream. During the present investigation the most notable example of erosion occurred at the upstream end of the main mud bank on the Cheshire shore of the Upper Estuary. During recent years, the main channel above Eastham has remained for the greater part of its course on the Lancashire side so that the mud bank has been separated from the main channel by high banks of sand. The main flow of the tide has thus been mainly on the Lancashire side and the Stanlow Bank has been covered at high tide by water moving relatively slowly. This condition existed in 1931 when the Mersey Docks and Harbour Board carried out a quinquennial survey of the Upper Estuary. In 1932, however, the main channel near the Weaver Sluices moved over to the Cheshire side until it reached the edge of the Stanlow Bank, which was then bounded by a steep fret. From that time, the mud bank near the Weaver Sluices was eroded by fretting at a considerable rate. When the main channel moved away from the mud bank a subsidiary channel was left flowing along the outside edge of the bank, and fretting has occurred almost continuously since 1931. The approximate positions of the main channel in different years are shown in Fig. 117. The positions of the edge of the mud



The dotted line shows the position of the main channel.

FIG. 117—*Typical position of Upper Mersey Channel with positions of Mud Banks at a Height of 20 ft. or more above Liverpool Bay Datum*, 1931–36

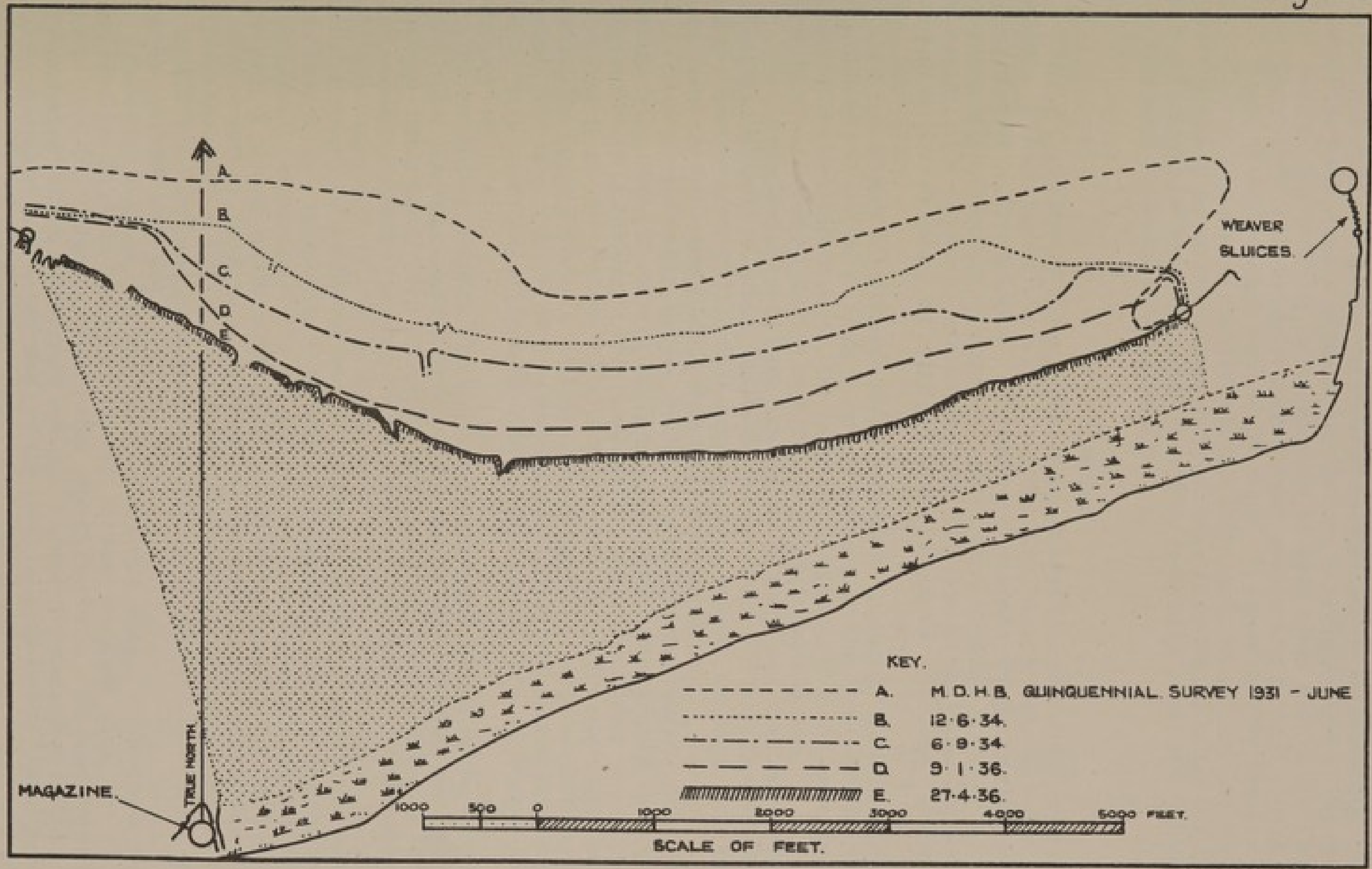
bank at different times between 1931 and 1936 are shown in Fig. 118 and the area of the bank eroded is given in Table 106.

TABLE 106—*Rate of Erosion between* 1931 *and* 1936 *of the Stanlow Bank near the Weaver Sluices*

Date.	Total observed period of fretting (months).	Total area eroded (sq. statute miles).	Approximate total volume eroded, taking thickness as 12 ft. (millions of cu. yds.).	Mean volume eroded per month (millions of cu. yds.).
1.6.31(A)				
12.6.34(B)	36	0·21	2·6	0·07
6.9.34(C)	39	0·30	3·7	0·37
9.1.36(D)	55	0·43	5·3	0·10
27.4.36(E)	59	0·53	6·6	0·33

LINE OF MUD FRET, STANLOW BANK, NEAR WEAVER SLUICES.

Fig. 118.



In Table 106 is also shown the approximate volume of material eroded, calculated on the assumption that the depth of material removed was on the average 12 ft. This value is the mean of a number of estimates of the height of the exposed mud fret made between 1934 and 1936. The volume of material eroded in 5 years (6·6 million cubic yards) is equivalent to approximately 0·6 per cent. of the total capacity of the Upper Estuary from Rock Light to Warrington. This material has probably been deposited in some other part of the Estuary. The greater part of the material washed away appeared to be mud, though there were strata of sand in some parts of the bank. It seems that the Stanlow Bank as a whole is composed of material which is fairly easily eroded and that the bank owes it stability not so much to its own resistance to erosion as to the fact that it is largely separated from the main channel by high sand banks and is therefore not subjected to the full force of the tide.

Summary

In the upper Mersey Estuary, the erosion of mud from inter-tidal banks occurs when a channel moves into such a position that rapidly moving water flows along the side of the mud bank. The bank is then eroded by the breaking off and dispersal of large pieces of mud and a roughly vertical mud face known as a " fret " is formed. The erosion of mud taken from inter-tidal banks in the Estuary was studied in the laboratory by a method which caused the " fretting " of the mud on a small scale.

The erodibility of a sample of mud depends largely on its water content; the difficulty of erosion of muds in general increases as they lose water by drying. For a given moisture content, the difficulty of erosion of muds increases with decreasing sand content, that is with increasing proportions of clay.

The erodibility of muds from the Mersey Estuary and from comparatively unpolluted estuaries in Suffolk and Essex was compared. When allowance is made for the different silica and moisture contents of the samples, the muds from Suffolk and Essex are rather less erodible than those from the Mersey.

In some experiments, Mersey muds were stirred in suspension in saline water, sewage being added in some cases. These suspensions were allowed to settle and determinations of erodibility were made on the mud removed after various periods of drying at air temperature. The presence of sewage in the suspensions in concentrations up to 5 per cent. had no appreciable effect on the erodibility of the muds. The rate of drying at air temperature of muds settled from suspension in saline water was not appreciably affected by the addition of sewage to the suspensions.

In the Mersey Estuary, the suspended mud which settles to the bottom at slack water is again brought into suspension during the succeeding tide, provided that the stream velocity is sufficiently high to erode the material from the bottom. The conditions affecting erosion of this type were studied in the laboratory by allowing suspensions of mud in saline water to settle to the bottom of beakers under standardised conditions and by measuring the rate at which this material was brought into suspension by paddles revolving in the water at known speeds. The difficulty of erosion of the settled mud was not appreciably affected by the presence of sewage in the suspensions in concentrations of 5 per cent. Under similar conditions, the erosion of settled suspensions of Mersey mud was not more difficult than that of suspensions of mud from comparatively unpolluted estuaries in Suffolk and Essex and from the estuaries of the Rivers Wye and Severn, which are less polluted than the Mersey.

Between the years 1931 and 1936, considerable erosion of the upper part of the Stanlow Bank in the upper Mersey Estuary occurred when the channel moved so as to impinge on the seaward edge of the bank. The area eroded was approximately half a square mile and the estimated volume 6·6 million cubic yards, equivalent to 0·6 per cent. of the total capacity of the Upper Estuary. The main part of the Stanlow Bank, where erosion has not recently occurred to any great extent, is separated from the main channel by sand banks and is, therefore, not subjected to high stream velocities.

Reference

(1) Lüders, K. *Veröff. Inst. Meereskunde Berlin*, 1933, A, Heft 24.

CHAPTER XX

DREDGING IN THE SEA CHANNELS IN LIVERPOOL BAY

Before the year 1890 the main navigable channel through Liverpool Bay occupied a position not very different from that which it occupies to-day; the depth over the Bar at the seaward end of the channel was, however, only about 10 ft. below Datum, and this restricted the entry of large ships into the Estuary. After some preliminary experiments in which a kind of harrow was dragged over the bed of the channel, dredging on the Bar was begun in the year 1890. Since that time dredging, both on the Bar and in certain other parts of the channel, has been carried out continuously by the Mersey Docks and Harbour Board. The areas in which the greater part of the dredging is done are shown in Fig. 119; occasionally some dredging is also done outside these areas. The main sites on which the spoil is deposited are also shown.

Method of Dredging

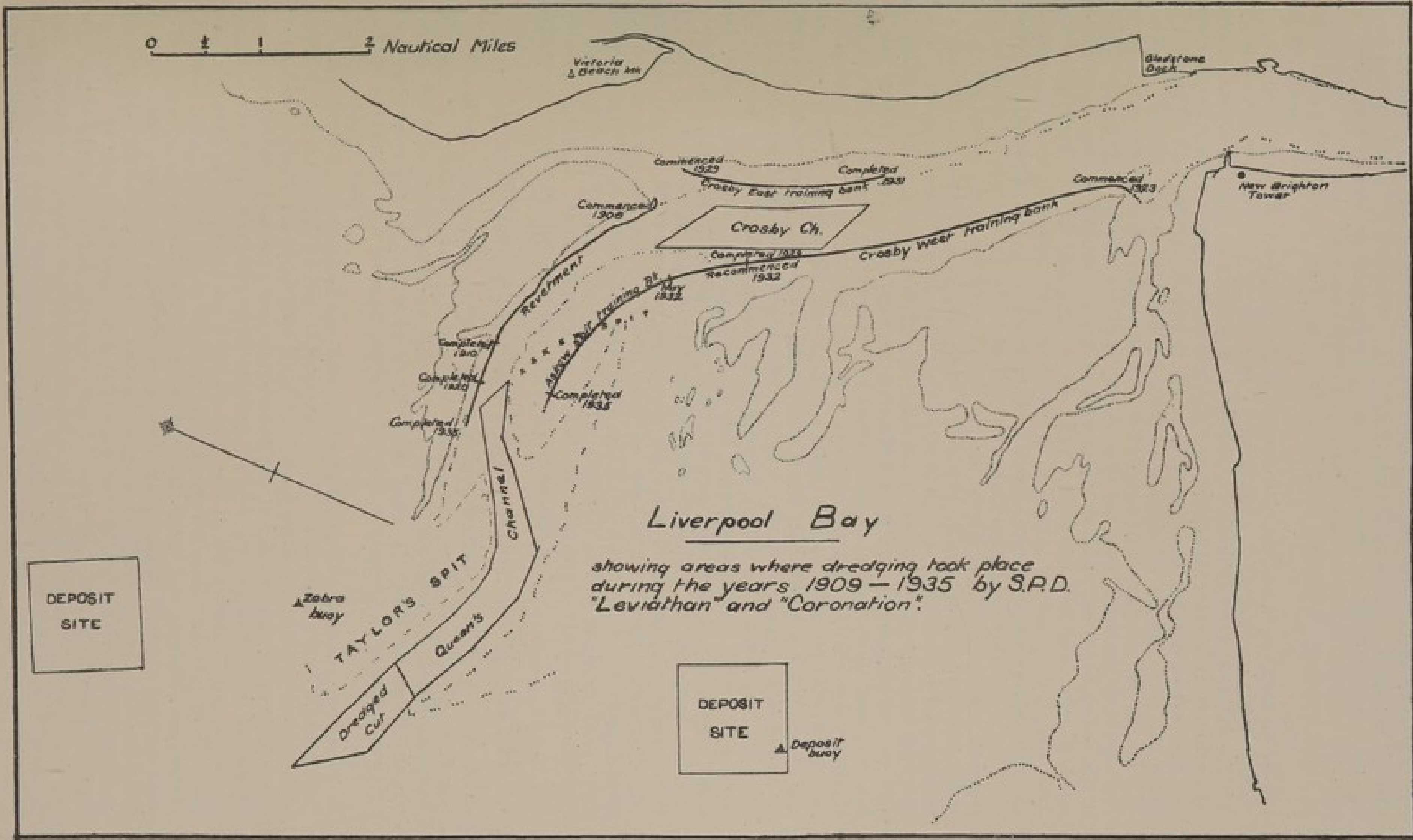
The dredgers used by the Mersey Docks and Harbour Board are of the suction type; a dredger carries one or more steel tubes, usually about 60 ft. long, one end of which can be lowered to the bed of the Estuary. A mixture of water and solid material from the bottom is then pumped into hoppers in the dredger, where the solid material is retained and the water overflows. When the pumps are started the submerged end of the suction tube buries itself in the sea bed, and for efficient dredging it should be buried for a distance of not less than 15 ft. In order to dredge efficiently by this method the suction tube should bury itself easily in the material on the bottom, and the material should be such that it does not block up the grid with which the end of the tube is provided to prevent damage to the pumps by large stones. The method works well on a sandy bottom, since the suction tubes do not become choked and after discharge into the hoppers of the dredger the sand falls rapidly out of suspension and the water runs away. If muddy material is dredged, however, the tubes do become choked and, moreover, part of the mud is washed out of the hoppers with the water. In Liverpool Bay there are areas in which the bed is composed of clean sand which is easily dredged, but there are also well-defined areas in which the bed consists of sand mixed with mud, and on these the time taken to obtain a full load by a dredger is much longer than on sand. It has been suggested that dredging by suction dredgers in the Bay has, in recent years, become more difficult owing to the formation or enlargement of muddy areas. An examination was made during the investigation of the records of two of the largest dredgers, in an attempt to determine whether any marked change has occurred in recent years in the time taken to load a given quantity of material. The names of the dredgers employed by the Mersey Docks and Harbour Board since 1890, with the periods of dredging and the weight of spoil removed, are given in Table 107 (p. 326).

The dredgers are manned by double crews and, weather permitting, work continuously day and night except when refuelling or under repair. During each 24-hour period several loads are dredged by each vessel and are dumped on the deposit sites. Each vessel has a log which is written up on board, and in which are entered particulars of the whole of the dredging and dumping operations. The log contains the position from which each load was raised and the total length of time taken in obtaining it. Particulars are also given of any periods during which the pumps were not working so that the time during which the pumps were working to obtain each load is known. Interruptions in pumping are often caused when the dredger is swinging at the turn of the tide; bad weather and mechanical failure also sometimes cause interruptions. The estimated total weight given for each load is based on the draught of the dredger before and after loading. The nature of the material dredged is also recorded.

Examination of Dredging Logs

Since 1890 a large mass of information in the logs of the dredging fleet has accumulated. In the present investigation the rates of loading of two of the dredgers, the "*Leviathan*" and the "*Coronation*," have been examined for each

Fig. 119.



0 ½ 1 2 Nautical Miles
Victoria Beach Mk.
Gladstone Dock
New Brighton Tower
Commenced 1929
Completed 1931
Crosby East training bank
Commenced 1923
Crosby West training bank
Crosby Ch.
Commenced 1906
Revetment
Recommenced 1932
May 1932
Completed 1910
Completed 1935
Channel
Queen's
TAYLOR'S SPIT
Dredged Cut
Zebra buoy
DEPOSIT SITE
Liverpool Bay
showing areas where dredging took place during the years 1909 — 1935 by S.P.D. "Leviathan" and "Coronation".
DEPOSIT SITE
Deposit buoy

day in which the vessels were in commission. The "*Leviathan*" was chosen because she is the largest of the vessels employed and least likely to be affected by rough weather; "*Coronation*" was chosen because she began dredging as early as 1903, and is still in commission. In all, records of 17,304 loads by the "*Leviathan*", taken between 1909 and 1935, and of 11,317 loads by the "*Coronation*" between 1909 and 1935 have been examined, giving a total of 28,621 loads.

On examining the dredging logs it is apparent that the time taken to obtain a load varies considerably in different parts of the sea channels. The first area seaward of the Estuary in which it is particularly difficult to work is on the eastern side of the Crosby Channel. The dredging logs frequently state that the difficulty of loading in this position is due to the shallow depth of erodible deposit on the bottom; the suction tube therefore cannot be sunk far enough into the loose material for efficient dredging and the vessel has frequently to be moved. It would appear that in this position the channel has been deepened so much that there is now only a shallow layer of mud or sand overlying the boulder clay which forms the solid bed of this part of the Bay. Between 1909 and 1911 the top layer of boulder clay was itself removed by a bucket dredger. It would seem that the chief difficulty of dredging in the Crosby Channel is due not so much to the nature of the settled material on the bed as to its shallow depth.

Other areas where dredging is difficult are on the north side of the Dredged Cut and on the south side of the Queen's Channel. Each dredger, however, takes loads from positions in which loading is easy as well as from areas where loading is difficult. There is some difficulty in considering separately the times of dredging in the muddy areas. The position of loading is given by bearings to any two buoys in the Channel; the positions of these buoys have frequently been changed as the deep channel has moved, and there is some doubt as to their exact position at a given date, especially during the earlier years. The muddy areas are relatively small, and to be certain that a dredger at any time was loading from one of them it would be necessary to have accurate shore bearings. The nature of the material on the bottom presumably depends on the tidal streams in the Bay, and these must alter as the position of the Channel changes. Again, if a shoal is dredged away it may be that the fresh material deposited in the deeper water will not be of the same nature as that formerly deposited on the shoal. It was therefore impossible to consider separately the times of loading of dredgers when working in areas of material either easy or difficult to dredge, since both the dredgers have always worked in both easy and difficult positions. Average figures for the weight in tons loaded per hour by each of the two dredgers have been obtained for each month during the periods of dredging. These figures should indicate any marked change in the difficulty of dredging.

Rate of Loading Dredgers during Period 1909 to 1935

The monthly averages of the number of tons loaded per hour by each of the dredgers "*Leviathan*" and "*Coronation*" are given in Tables 108 (p. 327) and 109 (p. 330) for those areas in the Bay in which the dredgers mainly worked. The yearly averages for each area are given in Table 110 (p. 335), and the yearly average number of tons pumped per hour by each dredger in all positions is given in Table 111 (p. 336).

The monthly average of the rate of dredging in five positions in Liverpool Bay is shown in Fig. 120 for the "*Leviathan*" and in Fig. 121 for the "*Coronation*." From these figures it is clear that the rate of dredging has fluctuated considerably from time to time, but there is no evidence of any marked change in any one direction from 1909 to 1935; the most marked changes are in the time of loading of the "*Coronation*" working on Taylor's Spit and in the Queen's Channel, where there was a continuous fall in the rate of dredging between 1909 and 1915; since 1915, however, the rate of dredging in these two areas has remained reasonably steady. The "*Leviathan*" did not work sufficiently long on Taylor's Spit for comparison with the "*Coronation*," but she worked in Queen's Channel from 1909 onwards. In this area there was a fall in her rate of dredging between 1909 and 1915 rather similar to that shown by the "*Coronation*," but not so well marked. The "*Leviathan*" began working in the Dredged Cut in 1909 and, though her rate of dredging in this position has fluctuated considerably, the rate in 1931 was not greatly different from that when dredging began in 1909. In this position the rate of loading by the "*Coronation*" has if anything increased between 1915 and 1931. The original data show clearly that it is much more difficult to dredge on one side of Queen's Channel and the Dredged Cut than it is on the other side, and it is evident that fluctuations in the rate of dredging depend largely on the proportion of the total spoil which is taken from the difficult side. This proportion depends to some extent on which side of the Channel is tending to silt up, but it also depends partly on other factors. Thus the "*Coronation*," besides dredging in the Bay, keeps clear the entrances to docks in the Narrows, and as the amount of this dredging increases there is less time in which she can dredge in the Bay. The work on the dock entrances is carried out mainly at the time of high water. Between the times of high water the dredger may work in the easily dredged areas in the Bay so that work can conveniently be resumed at the dock entrances at the next high water.

The average yearly rates of dredging in tons per hour in different areas in the Bay by the two vessels considered is shown in Figs. 122 and 123, and the yearly averages for material taken from all positions in the Bay are given in Fig. 124. With the exception of the period between 1909 and 1915 for the "*Coronation*," there is no noticeable indication that the rate of dredging has decreased between 1909 and 1935.

From the examination of the bottom deposits in the Bay during the present investigation it appears that the high banks at the sides of the main channel are composed almost entirely of sand and the deposits in the deep channels are often a mixture of mud and sand; it is this mixture which is difficult to dredge. The composition of the muddy sand was discussed in Chapter VII, and it was shown that it is probably continuous with similar material found over large areas in the Irish Sea. In the early days of dredging when relatively high sand banks were being removed the material dredged probably contained a high proportion of sand; later the proportion of mud increased as the deeper channels were included in the areas dredged. This may partly account for the fall in the rate of dredging for the "*Coronation*" between 1909 and 1915 on Taylor's Spit and in Queen's Channel.

Examination of Samples of Dredged Material

Two samples of material of the kind which is often found sticking to the suction end of dredger tubes and which causes difficulty in dredging were examined; these samples, with a record of the positions from which they were obtained and information on the depth below the bed of the suction tube nozzle, were furnished by the Engineer's Department of the Mersey Docks and Harbour Board. The content of organic carbon in the two samples is shown in Table 112.

TABLE 112—*Organic Carbon Content of Two Samples of Mud taken from Dredger Suction Tubes*

Sample No.	Position.	Organic carbon (per cent. of dry weight).	
		Sample as taken.	After removal of sand by sedimentation.
B. 266	Queen's Channel	1·13	2·65
B. 267	Dredged Cut	0·70	2·35

Both samples contained a high proportion of sand; the organic carbon content of the mud separated from sand by sedimentation was of the same order as that found in muds taken from the Upper Estuary or separated from samples from the bed of the Irish Sea.

Sample B. 266 was taken in 1934 from a position on the south side of the Queen's Channel. The depth of water at the position of dredging was 24 ft. below Liverpool Bay Datum, and the nozzle of the suction tube was 20 ft. below the sea bed, so that the sample was taken from a depth of 44 ft. below Liverpool Bay

Fig. 120.

DREDGING DATA EXTRACTED FROM LOG BOOKS & SHEETS OF SAND PUMP DREDGER "LEVIATHAN". MONTHLY AVERAGE RATE OF DREDGING.

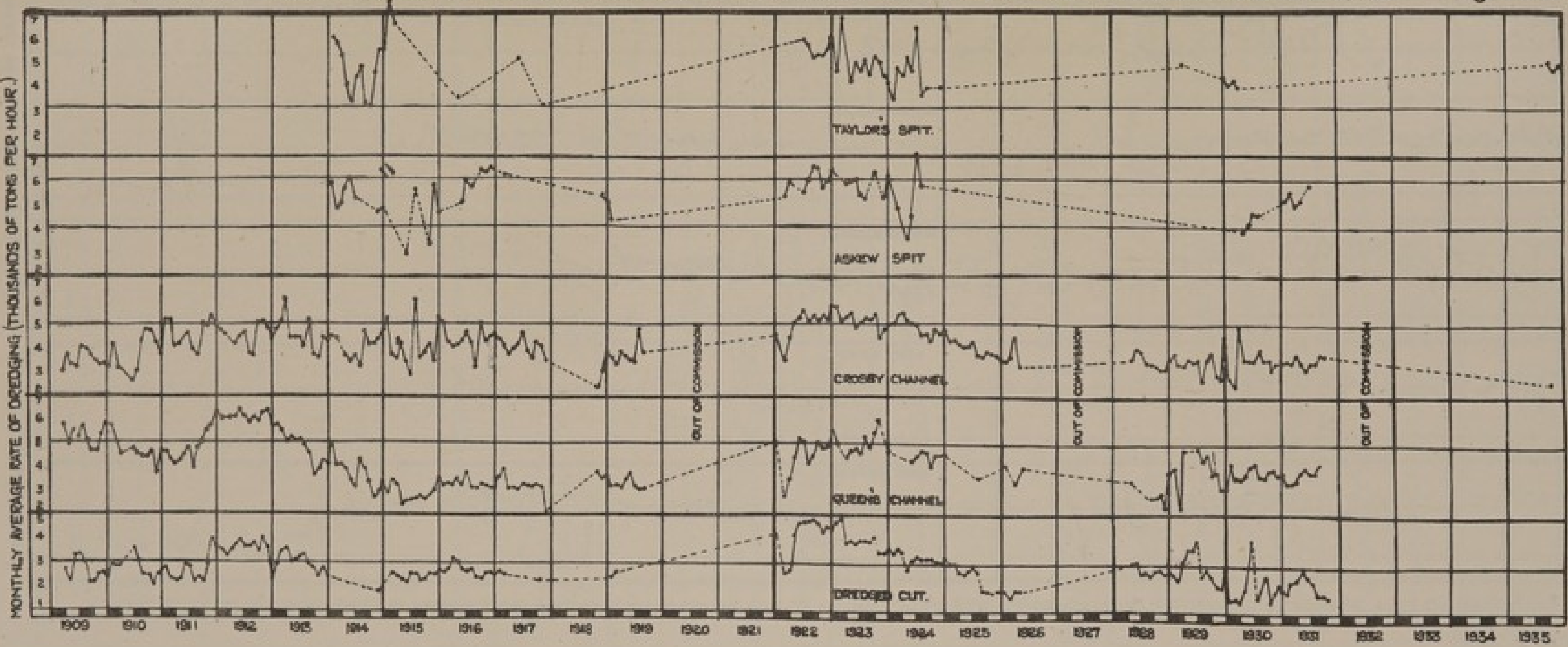
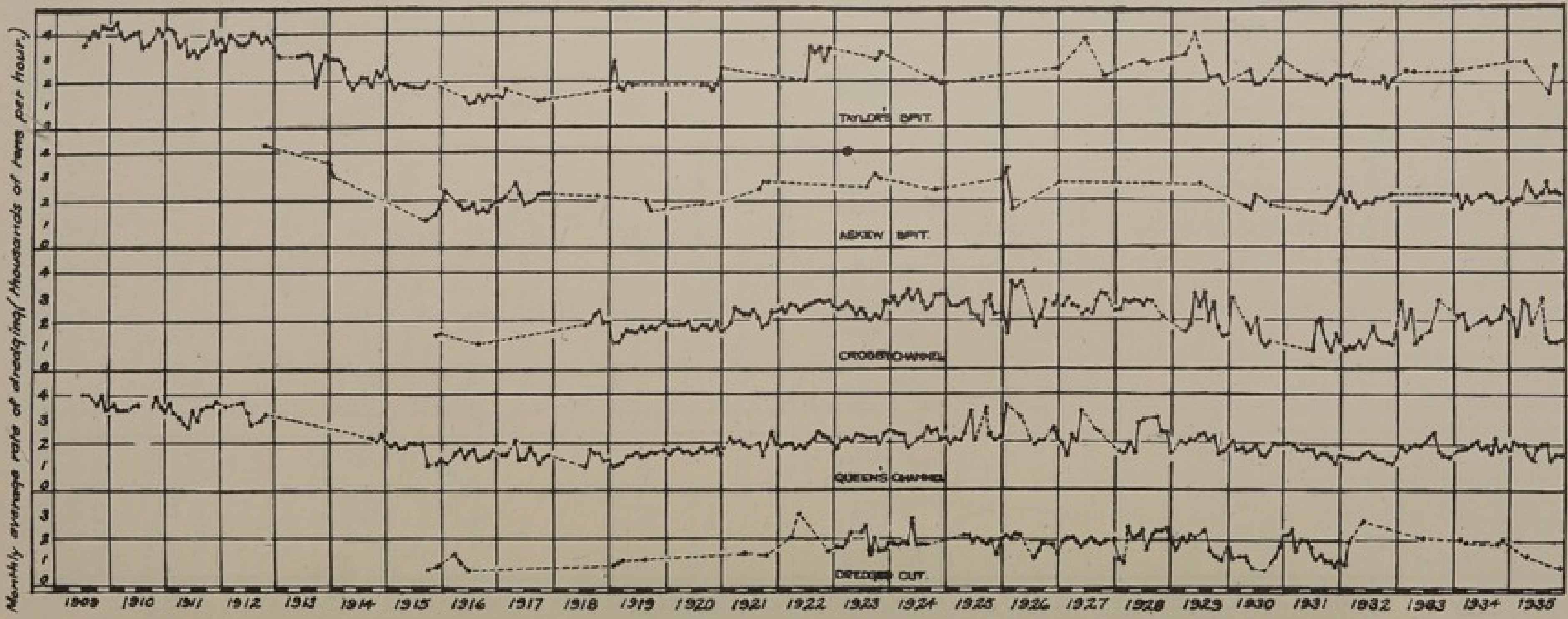


Fig. 121.

DREDGING DATA EXTRACTED FROM LOG BOOKS & SHEETS OF SAND PUMP DREDGER "CORONATION". MONTHLY AVERAGE RATE OF DREDGING



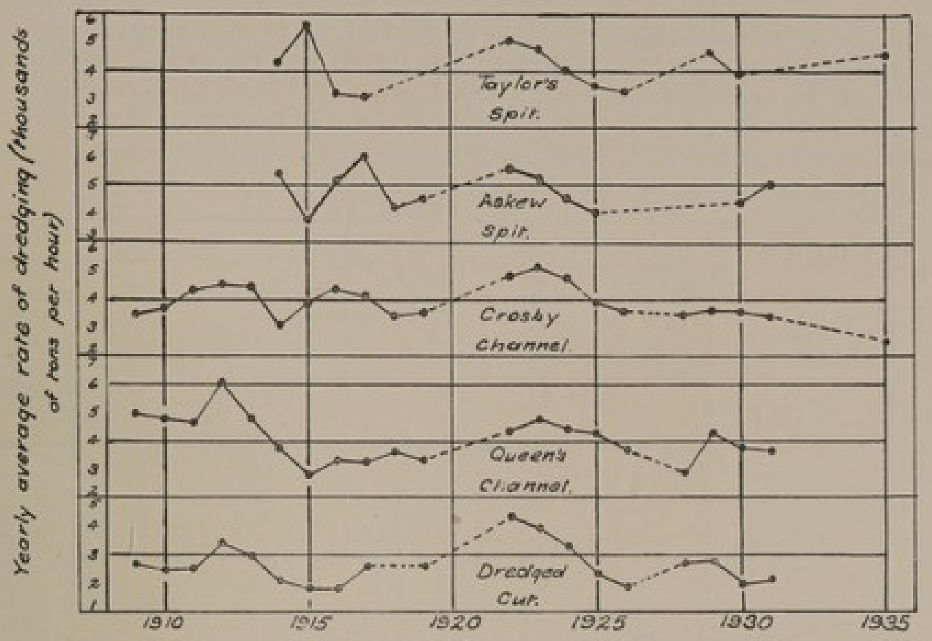


Fig. 122—Dredging Data extracted from Log Books and Sheets of Sand Pump Dredger "Leviathan" Yearly Average Rate of Dredging

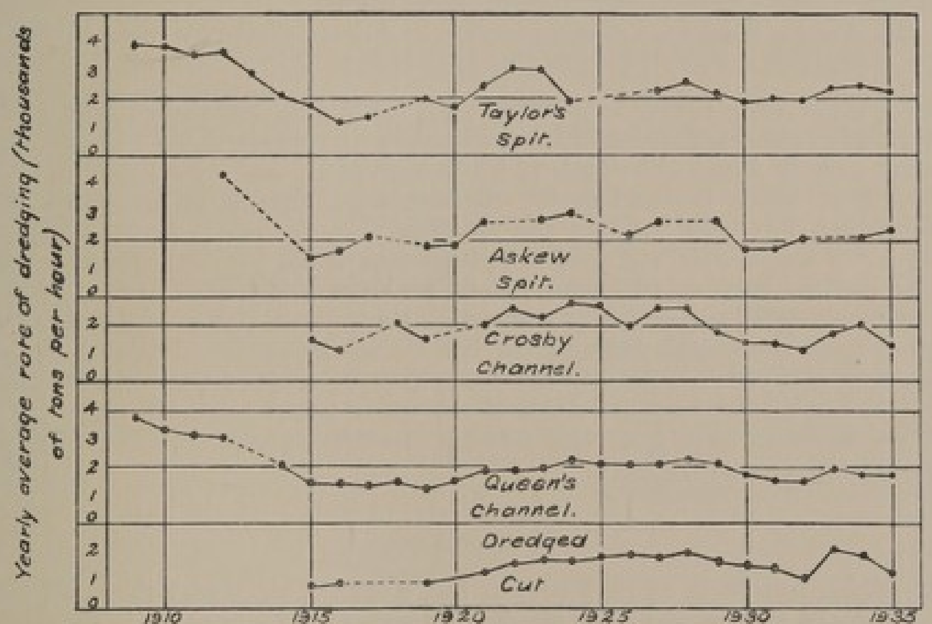


Fig. 123—Dredging Data extracted from Log Books and Sheets of Sand Pump Dredger "Coronation" Yearly Average Rate of Dredging

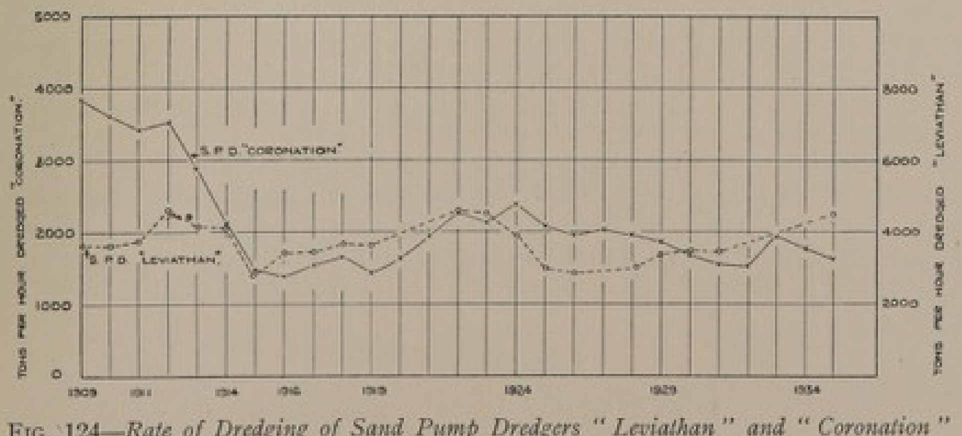


Fig. 124—Rate of Dredging of Sand Pump Dredgers "Leviathan" and "Coronation" Average for all Positions in Liverpool Bay

Datum. Sample B. 267, obtained also in 1934, came from a position on the north side of the Dredged Cut; the sounding was 27 ft. and the nozzle 14 ft. below the bed, so that the sample came from a depth of 41 ft. below Liverpool Bay Datum. The two positions were marked on a series of charts of Liverpool Bay and the depth of water over each position in different years was read off. The changes which have occurred in the depth of water are shown in Fig. 125. The mud brought up

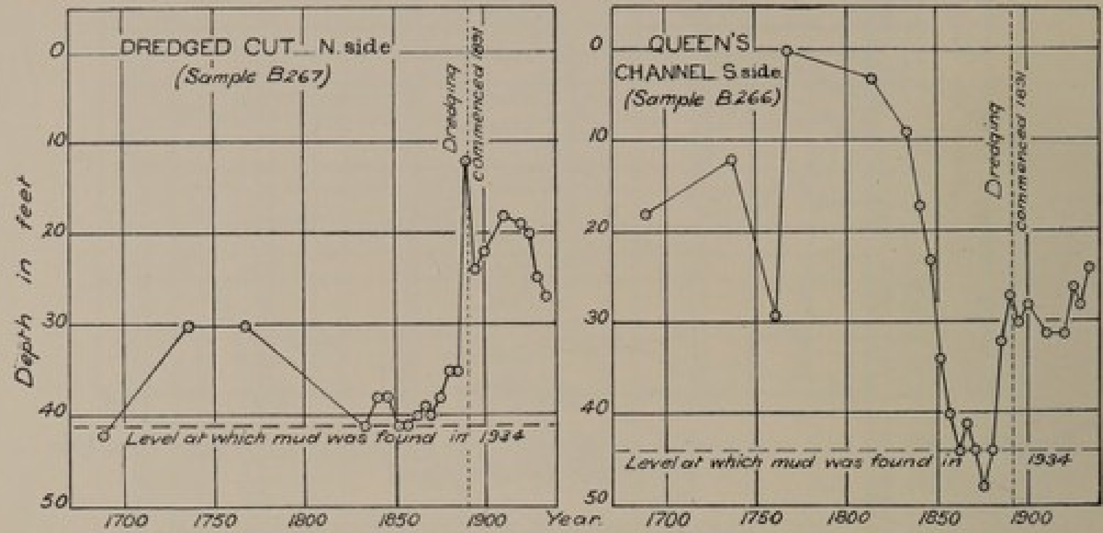


Fig. 125—*Depth of Water below Liverpool Bay Datum shown on Mersey Docks and Harbour Board Charts over Two Positions where Mud has been found by the Sand Pump Dredgers*

by the suction tube could have been laid down only when the depth of water was as great as the depth from which the sample was obtained. In Queen's Channel the latest year in which the depth of water was 44 ft. below Liverpool Bay Datum (the depth at which the end of the suction tube brought up the mud) over the position given was 1880, and in the Dredged Cut the latest year in which there was 41 ft. of water over the position given was 1856. It would seem, therefore, that the last occasions on which mud could have been deposited in the two positions were 1880 and 1856, respectively, since after these times this mud has been covered by other deposits. Some uncertainty must arise from the nature of the method of sampling, but the calculations illustrate that because of the considerable depth below the bed of the Bay at which the dredger tubes work the deposits at this depth are likely to have been laid down at earlier periods than the material now forming the surface of the bed.

Summary

Dredging has been carried out by the Mersey Docks and Harbour Board in different parts of the main navigable Channel in Liverpool Bay since the year 1890. Suction dredgers are used. Difficulties are encountered in dredging muddy sand since the mud clogs the suction tubes and does not easily settle in the hoppers of the dredgers.

The records of two dredgers for the period 1909 to 1935 were examined and the weight of material dredged per hour was calculated. The weight loaded per hour varies in different parts of the Bay and is less when dredging muddy sand than clean sand. From the figures examined there is no evidence that the difficulty of dredging has increased during the period 1909 to 1935.

Two samples of mud brought up in 1934 by the suction tubes of a dredger from depths of 20 and 14 feet below the sea bed in Liverpool Bay have been examined. An examination of the charts of the Bay suggests that these two mud samples were deposited not later than 1880 and 1856. The organic content of both samples was similar to that of mud from inter-tidal banks in the Upper Mersey Estuary.

CHAPTER XXI

METHODS USED IN MEASURING THE CAPACITY OF THE UPPER ESTUARY

General Description of Methods

The Mersey Docks and Harbour Board was established by Act of Parliament in 1857. During the period from 1861 until the present time the Marine Surveyor's Department of the Board has carried out surveys of the Upper Estuary between New Brighton and Warrington; the surveys were made at intervals of ten years until 1881 and since then have been made at five-yearly intervals. From the results of these surveys, the Mersey Docks and Harbour Board have calculated the capacity of the Upper Estuary, that is, the volume of water between the bed of the river and the highest level reached by a high spring tide. There is thus evidence of the changes which have occurred since 1861 in the capacity of the Upper Estuary. The figures obtained by the Board show that the capacity fluctuated between successive surveys in the period 1861 to 1906. In the year 1906 the capacity was approximately 990 million cubic yards but between 1906 and 1926 it steadily declined from 990 to approximately 940 million cubic yards. It was suggested that the decrease during this period of 20 years was due to the effect of the sewage which was discharged into the Upper Estuary and which was said to have led to an increase in the growth of inter-tidal mud banks in the upper basin. During the present investigation, which was carried out to examine the effects of the discharge of sewage on the formation and stability of mud banks, it was essential to examine the methods by which the capacity of the Upper Estuary had been determined so as to estimate the probable accuracy of the values found.

In the measurements of the capacity of the Upper Estuary it was first necessary to carry out a " land survey," that is a triangulation in which the positions of suitable land marks on the shores of the Estuary are accurately fixed. From the positions of these main reference points the positions of subsidiary marks on the shore can be fixed, and from the complete system of fixed marks the position of any point in the Estuary at which a sounding is taken can be found by means of sextant angles. The " capacity " of the Upper Estuary has throughout the series of surveys been taken as the volume lying between the bed of the Estuary and the highest level reached at all points by a tide rising, at Prince's Pier in the Narrows, to a height of 31 ft. above Liverpool Bay Datum. This volume is rather greater than the total volume of water in the Upper Estuary when a 31-ft. tide has risen to its maximum height at the mouth of the Narrows, since near the head of the Estuary the time of high water is later than it is in the Narrows. The height reached by 31-ft. tides was observed by the Mersey Docks and Harbour Board at several points from the Narrows to Warrington. From these observations the average height at intermediate points was calculated and taken as the maximum height reached by the standard tide. The depth of the bed of the Estuary at any point below the high water level of a 31-ft. tide is usually measured by taking a sounding, which gives the distance of the bed below the water level at that point at the time at which the sounding was taken. While sounding is in progress the height of the tide is observed on a tide pole erected near the shore of the Estuary near the position of sounding. The height of the zero mark on the tide pole with reference to the fixed Datum of the survey is obtained by levelling, and thus the height of the tide above Datum at this place at any time is known. When this correction is applied to the sounding, the result gives the height of the bed at that point above or below Liverpool Bay Datum, and since the height reached by a 31-ft. tide above the same Datum is known, the distance between the bed and this height can be calculated. In some parts of the Upper Estuary it is more convenient to obtain the height of the bed directly by levelling at low water. In the method used by the Mersey Docks and Harbour Board, the capacity of the Upper Estuary is calculated from the areas of a number of cross-sections which in general are approximately at right angles to the centre line of the Estuary. From these areas and from the longitudinal distances between successive cross-sections, the volume is computed. Thus, in order that the measurements of capacity throughout the period of the surveys should be comparable, it is necessary that the following main conditions be fulfilled:

> (1) The accepted positions of the main and subsidiary reference points should have been the same in each survey, (2) the reference datum and the height taken as the level of the 31-ft. tide above this datum should have remained unchanged, (3) the positions of the cross-sections and the measured distances between them should have been accurately determined throughout, (4) the methods used in sounding, levelling and applying tidal corrections should have been of the same degree of accuracy during the series of surveys, (5) the shape of each cross-section, which is obtained from the length of the section and the soundings taken, should always have been drawn and its area measured to the same degree of accuracy, and (6) the volume of the Estuary, which is obtained from the areas of cross-sections and the distances between them, should have been calculated accurately and by the same methods throughout the series.

Before the first measurement of capacity in 1861 a triangulation of the principal land marks on each shore was carried out; this was based on a previous triangulation completed in 1843 which had been made by H.M. Ordnance Survey Department in collaboration with the Corporation of Liverpool. The triangulation of 1860 was used continuously up to 1930, when a re-triangulation was carried out by the Mersey Docks and Harbour Board. The positions found in 1930 agreed with those which had been used since 1860, so that the hydraulic surveys throughout the series have been based on the same reference frame-work.

For the first hydraulic survey in 1861, the positions of the cross-sections along which soundings are taken were fixed, the positions of the section ends being defined by measurements from fixed marks. The measurements made were recorded, and the positions of the section ends for subsequent surveys have been obtained from the same measurements, so that the same cross-sections have been used throughout the series of surveys. From time to time changes in the coast line have occurred as a result of erosion or the demolition or construction of works on the foreshore. Where these changes have occurred, the same cross-sections have been used, but the positions of the section ends affected have been re-determined. The cross-sections are not spaced at equal distances apart, and owing to the shape of the Estuary are not always parallel to each other. The distances between successive cross-sections were measured when the capacity of the Estuary in 1861 was calculated and the same distances have been accepted in all subsequent surveys. The method by which the distances between sections were originally measured is unknown; the accepted values are given in Table 113.

TABLE 113—*Mean Distances between Cross-Sections used in the Calculation of the Capacity of the Upper Estuary*

Compartment No.	Rock Light to Warrington. Sections Nos.	Mean distance between Sections (yds.).
1	0 to 21	216
2	21 ,, 26	216
	26 ,, 47	226·5
3	47 ,, 74	393
	74 ,, 83	360
4	83 ,, 100	343·5
	100 ,, 110	189
5	110 ,, 124	348
	124 ,, 133	304·5
6	133 ,, 161	304·5

During each survey a line of levels is run along each side of the Estuary, and is connected across between Runcorn and Widnes. These levels are connected to all available Ordnance bench marks as well as to subsidiary permanent marks, the heights of which have been measured, and to pegs at the end of each section. At low tide, lines of levels are taken on each section as far as possible across the foreshore on each side of the Estuary, the intervening gap being filled by soundings which are usually taken at about the time of high water. Soundings are now taken from motor launches, which, starting from one side of the Estuary, sound across the section until they have overlapped the part of the foreshore which has been levelled. An adjacent section is sounded on the return journey. During sounding the launch moves slowly ahead without stopping for individual soundings, and at intervals the position of the launch is fixed by taking simultaneous angles with sextants between marks on the shore. The position is plotted on a working sheet by means of station pointers. The banks and channels in the Upper Estuary are constantly moving, and in carrying out a survey it is, therefore, desirable that the work should be completed in as short a time as possible. For this reason several motor launches are now used and the field work is continued with all speed until the survey has been completed. It is necessary, however, to choose calm days for the work, and the men are employed on shore during rough or foggy weather. Sounding is done at about the time of high water when the tidal stream is slack and it is relatively easy to keep a lead line vertical; near high water also the rate at which the tide rises or falls is least. In the earlier surveys it is probable that rowing boats were used, and that the time taken to complete a survey was longer than during recent years.

In sounding, hemp lead lines are used, and the depths are taken to the nearest half foot where possible, or to the nearest foot; in shallow water in the Upper Estuary, depths are taken to the nearest 3 in. In all cases the soundings are called to the nearest mark whether it is above or below the water line. Tidal corrections to the nearest 3 in. are made to the soundings. The Mersey Docks and Harbour Board have a number of automatic recording tide gauges at various points in the Estuary, but these are not relied upon for correcting soundings, except in the Narrows, where Prince's gauge is used.

The plans of the first surveys are on a scale of 500 ft. to the inch; but after 1896 a scale of 880 ft. to the inch was adopted for the plans above Eastham, and a scale of 500 ft. to the inch has been used for the plans below Eastham. These are all reduced to a scale of 880 ft. to the inch for printing.

The positions of the ends of each section together with the " fixes " taken during sounding are plotted on an office working sheet which has been prepared beforehand, and which contains the fixed triangulated marks forming the framework of the survey. From these sheets each cross-section is then drawn. A line is first drawn representing Liverpool Bay Datum, and a length is marked off giving the length of the section, this being measured between the positions of the section ends shown on the working sheet. A second line representing the top water level is then drawn parallel to the line representing the Datum; the horizontal scale used is 264 ft. or 4 chains to the inch, and the vertical scale 20 ft. to the inch. The lines of levels from the ends of the sections are then drawn as verticals, and the soundings are transferred from the office sheet to the section drawing, the horizontal distances being measured from the Cheshire end of the section in each case. Where the soundings overlap and are different from the levels the latter are accepted as being correct. The ends of the verticals are then joined with straight lines representing the bed of the Estuary, and the area between the bed and the line representing the top water level is measured. In recent years these areas have been measured by planimeter, the mean of three readings being taken, but before about 1896 it is probable that the areas were measured by some method of counting squares.

When this has been done the area of each cross-section on which soundings were taken is known, and the volume of the whole Upper Estuary is calculated from the areas found and from the distances between adjacent cross-sections. For the first survey, carried out in 1861, the cross-sections were divided into groups and the longitudinal distance between the extreme sections in each group was measured. This distance, divided by the number of intervals between the sections in the group, gave the mean distance between adjacent cross-sections, this mean distance varying from one group to another. The values so obtained have been used in the calculation of the capacity of the Estuary in every survey. The volume has been computed for each survey by a formula similar in principle to Simpson's rule.

A few surveys were made before the setting up of the Mersey Docks and Harbour Board. The first of these of which information has been obtained was carried out in 1765, but this and other surveys made before 1800 for navigational purposes are not regarded as being sufficiently accurate to give a reliable estimate of the volume of the Estuary. A more extensive survey was made for the Corporation of Liverpool between 1819 and 1821, but it was subsequently found that the levels of high water adopted in the upper part of the Estuary were inaccurate. Another survey was begun in 1833. The original charts do not indicate the manner in which the capacity of the Estuary was calculated in this survey and, although figures showing the capacity at high water are given, the results have not been included for comparison with those of more recent surveys.

The most important documents which are available relating to the periodical surveys made by the Mersey Docks and Harbour Board between 1861 and 1931 are listed in Table 114.

TABLE 114—*Data available on the Surveys of the Upper Mersey Estuary by the Mersey Docks and Harbour Board between* 1861 *and* 1931

Year.	Data.	Scale.
1860	Plan of Triangulation	500 ft. to 1 in.
1860	Record Book	—
1860	Field Book of coast details	—
1861, 1871, 1881 and then quinquennially to 1931	Fair Drawings of hydraulic surveys showing soundings and coastline	880 ft. to 1 in. and in earlier years 500 ft. to 1 in.
For each survey ..	Drawings of cross-sections, and areas of cross-sections	Horizontal 264 ft. to 1 in. Vertical 20 ft. to 1 in.
For all surveys except those of 1861 and 1871	Files of original sounding sheets (including levels) and tidal corrections	—
For each survey ..	Files of the original computations of cubic capacities	—
1930	Diagram with tabulated angles and distances from trigonometrical survey	3,040 ft. to 1 in.

LAND SURVEYS

In 1843 a triangulation from Southport to Warrington was carried out by H.M. Ordnance Survey Department in collaboration with the Corporation of Liverpool. In 1860 a more detailed triangulation of the shores of the Estuary was made, the survey being based on measurements taken during the triangulation of 1843. The survey of 1860 was used as a basis for all other measurements made in the Upper Estuary until 1930, and its accuracy is therefore a matter of importance. It was plotted on a scale of 500 ft. to 1 in., and on this scale a length of 0·01 in. on the plan (equivalent to 5 ft.) is the least length that is normally visible or can be scaled. The lengths of the sides of most of the triangles used in 1860 were between 10,000 and 20,000 ft. The method by which the survey was originally plotted is not known, but it appears that 27 lines were taken from the survey of 1843, and were used as base lines. No information is available on the angles observed or the triangulation errors in 1860, but an indication of the accuracy of the survey can be obtained by comparing the length of certain lines given by the 1860 survey with the corresponding length found in 1843. The base line used in 1860 was taken directly from the 1843 plan, but the length of the test lines was computed by a different system of triangles in the two surveys. Thus on the assumption that the 1860 survey was begun at the Liverpool end of the Estuary, the line between Hale Church and Weston Point Church at the upper end of the Estuary may be taken as a closing line; the length obtained in 1860 was 7,612·6 ft. and in 1843 it was 7,608·8 ft., the difference being 3·8 ft. or 0·05 per cent. The length of the line between Birkenhead Church and St. James's Church was similarly given as 8,083·4 ft. in 1843, and as 8,077·6 ft. in 1860, the difference being 5·8 ft. or 0·07 per cent. The accuracy of the survey carried out in 1860 thus appears to be of the same order as that of the Ordnance Survey of 1843, and to be sufficient for the purpose for which it was made.

In 1924 a third trigonometrical survey was begun by the Mersey Docks and Harbour Board, and the work was finished in 1930. This triangulation was undertaken because many of the marks which had been included in the survey in 1860 had either been demolished or had become obscured by developments on shore. In the new survey, which covered the area between Rock Light and Runcorn, the position of new shore marks was determined. The triangulation was based on two Ordnance Survey lines, one at either end of the Estuary. From these base lines the triangulation closed on the line between Dungeon Point and Stanlow Point with a closing error not exceeding 6·5 ft. in a length of 13,718 ft., or 0·05 per cent., which is within the desired limit of accuracy. Check calculations made on several of the triangles used show a similar degree of accuracy.

In the earlier hydraulic surveys the outline of the Estuary and the reference marks were plotted as required from the original data of the triangulation. In later years the Mersey Docks and Harbour Board collaborated with H.M. Ordnance Survey Department in the construction of a plan of the Estuary showing the topography and sounding marks, all available data being used. While this system was in force a fresh plan of the Estuary was in fact drawn on each occasion. In 1919 the reference marks used in quinquennial surveys were transferred by the Mersey Docks and Harbour Board to slates, and in 1928 to aluminium sheets. When this had been done the positions of the given points were fixed without the possibility of distortion, and positions were transferred from the slates or aluminium sheets at each quinquennial survey.

Liverpool Bay Datum

The old primary levelling of Great Britain was carried out between the years 1840 and 1860, and it appears that Ordnance levels were established in the Mersey area before the first quinquennial survey of 1861. The datum with which the Ordnance levelling of 1840 to 1860 was connected was mean sea level at Liverpool as determined from a fortnight's observations in 1844. Between the years 1912 and 1921 the primary network of levels was re-surveyed, the datum to which the new system was referred being mean sea level at Newlyn derived from observations made during the period 1915 to 1921. It was found that the old Ordnance Datum at Liverpool was 0·13 ft. above mean sea level at Newlyn. It is thought that this change did not represent any vertical movement of the land, but was due rather to inaccuracy in obtaining the mean sea level at Liverpool. The levels and soundings of the quinquennial surveys of the Estuary are referred to a level 10 ft. below the Statutory Datum of the Old Dock Sill, which is 4·67 ft. below the old Liverpool Ordnance Datum. The line 10 ft. below the Old Dock Sill or 14·67 ft. below the old Ordnance Datum is known as Liverpool Bay Datum (L.B.D.), and was established in 1862 as the permanent Datum for the Bay. This level is approximately the level of low water at equinoctial spring tides, and is about 1 ft. 9 in. below the level of mean low water of ordinary spring tides. The levels of all the surveys of the Upper Estuary from 1861 are referred to Liverpool Bay Datum.

The Height of High Water at Spring Tides

In the Mersey Conservancy Act of 1842 it was enacted that the limit of the jurisdiction of the Conservators over the construction of piers and other works on the river should be the line of the high water mark of a tide, uninfluenced by wind, rising to a height of 21 ft. above the sill of the gates of the Old Dock in Liverpool. This is equivalent to a height of 31 ft. above Bay Datum. In 1860, therefore, and in connection with the 1861 survey, the heights to which a 31-ft. tide at Liverpool rose at various points along the Estuary were observed for tides between the 15th and 18th of September, and a line of top water level was drawn on each section at a height corresponding with the position of the section. These heights gradually stepped up from 31 ft. above Bay Datum at Liverpool to 35 ft. at Warrington. The section ends or intersections of the top water line and the bed of the Estuary determined the line of the high water mark at each section and on either side of the Estuary.

In 1895 the Mersey Docks and Harbour Board made fresh observations during a period of eight months of the height of high water in different parts of the Upper Estuary for a tide rising 31 ft. above Bay Datum at Prince's Pier. The levels obtained in 1895 in the upper parts of the Estuary were considerably lower than those obtained in 1860. In 1931 the Mersey Docks and Harbour Board obtained further mean values of the top water level in different parts of the Estuary for tides rising to a height of 30 ft. 6 in. to 31 ft. 6 in. at Prince's Pier;

the new levels were obtained from the records of self-recording gauges. The values obtained agree fairly closely with the accepted top water levels of 1860. During the present investigation another attempt was made to determine whether any real difference has occurred in the height reached by a standard tide in different parts of the Upper Estuary, the data being obtained from records of automatic gauges. The mean observed height reached by a standard tide at a given position in the Upper Estuary was found to vary considerable from year to year. Similar variations occurred in the recorded mean tide level and in the recorded mean sea level, computed from the records given by a self-recording gauge at Prince's Pier. There does not appear to be any correlation between the observed variations from year to year in the top water level and the observed changes in the capacity of the Upper Estuary. The cause of the observed differences in tidal height from year to year is unknown, but they may be due partly to changes in meteorological conditions and partly to the unreliability of automatic gauges. The Mersey Docks and Harbour Board in computing the capacity of the Estuary have, in all cases, used the line of levels established in 1860, though for the survey of 1896 the 1895 top level was first used and then discarded.

Positions of Cross-Sections

In the survey made in 1861 the cross-sections along which soundings were taken were numbered from 1 to 161, beginning at Rock Light. In 1871 some revisions were made; Section 0 was introduced and the alignment of Nos. 1 and 2 was altered, while higher up the Estuary, between Nos. 45 and 116, 15 additional sections were introduced; these were denoted by the suffix "A". In 1881 one additional section, No. 81A, was introduced. The introduction of the new sections did not materially affect the comparability of the capacities computed in the three surveys between 1861 and 1881. The computations for 1861 and 1871 were made after the survey in 1881, and in the calculations the "A" sections were introduced into the two earlier surveys, the areas being assumed to be the same as those found by measurement in 1881. Seven of the 178 sections have not been used in computing the capacity of the Estuary, but the same 171 sections have been employed in the calculation from each periodical survey.

The method by which the mean distances between adjacent sections was determined in 1861 is not known. It appears, however, that the distances were measured after the survey of 1881, and were used in the computations for the previous two surveys. During the present investigation the distances between sections were re-measured, the distances between each pair of sections being scaled off from the plan of the 1931 survey of which the fixed points were plotted on an aluminium sheet in 1928. The method used when the sections were not parallel was to scale the two perpendiculars at each end of the pair of sections and adopt their mean. A comparison of the results obtained is given in Table 115.

Table 115—*Comparison of the Distances between the Sections used in the Quinquennial Surveys of the Upper Estuary*

Distances measured by the Mersey Docks and Harbour Board in 1881 and re-measured by Department of Scientific and Industrial Research in 1934

Cross-Sections Nos.	No. of Intervals.	M.D.H.B. Standard Distances.		D.S.I.R. Re-measured Distances.		Differences.	
		Mean (yds.).	Total (yds.).	Mean (yds.).	Total (yds.).	Distance (yds.).	Per cent. of standard distance.
0–21	21	216	4,536	213·4	4,482	− 54	− 1·19
21–26	5	216	1,080	221·4	1,107	+ 27	+ 2·50
26–47	23	226·5	5,210	210·2	4,834	− 376	− 7·22
47–74	33	393	12,969	371·1	12,245	− 724	− 5·58
74–83	15	360	5,400	375·9	5,638	+ 238	+ 4·41
83–100	17	343·5	5,840	269·1	4,574	− 1,266	− 21·68
100–110	7	189	1,323	162·0	1,134	− 189	− 14·28
110–124	13	348	4,524	323·5	4,206	− 318	− 7·03
124–133	9	304·5	2,740	286·9	2,582	− 158	− 5·77
133–161	27	304·5	8,222	330·2	8,915	+ 693	+ 8·43
(0–161)	170	—	51,844	—	49,717	− 2,127	− 4·10

The results indicate that the method used in 1881 was different from that adopted during the present investigation, since in the total length of the Estuary the re-measurement shows a decrease of 1 mile 367 yards, or 4·1 per cent. This difference cannot be explained since the method of measurement originally used is not known.

Sounding and Levelling

The height of the bed of the Estuary above or below Bay Datum is obtained both by levelling and by sounding. The use of levelling, which is the more accurate method of the two, has apparently increased from 1896 onwards, and sections or parts of sections in the upper part of the Estuary which had previously been surveyed by sounding were afterwards levelled. As the positions of the ends of the sections are marked out, lines of levels are run along the shore on each side of the Estuary and are connected with Ordnance bench marks, thus obtaining the level of the peg or mark at each end of each section. This system of levelling is also connected to the permanent tide gauges and to temporary tide poles when required for reducing soundings. The ends of the cross-sections are then levelled at times of low water when the banks are exposed, the horizontal distances being obtained from marked measuring wires. Where the banks near the section ends are too soft for levelling at low water the ground line has to be obtained by sounding at high water, but on some sections it is possible at low water to carry the levelling across the river, thus connecting the system of levels at each side. From an examination of the records it is concluded that a fair estimate of the accuracy of levelling is a margin of error of plus or minus 3 in. The margin appears to be rather more in the earlier surveys and rather less in the later surveys. This margin is within the limit of error that can be measured by scale on the plotted sections.

The methods of sounding vary according to the position in the Estuary and the depth of water. In the Narrows from Rock Light to Dingle, soundings are taken at low water during the stand of the tide, two sections usually being sounded at each tide. A hemp line with a 14-lb. lead is used. For the quinquennial surveys, as already mentioned, the soundings are called to the nearest mark whether this is above or below the water line. When possible, the soundings are taken to the nearest 6 in., and at other times to the nearest foot. Above Dingle sounding is done at about the time of high water, the soundings being called to the nearest 6 in. In some places, where the water is shallow and the banks are soft, soundings are taken at high water with a pole, and are read to the nearest 3 in. In the shallow reaches of the Estuary above Widnes the channel, if too deep to be waded, is sounded with a pole, the position on the cross-section being taken from wire lines stretched across the river. The tidal reduction is obtained from readings of the tidal height taken every 10 minutes during sounding; the reductions are made to the nearest 3 in. The horizontal distances of the soundings are obtained by sextant angles read to degrees and minutes and plotted by station pointers.

Areas of Cross-Sections

After the positions of soundings have been plotted by means of station pointers on the " Hydraulic Survey Plan " the distances between the soundings are scaled off from these plans and are transferred to section drawings, all distances being measured from the Cheshire side. Any distortion or shrinkage of the hydraulic plans at the time when the sections are drawn therefore directly affects these measurements. It has been found that there is now a considerable shrinkage in the earlier plans, but as they were used for the construction of the sections a short time after they were plotted, it is not likely that any serious shrinkage had occurred at that time. The earlier drawings of cross-sections are also now found to have shrunk, but this is attributed largely to their having been colour-washed after their areas were determined. The shrinkage does not therefore affect the accuracy of the areas originally obtained.

The cross-sections of the Estuary in each of the periodical surveys have been plotted to a horizontal scale of 264 ft. (4 chains) to an inch, and to a vertical scale of 20 ft. to an inch; thus the least dimensions which can ordinarily be plotted or read by scale from the sections are equivalent to about 2 ft. horizontally or 3 in. vertically. From scaled measurements of the sections of the 1931 survey the total length of the top water level of the 171 sections is 978,890 ft., giving an average length for a section of 5,724 ft. The margin of error in measuring the horizontal scale to an accuracy of 2 ft. is thus about 0·035 per cent. The total area of the cross-sections for the 1931 survey is 3,136,295 sq. yds., giving an average area for each section of 18,341 sq. yds., and an average depth of 28·8 ft.; an error of 3 in. in this depth is 0·087 per cent. If the correct area of each average cross-section is 5,724 ft. × 28·8 ft., and it is measured by scale from the section as 5,726 ft. × 29·0 ft., the difference in area, due to the limit of accuracy within which dimensions can be scaled, amounts to 134 sq. yds. or 0·73 per cent.; this error may be positive or negative.

In recent surveys the areas of the cross-sections have been measured by means of a planimeter before the drawings were coloured or mounted. It is now the practice to check a planimeter over a scaled square on each day before it is used. The mean of three readings is adopted and the area in square yards is written on each section. It is not known when the Mersey Docks and Harbour Board first used planimeters, but records of readings are available for 1906, and it is probable that they were first used in 1896.

Computation of Capacity

From the measured areas of cross-sections and from the distances between them the capacity of the Estuary is calculated. The records of the computations for each survey since 1861 are preserved; they show that the computations for the first three surveys were made in 1881, and that the method used throughout the surveys has been the same. In all cases the capacity has been computed by the use of a modified form of Simpson's Rule. This formula may be used for the measurement of volumes in either of two forms :—

(1) For an even number of equidistant cross-sections :—

$$V = x\left(\frac{S_0}{2} + S_1 + S_2 \ldots . + \frac{S_m}{2}\right)$$

(2) For an odd number of sections :—

$$V = \frac{2x}{3}\left(\frac{S_0}{2} + 2S_1 + S_2 + 2S_3 + \ldots\ldots + 2S_{(n-3)} + S_{(n-2)} + 2S_{(n-1)} + \frac{S_n}{2}\right)$$

where V = volume, x = the distance from section to section, and S_0, S_1, S_2 .. are the areas of adjacent sections.

The essential points about the use of the formula are that the distances between adjacent cross-sections should be the same in each case, and that the appropriate formula should be used according to whether there is an even or an odd number of cross-sections. If the formula indicated for an odd number of sections is used for an even number, incorrect results are obtained. In the method used by the Mersey Docks and Harbour Board, the distance between adjacent cross-sections is variable. The Estuary is divided into a number of compartments, each containing an even number of sections, but the formula used is that designed for use with an odd number of sections. In order to appreciate the effect of the use of the less appropriate formula the volume of the Estuary in 1906 and 1931 has been calculated by the more appropriate formula for comparison with the results obtained by the Mersey Docks and Harbour Board (Table 116).

The figures indicate that the capacities as computed by the formula adopted by the Mersey Docks and Harbour Board are lower than those resulting from the

TABLE 116—*Comparison of the Calculated Volume of the Upper Estuary from Two Surveys carried out by the Mersey Docks and Harbour Board using* (1) *Formula for an Odd Number of Sections, and* (2) *Formula for an Even Number of Sections*

Sections Nos.	Capacity of Estuary (cu. yds.).			
	Mersey Docks and Harbour Board. (1) Using formula for odd number of sections.	(2) Re-calculated by formula for even number of sections.	Difference (2 minus 1).	Difference as a percentage of (1).
1906 Survey				
0–21	153,245,376	154,907,208	+ 1,661,832	1·08
21–47	184,025,853	188,821,941	+ 4,796,088	2·60
47–83	586,813,726	593,037,366	+ 6,223,640	1·06
83–100	41,781,737	41,797,080	+ 15,343	0·04
100–133	20,758,650	21,261,937	+ 503,287	2·42
133–161	4,119,073	4,118,971	— 102	0·0
Total	990,744,415	1,003,944,503	+ 13,200,088	1·33
1931 Survey				
0–21	147,069,187	148,673,016	+ 1,603,829	1·09
21–47	178,507,907	182,957,210	+ 4,449,303	2·49
47–83	548,220,703	553,658,670	+ 5,437,967	0·99
83–100	39,156,824	39,209,151	+ 52,327	0·13
100–133	21,877,092	22,115,292	+ 238,200	1·09
133–161	4,253,317	4,263,000	+ 9,683	0·23
Total	939,085,030	950,876,339	+ 11,791,309	1·26
Difference between Surveys (1906 and 1931)				
Total	51,659,385	53,068,164	1,408,779	
Difference as a percentage of 1906 capacity	5·21	5·29		

use of the more correct formula. The difference varies in different groups of sections, but on the total computed capacity it is 1·33 and 1·26 per cent. for 1906 and 1931, respectively. Taking the change in capacity between 1906 and 1931, however, the loss in capacity given by the method used by the Mersey Docks and Harbour Board is 5·21 per cent. of the 1906 value, while the corresponding loss given by the other method is 5·29 per cent.

The cubic capacity of the Estuary for 1906 and 1931 has also been calculated using the more appropriate formula and the re-measured distances between sections referred to in Table 115. The results are as follows :—

1906 .. 958·2 million cu. yds. (M.D. & H.B. value 990·7 million cu. yds.).

1931 .. 907·4 million cu. yds. (M.D. & H.B. value 939·1 million cu. yds.).

Difference .. 50·8 million cu. yds. (5·3 per cent. of 1906 value).

Although the figures for the capacity obtained by using the re-measured distances are considerably less than those given by the Mersey Docks and Harbour Board the percentage difference between the two surveys remains approximately the same, the loss in capacity being 5·3 per cent. of the 1906 value instead of 5·2 per cent.

The value for the capacity obtained by the use of the more appropriate formula, and after re-measurement of the distances between sections, may be regarded as approaching more nearly to a true estimate of the capacity, but owing to the arrangement of the sections, which are neither equidistant nor parallel within the compartments used in the calculations, it is doubtful whether the new figures give an accurate estimate of the true capacity. The main difficulty in computing the volume by the use of Simpson's formula is in deciding on the distance between adjacent sections which should be taken since, particularly where they are not parallel, the sections may be deeper on one side of the Estuary than on the other. In this case the effective distance between the sections should be measured nearer to the side of the Estuary where the greater part of the volume of water occurs. The re-calculation of the volume of the Estuary by other methods is discussed at the end of the present chapter.

Replicate Measurements of the Areas of Cross-Sections

In attempting to estimate the accuracy of the measurements of the capacity of the Estuary by the methods employed, replicate determinations of the area of one of the cross-sections (No. 47) were first made. Soundings were taken between South Dingle Jetty on the Lancashire side of the cross-section to an arbitrary point at approximately low water level on the Cheshire side; soundings were corrected from readings of a tide gauge on South Dingle Jetty and the area of the section to the height of high water of a 31-ft. tide was computed. The results are shown in Table 117. The differences between cross-sectional areas obtained on the same day were small, amounting to less than 0·6 per cent., though there was a difference of nearly 4 per cent. between the areas obtained in October and November. This difference may have been partly due to dredging in the neighbourhood of Dingle Jetty and partly to a strong gale which occurred at the period of spring tides between the two determinations and which may have caused movements of sand banks. The figures indicate the necessity for completing surveys of the Estuary in a short period, since frequent changes in the position and shape of sand banks in the Upper Estuary occur. Although the material may not be transported any great distance from its original position it is possible that sand or mud moving from one section to another during the survey might cause errors in the value of the capacity obtained.

Table 117—*Areas of Cross-Section No.* 47 *between the Same Arbitrary Limits, obtained from Soundings in October and November* 1933

Date.	Area (sq. yds.).	Difference (per cent.).	Mean area (sq. yds.).	Percentage of first mean value.
30.10.33	29,694 29,856 29,683	0·55 0·58	29,744	100
10.11.33	30,928 30,750	0·58	30,839	103·7
14.11.33	30,780 30,757	0·07	30,768	103·4

In April, 1936, during high spring tides, duplicate soundings of a small compartment in the Upper Estuary were made in collaboration with the Mersey Docks and Harbour Board, who were then carrying out their 1936 quinquennial survey. The positions of the cross-sections sounded are shown in Fig. 126; they were chosen as being representative of conditions in the Upper Estuary since the bottom on the Lancashire side consisted of sand, and on the Cheshire side of mud. The preliminary work was carried out by the Mersey Docks and Harbour Board, but the work was watched and calculations were checked by the staff of the Department. Levelling was carried out on each section over the mud bank on the Cheshire side for as far as it was possible to walk, this work being done by the Mersey Docks and Harbour Board. The remainder of the section was sounded at the same time from two boats, one in charge of the Mersey Docks and Harbour Board, and the other in charge of the Department's staff. In the latter boat, however, the soundings were called by a leadsman borrowed from the Harbour Board to ensure that there should be no difference in the method of calling soundings. The soundings were plotted on an office working sheet and were later re-plotted on a fair sheet. They were then transferred to section drawings by the methods used by the Mersey Docks and Harbour Board. The areas were measured by planimeter, the areas accepted being the mean of measurements made by three persons

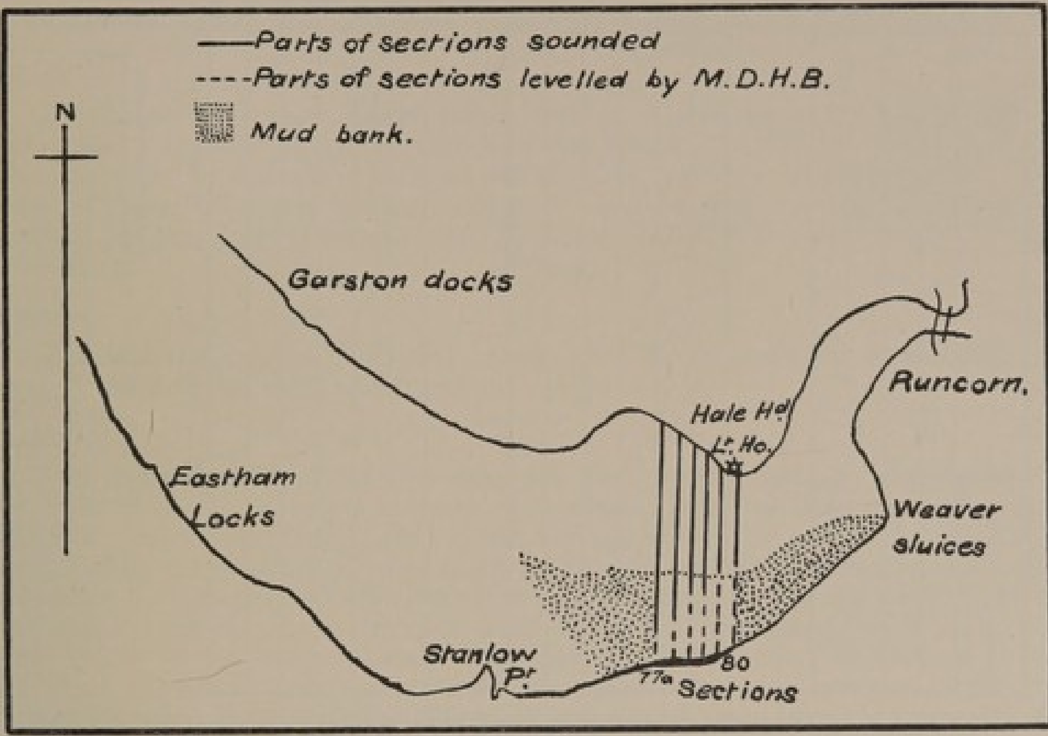


FIG. 126—*Part of Upper Mersey Estuary showing the Six Cross-Sections surveyed (21st to 23rd April, 1936) for Comparison with Results obtained by the Mersey Docks and Harbour Board during the same Period*

using different instruments. At the same time the Mersey Docks and Harbour Board worked out the areas of the same cross-sections and the volume of the compartment between them. The results are compared in Table 118. The areas of the cross-sections obtained by the Mersey Docks and Harbour Board were sometimes higher and sometimes lower than the corresponding areas obtained by the Department; the greatest difference was 3·1 per cent. The difference in the calculated capacities of the compartment was only 0·2 per cent.

TABLE 118—*Capacity of the Compartment of the Estuary between Sections 77A and 80, measured and computed by the Mersey Docks and Harbour Board and by the Department of Scientific and Industrial Research*

Sections Nos.	Means of Section areas (sq. yds.).		Difference (1–2).	Difference as a percentage of the M.D.H.B. figures.
	M.D.H.B. (1)	D.S.I.R. (2)		
77A	23,091	23,484	− 393	− 1·7
78	22,962	22,557	+ 405	+ 1·8
78A	20,867	21,249	− 382	− 1·8
79	19,277	19,595	− 318	− 1·6
79A	17,658	17,794	− 136	− 0·8
80	16,297	15,790	+ 507	+ 3·1

Accepted mean distance between Sections 326·7 yards.
1936 Capacity of Compartment :
M.D.H.B. Total Capacity of Compartment 31·080 million cubic yards.
D.S.I.R. " " " " 31·142 " "
Difference .. .. 0·062 or 0·20 per cent.

The areas of selected cross-sections found in each quinquennial survey by the Mersey Docks and Harbour Board between the years 1871 and 1931, expressed as a percentage of their respective areas in 1931, are shown in Fig. 127. The cross-sections selected are those in the compartment between Rock Light and Seacombe (Sections 0 to 21), where there has been comparatively little change in capacity since 1871, and from Mt. Manisty to the River Weaver (Sections 67A to 83), where large changes in capacity have occurred. It will be seen that although in places there are considerable divergences, in general the curves for adjacent

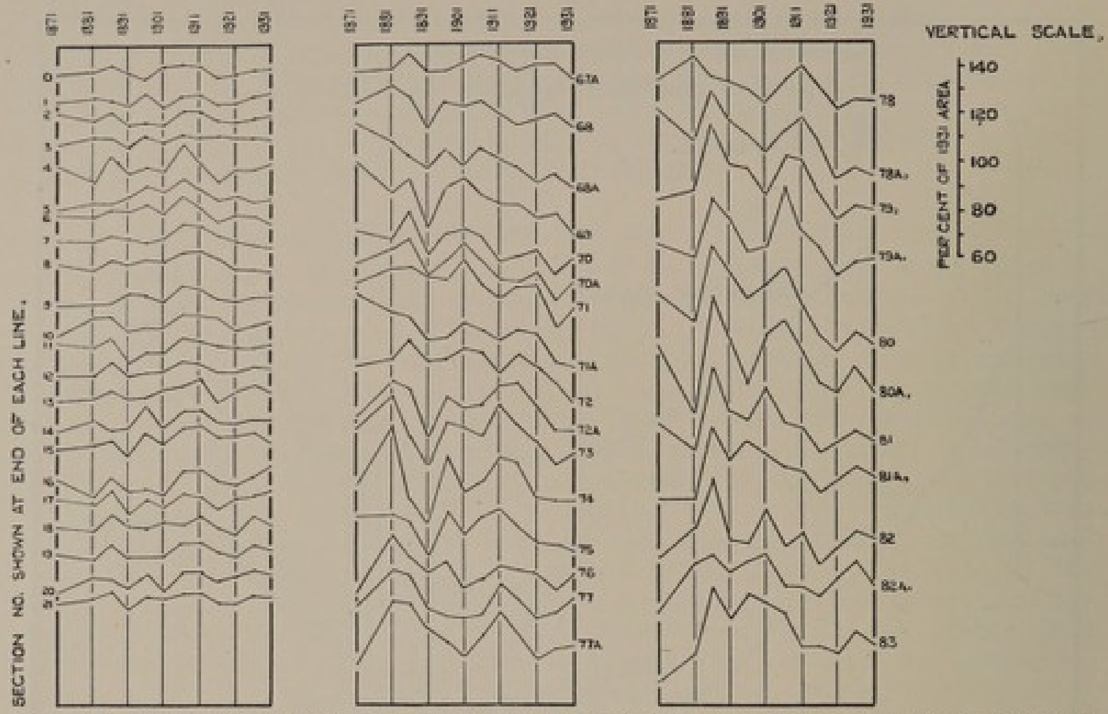


Fig. 127—*Areas of Cross-Sections for each Survey from* 1871 *to* 1931, *expressed as Percentages of the Corresponding* 1931 *Areas. Area in* 1931 = 100 *per cent. in each case*

cross-sections are fairly closely related, the tendency of any one cross-section to increase or decrease from one survey to the next being reflected to a varying degree in adjacent cross-sections. This regularity suggests that the measurements of the cross-sections are reasonably accurate and that the changes found from one survey to another were due to the movement of banks in the Upper Estuary.

Computation of Capacity by Various Methods

From the data provided by the Mersey Docks and Harbour Board the computation of the capacity of the Upper Estuary for each survey has been repeated by the method used by the Board in order to check the original work. It was found that in some years minor mistakes in working had been made, the errors usually being arithmetical, although in some cases incorrect areas of cross-sections had been used. The amended figures for the capacities compared with the original figures are shown in Table 119. The errors discovered do not substantially affect the relative volumes of the Upper Estuary in the different surveys.

Table 119—*Volume of the Upper Estuary, re-calculated from the Original Data and compared with the Volume originally computed by the Mersey Docks and Harbour Board*

Year	Capacity of Mersey Estuary (millions of cu. yds.).			Difference as a percentage of Mersey Docks and Harbour Board figures.
	M.D.H.B. computations.	D.S.I.R. computations.	Difference.	
1861	979·3	982·9	+ 3·6	+ 0·37
1871	954·6	954·7	+ 0·1	+ 0·01
1881	962·2	962·2	0	0
1886	1,003·1	1,003·1	0	0
1891	946·1	947·9	+ 1·8	+ 0·19
1896	982·3	976·2	− 6·1	− 0·62
1901	980·3	980·3	0	0
1906	990·7	990·7	0	0
1911	973·8	973·8	0	0
1916	956·7	956·7	0	0
1921	942·4	943·7	+ 1·3	+ 0·14
1926	939·2	939·2	0	0
1931	939·1	939·1	0	0

The volume of the Upper Estuary for each survey has also been calculated from the original data by a number of other methods in order to determine whether the relative differences in the capacities from survey to survey found by the Mersey Docks and Harbour Board were reproduced when other methods of computation were used. The additional methods adopted were the following :—

Method B

The capacity of each compartment was calculated by a method similar to that used by the Mersey Docks and Harbour Board (Method A) except that the more suitable formula for an even number of sections was employed. The standard mean distances between adjacent cross-sections in each compartment as used by the Mersey Docks and Harbour Board were also used in these calculations.

Method C

This was the same as Method B except that the re-measured mean distances between the cross-sections were used.

Method D

The re-measured distance between each pair of cross-sections was employed. The volume of the Estuary between each pair of cross-sections was calculated separately, the volume being taken as the average area of the pair of cross-sections multiplied by the distance between them. The method is thus similar to Method C. In Method C, however, the cross-sections in each compartment are assumed to be equidistant, and the mean distance between them is obtained by dividing the whole length of the compartment by the number of intervals. In Method D the individual distances between successive cross-sections are unequal since the sections are actually at different distances apart.

Method E

This method is entirely different in principle from other methods used; it does not involve the measurement of the areas of cross-sections, and it was thought that it might indicate whether an abnormal value for the capacity found in any year could be traced to the incorrect measurement of the areas of sections.

In previous computations of capacity the Narrows and Upper Estuary have always been divided into "Compartments." In computing the volume by Method E the compartments were grouped as follows :—

Compartment	1	between Cross-Sections 0–21	Considered as one compartment (the Narrows).
,,	2	,, ,, ,, 21–47	
,,	3	,, ,, ,, 47–58	Dingle to Mt. Manisty.
,,	4	,, ,, ,, 58–67A	
,,	5	,, ,, ,, 67A–74	Mt. Manisty to River Weaver.
,,	6	,, ,, ,, 74–83	
,,	7	,, ,, ,, 83–100	River Weaver to Runcorn Bridge.

The relatively small part of the Upper Estuary above Section 100 was not considered, since this area contains a large proportion of marshy ground, which, especially in earlier years, was not surveyed with the same accuracy as the remainder of the Estuary. The Upper Estuary between Sections 0 and 100 was considered as divided by horizontal planes into four portions :—

1. Below Liverpool Bay Datum (L.B.D.).
2. Between L.B.D. and 10 ft. above L.B.D.
3. Between 10 ft. and 20 ft. above L.B.D.
4. Between 20 ft. above L.B.D. and the high water mark.

The level of the high water mark in the Upper Estuary was taken at the same value as that adopted by the Mersey Docks and Harbour Board in their computations, but for convenience the average level was used for each of the four compartments considered. These average levels were :—

Between Cross-Sections	0–47 ..	31·0 ft. above L.B.D.
	47–67A ..	31·6 ft. above L.B.D.
	67A–83 ..	32·7 ft. above L.B.D.
	83–100 ..	33·3 ft. above L.B.D.

The soundings and levels shown on the fair drawings of the chart of the Upper Estuary for each survey were used when available, but for some of the earlier surveys lithographic reproductions had to be employed. On each chart the contours at a height of 0, 10 and 20 ft. above L.B.D. are drawn; in some cases the contours did not agree exactly with the soundings and the contours were re-drawn.

In working out the capacity of the Estuary for any year the fair drawing was first divided into compartments and the capacity of each compartment was calculated separately. The areas lying between the contour lines were first measured by planimeter. The soundings below L.B.D. were added together, and the total was divided by the number of soundings to give the mean depth of water below the drying or Datum line. If the soundings were unevenly spaced, some values were omitted, and occasionally values were interpolated where there was an obvious gap. In this way an attempt was made to give appropriate weight to soundings at all depths. The average depth of water below Datum multiplied by the area enclosed by the Datum line gives the volume of the Estuary below Datum.

The method of calculation of the volumes between the other horizontal planes can be seen from Fig. 128. The volume between the Datum line and the 10-ft. contour consists of two parts; a " wedge " where the bed of the estuary is between 0 and 10 feet above Liverpool Bay Datum and a " prism " above that part of the estuary the bed of which is below Liverpool Bay Datum. The volume of this prism is the area enclosed by the 0 contour multiplied by the height of 10 ft. The volume of the wedge is the area between the 0 and 10-ft. contours multiplied by the average depths between those contours; this depth was found as before by taking the mean of the soundings between these levels.

Similarly the volume between the 10-ft. and 20-ft. contours consists of :—

1. A prism of height 10 ft. and area enclosed by the 0 contour.
2. A prism of height 10 ft. with an area equal to the difference between the areas of the 0 and 10-ft. contours.
3. A wedge with an area equal to the difference in area between the 10-ft. and 20-ft. contours. The volume of this wedge is the area multiplied by the mean height.

The volume between the 20-ft. contour and high water level is similarly found except that the height above Datum of the high water level increases between Rock Light and Runcorn. The method of setting out the calculation of the volume between any two contours is shown in the Table given in Fig. 128.

The volumes between adjacent horizontal planes were found separately for the four longitudinal compartments of the Estuary considered, and the sum of these gave the volume for the whole of the Upper Estuary between Rock Light and Runcorn. A specimen page of working is shown in Table 120 (p. 336). The same methods were used in computing the capacity of the Estuary for each survey except that adjustments had to be made for differences in the scale of charts and for small differences caused by distortion of the charts; the adjustments necessary were not large in the later surveys, but were considerable in the early ones. A comparison of the scales of the various fair drawings was made by measuring the area of part of the Estuary contained by lines joining the positions of permanent shore marks plotted on each chart.

Comparison of Results of Computations

The volumes of the Upper Estuary between cross-sections 0 and 100, as computed by the four additional methods used, are compared in Table 121 (p. 337) with the capacity given by the method used by the Mersey Docks and Harbour Board; the same information is shown diagrammatically in Fig. 129. It will be seen that the four methods which involve the measurement of the areas of cross-sections (Methods A, B, C, and D) give different values for the capacity. The values given by Method B, in which the more appropriate form of Simpson's Rule is used, but in which the distances between cross-sections are the same as those adopted by the Mersey Docks and Harbour Board, are somewhat higher than those given by the Dock Board's calculations (Method A). The values given by Methods C and D, in which the re-measured distances between sections were employed, are lower than the values given by the first two methods. These values agree, on the whole, with those given by the entirely different method of computation in which cross-sections were not used, but in which the volume of the

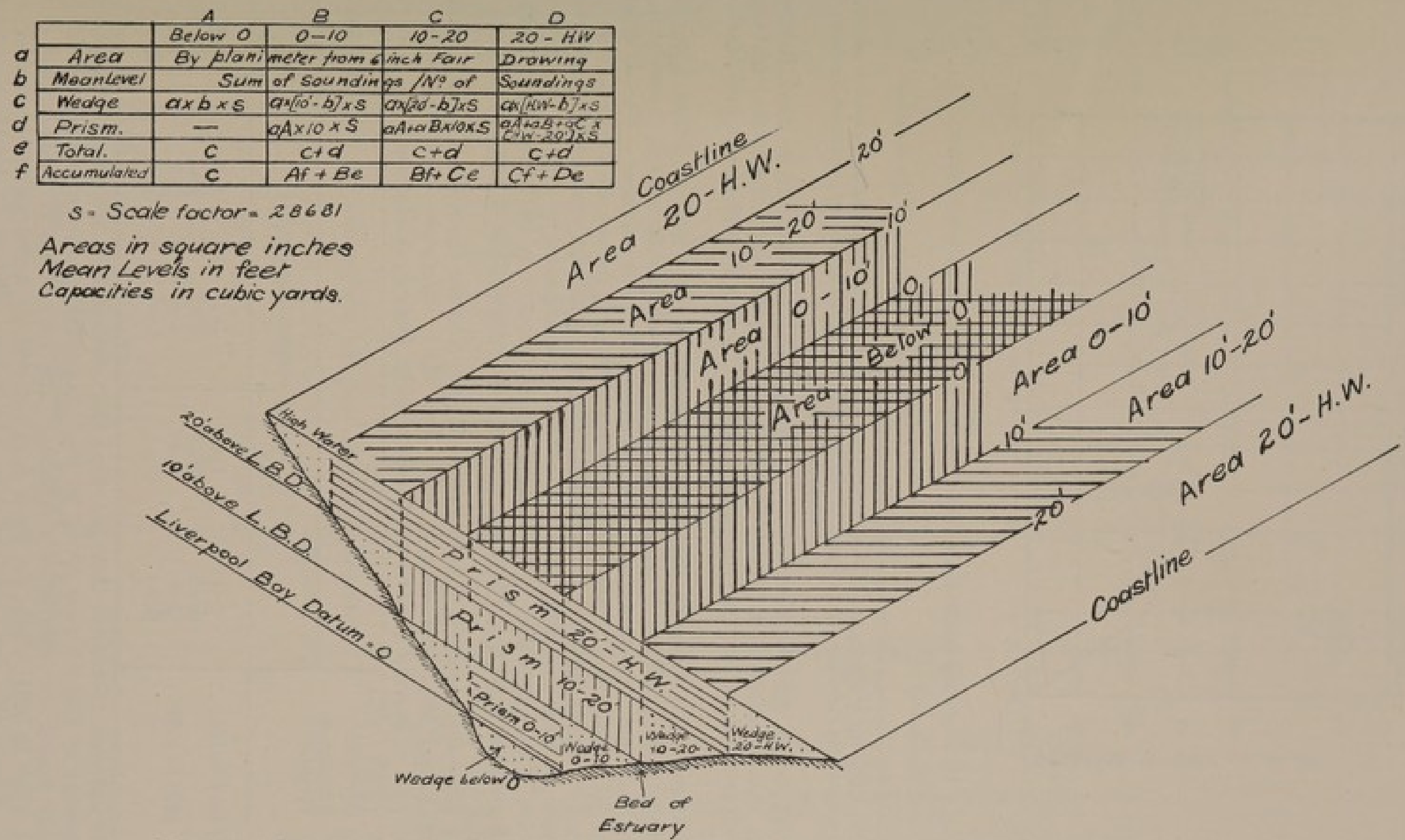
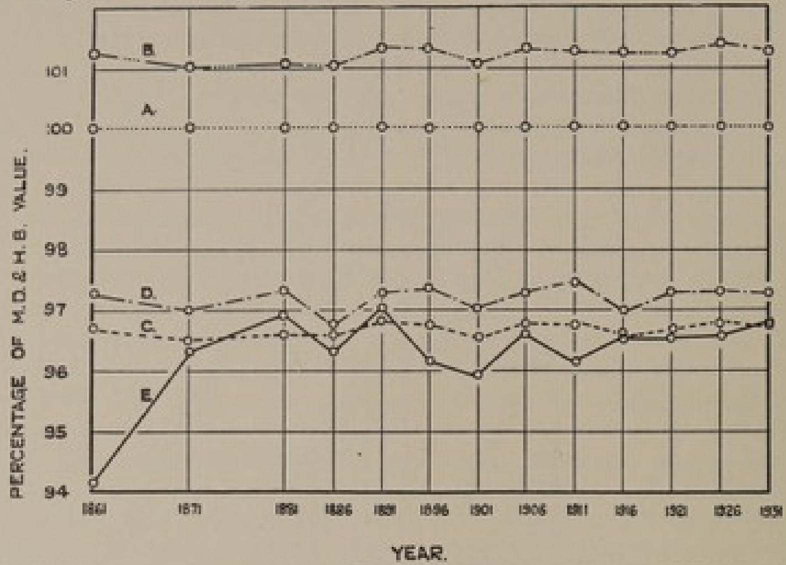


FIG. 128—*Diagram showing the Method used to calculate the Capacity of the Mersey Estuary between Horizontal Planes*

Estuary between horizontal planes was computed. The main divergence of the last method occurs in 1861, and is due to the fact that the drawings of the cross-sections for this year do not agree in every case with the soundings on the fair chart.



A. O.........O Standard distances between sections. Formula for odd No. of sections (M.D.H.B.).
B. O—...—O " " " " " even " "
C. O- - - - -O Remeasured " " " " even " "
D. O—·—·O " " " " Capacity computed between each pair of sections.
E. O———O Capacity computed between horizontal planes.

FIG. 129—*Capacity of the Upper Mersey Estuary (Sections 0 to 100) computed by Several Methods and expressed as a Percentage of the Value for the Same Year obtained by Mersey Docks and Harbour Board (Method A)*

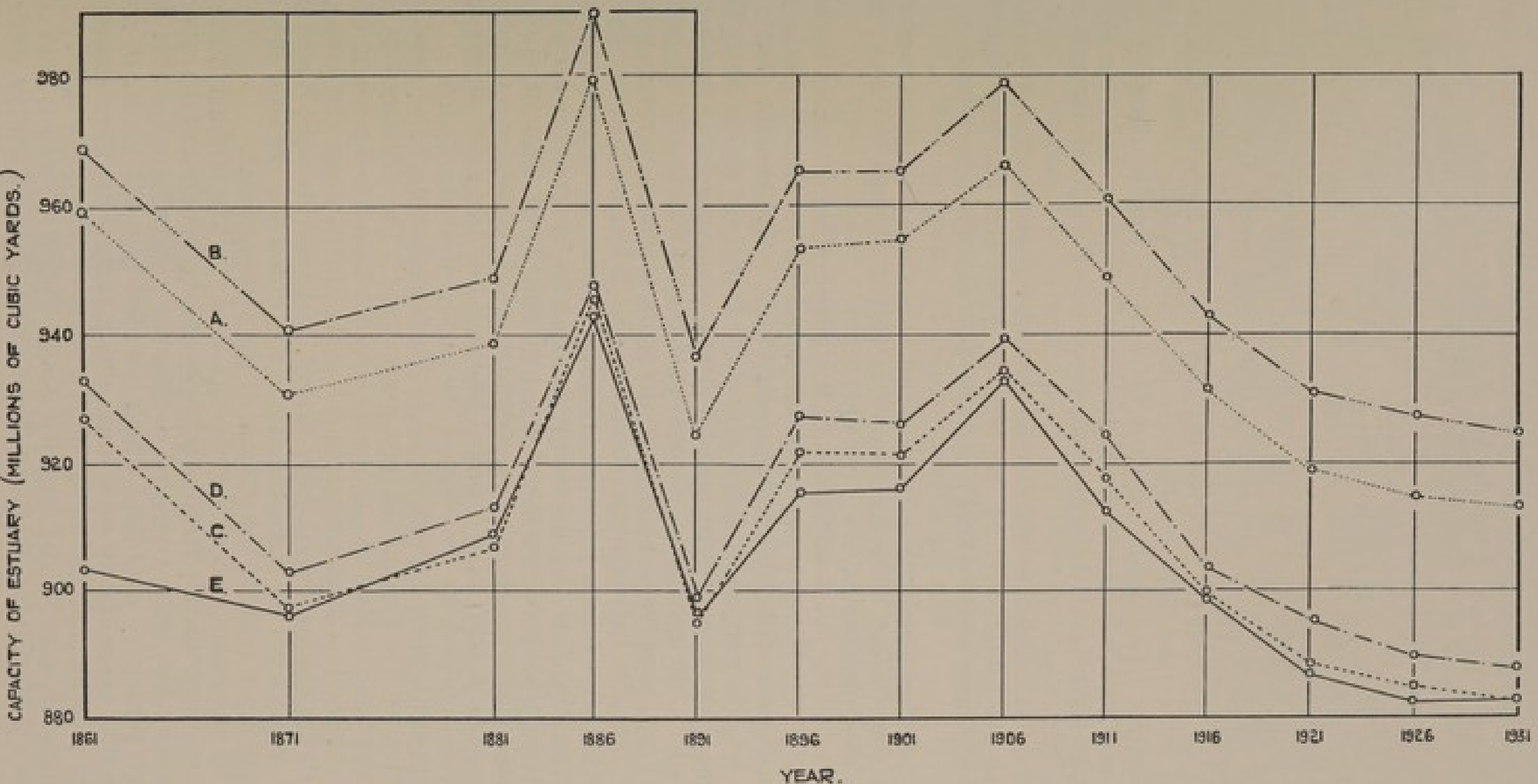
If a method of computation involving the use of cross-sections is used, it would appear that a more correct result is obtained by using the re-measured distances between sections rather than the values adopted by the Mersey Docks and Harbour Board.

Although the value of the capacity found for any survey differs according to the method of computation, the figures show that the changes in capacity from survey to survey computed by the different methods are similar. This is shown in Fig. 130, where the values of the capacity in each survey as computed by the different methods are given. The differences in capacity between 1871 and 1931 and between 1906 and 1931, when the capacity is computed by each of the methods used, are shown in Table 122. The apparent loss from 1871 and from 1906 to 1931 is roughly the same whichever method of computation is used.

TABLE 122—*Difference in Capacity of the Upper Estuary (Sections 0 to 100) between 1871 and 1931 and between 1906 and 1931. Capacity computed from Mersey Docks and Harbour Board Data by 5 Methods*

Period.	Difference in capacity expressed as a percentage of the 1931 value.				
	Capacity computed by Method :				
	A	B	C	D	E
Years 1871 to 1931 ..	2·0 (loss)	1·8 (loss)	1·7 (loss)	1·7 (loss)	1·5 (loss)
" 1906 to 1931 ..	5·8 (loss)	5·9 (loss)	5·9 (loss)	5·8 (loss)	5·7 (loss)

It appears, therefore, that provided the original data are correct the changes in capacity of the Estuary given by the computations of the Mersey Docks and Harbour Board are substantially reliable. The year in which there is most doubt of the result is 1861, where the chart does not entirely agree with the cross-sections prepared from the same original data. It is now difficult to determine whether the chart is more or less reliable than the sections. The accuracy of the sounding and levelling in earlier surveys cannot now be estimated, though there is nothing in the original records to suggest that the data were substantially less accurate in earlier than in recent years.



Methods used :—

A. O......O Standard distances between sections. Formula for odd No. of sections (M.D.H.B.).

B. O———O ,, ,, ,, ,, ,, even ,, ,,

C. O- - - - -O Remeasured ,, ,, ,, ,, even ,, ,,

D. O— · —O ,, ,, ,, ,, Capacity computed between each pair of sections.

E. O———O Capacity computed between horizontal planes.

FIG. 130—*Capacity of the Upper Mersey Estuary (Sections 0 to 100) computed by Different Methods*

Summary

In the years 1861, 1871, 1881, and thereafter at five-yearly intervals the Mersey Docks and Harbour Board surveyed and calculated the capacity of the Upper Estuary between the mouth of the Narrows and Warrington. During the present investigation the methods used in these measurements have been examined and an estimate has been made of the degree of accuracy attained.

During the surveys of the Estuary the positions at which soundings were taken were obtained by measuring with sextants the angles between fixed shore marks. The positions of subsidiary shore marks were derived from triangulations of the shores of the Estuary made in 1860 and 1930. The results of the two triangulations are in agreement and also agree with the results of an earlier triangulation made in 1843.

The Mersey area was levelled by the Ordnance Survey Department before the first survey of the Estuary by the Mersey Docks and Harbour Board in 1861, and the same datum has been used in all the surveys. The capacity of the Estuary is taken as the volume between the bed and the highest points at all positions reached by a tide rising at Prince's Pier to a height of 31 ft. above Liverpool Bay Datum. The height reached by a 31-ft. tide in different parts of the Upper Estuary differed in several series of observations made by the Mersey Docks and Harbour Board, but the same values were used by them in each computation of capacity.

The capacity of the Estuary is determined from the areas of cross-sections. The same sections have been used by the Mersey Docks and Harbour Board in each survey and the same longitudinal distances between them were used in the calculations.

For each survey the soundings or levels along each cross-section were plotted and the areas of the sections were measured; in recent surveys the areas have been measured with a planimeter.

From the areas of the cross-sections and the longitudinal distances between them the capacity of the Estuary has been calculated by the Mersey Docks and Harbour Board, using a modified form of Simpson's Rule. The formula used is not entirely suitable for the purpose and the capacities found are rather more than one per cent. lower than the capacities calculated from the same data using a more appropriate formula. The calculated changes in capacity during various periods from 1861 to 1931 are, however, substantially the same whichever formula is used. The longitudinal distances between the cross-sections used in each survey by the Mersey Docks and Harbour Board do not agree with measurements made during the present investigation. If the re-measured distances are used in calculating the capacity of the Estuary, values about 3·5 per cent. lower than those of the Mersey Docks and Harbour Board are obtained. The percentage differences between the capacities in successive surveys, however, are again not significantly different from those obtained by the Mersey Docks and Harbour Board.

During the present investigation replicate measurements of the area of a typical cross-section of the Upper Estuary were made. The difference in area found in duplicate determinations on any one day did not exceed 0·6 per cent. of the total area. The volume of a small compartment of the Estuary was also measured and compared with the volume found by the Mersey Docks and Harbour Board from a similar survey carried out at the same time; the difference between the two values was about 0·2 per cent. of the volume of the compartment.

In view of the uncertainty regarding the values of the longitudinal distances between the cross-sections used by the Mersey Docks and Harbour Board the capacity of the Upper Estuary has been computed during the present investigation from the results of each survey by a method which does not involve the use of cross-sections. The results agree closely with those obtained by using the re-measured distances between sections and the more suitable form of Simpson's Rule.

The most doubtful value of the capacity of the Upper Estuary is that computed by the Mersey Docks and Harbour Board from the first survey made in 1861. The chart of the Estuary for that year does not agree with the areas of the cross-sections obtained from the same original data. With this exception it is concluded that the figures obtained by the Mersey Docks and Harbour Board for the changes in the capacity of the Upper Estuary are substantially correct.

CHAPTER XXII

CHANGES IN THE CAPACITY OF THE UPPER ESTUARY AND IN THE POSITION OF BANKS AND CHANNELS

The observed changes in the capacity of the Upper Estuary between Rock Light and Runcorn since 1861 were shown in Fig. 130 (Chapter XXI). Between 1871 and 1886 the capacity increased by about 50 million cubic yards; the capacity in 1886 was the highest recorded. Between 1886 and 1891 there was a drop of over 50 million cubic yards; between 1891 and 1906 the capacity again rose by rather more than 40 million cubic yards but during the period 1906 to 1926 it fell continuously, over 50 million cubic yards being lost. The capacity in 1931 was about the same as in 1926. In the present Chapter an attempt is made to determine more exactly the areas and levels in the Estuary at which changes in capacity have occurred and to correlate these changes with the movements of the banks and channels in the Upper Estuary.

Dredging and Construction of Works

Changes in capacity have to some extent been brought about by dredging and by the construction of works along the shores of the Estuary. The principal works constructed below the high water mark of a 31-ft. tide between 1861 and 1931 were :—

1861 to 1881. Alterations to Dock entrances and walls.
1887 to 1894. The Manchester Ship Canal.
1891 to 1896. The River Weaver diversion and slag embankment.
1896 to 1901. Dock walls.
1901 to 1906. Reclamation of Tranmere Foreshore.
1906 to 1931. Dingle Embankment.
1921 to 1931. Bromborough Dock.
1926 to 1931. Otterspool (Aigburth) Promenade.

The reduction in area of each cross-section affected by artificial abstractions has been measured by comparing the charts of the surveys before and after the alteration. The decrease in computed capacity has been obtained from the reductions in area of the cross-sections and from the distances between the section ends on that side of the Estuary where the reductions occurred. It is difficult to ascertain the exact levels to which shore works were built out into the Estuary, but it is certain that almost the whole of the abstractions occurred between the 20-ft. contour and the high water mark. The reductions in capacity brought about by the building of the principal works on the shores of the Estuary are shown in Table 123, in which the volumes of material removed by dredging are also shown.

Table 123—*Artificial Works and Total Dredging above Rock Light during the Periods between Successive Surveys*

Period.	Artificial Works (millions of cu. yds.).	Dredging (millions of cu. yds.).
1861–1871	0·2	0
1871–1881	0	0
1881–1886	0	0
1886–1891	4·2	0
1891–1896	2·6	0·3
1896–1901	0	3·3
1901–1906	1·8	8·2
1906–1911	0	11·3
1911–1916	2·0	13·6
1916–1921	0·1	13·8
1921–1926	0·2	11·8
1926–1931	3·6	11·7
Total	14·7	74·0

The loss in capacity directly due to the construction of shore works between 1871 and 1931 was approximately 14·5 million cubic yards or about 1·5 per cent. of the capacity of the Estuary in 1871. Between 1901 and 1931 when the reduction in the capacity of the Estuary was 41·2 million cubic yards, the volume lost by the building of shore works was about 7·7 million cubic yards or approximately 18·7 per cent. of the total loss. The largest change in the volume due to artificial works was caused by the building of the Manchester Ship Canal which was begun in 1887 and was opened to traffic in 1894. For part of its length between Eastham and Runcorn the seaward bank of the Canal was built on the foreshore of the Estuary; a large area of marsh covered by spring tides was cut off and a wall was built which cut off the estuary of the River Weaver from that of the Mersey. The effect of the building of the Manchester Ship Canal was complex. Part of the Estuary which was previously sounded, and the volume of which was included in that computed from surveys, was enclosed and the observed value of the capacity of the Estuary in subsequent surveys was thus lower by the volume cut off. The Manchester Ship Canal between Eastham and Latchford is however tidal; water flows into the Canal at Eastham on any tide rising to a height greater than 26 ft. 2 in. above Liverpool Bay Datum. The loss of tidal water was therefore smaller than that indicated by the change in capacity computed from the surveys. In addition to these changes the building of the Canal caused other alterations in the Estuary, the chief of these being the prevention of direct access of the Estuary water to the estuary of the River Weaver. The fresh water discharged by the River Weaver is now admitted to the Estuary of the Mersey through sluices but the scour caused by tidal water entering the Weaver has been lost.

In recent years there has been a considerable amount of dredging between Rock Light and Eastham, this being necessary to keep open the approaches to docks and to the Manchester Ship Canal. The total amount of material removed from the Upper Estuary between 1891 and 1931 was about 74 million cubic yards giving a yearly average of about 1·9 million cubic yards (Table 123). The dredging is done by various Authorities and an estimate of the quantity removed can only be very rough since in most cases the volume is calculated from the draught of the dredger or hopper before and after loading. The greater part of the material removed by dredging is taken from the bed of the Estuary below the level of low water at spring tides and the change in the volume does not therefore directly affect the volume of tidal water passing into and out of the Estuary. The volume lost by the construction of shore works lies almost entirely between 20 feet above Liverpool Bay Datum and the high water mark, and the volume lost therefore directly affects the scouring capacity. In addition it is probable that over long periods the capacity is affected more by artificial works than by dredging. When the foreshore is built over, the area over which soundings are taken is permanently reduced; if the bed of the Estuary below low water mark is lowered by dredging it seems probable that the effect is temporary and that material from Liverpool Bay will move into the Upper Estuary and fill the holes made by dredging.

Changes in the Volume of Different Compartments

In Fig. 131 are shown the changes in volume which occurred between 1871 and 1931 in different compartments of the Upper Estuary. The first diagram gives the capacity of each compartment computed from the data obtained during the surveys; in the second diagram the volume cut off from the Estuary by the building of shore works has been added to the observed capacity of the appropriate compartments during each succeeding survey. For the first two compartments (A and B), that is between Rock Light and Dingle and between Dingle and Mount Manisty, there was no net loss in capacity from 1871 to 1931 nor did any loss occur in the fourth small compartment (D) between the River Weaver and Runcorn. Almost the whole of the total loss in capacity occurred in the third compartment (C) between Mount Manisty and the River Weaver. This compartment includes the greater part of the shallow and wide upper basin and it is in this area that almost the whole of the mud in the Upper Estuary is found. The proportion of the total loss in capacity in the Upper Estuary between Rock Light and Runcorn which occurred in each of the four compartments during the two periods 1871 to 1931 and 1906 to 1931 is shown in Table 124. Between 1871 and 1931 the loss which occurred between Mount Manisty and the River Weaver (Sections 67A to 83) was nearly twice as great as the total loss, the latter being reduced by gains in capacity in the compartments between Dingle and Mount Manisty and between the Weaver and

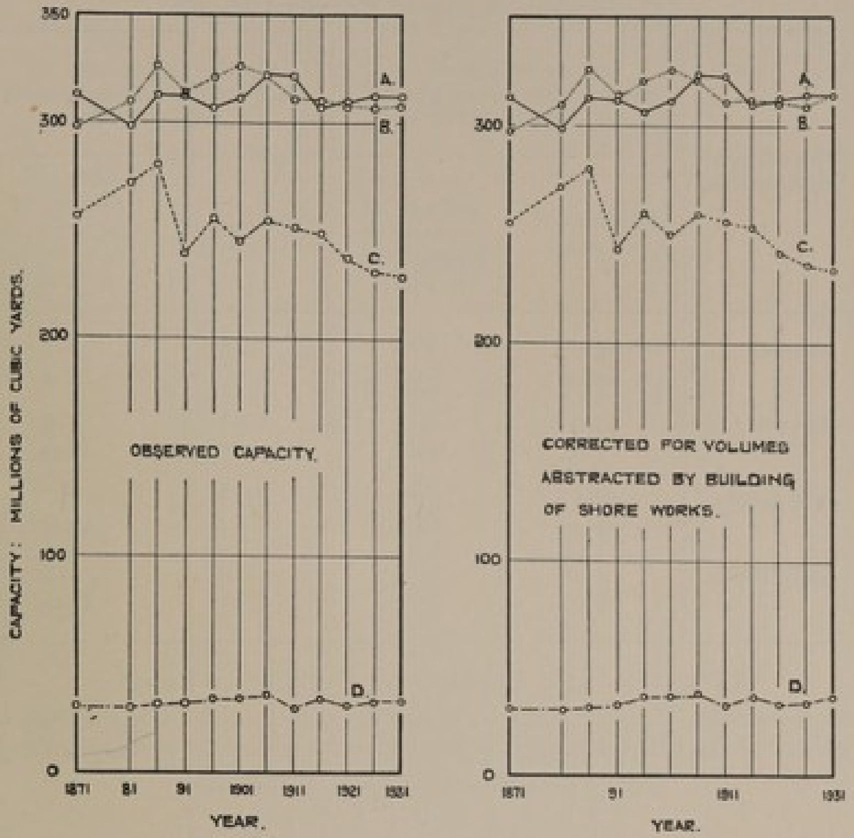


FIG. 131—*Changes in Capacity of Different Compartments of the Mersey Estuary between the Years 1871 and 1931 computed by Method of Horizontal Planes*

Runcorn. In the period between 1906 and 1931 there was a reduction in capacity in each of the four compartments considered, about half the loss occurring between Mount Manisty and the Weaver. The four compartments into which the Estuary

TABLE 124—*Changes in Capacity in Different Compartments of the Upper Estuary Periods 1871 to 1931 and 1906 to 1931*

Period.	Total loss in capacity (millions of cu. yds.).	Change in capacity in each compartment (millions of cu. yds.). In brackets: loss in capacity in each compartment as percentage of total loss.			
		Sections 0 to 47.	Sections 47 to 67A.	Sections 67A to 83.	Sections 83 to 100.
1871 to 1931	13·6	0·8 Loss	10·0 Gain	26·1 Loss	3·3 Gain
1906 to 1931	50·1	10·0 Loss (20·0%)	13·4 Loss (26·7%)	24·8 Loss (49·5%)	1·9 Loss (3·8%)

has been divided are of unequal size. The percentage of the capacity of each which has been lost during the two periods considered is shown in Table 125. During the period 1871 to 1931 there was an increase in capacity between sections 0 and 67A but the compartment between Mount Manisty and the Weaver lost 10 per cent. of its 1871 capacity. Most of this loss occurred between 1906 and 1931.

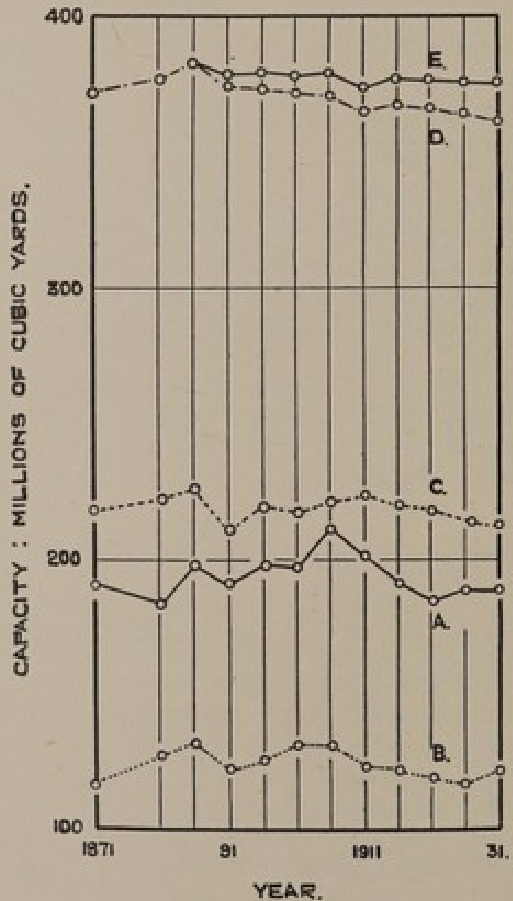
TABLE 125—*Changes in Capacity in Different Compartments of the Upper Estuary during the Periods* 1871 *to* 1931 *and* 1906 *to* 1931

Capacities by Method of Horizontal Planes

Compartment. Sections Nos.	Change in capacity of compartment during period 1871 to 1931		Change in capacity of compartment during period 1906 to 1931	
	(millions of cu. yds.).	(as a percentage of capacity of compartment in 1871).	(millions of cu. yds.).	(as a percentage of capacity of compartment in 1906).
0 to 47	0·8 Loss	0·3 Loss	10·0 Loss	3·1 Loss
47 to 67A	10·0 Gain	3·4 Gain	13·4 Loss	4·2 Loss
67A to 83	26·1 Loss	10·2 Loss	24·8 Loss	9·7 Loss
83 to 100	3·3 Gain	10·8 Gain	1·9 Loss	5·3 Loss

ACCRETION AND EROSION AT DIFFERENT LEVELS

It was shown in Chapter XXI that the total volume of the Estuary computed by the method of horizontal planes agreed closely with the corresponding volumes



Height above L.B.D. (ft.)

Below L.B.D... .. .. .. ———— Curve A.
0 to 10 .. .. " B.
10 to 20 .. .. - - - - - - - - " C.
20 to High Water .. .. .. ·—·—· " D.
Curve D with volumes artificially abstracted added .. .. .. ———— " E.

FIG. 132—*Changes in Capacity of the Upper Mersey Estuary between Different Levels during the Period* 1871 *to* 1931

TABLE 126—*Capacity of the Upper Estuary, Rock Light to Runcorn (Sections 0 to 100), between Horizontal Planes during the Period* 1861 to 1931

(Millions of Cu. Yds.)

	1861.	1871.	1881.	1886.	1891.	1896.	1901.	1906.	1911.	1916.	1921.	1926.	1931.
Below 0 ft. (L.B.D.) ..	195·0	191·0	183·2	198·2	190·3	198·5	196·8	211·0	200·8	190·4	184·5	188·8	188·5
Between 0 and 10 ft. ..	119·8	117·0	127·5	131·6	122·2	125·2	131·0	130·9	123·1	121·4	119·1	116·5	121·8
Between 10 and 20 ft.	216·2	216·7	221·6	230·2	210·0	219·3	216·9	220·5	223·6	219·5	217·7	213·0	212·1
Between 20 ft. and H.W. of 31-ft. tide ..	372·5	371·7	377·0	383·1	374·3	372·8	371·3	370·5	364·9	366·6	365·8	364·4	360·4
Below 10 ft. above Liverpool Bay Datum ..	314·8	308·0	310·6	329·8	312·4	323·8	327·8	342·0	324·0	311·8	303·8	305·2	310·3
Below 20 ft. above Liverpool Bay Datum ..	531·0	524·7	532·3	560·0	522·4	543·1	544·8	562·5	547·5	531·3	521·2	518·2	522·4
Below H.W. of 31-ft. tide	903·5	896·4	909·3	943·1	896·8	916·0	916·1	932·9	912·4	897·9	887·0	882·6	882·8

computed from the use of cross-sections. Since the method of horizontal planes appears to be reliable it has been used to calculate the changes which have occurred in the capacity of the Estuary at different levels; the results are given in Table 126. In this Table the calculated capacity has been included for the survey made in 1861, but since in this year the value obtained does not agree with the value obtained by the use of cross-sections the results have not been used for comparison with those of later surveys. The changes which occurred in the capacity between different levels from Rock Light to Runcorn during the period 1871 to 1931 are shown in Fig. 132. This information, with similar data for the period 1906 to 1931, is also given in Table 127. Between 1871 and 1931 the greatest loss in capacity occurred between the levels 20 feet above Liverpool Bay Datum and high water mark, this loss amounting to approximately 11·3 million cubic yards. During this period, however, a volume of about 14·5 million cubic yards had been abstracted by the building of shore works; if this volume is allowed for, there was a gain in capacity during the period of 3·2 million cubic yards between high water and the 20-ft. contour. During the period 1906 to 1931 an apparent reduction in capacity of 10·1 million cubic yards between high water and the 20-ft. contour included a reduction of 5·8 million cubic yards due to building, the net reduction being thus 4·3 million cubic yards. Between 1906 and 1931 the greatest loss in capacity occurred below Liverpool Bay Datum.

TABLE 127—*Changes in Capacity at Different Levels in the Upper Mersey Estuary between* 1871 *and* 1931 *and between* 1906 *and* 1931

Rock Light to Runcorn

Period.	Total loss in capacity (millions of cu. yds.).	Change in capacity between different levels above Liverpool Bay Datum (millions of cu. yds.).			
		Below L.B.D.	L.B.D. to 10 ft.	10 ft. to 20 ft.	20 ft. to H. W.
1871 to 1931	13·6	2·5 Loss	4·8 Gain	4·6 Loss	11·3 Loss
1906 to 1931	50·1	22·5 Loss	9·1 Loss	8·4 Loss	10·1 Loss

The data on the changes in capacity at different positions in the Estuary during the period 1906 to 1931 are grouped in Table 128. In the first compartment, between Rock Light and Dingle, a large reduction in capacity occurred through the deposition of material in the deep water channel. In the second compartment,

TABLE 128—*Changes in Capacity during the Period* 1906 *to* 1931 *in Different Compartments and at Different Levels in the Upper Mersey Estuary*

Capacities in Millions of Cu. Yds. Figures in Brackets do not include Losses due to Artificial Works

Height above L.B.D. (ft.).	Sections 0–47.	Sections 47–67A.	Sections 67A–83.	Sections 83–100.	Total. Sections 0–100.
20 to High Water	Gain 1·1 (Gain 1·2)	Loss 1·9 (Gain 3·8)	Loss 8·6	Loss 0·7	Loss 10·1 (Loss 4·3)
10–20	Gain 1·1	Gain 0·2	Loss 8·4	Loss 1·3	Loss 8·4
0–10	Loss 0·2	Loss 2·7	Loss 6·3	Gain 0·1	Loss 9·1
Below L.B.D.	Loss 12·0	Loss 9·0	Loss 1·5	0	Loss 22·5
Below High Water (total)	Loss 10·0 (Loss 9·9)	Loss 13·4 (Loss 7·7)	Loss 24·8 (Loss 24·8)	Loss 1·9 (Loss 1·9)	Loss 50·1 (Loss 44·3)

between Dingle and Mount Manisty, the largest reduction also occurred below Liverpool Bay Datum, that is in channels which do not dry out at low water of a spring tide. In this compartment, however, there was also some loss between the 0 and 10-ft. contours. The total reduction in the first two compartments amounted approximately to half the reduction in the whole of the Upper Estuary. In the third compartment between Mount Manisty and the Weaver Sluices occurred the greater part of the remaining loss in capacity, the loss being divided into three approximately equal parts due to deposition below the 10-ft. contour, between the 10 and 20-ft. contours and between the 20-ft. level and the high water mark. In the Narrows (Sections 0—47) most of the bed lies below Liverpool Bay Datum. In passing from the Narrows to the head of the Estuary the area of the bed which is below Liverpool Bay Datum becomes smaller and is negligible in the compartment between the Weaver Sluices and Runcorn. In the third compartment, that is between Mount Manisty and the Weaver Sluices, the greater part of the bed lies between the 10 and 20-ft. contours, and a considerable area is above 20 feet. The extent of the deposition of new material at different levels in the Estuary may be considered by comparing the loss in capacity between different horizontal planes with the area of the bed between those planes. This has been done for the period 1906 to 1931 and the results are shown in Table 129. During the period considered

TABLE 129—*Accretion per Unit Area between* 1906 *and* 1931 *between Rock Light and Runcorn Bridge at Different Levels*

Adjustments for Artificial Works Included

Levels.	Loss between 1906 and 1931 (millions of cu. yds.).	Area in 1931 (millions of sq. yds.).	Volume / Area (yds.).
Below L.B.D. ..	22·5	25·6	0·88
L.B.D. to 10 ft. ..	9·1	22·5	0·40
10 ft. to 20 ft. ..	8·4	29·0	0·29
20 ft. to H.W. ..	4·3	21·2	0·20
Total ..	44·3	98·3	0·45

the loss in capacity of the Estuary was equivalent to the deposition of material over the whole of the bed to a depth of 0·45 yds. (about 1 ft. 4 in.). Below Liverpool Bay Datum, however, the deposition per sq. yd. of surface was more than four times as great as in the area above the 20-ft. contour, the extent of the deposition being intermediate for the intermediate levels.

The surface of almost the whole area of mud banks in the Estuary lies between the 20-ft. contour and the high water mark, the greater part of the mud occurring along the Cheshire shore in the compartment between Mount Manisty and the Weaver Sluices. Small areas of mud occur below Liverpool Bay Datum seaward of Mount Manisty, but the quantity of mud is insignificant by comparison with the main mud bank. In general the bed of the channels which do not dry out at low water, together with the surface of the inter-tidal banks up to a height of 20 ft. above Liverpool Bay Datum consist of sand. The loss in capacity between 1906 and 1931 at different levels in each compartment is known and the nature of the bottom has been determined. The approximate losses in capacity over areas with a bed composed of sand, mud and a mixture of the two are as follows (Table 130). The reduction in capacity in areas with a bottom of sand or of sand containing a little mud was nearly five times as great as over areas in which the bottom is mud. The true loss in capacity due to the deposition of mud is moreover considerably less than is indicated in Table 130, since in the loss of 8·6 million cu. yds. over "areas now covered with mud" is included the greater part of a loss of 5·9 million cu. yds. due to the building of shore works above the 20-ft. contour.

TABLE 130—*Approximate Loss in Capacity between* 1906 *and* 1931 *over Areas in the Upper Mersey Estuary with Different Types of Bed*

Nature of the bed of the Estuary.	Loss of capacity between 1906 and 1931 (millions of cu. yds.).
Mud	8·6 (Part of this loss is due to artificial works)
Sand with a little mud	10·5
Sand	31·0

The change in capacity of the Upper Estuary between 1906 and 1931 has thus been due to the deposition of fresh material over the whole bed of the Estuary, the extent of the deposition being greatest in the deepest parts of the Estuary. The bulk of the material deposited appears to be sand.

CHANGES IN THE VOLUME OF INTER-TIDAL WATER

An extraordinary spring tide in the Mersey rises at Prince's Pier from a height of approximately 0 ft. to approximately 31 ft. above Liverpool Bay Datum, the corresponding heights for an extraordinary neap being 10 and 20 ft. The water which passes in and out of the Upper Estuary during the flood and ebb is available for scouring the channels seaward of the Narrows. The approximate changes which have occurred in the volume of tidal water during the periods 1871 to 1931 and 1906 to 1931, computed by the method of horizontal planes, are shown in Table 131. Between 1871 and 1931 the loss in the volume of tidal water at extraordinary springs was about 1·6 per cent. of the 1931 volume, the corresponding loss for extraordinary neaps being 2·2 per cent. During the period 1906 to 1931 there was a reduction of approximately 4 per cent. in the volume of tidal water entering both at springs and at neaps.

TABLE 131—*Changes in the Volume of Inter-Tidal Water entering the Upper Mersey Estuary during the Periods* 1871 *to* 1931 *and* 1906 *to* 1931

	Springs; L.B.D. to H.W. (millions of cu. yds.).	Neaps; 10 to 20 ft. above L.B.D. (millions of cu. yds.).
Volume of inter-tidal water in 1931 ..	694·1	211·9
Change in volume between 1871 and 1931	11·0 loss	4·6 loss
Change in volume between 1906 and 1931	27·8 loss	8·6 loss

CHANGES IN THE AREA AND POSITION OF INTER-TIDAL BANKS

Almost the whole of the mud in the Upper Estuary is now contained in banks the surfaces of which lie at a height of more than 20 ft. above L.B.D. No information is available on the nature of similar banks in earlier years, but it is likely that the mud in the Estuary has always been deposited on the highest banks where the velocity of the tidal stream is comparatively low. The position of the 20-ft. contour since 1861 can be obtained from the surveys made by the Mersey Docks and Harbour Board; the changes which have taken place in the distribution of the banks lying above 20 ft. are shown in Fig. 133. The areas in black in this figure represent the banks rising to a level of 20 ft. or more above L.B.D. Since at high water the tide rises to a greater height above Datum near the head of the Estuary than in the Narrows, 20-ft. banks at the seaward end of the Estuary are at a somewhat greater height relative to the height of high water than are 20-ft. banks at Runcorn. This difference is, however, comparatively small, amounting to 1 ft. 5 in. at springs and 8 in. at neaps between Eastham and Runcorn.

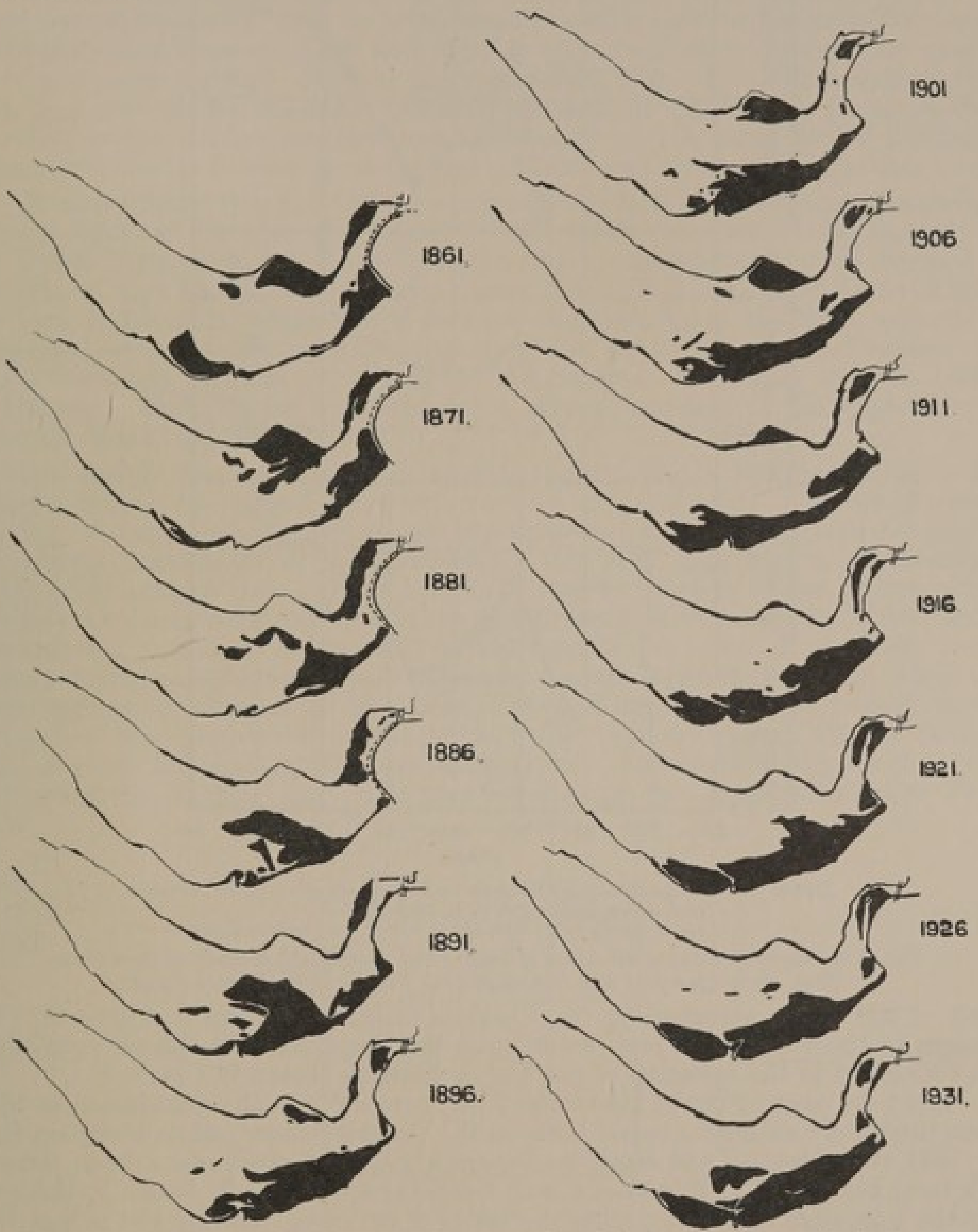
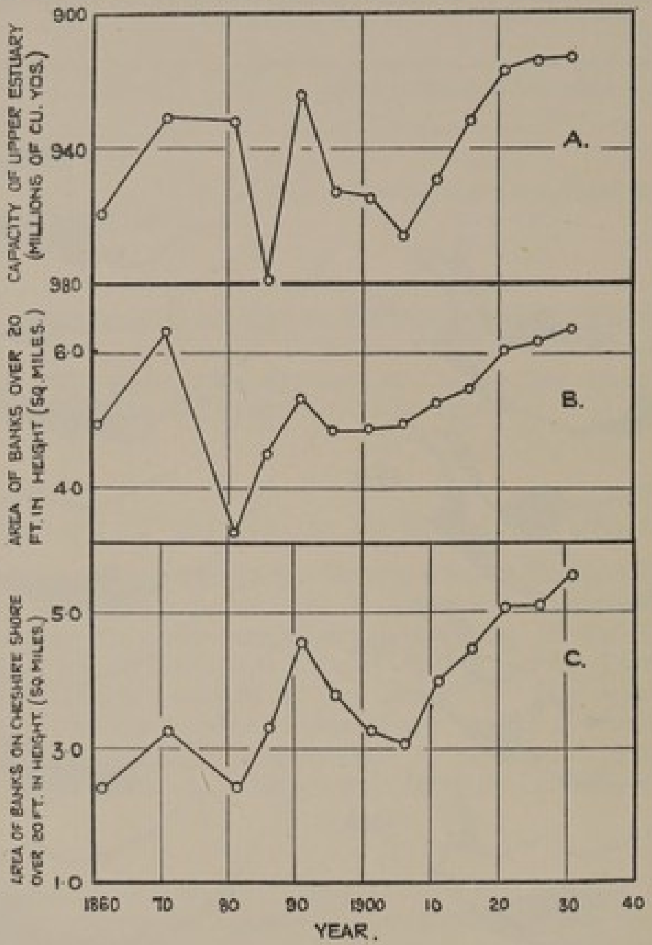


Fig. 133—*Areas of Banks rising to 20 ft. or more above Liverpool Bay Datum in the Upper Estuary of the Mersey from* 1861 *to* 1931

From Surveys made by the Mersey Docks and Harbour Board

The survey for 1931 shows that the greater part of the banks lying above the 20-ft. contour adjoined the Cheshire shore between Mt. Manisty and the Weaver Sluices; this area in 1931 consisted almost entirely of mud. Since 1861 there has always been a high bank in a similar position, but its area has fluctuated from time to time. It is probable that the changes in the position of the upper end of this bank were influenced by the closing of the River Weaver Estuary between 1886 and 1891. Another feature of the series of diagrams is the periodic appearance and disappearance of a bank above the 20-ft. contour in Dungeon Bay on the Lancashire side of the Estuary. There is now an extensive bank in this position, but it lies below the 20-ft. contour and is composed almost entirely of sand. Along the shore of Dungeon Bay there is, however, the remains of a mud fret and the mud is similar in appearance and composition to that now found on the Stanlow Bank. It is likely that the Dungeon Bank was capped with mud at the times when its height was higher than the 20-ft. contour.

The areas of banks between Dingle and Runcorn during the period 1861 to 1931 are shown in Curve B of Fig. 134, and the corresponding areas of those



Curves: A. Volume of Estuary between Sections 0 and 100. (Scale reversed).
B. Total area of Banks over 20 ft. above L.B.D.
C. Area of Banks over 20 ft. above L.B.D. on Cheshire Shore.

FIG. 134—*Relation between the Areas of Inter-Tidal Banks with Heights of more than 20 ft. above Liverpool Bay Datum and the Volume of the Mersey Estuary*

parts of the banks attached to the Cheshire shore are shown in Curve C. The changes in the area of the high banks may be compared with the changes which have occurred in the capacity of the Upper Estuary shown in Curve A.

The total area of banks above the 20-ft. contour was at a maximum in **1871**, when there were extensive banks both on the Cheshire shore and in Dungeon Bay. By 1881 the height of the bank in Dungeon Bay had everywhere been reduced to a level below the 20-ft. contour, and the total area of 20-ft. banks in this year was the minimum recorded during the series of surveys. During the period 1881 to 1931 the total area increased until in 1931 it was approximately the same as in 1871. It will be seen, however, that between 1861 and 1931, though fluctuations occurred from time to time, the area of banks attached to the Cheshire shore and

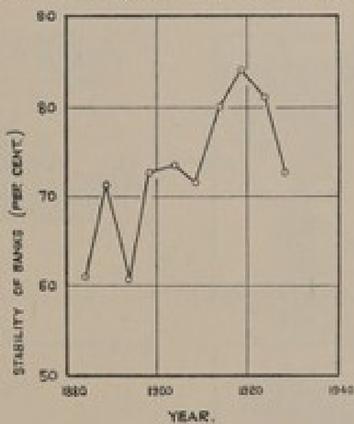
TABLE 132—*Relative Area of Banks more than 20 ft. above Liverpool Bay Datum adjoining the Cheshire Shore and in the Remainder of the Upper Mersey Estuary*

Year.	Area of banks over 20 ft. in height on Cheshire shore as a percentage of total area of similar banks.
1861	48
1881	73
1891	85
1906	61
1916	81
1931	87

lying above the 20-ft. contour increased. The proportion of the total area of 20-ft. banks represented by the banks attached to the Cheshire shore is given for a number of surveys in Table 132. The proportion rose sharply from 1861 to 1891, in which year there was no bank above the 20-ft. contour in Dungeon Bay; it fell again during the period 1891 to 1906, when the high bank in Dungeon Bay again developed, and between 1906 and 1931 it increased since during this period there was again no 20-ft. bank on the Lancashire side. The figures suggest that there is a periodic development and disappearance of the bank in Dungeon Bay, but that on the whole there has been a tendency for the main part of the banks lying above the 20-ft. contour to become concentrated on the Cheshire side.

If curves A and B in Fig. 134 are compared, it will be seen that there is a general relation between the area of banks above the 20-ft. contour and the capacity of the Upper Estuary, a decrease in capacity being accompanied by an increase in the area of high banks. It has been shown that the deposition of material near the high water mark which would increase the area above the 20-ft. contour is in general accompanied by deposition over the whole bed of the Estuary, the deposition being greatest below L.B.D. An increase in the area of 20-ft. banks is, therefore, probably an indication of a general increase in the deposition of material throughout the Estuary.

An attempt has been made to measure the stability of the high banks in the Estuary during the period for which surveys are available. For this purpose, tracings of consecutive surveys were superimposed and the area common to the two surveys was measured by planimeter. This area, expressed as a percentage of the total area of banks above the 20-ft. contour present in the earlier of the two surveys considered, has been taken as a measure of the stability of the banks. The extreme values of this quantity would occur if the whole of the 20-ft. banks present during one survey had disappeared by the succeeding survey, when the percentage of stability would be 0, and if none of the 20-ft. banks present in one survey had been eroded during the period before the next survey when a value of 100 per cent. for the stability would be given. The changes expressed in this way are shown in Fig. 135. The greatest changes in the distribution of 20-ft.



$$\text{Stability of 20-ft. banks from one Survey to the next} = \frac{\text{Area common to the two surveys}}{\text{Total area in first survey}} \times 100.$$

Fig. 135—*Stability of the Banks in the Upper Estuary with Heights greater than 20 ft. above Liverpool Bay Datum*

banks occurred during the period 1891 to 1896. Between this time and the period 1916 to 1921 the stability of the banks increased, but from 1921 to 1931 there was a sudden decrease in stability.

Channel Movements

It is possible that changes in the capacity of the Upper Estuary may be correlated with the extent to which the main channel running between the sand and mud banks altered in position during different periods, and an attempt has been made to measure the extent of the channel movement during the period for which surveys are available. The main channel, between the upper limit of Liverpool Harbour, near Eastham, and Runcorn Railway Bridge, was surveyed and buoyed by the Bridgewater Canal Trust from 1867 to 1876 and since 1876 these duties have been carried out by the Upper Mersey Navigation Commission. Records are available which show the position of the main channel for each month from 1867. Information received from the Upper Mersey Navigation Commission shows that before 1920 the position of the channel buoys was fixed by compass bearings, transits and linear measurements, but that since 1920 the positions have been fixed by sextant angles. It is known that the main channel may change its course either by erosion of one of its banks or by occupying and deepening a subsidiary channel; examples of both these processes have been observed during the present investigation. The larger movements usually take place by the occupation of an alternative channel. This frequently occurs for example in Dungeon Bay where there are usually two channels, one near the shore and the other cutting across the Bay; the channel which happens to be the deeper at any time is buoyed and used for navigation.

The centre lines of the buoyed channels were first traced from the original monthly charts, and the areas contained between successive channel tracks were measured by planimeter, allowance being made for any difference in scale in the charts.

In the second method a grid of squares was constructed to cover that part of the Estuary between Eastham Ferry and Hale Head, a second grid of smaller squares being used to cover the small area between Hale Head and Runcorn Railway Bridge. The tracings showing the original tracks were laid on the grid and a mark was given to each square for each monthly occasion on which the buoyed channel passed through it. In this way, annual charts were made showing

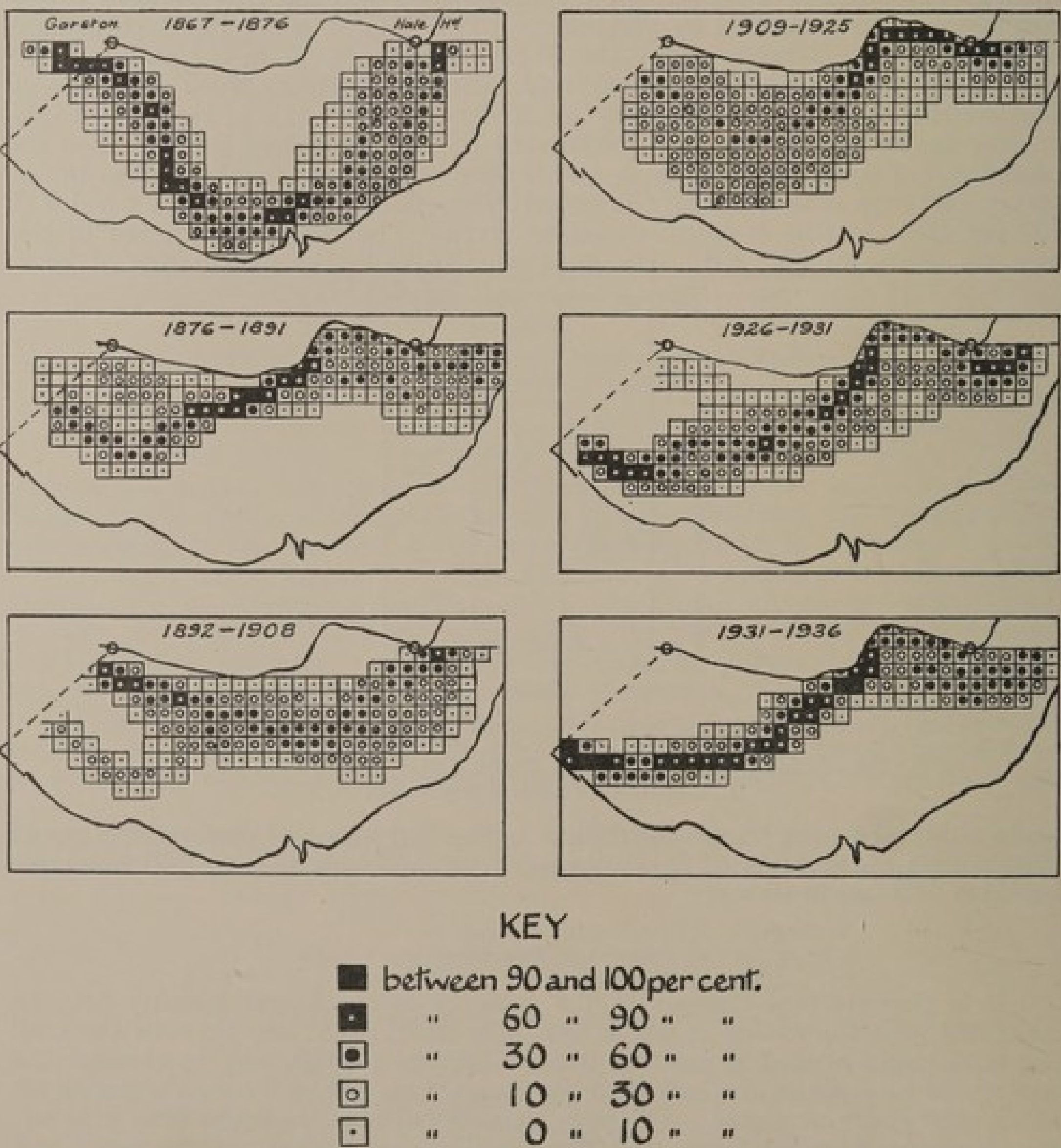


FIG. 136—*Stability of the Main Channel through the Upper Mersey Estuary during the Period 1867 to 1936. Garston to Hale Head*

The diagrams show the number of months during which the channel passed through each square as a percentage of the total number of months in the period the squares through which the channel had passed and giving for each square the number of months in the year for which the channel had passed through it. The number of months in which the channel had passed through a given square, expressed as a percentage of the total number of months in the period, has been calculated. The results obtained are illustrated in Figs. 136 and 137. In the

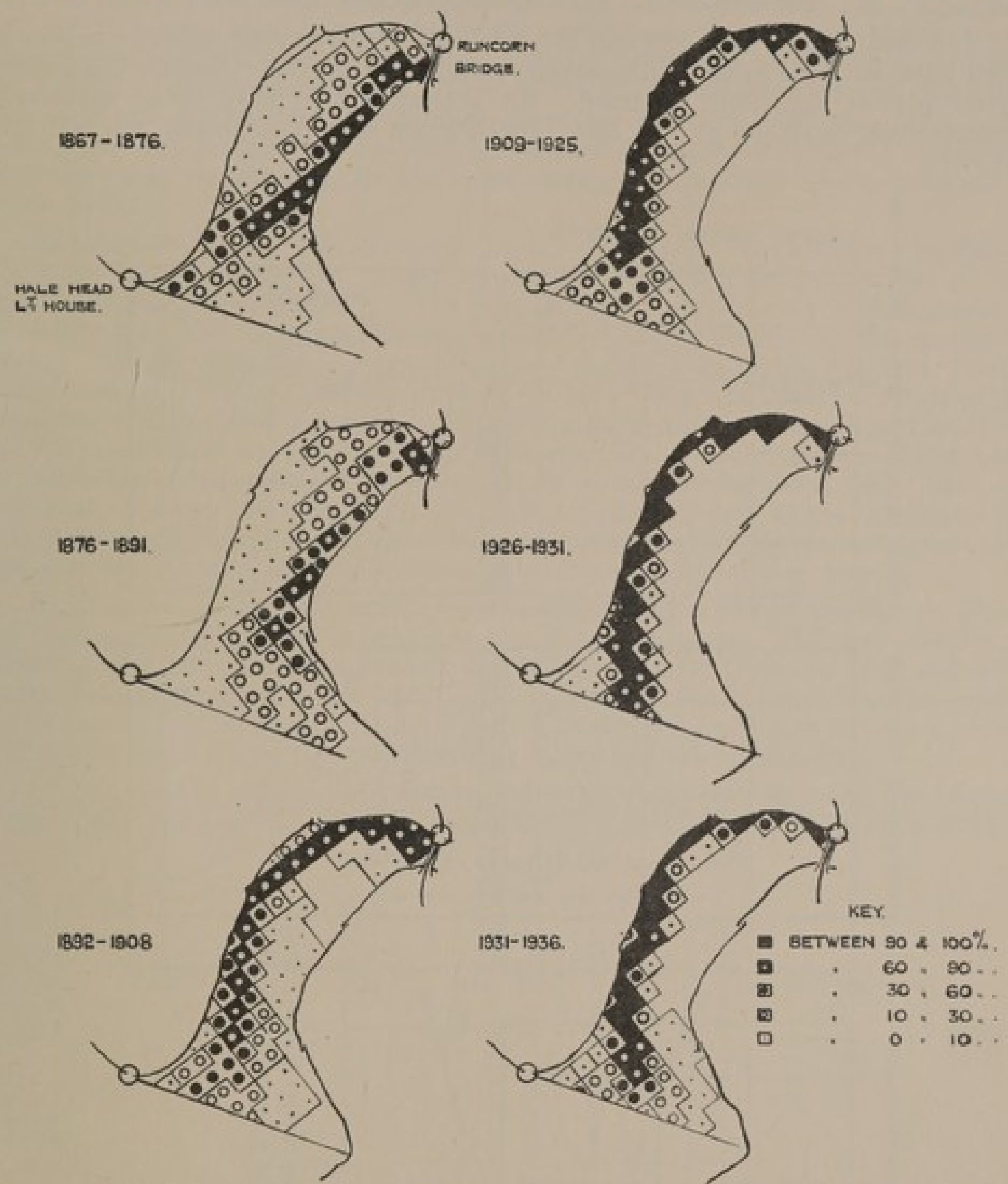


Fig. 137—*Stability of the Main Channel through the Upper Mersey Estuary during the Period 1867 to 1936. Hale Head to Runcorn Bridge*

The diagrams show the number of months during which the channel passed through each square as a percentage of the total number of months in the period

first period from 1867 to 1876, the main channel was near the Lancashire coast at Garston and flowed to Stanlow; the lateral movements in this part of its course were relatively small. The channel then flowed in a less well defined course to Hale Head, avoiding the Cheshire shore between Ince and the River Weaver. Above Hale Head the channel flowed mainly along the Cheshire coast. In the second period between 1876 and 1891, the channel moved over to the Lancashire coast between Garston and Hale, some erosion of the banks between Ince and the River Weaver occurring. It was at this time that the Manchester Ship Canal was completed, the Weaver Estuary being cut off about the year 1891. In the third period between 1892 and 1908 the channel sometimes entered the shallow upper reaches from the Lancashire side and sometimes from the Cheshire side and its course to Hale was very indeterminate; above Hale, however, the channel became increasingly stabilised along the Lancashire shore. During the period 1909 to 1925 the channel showed still greater instability seaward of Dungeon Point but there was a tendency for it to occupy the inshore channel in Dungeon Bay; from Hale Head to Runcorn the channel was almost completely stabilised on the Lancashire side where it has since remained. In the periods 1926 to 1931 and 1932 to 1936, the course of the main channel became increasingly more stabilised between Eastham and Dungeon Point, avoiding the shore banks between Stanlow and the Weaver Sluices.

The diagrams in Figs. 136 and 137, while showing the main changes in position which have occurred in different periods, do not indicate the extent of small lateral movements of the main channel. An attempt to express these movements quantitatively is shown in Fig. 138. In Diagram A is plotted the average area,

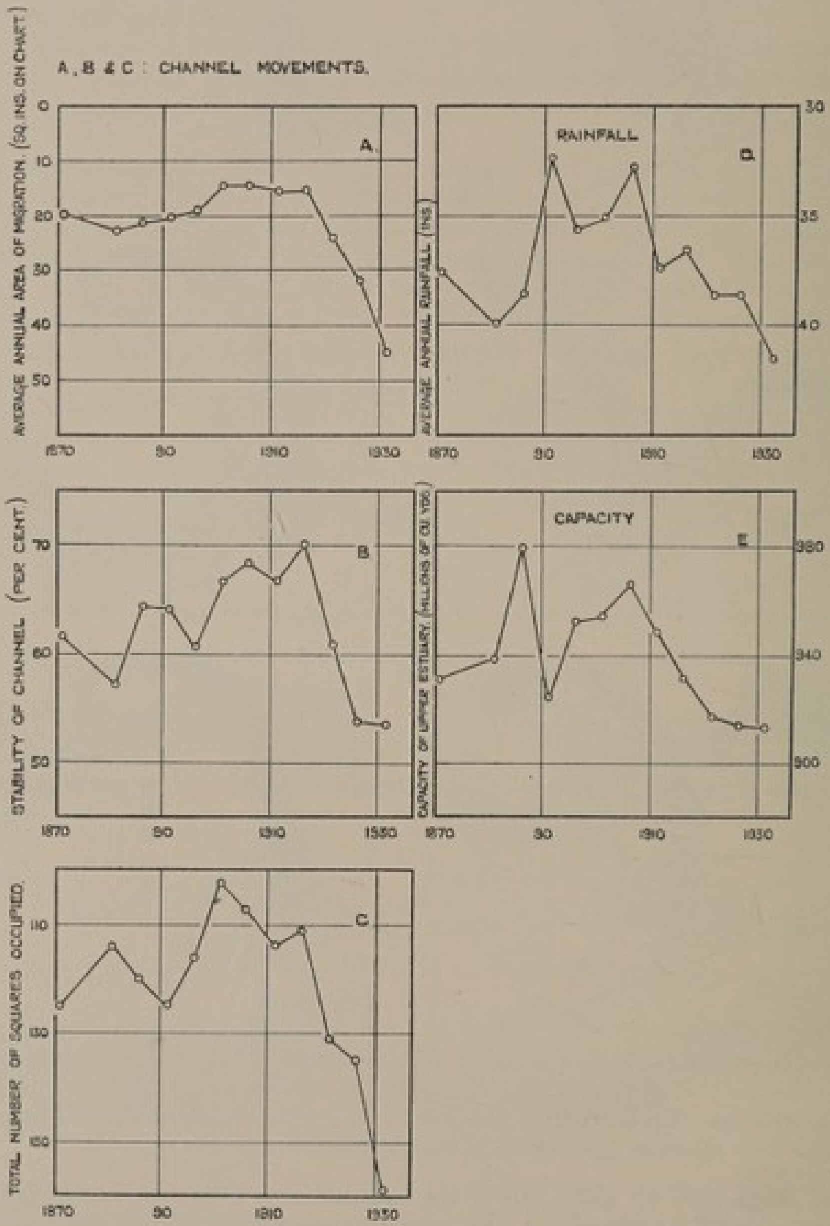


FIG. 138—*The Movements of the Main Channel in the Upper Mersey Estuary during the Period* 1867 *to* 1931 *compared with the Rainfall over the Mersey Catchment Area and the Capacity of the Estuary* (*Sections* 0 *to* 100)

computed from monthly charts, over which the channel moved annually during the period between two successive determinations of the capacity of the Upper Estuary. The curve shows that this area remained reasonably constant from 1871 to 1916 but has steadily increased since that date. This increase is due to a large number of relatively small movements rather than to infrequent but large changes in the position of the channel. The changes which have occurred in the stability of the channel are shown in another way in Diagram B. This diagram has been prepared from figures of the type given in Figs. 136 and 137, in which was shown the percentage of the total possible number of occasions on which squares were occupied by the channel. If the percentages for each square are added together and divided by the total number of squares through which the channel had passed during each period, the values for the stability of the channel shown in Diagram B are obtained. The values obtained in this way minimise the effect of large movements in which the channel suddenly occupies an alternative bed. In Diagram C, Fig. 138, is shown another estimate of the stability of the channel, the ordinates representing the total number of squares through which the channel passed during each period. The three curves A, B and C are similar in their general shape and show that the stability of the channel decreased between 1916 and 1931. This decrease was due to the more frequent movement of the channel through relatively short distances rather than to the large changes in position which occurred in earlier years.

In Diagram D, Fig. 138, is shown the average annual rainfall over the Mersey catchment area, during the periods between successive determinations of the capacity of the Upper Estuary. The rainfall figures are the unweighted means of the values from the following stations selected on the advice of the Meteorological Office of the Air Ministry :—Nantwich, Rawtenstall, Congleton, Fairfield, Northwich, Runcorn, Oldham, Whaley Bridge, Arnfield Reservoir. The curve is of the same general shape as the curves showing the stability of the channel and indicates that the decrease in stability between 1916 and 1931 occurred during a time when the rainfall was increasing from one 5-yearly period to the next. The data are inadequate to show whether there is a real connection between the rainfall in the Mersey area and the extent of the channel movements, but the curves suggest that increased rainfall may lead to a decrease in the stability of the channel.

In Diagram E, Fig. 138, are shown the changes observed by the Mersey Docks and Harbour Board in the capacity of the Upper Estuary. The most consistent feature of this curve is the continued decrease in capacity between 1906 and 1931. During the greater part of this period the stability of the channel was decreasing, that is to say that accretion in the Upper Estuary was occurring during a period in which movements of the channel were becoming more frequent.

In Fig. 139 is shown the relative extent of the movements of the channel in the Upper Estuary in different months of the year during the period 1867 to

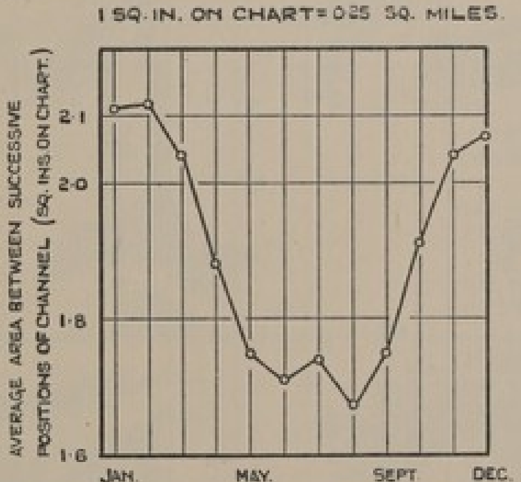


Fig. 139—*Average Monthly Movement of the Main Channel in the Upper Mersey Estuary during the Period* 1867 *to* 1931
The average movement in any month is the mean for 64 *years*

1931. The figures were obtained by averaging the movements in each month throughout the period. There is a well marked periodicity in the migration of the channel, the maximum movements occurring during the winter months.

Dredging in the Sea Channels

The Mersey Docks and Harbour Board carry out frequent surveys of the navigable channels in Liverpool Bay and at longer intervals survey the whole of the area of the Bay including the inter-tidal banks. It is, however, a matter of great difficulty to determine the changes which have occurred in the capacity of the Bay since, though bounded on two sides by the Lancashire and Cheshire coasts, it is open to the sea. The Bay has, therefore, no well-defined limits, and it is probable that there is a continuous interchange of sand and other material between it and the area lying outside it. In addition, the depth of the main channel and the positions of the banks in the Bay have been considerably altered by dredging and by the building of training walls and revetments. The total weight of material dredged from the sea channels between 1891 and 1932 was approximately 475 million tons. The greater part of the dredged material is taken from the main channel and deposited in the Liverpool Bay area some miles from the position of dredging; the material is thus not removed from the Estuary system and a considerable part of it probably remains in the Bay. In Table 133 are shown the weight and approximate volume of material dredged, with the reduction in depth which this would represent if the dredging had been carried on uniformly over the whole area of the Estuary. Between 1891 and 1932 the volume dredged from the sea channels was equivalent to a layer which if spread over the Upper Estuary would have had a depth of nearly 5 ft.

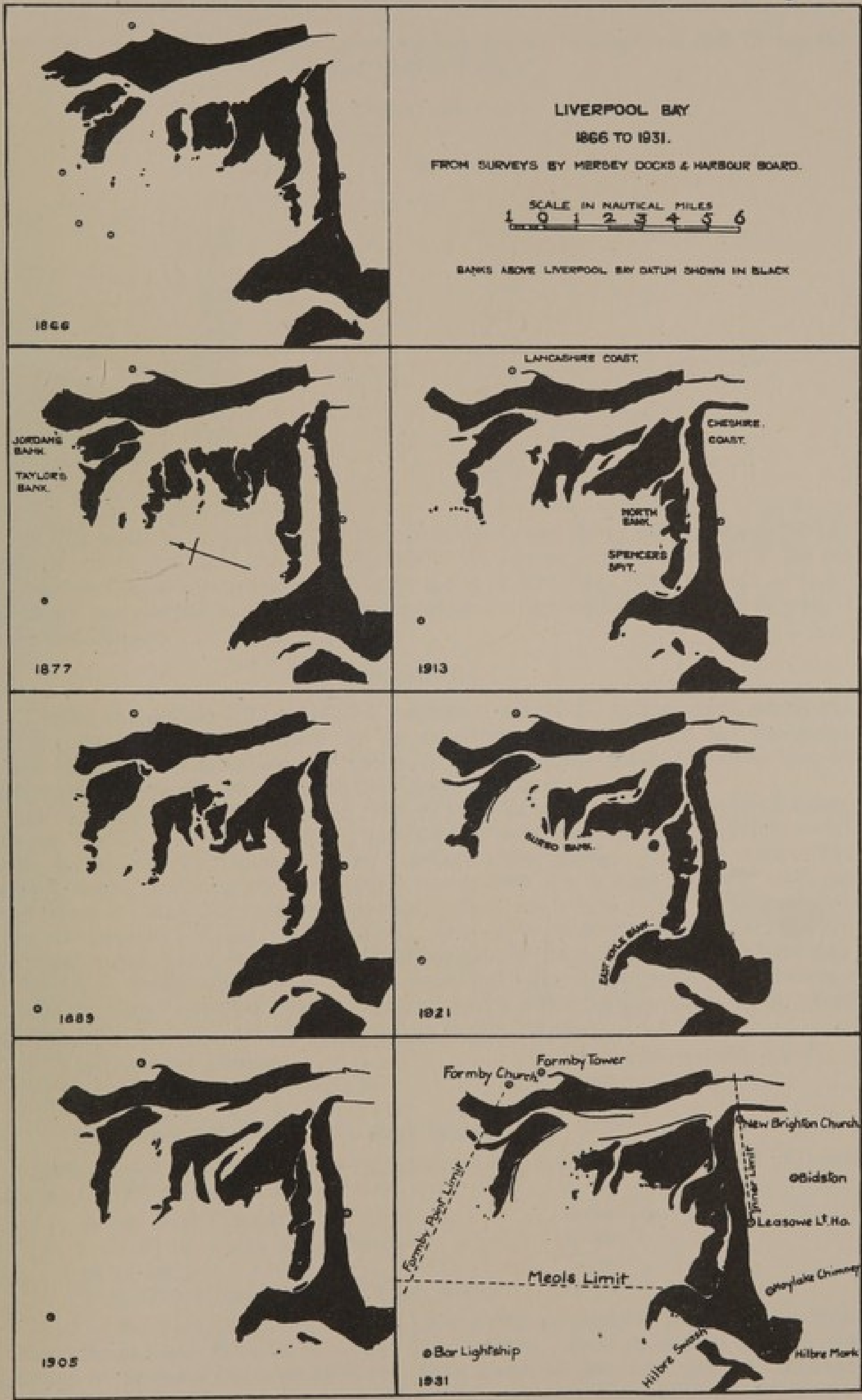
TABLE 133—*Amount of Dredging in the Mersey Estuary, Reduction in Capacity of the Upper Estuary and Average Change in Level over the Area of the Estuary calculated from these Amounts*

	Amount (millions of tons).	Amount (millions of cu. yds.) (A).	Calculated change in the mean level represented by the amounts in Col. A.		
			Over the area of the Upper Estuary (36 sq. miles). ft. in.	Over the area of the Outer Estuary (70 sq. miles). ft. in.	Over the area of the whole of the Estuary (106 sq. miles). ft. in.
Reduction in capacity of the Upper Estuary between 1906 and 1931	—	51·7	1 5	0 9	0 6
Amount of dredging in the sea channels between 1906 and 1931	361·9	135·7	3 8	1 11	1 3
Amount of dredging in the Upper Estuary between 1906 and 1931	—	65·0	1 9	0 11	0 7
Total amount dredged in the sea channels from 1891 to 1932	475·1	178·2	4 10	2 6	1 8
Maximum amount dredged in the sea channels in any one year (1924)	25·2	9·4	0 3	0 2	0 1
Total amount dredged in the Upper Estuary from 1897 to 1932	—	80·4	2 2	1 1	0 9

AREA OF INTER-TIDAL BANKS IN LIVERPOOL BAY

In Fig. 140 are shown the positions of the channels and the inter-tidal banks in Liverpool Bay at various times between 1866 and 1931; the same navigable channel has been used throughout this period. In 1891 dredging on the Bar was begun, and has been continued since that date; dredging in the Queen's and Crosby Channels was begun in the years 1894 and 1896, respectively. Between 1891 and 1900 the depth of water over the Bar had been increased from about 10 ft. to between 25 and 30 ft., and this depth has in general been maintained up to the present time. There is, however, no obvious correlation between the depth of

Fig. 140.



LIVERPOOL BAY
1866 TO 1931.
FROM SURVEYS BY MERSEY DOCKS & HARBOUR BOARD.
SCALE IN NAUTICAL MILES
1 0 1 2 3 4 5 6
BANKS ABOVE LIVERPOOL BAY DATUM SHOWN IN BLACK
1866
JORDAN'S BANK.
TAYLOR'S BANK.
1877
LANCASHIRE COAST.
CHESHIRE. COAST.
NORTH BANK.
SPENCER'S SPIT.
1913
1889
BURBO BANK.
EAST HOYLE BANK.
1921
1905
Formby Church
Formby Tower
New Brighton Church
Inner Limit
Bidston
Leasowe Lt. Ho.
Formby Point Limit
Meols Limit
Hoylake Chimney
Bar Lightship
Hilbre Swash
Hilbre Mark
1931

the sea channels and the amount of dredging carried out in any year. During the period 1866 to 1935 some reduction in the area of the sand banks in the Bay lying above Liverpool Bay Datum seems to have occurred (Table 134).

TABLE 134—*Area of Banks above Liverpool Bay Datum in Liverpool Bay during the Period* 1866 *to* 1935

(The Same Arbitrary Limits to the Bay for Each Year)

Year.	Area of banks (sq. miles).
1866	25·9
1877	27·1
1889	25·4
1913	22·5
1921	22·5
1926	20·4
1928	20·1
1929	21·0
1930	22·1
1931	22·0
1933	22·1
1934	20·7
1935	21·6

In the areas in Table 134 are included the banks lying within the arbitrary limits shown in the 1931 chart in Fig. 140. As Liverpool Bay is open to the sea and large artificial alterations have been made in the Bay, it is difficult to trace any direct correlation between the fluctuations in the capacity of the Bay and of the Upper Estuary.

SUMMARY

During the period 1871 to 1931 a volume of nearly 15 million cubic yards was cut off from the Upper Estuary by the construction of works on the foreshore. In the same period a volume of about 74 million cubic yards was removed by dredging from the deeper parts of the Upper Estuary.

In the periods 1871 to 1931 and 1906 to 1931 the capacity of the Upper Estuary between Rock Light and Runcorn, which is between 900 and 1,000 million cubic yards, decreased by 13·6 and by 50·1 million cubic yards. In both periods the greatest losses occurred in the compartment between Mount Manisty and the River Weaver; here the reduction in each period amounted to about 10 per cent. of the total volume of this compartment. Part of the loss in capacity between the high water mark and a height of 20 ft. above Bay Datum was due to the construction of shore works which were built mainly between these levels. If allowance is made for these artificial changes, the following reductions in capacity occurred between 1906 and 1931 at different levels in the Estuary :—

Below Bay Datum	22·5 million cubic yards.
0 to 10 ft. above Bay Datum	9·1 ,, ,, ,,
10 to 20 ft. ,, ,, ,, ...	8·4 ,, ,, ,,
20 ft. above Bay Datum to High Water ..	4·3 ,, ,, ,,

These losses in capacity are equivalent to the uniform deposition of fresh material to the following depths :—

Below Bay Datum	0·88 yard.
0 to 10 ft. above Bay Datum	0·40 ,,
10 to 20 ft. ,, ,, ,, ...	0·29 ,,
20 ft. above Bay Datum to High Water ..	0·20 ,,

Most of the mud at present in the Upper Estuary occurs in banks the surfaces of which lie at more than 20 ft. above Bay Datum. It is estimated that of the reduction in capacity between 1906 and 1931, about 62 per cent. occurred through the deposition of material over areas where the bed is now composed of sand, 21 per cent. in areas in which the bed is of sand mixed with a little mud, and 17 per cent. by deposition over mud banks. The last value of 17 per cent. includes the greater part of the reduction in capacity due to the construction of works on the foreshore and the true reduction brought about by the deposition of mud was thus considerably lower than 17 per cent. of the total reduction of 50·1 million cubic yards during the period 1906 to 1931.

The losses in capacity of the Upper Estuary represent a reduction in the tidal volume of about 1·6 per cent. at springs and 2·2 per cent. at neaps during the period 1871 to 1931, and a reduction of approximately 4 per cent. at both springs and neaps during the period 1906 to 1931.

A reduction in capacity of the Estuary by the deposition of material over the whole bed leads to an increase in the area of inter-tidal banks of a height greater than 20 ft. above Bay Datum. The surface of these high banks now consists mainly of mud. A large proportion of their area is represented by the Stanlow Bank which adjoins the Cheshire shore between Mount Manisty and the Weaver Sluices. At some periods there has also been a bank more than 20 ft. above Bay Datum in Dungeon Bay on the Lancashire side of the Estuary. From 1906 to 1931 the area of the Stanlow Bank relative to the total area of banks 20 ft. above Bay Datum has increased. An estimate of the relative stability at different periods of the banks lying above the 20-ft. contour has been made by measuring from charts of the Estuary the changes in the banks during each quinquennial period. From 1896 to 1921 the stability of the banks above the 20-ft. contour increased, but from 1921 to 1931 there was a decrease in stability.

The main channel in the Upper Estuary frequently changes its course, either by erosion of its banks or by occupying another channel. An estimate has been made by several methods of the extent to which these movements occurred during the period 1867 to 1936. Up to the year 1925 the main channel entered the upper basin from the Narrows sometimes on the Lancashire side and sometimes on the Cheshire side; since 1926 it has flowed near Eastham close to the Cheshire shore. Between Hale Head and Runcorn the channel up to the year 1909 frequently altered its course, but since then it has usually remained close to the Lancashire shore. The total movement of the main channel has increased since the year 1916. This increase was due to a large number of small movements of the channel rather than to occasional large movements. The increased movement of the channel after 1916 occurred during a period of relatively heavy rainfall in the Mersey catchment area. During the same period the capacity of the Estuary decreased. The movements of the channel occurred mainly during the winter months.

During the period 1866 to 1935 the area of inter-tidal banks in Liverpool Bay decreased from about 26 to 22 square miles.

APPENDIX I

ANALYTICAL METHODS

Estuarine Deposits, Sewage Sludge and other Solid Matter

Moisture

About 100 gm. of wet mud were dried to constant weight at 105° C., and the loss in weight was determined.

Organic Carbon[1]

To a known weight (0·2 — 1·0 gm.) of the sample (not previously dried) 150 ml. of concentrated sulphuric acid were added. The mixture was aspirated for 30 min. with air free from carbon dioxide, to remove chlorides and carbonates; 10 ml. of a saturated aqueous solution of chromium trioxide were added and the mixture was heated sufficiently to maintain steady gas evolution. The gas was scrubbed with dilute potassium iodide or with saturated ferrous sulphate solution to remove hydrogen chloride and free chlorine; it was then passed through a measured volume of standard baryta. Excess baryta was determined by titration with N/6 or N/60 hydrochloric acid using phenolphthalein as indicator. For small amounts of carbon the absorption tube was swept free from carbon dioxide while it was being filled and also during the titration of the excess baryta.

Kjeldahl Nitrogen[1]

A known weight (0·2 — 1·0 gm.) of the sample (not previously dried) was digested with 3 ml. of concentrated sulphuric acid until colourless. Hydrogen peroxide (perhydrol) was sometimes added towards the end of the digestion period. The digest was diluted, transferred to the distillation apparatus (Parnas-Wagner), rendered alkaline with a 40 per cent. solution of sodium hydroxide and steam-distilled. The distillate was collected in N/70 sulphuric acid; excess acid was determined after boiling by titration to methyl red with N/140 sodium hydroxide.

Sulphide Sulphur

10 gm. of wet mud were acidified with excess 10 per cent. solution of phosphoric acid and the mixture was aspirated with air for one hour. Hydrogen sulphide was trapped by scrubbing the gas with a 2 per cent. solution of cadmium acetate. The precipitated cadmium sulphide was coagulated by heating on a water bath, filtered through a small Gooch crucible packed with asbestos, and washed with hot water. The precipitate was transferred to a flask containing standard iodine solution and dilute sulphuric acid was added. After standing for 20 minutes the excess iodine was titrated with standard thiosulphate.

Total and Sulphate Sulphur

The total sulphur in mud was determined by oxidising all forms of sulphur to sulphate with hot concentrated nitric acid and potassium chlorate solution. Sulphate sulphur was determined in the residue left from the determination of sulphide sulphur. The residue was filtered and the filtrate was precipitated with barium chloride by the usual method. The elementary sulphur remaining in the sample after the removal of sulphide and sulphate was oxidised, usually with sodium peroxide, and determined as sulphate.

Loss on Ignition

The weighed sample (dried at 105° C.) was ignited in a muffle furnace and the loss in weight was determined.

Iron

1 to 2 gm. of dried mud were mixed with an equal weight of sodium peroxide in a nickel crucible and heated, cautiously at first, until oxidation was complete. The mixture was acidified with 10 per cent. hydrochloric acid, dried on the water bath and again extracted with 10 per cent. hydrochloric acid and filtered. The filtrate was titrated in the cold with standard titanous chloride solution, using ammonium thiocyanate as indicator. The titanous chloride solution used was kept out of contact with the air and was standardised on each occasion against a standard ferric chloride solution.

Silica

A mixture of 1–2 gm. of dried mud and 10 gm. of sodium carbonate was fused in a platinum crucible. The fused mass was acidified with 10 per cent. hydrochloric acid, dried on the water bath and heated overnight at 110°–120°C. It was then extracted with 10 per cent. hydrochloric acid, filtered and washed. The silica remaining on the filter paper was dried at 105°C., transferred to a weighed crucible, ignited, cooled and weighed.

Sesquioxides

The filtrate from the determination of silica was neutralised with ammonia and heated nearly to boiling. The liquid was then made alkaline with ammonia and boiled for about two minutes. The precipitate was filtered, washed with 2·5 per cent. ammonium nitrate solution and partially dried, when it could be transferred from the filter paper to a weighed crucible; it was then ignited, cooled and weighed. The ignited precipitate consisted mainly of ferric oxide and alumina and contained a small amount of other substances including phosphates. In a sample of mud, the content of aluminium oxide is approximately the difference between the contents of sesquioxides and ferric oxide.

Calcium

The filtrate from the determination of sesquioxides was evaporated to a small bulk, and boiling ammonium oxalate solution was added. The liquid was maintained at the boiling point for some hours and was then filtered through paper. After washing the precipitate, the base of the filter was punctured and the precipitate was washed into a beaker. It was treated with dilute sulphuric acid and warmed to about 60°C. and the liberated oxalic acid was titrated with standard permanganate.

Magnesium

The filtrate from the determination of calcium was boiled and a solution of sodium ammonium phosphate was added. The precipitate of magnesium ammonium phosphate was filtered through a weighed Gooch crucible packed with asbestos, washed and dried. After ignition, the precipitate was weighed as magnesium pyrophosphate.

Phosphate[(2)]

10 gm. of dried mud were heated with 50 ml. of fuming nitric acid for several hours, when the residual solids were filtered off. The filtrate was heated to 80° to 90°C. and 10 ml. of molybdate reagent were added. The precipitate of ammonium phosphomolybdate was filtered through a weighed Gooch crucible, washed with 2 per cent. ammonium nitrate, dried and weighed.

Petroleum Ether Extractives

30 gm. of dried mud were acidified with dilute hydrochloric acid and dried on a water bath. The dried mud was ground, transferred to a Soxhlet thimble and extracted in a Soxhlet apparatus with petroleum ether (B.P. 40° to 60°C.). The petroleum ether was removed from the extract by distillation. Sulphur was largely removed from the residue by shaking with a small quantity of petroleum ether and decanting the ether from the undissolved sulphur. The ether was then evaporated and the residue weighed.

Estuarine, Sea and Fresh Water, Sewage, Tannery Effluents, and Suspensions

Salinity

Chlorides were determined by titration of a 10 ml. sample with standard silver nitrate using potassium chromate as indicator. From the concentration of chloride the salinity value was obtained from Knudsen's Tables[(3)].

Dissolved Oxygen

The samples were taken with a displacement sampler. The dissolved oxygen content was determined by the method of Winkler, using the Rideal-Stewart modification[(4)].

Biochemical Oxygen Demand

Determinations were made with suspensions of mud in sea and tap water and with samples of estuary water. If suspensions containing mud were stored in an incubator replicate values of the B.O.D. of the samples frequently varied considerably. During incubation the mud settles and so is partly taken out of contact with the water containing the dissolved oxygen. More concordant results were obtained when the stoppered bottles containing the suspensions were overturned at intervals of about one minute by means of a mechanical device. If the bottles were placed in racks attached to a slowly rotating wheel with a horizontal axis, the mud was prevented from settling and satisfactory replicate values were obtained. The determinations of dissolved oxygen in this test were made as already indicated.

Free and Saline Ammonia

The sample of water was distilled in the presence of sodium carbonate, the ammonia in the distillate being estimated colorimetrically by Nessler's reagent[4].

pH Value

*p*H values were determined colorimetrically, the colours being matched in a Hellige comparator. No corrections were made for the effect of salt; corrections of this kind would not affect the results by more than 0·2.

Suspended Matter

100 ml. of the sample were allowed to stand overnight, the sediment was collected on a weighed Gooch crucible, dried at 105° C., washed free from chlorides, dried and weighed.

Oxygen Consumed from Potassium Dichromate[5]

The dried and weighed suspended matter was transferred with the asbestos pad to a 50-ml. flask. Equal volumes of N/8 potassium dichromate and concentrated sulphuric acid were added. The asbestos pad was broken up by shaking the flask which was then heated at 100° C. for three hours in an oven. After cooling the contents of the flask were washed into a larger flask with 50 ml. of distilled water to reduce the concentration of sulphuric acid and 2 ml. of saturated potassium iodide were added; the liquid was allowed to stand for five minutes, and was then titrated with N/8 sodium thiosulphate solution. Starch was used as an indicator.

Organic Carbon and Kjeldahl Nitrogen

Organic carbon and Kjeldahl nitrogen were determined by the methods described on p. 205.

Rate of Sedimentation of Mud through Distances of 4 in. to 40 ft.

The methods used for measuring rates of sedimentation are described in Chapter X. Diagrams of the apparatus used for measurements in tubes 9 ft. and 40 ft. long are given in Fig. 141.

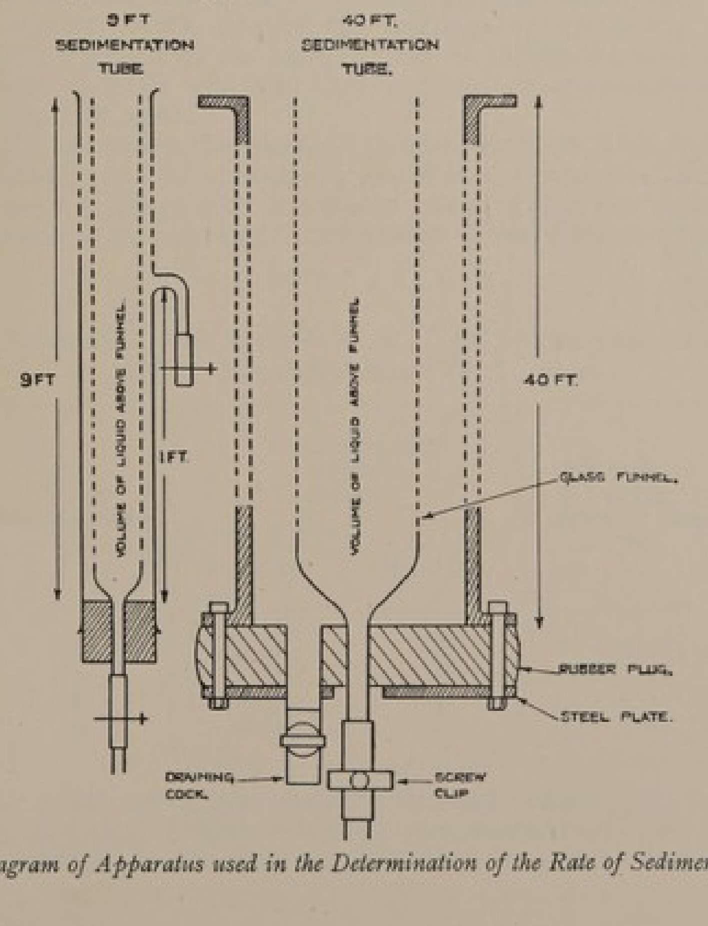


FIG. 141—*Diagram of Apparatus used in the Determination of the Rate of Sedimentation of Mud*

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(3) KNUDSEN, M. Hydrographical Tables. Williams and Norgate, Copenhagen and London, 1901.

(4) MINISTRY OF HEALTH. Methods of Chemical Analysis as Applied to Sewage and Sewage Effluents. H.M. Stationery Office, 1929.

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APPENDIX II

METHODS USED IN MEASURING THE VELOCITY OF TIDAL AND FRESH-WATER STREAMS

In the tidal part of the Estuary stream velocities were measured by means of current meters, captive floats or free-drifting floats.

Current meters were usually suspended from a small davit on one of the motor boats or from a dinghy when working over high banks. Observations were also taken from the Light Vessels in the sea channels. The current meters used were :—

Nos.	601	Watts
,,	603	Watts
,,	1314	Watts
,,	330	Large Gourley–Price
,,	179	Ekman
,,	180	Ekman

All the instruments were calibrated periodically either at the National Physical Laboratory or by the Admiralty. In the Watts meter, vanes are caused to revolve about a vertical axis by the stream, an electrical circuit being closed at the end of each revolution or after every fifth revolution. The electric current from a dry cell is carried by waterproofed cables to ear-phones and the observer times by stop watch a given number of signals. These meters do not register the direction of the tidal stream. Difficulty is often experienced in keeping the meter at the required depth in a strong tide and on some occasions a special streamlined sinker weighing 100 lbs. was used in place of the usual smaller sinker. The Gourley–Price meter is similar to the Watts meter but is larger. In the Ekman meter the propeller is started by a messenger and stopped by a second one, the number of revolutions made by the propeller during the interval being registered on dials on the instrument. The Ekman meter also registers the direction of the stream by means of a mechanism containing a compass.

The three types of meter were satisfactory in deep water but not in shallow water, unless the sea was smooth, owing to the turbulence sometimes set up. Difficulty was experienced in using meters in water containing high concentrations of suspended matter, which clogged the bearings of the rotary vanes. In the Upper Estuary the speed of the tidal stream is influenced considerably by the presence of banks and the velocities observed may differ considerably at stations only a short distance apart.

In Table 135 are shown the recorded stream velocities taken by two calibrated meters suspended from the same boat, the distance between them being about 15 ft. Continuous readings with one meter indicated that the differences in Table 135 are due mainly to fluctuations in the stream velocity and not to inaccuracies in the meters.

TABLE 135—*Comparison of the Velocity of the Tidal Stream recorded by Two Current Meters suspended about* 15 *ft. apart*

No. of determinations.	Mean velocity of stream (knots).		Difference as a percentage of value by Meter 330.
	Meter 330.	Meter 601.	
6	0·92	0·99	+ 7·6
13	1·38	1·31	− 5·1
11	1·70	1·59	− 6·5
4	2·13	2·10	− 1·4

In shallow water or at low stream velocities observations were sometimes made by means of a captive float such as an orange or a small float of canvas vanes on a wooden framework; the float was attached to a light line and the length run out in a given time was measured. In this method the general direction of the stream was observed by sextant angles between the float and fixed shore objects. In other cases the captive float consisted of a light spar provided with an oblong steel framework, 2 ft. 6 in. by 3 ft., covered with canvas; a small block of cork was fixed to the top end of the spar to provide buoyancy. These floats were not appreciably affected by wind.

In some cases the velocity of the tidal stream was measured by allowing a float to drift freely, its position being fixed at intervals by sextant angles. If the float went ashore or was held up in an eddy it was picked up and dropped in the main stream.

The current velocity in fresh-water rivers was measured either by current meter or by small floats. A current meter was used by suspending it from a block on a wire across the river; the meter could be hauled to any required distance from the bank by means of an endless rope and lowered to the required depth. During observations of the current velocity the height of the river was noted on a river gauge, the zero of which had been connected by levels to an Ordnance bench mark. In the computation of the discharge of a river the velocity in feet per second at different depths on the same vertical was plotted against the depth; an example of such a curve is shown in Fig. 142. The areas enclosed by these curves for each

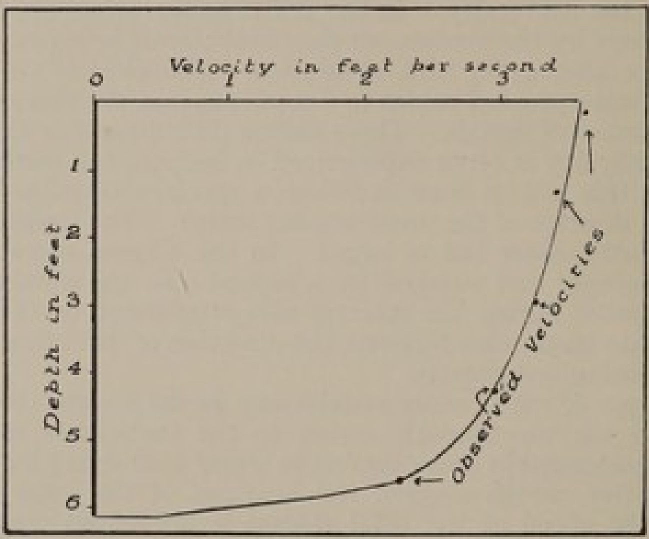

FIG. 142—*Typical Vertical Velocity Curve* (*River Mersey, 15th January*, 1934)

vertical were then measured by planimeter. The distance across the stream was then plotted as a base line and on this line perpendiculars were erected at the positions where gaugings were taken, the length of each of the perpendiculars being made proportional to the areas obtained from the " vertical velocity curves." A curve was then drawn touching the end of each perpendicular; the area between the base line and the curve drawn in this way is proportional to the discharge, in cu. ft. per second, across the section. An example of such a discharge diagram is shown in Fig. 143.

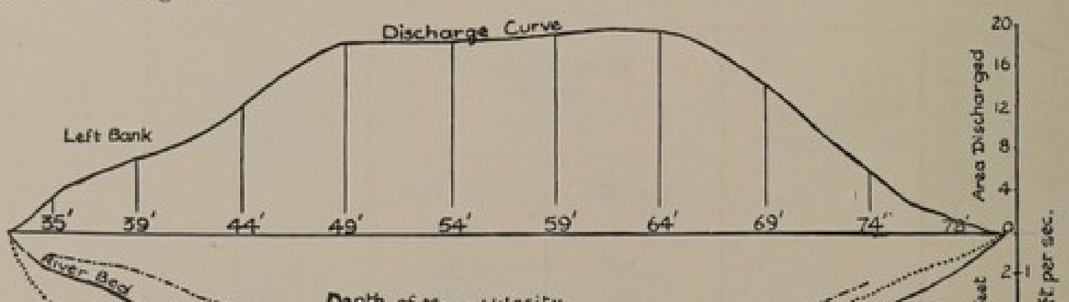

FIG. 143—*Typical Discharge Curve from Stream Gauging Observations obtained on the River Mersey at Flixton, 15th January*, 1934

TABLES

TABLE 1—*Area and Character of the Catchment Areas of the Streams draining into the Mersey Estuary*

Catchment areas.	Area. (sq. miles)	Total	Outfall.	Entry of stream into Estuary.	Distance of point of entry from Warrington Bridge. + below Warrington − above Warrington (miles).	General character of catchment area.
Above Howley Weir						
Irwell and tributaries ..	247·7		Manchester Ship Canal	Howley Weir ..	−17·0	Industrial and agricultural.
Irk	29·8		" " "	" "	−17·0	" "
Medlock	30·9		Bridgewater Canal ..	Into Manchester Ship Canal through locks at Runcorn and flood sluices.	+10·5	" "
Mersey and tributaries	261·6		Manchester Ship Canal	Howley Weir ..	Confluence at Flixton −7·0; Howley Weir −0·5	" "
Bollin and tributaries ..	106·8	785·0	Manchester Ship Canal	" " ..	− 5·0	Agricultural.
Glazebrook	67·6		Manchester Ship Canal	" " ..	− 7·0	"
Redbrook	19·5		" " "	" " ..	− 6·5	"
Remainder draining into Manchester Ship Canal including—	21·1		" " "	" " ..	−11·0	Industrial and agricultural.
Worsley Brook ..			" " "			Industrial.
Longford Brook ..			" " "			"
Below Howley Weir						
Weaver River		544·0	" " "	Natural flow into Manchester Ship Canal and through Weaver Sluices into Mersey Estuary.	+12·2	Industrial and agricultural.
Upper Estuary						
Sankey Brook	73·0		Upper Estuary ..	Natural flow ..	+ 4·2	Industrial and agricultural.
Ditton Brook	26·3		" " ..	" " ..	+10·3	" "
Holpool Gutter ..	13·6		" " ..	Siphoned under Manchester Ship Canal.	+13·5	" "
Gowy River	73·8		" " ..	" " "	+15·8	" "
Poolehall Gutter ..	8·9		" " ..	" " "	+18·0	Agricultural.
Dibbin Brook	24·2		Bromborough Docks ..	Through Bromborough Docks.	+22·3	Industrial and agricultural.
Keckwick Brook ..	12·0		Upper Estuary ..	Howley Weir	+ 3·0	Agricultural.
Lumb Brook	3·6	282·0	" "	" "		"
Rams Brook	9·2		" " ..	Natural flow into Upper Estuary.	+11·4	"
Bowers Brook	3·8		" " ..	" " "	+10·3	Industrial and agricultural.
Penketh Brook	5·3		" " ..	" " "	+ 5·0	Agricultural.
Stewards Brook ..	2·5		" " ..	" " "	+ 4·2	"
Whittle Brook	5·8		" " ..	" " "	+ 4·2	"
Walton Brooks (various)	5·0		" " ..	" " "	+ 0·5	"
Padgate Brook ..	5·0		" " ..	" " "	− 0·5	"
Spittle Brook	5·0		" " ..	" " "	− 0·5	"
St. Helens Canal ..	5·0		" " ..	Natural flow into Upper Estuary through locks at Widnes.	+ 9·2	Industrial and agricultural.
Into Narrows						
Birket and Fender Brooks						
Birket	13·73		Birkenhead sewer	Through Great Culvert, Birkenhead.	+25·0	Industrial and agricultural.
Fender	7·88	27·5	" "		+25·0	
Rimrose Brook	5·9		Bootle sewer	Through sewer outfall under Gladstone Dock.	+29·0	" "
Into Liverpool Bay						
Alt River .. / Downholland Brook		92·0	Liverpool Bay ..	Natural flow across Sandbanks off Gt. Crosby.	+34·3	Industrial and agricultural.
Urban Catchments Warrington and below						
Liverpool, Garston and Bootle	21·1		Upper Estuary ..	Town sewer outfalls	+18 to +30	Industrial.
Warrington	1·2	37·4	" " ..	" " "	0	"
Wallasey and Birkenhead	12·0		" " ..	" " "	+22 to +29	"
Runcorn and its brook	3·1		" " ..	" " "	+ 9 to +12	"
Average Rainfall						
Estuary below Howley Weir	36·2					
Manchester Ship Canal surface catchment	0.9	37·1				
Total	1,805·0					

TABLE 2—*Records of the Flow of Certain Streams discharging into the Mersey Estuary*

River.	Date.	Time (G.M.T.).	Method of gauging.	Flow (gal. per sec.).	Stage (height above Ordnance Datum).
River Alt	19. 6.33		Meter	120	11′ 10″
	12. 7.33		,,	128	11′ 11″
	11.10.33		,,	563	13′ 10″
	1.11.33		,,	133	12′ 1¼″
	8. 1.34		,,	384	13′ 2″
	9. 6.34		Floats	72	11′ 1¼″
Downholland Brook ..	19. 6.33		Floats	100	
River Bollin	22. 9.33		Meter	253	
Glazebrook (Upper Station)	23. 6.33		Meter	211	33′ 2″
	16.10.33		,,	612	34′ 8″
	17. 1.34		,,	1,736	37′ 0½″
Glazebrook (Lower Station)	23. 6.33		Meter	229	30′ 9″
	16.10.33		,,	685	32′ 2″
River Gowy (tidal), fresh-water flow	27. 9.33	10·21	Meter	128	
	27. 9.33	11.17	,,	124	
	28. 9.33	12.00	,,	118	
	28. 9.33	12.45	,,	118	
	25. 6.34	15.00	,,	53	
Holpool Gutter (tidal), fresh-water flow	25. 6.34	16.15	Surface float	18	
River Irwell	20. 9.33		Meter	1,374	80′ 0″
	16.11.33		,,	5,399	80′ 11″
	16. 1.34		,,	7,791	81′ 9″
River Mersey (Flixton Bridge)	23. 8.33		Meter	1,146	34′ 10″
	22. 9.33		,,	779	34′ 5″
	18.10.33		,,	1,898	35′ 4″
	9. 1.34		,,	1,287	34′ 11½″
	15. 1.34		,,	3,632	36′ 11½″
	26. 2.35		,,	4,921	37′ 9½″
River Mersey (Howley Weir)	5.10.34	11.35 to 13.02	Meter	41,829	Roughly 18′
		13.02 to 13.55		18,705	,,
	8.10.34	12.52 to 14.20	Meter and	9,958	,,
		14.20 to 15.25	floats	7,554	,,
	18.10.34	11.50 to 13.10	Meter	8,304	,,
	30.10.34	11.47 to 13.14	,,	18,496	,,
	2.11.34	12.00 to 13.00	Surface floats	4,447	,,
	12.12.34	11.37 to 12.42	Meter	12,128	,,
	31.12.34	11.33 to 12.43	,,	16,380	,,
	7. 1.35	11.25 to 12.40	,,	11,585	,,
Red Brook	22. 9.33		Surface float	25	
Sankey Brook	17.10.33		Meter	384	21′ 3″
	19. 1.34		,,	652	22′ 1″
	12. 4.34		,,	234	21′ 2″
	8. 6.34		Floats	124	20′ 10½″
	5. 7.34	10.45 to 11.30	,,	102	20′ 10½″
	,,	13.00 to 13.40	Meter (A)	65	20′ 9½″
	,,	13.49 to 14.12	Floats	97	20′ 9½″
	,,	15.45 to 16.15	Meter (A)	102	20′ 9¼″
	,,	17.10 to 17·30	,, (A)	97	20′ 9¼″
	,,	18.40 to 19.12	,, (A)	113	20′ 9½″
	,,	20.00 to 20.26	,, (A)	108	20′ 9½″
	,,	21.15 to 21.50	,, (A)	108	20′ 10″
	,,	22.52 to 23.20	,, (A)	127	20′ 10¼″
	6. 7.34	00.50 to 01.20	,, (A)	127	20′ 10″
	,,	02.50 to 03.22	,, (A)	114	20′ 10″
	,,	04.51 to 05.18	,, (A)	103	20′ 10″
	,,	06.24 to 06.46	,, (A)	97	20′ 9½″
	,,	07.55 to 08.16	,, (A)	99	20′ 9½″
	24. 7.34		,,	146	20′ 11½″

(A) Indicates that gauging was made on a restricted cross-section above the cross-section normally used.

TABLE 3—*Approximate Daily Flow from Rivers and Streams into the Mersey Estuary*

Rivers, brooks, etc.	Flow (millions of gallons). From figures supplied by Manchester Ship Canal Co.	From stage-discharge curves obtained by gauging during the present investigation and averaged stage levels.	From other sources.	Accepted figure for flow.	Percentage of total fresh-water flow.	Remarks.
Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7
Irwell River ..	233·6	(236·7)	—	233·6	23·4	Col. 2 based principally on gaugings carried out by Manchester Ship Canal Co. in 1923. Col. 3 from stage discharge curve and gauge readings from City Engineer, Salford. Average for 6 months (1933) with allowance made for rainfall during gauging period. See footnote.
Irk River ..	18·7	—	12·5	15·6	1·6	Col. 2 as above. Col. 4 from gaugings taken daily by the City Engineer, Manchester, in 1914 for 12 months.
Medlock River	—	—	15·0	15·0	1·5	Col. 4 from gaugings taken daily by the City Engineer, Manchester, in 1922 for 12 months.
Worsley Brook	3·7	—	—	3·7	0·4	Col. 2 based principally on gaugings carried out by Manchester Ship Canal Co. in 1923.
Longford Brook	1·3	—	—	1·3	0·1	Col. 2 based principally on gaugings carried out by Manchester Ship Canal Co. in 1923.
Mersey River..	207·5	211·2	—	209·3	20·9	Col. 2 as above. Col. 3 from stage-discharge curve and 12 months' gauge readings from the automatic level recording gauge at Flixton Bridge. This was read from February, 1934 to February, 1935, which was a normal year and no adjustment for rainfall has been made.
Glazebrook ..	8·1	—	—	8·1	0·8	Col. 2 as above.
Red Brook ..	3·7	2·2	—	3·7	0·4	Col. 2 as above and accepted as only one gauging was taken during the present investigation.
Bollin River ..	33·0	22·4	—	33·0	3·3	Col. 2 as above and accepted as only one gauging was taken during the present investigation.
Sankey Brook..	—	33.2	52.3	52.3	5.2	Col. 3 adjusted for low levels during drought (see footnote). Col. 4 from average rainfall in catchment area less 15″.
Ditton Brook..	—	—	18·8	18·8	1·9	Col. 4 from a comparison of the catchment area with that of Sankey Brook.
Alt River ..	—	24·6 }	54·8 (Alt River and Downholland Brook together)	45·0 (Alt River and Downholland Brook together)	4·5 (Alt River and Downholland Brook together)	Col. 3 adjusted for low levels during drought (see footnote). Col. 4 from average rainfall in catchment area less 15″. (Alt River and Downholland Brook together)
Downholland Brook	—	20·4 }				
Weaver River..	—	—	182·9	182·9	18·3	Col. 4 from the Engineer of the River Weaver Navigation. A year's statistics were supplied from August, 1905 to July, 1906 (inc.). This was an average year for rainfall.
Holpool Gutter	—	—	4·4	4·4	0·4	Col. 4 from a comparison of the catchment area with that of the River Weaver.
Gowy River ..	—	—	24·9	24·9	2·5	Col. 4 from a comparison of the catchment area with that of the River Weaver.
Poolehall Gutter	—	—	3·1	3·1	0·3	Col. 4 from a comparison of the catchment area with that of the River Weaver.
Birkett and Fender Rivers	—	—	11·2	11·2	1·1	Col. 4 from a run-off of 28″ less 15″ of rainfall over the catchment area for the year.
Dibbin Brook..	—	—	16·2	16·2	1·6	Ditto, but from a run-off of 32″ less 15″ for the year.

TABLE 3—*continued*

Rivers, brooks, etc.	Flow (millions of gallons). From figures supplied by Manchester Ship Canal Co.	From stage-discharge curves obtained by gauging during the present investigation and averaged stage levels.	From other sources.	Accepted figure for flow.	Percentage of total fresh-water flow.	Remarks.
Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7
All other outfalls (apart from domestic sewage and industrial effluents)	—	—	36·8	36·8	3·7	Col. 4 from a run-off of 31″ less 15″ over catchment area per year.
Urban outfalls	—	—	39·3	39·3	3·9	Col. 4 from rainfall over catchment areas affected. 85 per cent. of rain assumed to run off.
Average rainfall						
Over Estuary below Howley Weir	—	—	44·2	44·2	4·4	Col. 4 from average rainfall obtained from "British Rainfall 1933", pp. 199–200.
Over Ship Canal	—	—	1·3	1·3	0·1	Col. 4 from average rainfall obtained from "British Rainfall 1933", pp. 199–200.
TOTAL ..	—	—	—	1,003·8	100	—

During the period over which the gauge levels were read, the rainfall was abnormally low and the flows observed were less than the mean flow for a period of average rainfall.

For Sankey Brook and the River Alt (with Downholland Brook) the flow during a year of average rainfall was estimated from the following equation :—

$$\text{Flow during a year of average rainfall} = \text{Mean flow during 1933} \times \frac{\text{Average annual rainfall} - 15''}{\text{Rainfall in 1933} - 15''}$$

For the River Irwell the same procedure was used, but it was found that this made the resultant flow too large in comparison with the Mersey and also with the figures obtained from the Manchester Ship Canal Co.

The flow of the Mersey was gauged during a year of normal rainfall : February, 1934 to February, 1935.

In consequence of the differences found in the figures for the Irwell, the figure given by the Manchester Ship Canal Co. was accepted.

The figure given in brackets in Col. 3 was obtained from the following equation :—

$$\text{Flow during a year of normal rainfall} = \text{Flow measured in 1933} \times \frac{\text{Average annual rainfall}}{\text{Rainfall in 1933}}$$

On the assumption that the average annual rainfall over the Irwell catchment area is 45 in. and the run-off 29 to 30 in., the flow of the Irwell has been estimated at 280 to 294 million gallons per day or 47 to 61 million gallons per day more than the figure accepted in Table 3. Gauging over a long period would be necessary to obtain a reliable average figure.

TABLE 5—*Organic Content of some Fresh-Water Streams discharging into the Mersey Estuary*

(Figures in brackets are estimated)

Stream.	Date.	Time (G.M.T.).	Total organic matter (parts per 100,000). Organic carbon.	Total organic matter (parts per 100,000). Kjeldahl nitrogen.	Soluble organic matter (parts per 100,000). Organic carbon.	Soluble organic matter (parts per 100,000). Kjeldahl nitrogen.	Flow of stream (thousands of gallons per day).	Total weight of organic carbon discharged per day (lb.).
River Mersey at Howley Weir	29/5/34	09·00	1·9	0·63			Mean value for the period = 124,000	Mean concentration of organic carbon = 1·72 parts per 100,000. Mean discharge of organic carbon = 21,380 lb. per day
		10·00	2·1	0·60				
		11·00	1·9	0·63				
		12·00	1·7	0·61				
		13·00	1·7	0·63				
		14·00	1·8	0·59				
		15·00	1·7	0·69				
		16·00	1·6	0·67				
		17·00	2·1	0·73				
		18·00	1·9	0·67				
		19·00	1·9	0·67				
		20·00	1·6	0·67				
		21·00	2·9	0·69				
		22·00	1·4	0·67				
		23·00	1·7	0·67				
		24·00	1·3	0·61				
	30/5/34	02·00	1·2	0·63				
		03·00	1·4	0·65				
		04·00	1·4	0·63				
		05·00	1·3	0·67				
		06·00	1·4	0·69				
		07·00	1·4	0·67				
		08·00	2·2	0·63				
River Mersey at Howley Weir	3/6/34	Low water	2·8	0·83	1.2	0·67	81,200	22,700
	4/6/34	,,	2·4	0·96	1·3	0·81	78,000	18,700
	5/6/34	,,	2·6	1·11	1·1	0·93	86,700	22,500
	6/6/34	,,	3·5	1·16	1·4	0·98	102,000	35,700
	7/6/34	,,	2·4	1·80	1·5	1·22	108,000	26,000
	8/6/34	,,	—	1·37	1·9	1·16	130,000	
River Mersey at Warrington Bridge	3/6/34	Low water	2·2	0·83	1·1	0·67	81,000	17,900
	4/6/34	,,	2·3	1·08	1.3	0·85	78,000	18,000
	5/6/34	,,	3·3	1·22	1·3	0·98	86,700	28,700
	6/6/34	,,	3·7	1·20	1·1	1·00	102,000	37,700
	7/6/34	,,	2·2	1·12	1·5	1·02	108,000	23,800
	8/6/34	,,	4·3	1·32	1·7	1·08	130,000	56,000
River Mersey at Warrington	31/5/34	Low water	2.1	0·83	1·3	0·67		
	,,	,,	2·2	0·83	—	0·67		
Sankey Brook ..	3/6/34		8·1	0·78	4·9	0·67	(10,700)	8,660
	4/6/34		8·1	4.80	3·7	4·40	(10,700)	8,660
	5/6/34		21·8	3·32	6.4	2·50	(10,700)	23,400
	6/6/34		21·2	2·88	5·8	1·96	(10,700)	22,700
	7/6/34		—	2·30	5·5	2·42	(10,700)	—
	8/6/34		10·5	2·85	4·4	2·11	10,700	11,200
Sankey Brook ..	5/7/34	09·00	20·0	1·0				
		09·30	14·2	2·4				
		10·00	13·2 (09·00–11·00: av. = 15·3)	2·7			8,760	13,400
		10·30	15·6	3·7				
		11·00	13·6	4·6				
		11·30	18·6	3·5				
		12·00	21·8	4·7				
		12·30	23·8 (11·30–13·30: av. = 20·7)	1·4			5,590	11,600
		13·00	21·6	5·0				
		13·30	17·8	4·5				
		14·00	13·0	4·8			8,340	10,840
		14·30	9·6	2·9				
		15·00	9·4 (14·30–16·00: av. = 10·2)	4·4			8,820	8,990
		15·30	10·2	3·5				
		16·00	11·6	4·3				
		16·30	10·2	4·1				
		17·00	10·6 (16·30–17·30: av. = 10·0)	3·8			8,390	8,400
		17·30	9·2	3·7				
		18·00	8·0	2·4				
		18·30	7·4 (18·00–19·00: av. = 6·8)	2·7			9,730	6,610
		19·00	5·0	2·6				
		19·30	9·6	2·7				
		20·00	9·4 (19·30–20·30: av. = 9·5)	3·4			9,350	8,880
		20·30	9·6	5·7				
		21·00	9·0 (21·00–21·30: av. = 8·5)	4·3			9,300	7,910
		21·30	8·0	4·2				
		22·00	7·2	3·8				
		22·30	9·0 (22·00–23·00: av. = 7·8)	3·3			10,900	8,510
		23·00	7·2	2·7				
		23·30	8·4	2·8				
		24·00	10·2 (23·30–01·00: av. = 6·8)	2·7			10,900	7,430
		00·30	5·0	2·5				
		01·00	3·4	2·3				

TABLE 5—*continued*

Stream.	Date.	Time (G.M.T.).	Total organic matter (parts per 100,000).		Soluble organic matter (parts per 100,000).		Flow of stream (thousands of gallons per day).	Total weight of organic carbon discharged per day (lb.).
			Organic carbon.	Kjeldahl nitrogen.	Organic carbon.	Kjeldahl nitrogen.		
Sankey Brook (contd.)	5/7/34	01·30	7·4 (av. = 6·3)	3·6			9,850	6,220
		02·00	6·4	0·6				
		02·30	3·0	2·1				
		03·00	8·4	2·5				
		03·30	9·4 (av. = 7·5)	—			8,860	6,660
		04·00	6·8	3·2				
		04·30	7·6	0·9				
		05·00	6·2	3·7				
		05·30	6·2 (av. = 5·9)	2·2			8,340	4,940
		06·00	7·6	2·4				
		06·30	3·8	2·3				
		07·00	2·0 (av. = 4·3)	2·2			8,550	3,680
		07·30	2·8	2·1				
		08·00	5·4	2·1				
		08·30	5·8	2·1				
		09·00	5·4	2·2				
River Alt	31/5/34	Low water	2·4	0·78	—	0·67	6,850	1,650
River Gowy	14/6/34	Low water	1·5	0·25	0·5	0·09		
	25/6/34	,,	1·4	0·58	0·9	0·38	4,600	644
Holpool Gutter ..	25/6/34	Low water	2·9	1·16	1·8	0·69	1,560	460

TABLE 7—*Volume of Sewage discharged into the Mersey Estuary in 1933*

No. of outfall (Fig. 4).	Authority.	Sewered population.	Approximate water consumption (gal. per head per day).	Treatment of sewage before discharge.
1	Formby U.D.C.	7,970	30	Septic tanks.
2, 3	Gt. Crosby U.D.C. / ,,	18,290	—	None.
4, 5	Waterloo-with-Seaforth	17,000	25	None.
6	Borough of Bootle	36,700	34	None.
7	,, ,, ,,	29,500	,,	
8	,, ,, ,,	2,400	,,	
9	,, ,, ,,	8,200	,,	
10	Liverpool Corporation	30,600	36	None.
11	(Total population 855,540; population connected to each outfall estimated from daily flows)	121,000	,,	
12		35,400	,,	
13		10,400	,,	
14		93,000	,,	
15		145,000	,,	
16		0	(storm water)	
17		89,200	36	None.
18		26,700	,,	
19		69,800	,,	
20		34,900	,,	
21		28,600	,,	
22		4,300	,,	
23		5,400	,,	
24		35,200	,,	
25		18,800	,,	
26		44,800	,,	
27		1,200	,,	
28		60,100	,,	
29		2,300	,,	
30	Whiston R.D.C.	10,073	—	5 small disposal plants using different methods.
31	,, ,,	636	—	
32, 33, 34	Municipal Borough of Widnes / ,, ,, ,, / ,, ,, ,,	472	32	None.
35, 36, 37	,, ,, ,,	3,990	,,	
38	,, ,, ,,	20,850	,,	
39	,, ,, ,,	4,400	,,	
40	,, ,, ,,	3,810	,,	
41	,, ,, ,,	6,350	,,	
42	,, ,, ,,	660	,,	
43	Warrington U.D.C.	1,163	19 domestic 40 total	None.
44	,, ,,	2,051		
45	,, ,,	137		
46	,, ,,	1,048		
47	,, ,,	4		
48	,, ,,	4,107		
49	,, ,,	2,679		
50	,, ,,	—		
51	,, ,,	1,612		
52	,, ,,	1,212		
53	Warrington R.D.C.	1,748	—	Mainly by septic tanks.
54	,, ,,	288	—	Septic tanks.
55	,, ,,	3,196	—	Mainly by septic tanks.
56	Runcorn R.D.C.	2,750	20	None.
57	,, ,,	1,400	,,	
58	,, ,,	600	,,	
59	,, ,,	200	,,	
60	,, ,,	8,500	,,	
61	,, ,,	250	,,	Biological treatment.

TABLE 7—*continued*

No. of outfall (Fig. 4).	Authority.	Sewered population.	Approximate water consumption (gal. per head per day).	Treatment of sewage before discharge.
62	Runcorn R.D.C.	1,700	26	} None.
63	" "	3,700	"	
64	" "	6,325	32	
65	" "	4,380	"	
66	" "	2,500	30	Biological treatment.
67	" " . . }	23,640	26	None.
68	" " . .			
69	Ellesmere Port U.D.C. . .	12,750	34	} Bacteria beds.
70	" " " . .	5,500	"	
71	" " " . .	5,250	"	None.
72	Bebington U.D.C.	1,500	29	Bacteria beds.
73	" " . . }		Trade wastes	
74	" " . .			
75	" " . . }	50	29	None.
76	" " . .			
77	" " . .			
78	" " . . }	6,650	"	Screened.
79	" " . .			
80	" "	3,600	"	Bacteria beds.
81	" "	550	"	} None.
82	" "	16,000	"	
83	" "	3,750	"	
84	County Borough of Birkenhead	3,160	25	} None.
85	" " "	6,480	"	
86	" " "	15,280	"	
87	" " "	10,360	"	
88	" " "	30,920	"	
89	" " "	1,280	"	
90	" " "	92,000	"	
91	County Borough of Wallasey }	30,000	25	} None.
92	" " "			
93	" " "			
94	" " "			
95	" " "			
96	" " " }	89,000	"	
97	" " "			
98	" " "			
99	" " "			
100	" " "	3,220	"	
101	" " "	5,300	"	Screened and settled.
102	Hoylake U.D.C.	11,090	45	Partial settlement.
103	" "	5,130	"	None.
104	" "	1,810	"	None.
105	" "	390	"	Partial settlement.

TABLE 10—*Estimated Volume of Effluents and Weight of Organic Carbon discharged from Tanneries into the Mersey Estuary*

No. of tannery.	District in which effluents are discharged.	Volume of effluent discharged (gal. per day).			Estimated weight of organic carbon discharged (lb. per day).			Total organic carbon (lb. per day).
		Soak water.	Liming water.	Spent tan liquor.	Soak water.	Liming water.	Spent tan liquor.	
2	Runcorn ..	3,500	1,250	1,350	55	31	194	280
3	Runcorn ..	32,500	18,000	23,500	505	456	3,370	4,331
4	Runcorn ..	11,200		2,800	229		401	630
5	Runcorn ..	6,000	4,000	4,000	93	101	573	767
6	Runcorn ..	15,400	13,400	8,100	238	340	1,160	1,738
7	Warrington	2,000	2,000	2,000	31	51	287	369
8	Warrington	2,500	5,000	3,600	40	126	516	682
9	Warrington	12,000	1,200	1,800	185	31	258	474
10	Warrington	8,000	1,700	4,000	123	44	573	740
11	Warrington	11,100	3,500	2,500	172	88	357	617
12	Warrington	10,800		2,900	220		414	634
13	Warrington	40,000	20,000	8,000	622	507	1,146	2,275
15	Warrington	138,200		21,800	2,820		3,150	5,970
16	Warrington	1,600	800	50	24	20	7	51
18	Warrington	2,000	8,000	2,000	31	203	287	521
19	Warrington	7,000	4,000	2,500	108	101	357	566
20	Warrington	3,400	750	85	53	20	13	86
21	Warrington	30,000		—	613		—	613
22	Bootle ..	5,000	860	860	77	22	123	222
23	Bootle ..	10,000	1,700	1,700	154	44	243	441
24	Bootle ..	3,800	5,700	9,500	60	146	1,360	1,566
25	Bootle ..	1,800	5,700	2,100	29	146	300	475
26	Bootle ..	10,000	3,500	1,300	154	88	190	432
27	Bootle ..	2,400	2,400	1,800	37	62	258	357
28	Birkenhead	39,500	22,000	10,000	613	558	1,430	2,601
29	Liverpool ..	5,300	2,600	1,760	82	66	251	399
30	Liverpool ..	35,000		6,200	710		888	1,598
31	Liverpool ..	3,700	1,200	860	134	31	123	288
32	Liverpool ..	21,700	3,400	1,100	337	86	159	582

TABLE 12—*Concentration of Dissolved Oxygen in the Mersey Estuary under Different Tidal Conditions*

Date.	Height of high water (ft.).	Depth of sample (ft.).	Salinity (gm. per 1,000 gm.).	Temperature (°C.).	Dissolved oxygen concentration (per cent. of saturation value).
30.5.33	23·4	0	21·8	15	59
		9	21·8	15	57
		18	22·2	15	57
		26	22·1	15	56
		0	21·9	15	59
		9	21·8	15	58
		18	21·9	15	55
		26	21·9	15	57
		0	21·0	15	59
		9	21·6	15	59
		18	21·9	15	58
		27	21·6	15	57
		0	21·5	15	62
		9	21·8	15	57
		18	21·8	15	58
		27	21·7	15	58
		0	22·3	15	57
		10	22·6	15	56
		20	22·5	15	57
		30	22·6	15	58
		0	22·7	15	57
		11	22·5	15	57
		22	22·6	15	57
		32	23·0	15	57
		0	24·6	15	63
		12	24·5	15	61
		24	24·3	15	60
		35	24·2	15	61
		0	25·1	15	60
		13	25·4	15	59
		26	25·2	15	60
		38	25·0	15	60
		0	26·3	15	61
		14	26·0	15	61
		28	25·8	15	61

Date.	Height of high water (ft.).	Depth of sample (ft.).	Salinity (gm. per 1,000 gm.).	Temperature (°C.).	Dissolved oxygen concentration (per cent. of saturation value).
30.5.33 (contd.)	23·4	42	26·2	15	61
		0	26·5	15	61
		15	26·5	15	61
		30	26·5	15	61
		43	26·4	15	63
		0	26·6	15	61
		15	26·7	15	61
		30	26·4	15	60
		44	26·7	15	60
		0	26·5	15	61
		16	27·0	15	63
		32	27·0	15	62
		47	27·1	15	63
		0	25·6	15	62
		16	27·0	15	63
		32	27·3	15	61
		46	25·4	15	62
6/6/33	26·4	0	23·0	19	82
		9	23·4	18½	72
		18	23·4	18½	75
		27	23·5	18½	75
		0	23·3	18½	74
		9	23·3	18½	74
		18	23·3	18½	75
		27	23·5	18½	73
		0	23·1	19	87
		9	23·7	18½	72
		18	23·5	18½	72
		29	23·9	18½	72
		0	23·7	18½	77
		9	23·9	18½	72
		18	24·0	18½	71
		27	24·0	18½	74

Date.	Height of high water (ft.).	Depth of sample (ft.).	Salinity (gm. per 1,000 gm.).	Temperature (°C.).	Dissolved oxygen concentration (per cent. of saturation value).
6/6/33 (contd.)	26·4	0	23·6	19½	90
		9	23·7	18½	76
		18	24·0	18½	75
		26	23·9	18½	72
		0	24·0	19	76
		8	23·8	19	75
		16	24·0	19	75
		24	24·0	19	74
		0	23·3	19	74
		7	23·6	19	74
		14	23·9	19	73
		22	24·0	19	74
		0	23·1	19½	78
		10	23·3	19½	77
		20	23·6	19½	75
		0	22·2	19½	72
		9	23·0	19½	75
		0	20·8	20	70
		18	23·0	20	80
		8	21·1	20	68
		16	23·2	20	72
		0	20·3	20½	63
		37	20·1	20½	68
		14	20·4	20½	67
		0	20·0	21	62
		6	20·0	21	61
		12	20·0	21	63
		0	19·5	21½	63
		6	19·6	21	64
		12	19·8	21	63
12/6/33	26·3	0	8·3	18	9
		5	9·3	18	9
		11	10·2	18	9
		0	7·2	18½	7

12/6/33 (contd.)	26·3	6	8·4	18½	7
		12	9·2	18½	7
		0	7·1	18½	7
		5	7·3	19	6
		9	7·9	19	5
		0	6·6	19	9
		5	6·6	19	4
		9	7·4	19	1
		0	5·8	19½	5
		5	6·3	19½	4
		9	6·5	19	4
		0	5·9	19½	2
		5	6·0	19½	2
		11	7·9	19	0
		0	15·2	19½	35
		3	15·8	19½	35
		7	13·8	19½	28
		0	18·9	19	37
		5	19·3	18½	38
		11	20·3	18½	35
		0	19·5	18½	35
		6	20·3	18½	38
		11	20·9	18	37
		0	21·7	18	44
		6	22·3	18	44
		12	22·1	18	50
		0	22·6	17½	46
		6	22·8	17½	45
		13	22·6	17½	42
		0	23·0	17½	48
		7	23·2	17½	48
		14	22·8	17½	49
		0	22·6	17½	44
		7	22·8	17½	46
		14	23·0	17½	48
		0	23·0	17½	45
		7	23·2	17½	47
		14	23·1	17½	49
		0	23·1	17½	49
		7	23·4	17½	51
		14	23·5	17½	53
15/6/33	23·4	0	24·5	17½	49
		11	25·0	17½	47
		22	25·3	17½	51
		33	24·7	17½	44
		0	24·6	17½	49

15/6/33 (contd.)	23·4	11	25·0	17½	49
		22	25·5	17½	54
		33	25·5	17½	49
		0	24·6	18	48
		11	25·2	18	51
		22	25·3	17½	49
		33	25·5	17½	53
		0	24·7	18	48
		11	25·2	17½	55
		22	25·7	17½	49
		33	25·8	17½	50
		0	25·1	18	49
		12	25·9	17½	56
		24	26·3	17½	50
		36	26·2	17½	48
		0	25·6	18	46
		12	26·2	17½	44
		24	26·8	17½	47
		36	26·6	17½	47
		0	26·5	18	60
		13	27·1	17½	49
		26	27·1	17½	50
		39	27·1	17½	51
		0	27·8	17½	49
		14	28·8	17½	52
		28	28·8	17½	48
		42	28·5	17½	53
		0	28·2	17½	58
		15	28·4	17½	56
		30	28·3	17½	57
		45	28·1	17½	55
		0	28·5	17½	59
		16	28·6	17½	56
		32	28·4	17½	55
		48	28·5	17½	59
		0	28·8	17½	62
		17	28·8	17½	61
		34	28·8	17½	61
		51	28·8	17½	57
		0	28·9	17½	67
		17	29·1	17½	65
		34	29·0	18	65
		51	28·9	18	63
		51	29·2	18	66
21/6/33	25·1	0	0·4	15	25
		5	0·4	15	22

21/6/33 (contd.)	25·1	0	0·4	15	24
		5	0·3	15	23
		0	1·0	15½	2
		7	0·5	15½	1
		0	3·4	16	7
		5	3·4	16	2
		9½	2·8	15½	0
		0	3·6	16	1
		5	3·4	16	2
		10	3·5	16	0
		0	2·9	16	3
		7	3·4	16	3
		0	1·8	16	2
		6	2·2	16	1
		0	0·6	16	5
		6	0·6	16	2
		0	0·4	15½	9
		5	0·4	15½	7
		0	0·4	15½	9
		5	0·4	15½	7
		0	0·4	15½	11
		4½	0·3	15½	8
26/6/33	25·5	0	0·9	19	16
		0	0·8	19	24
		0	0·8	20	21
		0	0·9	20	9
		4	1·1	20	9
		0	8·9	20	20
		8	10·2	20	26
		0	11·4	19½	31
		8	11·6	19½	45
27/6/33	25·4	0	26·2	17	60
		10	26·4	17	59
		20	26·7	17	57
		30	26·6	17	61
		0	26·0	16½	58
		10	26·2	16½	59
		20	26·4	16½	54
		30	26·8	17	57
		0	26·0	16½	62
		10	26·5	16½	57
		20	26·5	16½	54
		30	26·6	16½	56
		0	26·4	16½	60
		12	26·5	16½	57

TABLE 12—*continued*

Date.	Height of high water (ft.).	Depth of sample (ft.).	Salinity (gm. per 1,000 gm.).	Temperature (°C.).	Dissolved oxygen concentration (per cent. of saturation value).
27/6/33 (contd.)	25·4	24	27·0	16½	58
		36	27·5	16½	58
		0	27·2	16½	66
		20	27·3	16½	60
		30	27·1	16½	63
		40	27·6	16½	62
		0	27·8	16½	69
		16	27·9	16½	67
		32	27·8	16½	65
		48	27·8	16½	63
		0	28·8	16½	72
		17	28·7	16½	73
		34	28·3	16½	73
		51	28·7	16½	71
		0	29·2	17	80
		18	29·2	17	78
		36	29·1	17	79
		54	29·0	17	77
		0	29·5	16½	86
		18	29·4	16½	83
		36	29·7	16½	85
		54	29·6	16½	81
		0	30·1	17	95
		19	30·2	17	90
		38	30·0	17	90
		56	30·1	17	95
3/7/33	24·1	4	0·4	20	16
		5	0·4	20	20
		5	0·9	20	15
		2	0·5	20	5
		4	0·7	20	1
		2	6·6	20½	23

Date.	Height of high water (ft.).	Depth of sample (ft.).	Salinity (gm. per 1,000 gm.).	Temperature (°C.).	Dissolved oxygen concentration (per cent. of saturation value).
5/7/33	25·3	0	24·4	19½	99
		18	24·7	19½	96
		0	21·9	20	109
		16	24·6	20	95
		0	21·9	20½	101
		12	21·9	20½	96
		0	21·8	20½	99
		8	22·2	20½	104
		0	20·0	22	87
		6	19·9	22	86
		0	15·8	22½	48
		4	16·2	22½	36
		0	14·3	23	37
		0	11·6	23	18
		0	10·3	23	17
10/7/33	28·0	3	0·7	20½	7
		3	0·6	20½	3
		3	0·4	20½	0
		3	0·4	20½	0
11/7/33	27·5	3	0·6	20½	3
		3	0·6	20½	1
		3	0·6	20½	0
		3	0·6	20½	0
		3	0·5	20½	1
17/7/33	22·6	0	25·6	18	75
		9	26·3	18	72
		18	26·6	18	75
		0	25·0	18	78
		9	26·7	18	77
		18	26·6	18	71
		0	24·9	18	77
		9	25·2	18	74

Date.	Height of high water (ft.).	Depth of sample (ft.).	Salinity (gm. per 1,000 gm.)	Temperature (°C.).	Dissolved oxygen concentration (per cent. of saturation value).
17/7/33 (contd.)	22·6	18	26·1	18	71
		0	24·3	18	76
		8	24·4	18	75
		16	24·7	18	74
		0	23·9	18	76
		7	23·9	18	75
		14	23·8	18	74
		0	23·6	17½	78
		6	23·7	17½	75
		12	23·9	17½	74
		0	23·4	16½	75
		6	23·2	16½	74
		11	23·2	16½	74
		0	23·2	17	77
		9	23·2	17	75
		0	23·0	17	76
		8	23·1	17	75
		0	22·8	17	77
		6	22·9	17	76
		0	22·8	16	77
		6	22·8	16	76
		0	22·8	17	84
		5	22·8	17	81
21/7/33	24·8	8	29·2	19	95
		8	29·3	19	97
		8	29·4	18½	103
		8	28·4	18½	94
		8	28·5	18½	92
		8	29·0	18½	96
		8	28·9	18½	96
		8	29·0	19	96
		8	28·9	19	97
		8	29·0	19	107
		8	29·1	19	109

24/7/33	26·6	8	27·1	19½	72
		8	26·7	19½	71
		8	26·9	19½	71
		8	27·0	19½	80
		8	27·2	19½	73
		8	27·3	19½	85
		8	27·7	19½	78
		8	27·5	19½	72
		8	27·3	19½	72
		8	26·5	19½	66
		8	26·9	19½	69
		8	26·6	19½	68
27/7/33	26·9	8	25·2	20½	45
		8	25·1	20½	46
		8	25·2	20½	47
		8	25·8	20½	53
		8	26·0	20½	51
		8	26·3	20½	49
		8	26·1	20½	47
		8	26·2	20½	47
		8	26·2	20½	48
		8	26·2	20½	45
		8	25·9	21	42
30/7/33	24·5	8	26·3	19½	71
		8	26·5	19½	73
		8	26·3	19½	72
		8	26·4	19½	73
		8	26·4	19½	74
		8	26·7	19½	73
		8	26·1	19½	73
		8	25·9	19½	75
		8	26·7	19½	72
		8	26·9	19	69
		8	26·9	19	69
		8	26·9	19	69
		8	26·9	19	71
4/8/33	25·9	8	27·1	18½	56
		8	27·0	18½	59
		8	26·7	19	59
		8	27·3	19	54
		8	27·3	19	58
		8	27·6	19	58
		8	27·7	19	61
4/8/33 (contd.)	25·9	8	27·6	19	59
		8	28·0	19	60
		8	28·1	19	60
		8	28·3	19	60
		8	28·5	19	63
8/8/33	28·9	4	26·0	19½	40
		4	25·7	19½	38
		4	25·9	19½	38
		4	25·6	19½	27
		4	25·8	19½	27
		8	25·5	19½	29
		8	25·6	19½	20
		8	25·3	19½	32
		8	25·3	19½	33
		8	24·9	19½	41
9/8/33	28·3	4	25·4	18½	39
		4	24·9	19	37
		4	24·4	19	16
		4	24·6	19	40
		4	24·9	19	32
		4	25·2	19	33
		4	25·3	19	35
		4	25·1	19	43
		4	24·7	19	37
11/8/33	25·9	8	25·8	18½	32
		8	25·5	18½	32
		8	25·1	18½	32
		8	26·0	18½	33
		8	26·4	18½	35
		8	26·8	18½	32
		8	28·2	18½	43
		8	28·3	18½	42
		8	28·7	18½	43
		8	29·0	18½	45
		8	27·6	18½	48
14/8/33	21·5	8	27·7	18½	49
		8	27·7	19	49
		8	27·8	19	51
		8	27·8	19	49
		8	27·6	19	52
		8	27·7	19	55
		8	27·8	19	51
		8	27·9	20	53
14/8/33 (contd.)	21·5	8	27·9	19	48
		8	28·1	19	49
		8	28·1	19	47
		8	28·1	19	42
		8	27·8	18½	47
		8	27·7	18½	48
		8	27·5	18½	54
22/8/33	28·1	4	26·9	17	65
		40	27·8	17	57
		4	27·3	17	62
		32	27·5	17	54
		4	27·3	17	56
		16	27·3	17	59
		4	26·9	17	56
		24	26·7	17	58
23/8/33	28·5	4	26·4	16½	53
		52	27·6	16½	54
		4	27·1	16½	54
		53	27·6	16½	53
		4	26·8	16½	57
		53	27·6	16½	53
		4	26·8	16	54
		23	26·9	16	54
		4	26·9	16	53
		4	26·2	16	53
		16	26·6	16	53
		13	25·3	16	52
24/8/33	28·6	4	26·2	16½	53
		53	27·1	16½	51
		4	26·2	16½	53
		52	26·8	16½	53
		4	26·7	16½	52
		45	27·8	16½	46
		4	27·1	16½	39
		30	27·3	16½	39
		4	27·3	16½	37
		4	27·1	16½	40
		22	27·2	16½	39
		4	27·1	16½	43
		15	27·1	16½	45
		4	26·8	17	44

TABLE 12—*continued*

Date.	Height of high water (ft.).	Depth of sample (ft.).	Salinity (gm. per 1,000 gm.).	Temperature (°C.).	Dissolved oxygen concentration (per cent. of saturation value).
24/8/33 (contd.)	28·6	10	26·6	16½	35
		4	26·4	16½	43
		8	26·2	16½	42
		4	25·3	17	41
		8	25·4	17	45
		4	26·0	17	46
		8	26·7	17	43
		4	26·3	16½	43
		8	26·8	17	40
		4	26·4	17	46
		13	26·7	17	39
		4	26·5	17	43
		19	26·7	17	39
		4	26·5	17	41
		19	26·9	17	40
		4	26·6	17	46
		11	26·5	17	47
		4	26·8	17	35
		24	26·9	17	42
		4	27·0	17	42
		40	26·4	17	40
		4	26·3	17	40
		53	27·1	16½	36
		4	26·2	16½	45
		30	27·1	16½	46
		4	26·9	16½	43
		12	27·7	16½	51
		4	27·1	16½	42
		36	27·8	16½	47
		4	27·4	16½	48
		28	27·8	16½	49
4/9/33	29·0	60	28·6	18½	37

Date.	Height of high water (ft.).	Depth of sample (ft.).	Salinity (gm. per 1,000 gm.).	Temperature (°C.).	Dissolved oxygen concentration (per cent. of saturation value).
4/9/33 (contd.)	29·0	24	26·1	19	31
		23	24·1	19½	27
10/9/33	24·6	17	27·9	17	55
		18	26·5	18	60
		18	26·5	17½	59
25/9/33	26·3	3	27·3	14½	42
		3	27·5	14½	42
		3	27·5	14½	46
		3	27·4	14½	45
		2	27·1	14½	48
26/9/33	24·4	1	25·1	14½	40
		1	25·4	14½	39
		1	25·2	14½	40
		1	25·1	14½	41
		1	25·0	14½	36
		1	24·7	14½	31
27/9/33	22·9	1	24·5	14½	32
		1	24·4	14½	30
		1	24·3	14½	27
		1	24·4	14½	34
		1	24·5	14½	37
		1	23·9	14½	32
2/10/33	28·3	0	31·4	15	84
		40	31·5	15	85
		40	31·5	15	79
		40	31·5	15	82
		36	31·5	15	81
		31	31·2	15	77
		22	31·2	15	75
		20	31·2	15	72

Date.	Height of high water (ft.).	Depth of sample (ft.).	Salinity (gm. per 1,000 gm.).	Temperature (°C.).	Dissolved oxygen concentration (per cent. of saturation value).
2/10/33 (contd.)	28·3	19	31·2	15	67
		16	30·6	15	66
		14	30·3	15	60
		12	30·3	15	54
		11	30·6	15	53
		10	30·6	15	47
3/10/33	29·3	0	31·3	14½	95
		33	31·8	14½	97
		66	31·6	14½	87
		0	29·6	14½	50
		19	29·9	14½	51
		38	29·9	14½	50
4/10/33	29·4	0	29·9	14	49
		22	30·0	14½	50
		43	29·8	14	50
5/10/33	29·1	0	28·6	14	32
		16	28·7	14	36
		32	28·1	14	34
		0	32·7	14½	93
		24	32·0	14½	90
		48	32·6	14½	90
20/9/33	29·1	2	25·1	16	52
		8	25·1	16	62
		2	26·5	16	65
		12	26·4	16	65
		2	27·7	16½	56
		21	27·9	16½	53
		2	29·8	17	62
		29	29·8	16½	61
		2	29·7	17	79
		31	30·2	16½	73

10/10/33	23·6	0	0·7	16	0
		10	0·7	16	0
		0	0·9	16	0
		6	0·9	15½	0
		0	5·2	15	2
		7	5·2	15	2
		0	15·3	13½	28
		11	16·0	13½	30
		0	18·3	13½	40
		12	19·5	13½	44
10/11/33	22·4	0	24·2	8½	65
		15	24·9	8½	65
		30	24·7	8½	68
11/12/33	23·7	2	23·5	3½	77
		10	24·1	3½	76
		2	24·9	3	74
		8	25·1	3	74
		15	24·5	3	76
		2	26·9	3	73
		10	27·0	3	73
		18	26·9	3	73
		2	28·1	3	78
		12	28·1	3	80
		24	28·1	3	80
15/12/33	27·1	2	27·2	3	77
		16	27·7	3	77
		33	27·9	3	78
		2	26·7	2½	76
		14	26·7	2½	77
		27	26·7	2½	77
		0	24·2	2	79
		10	24·4	2½	78
		20	24·4	2½	77
		0	22·9	2	79
		7	23·1	2	79
		14	22·7	2	78
		0	19·8	2	73
		5	20·0	2	73
		10	20·8	2	75
20/12/33	30·3	2	0·9	7	2
		0	17·5	4	35
		10	17·9	4	27
		0	0·9	7	3
20/12/33 (contd.)	30·3	4	0·6	7	10
		0	16·0	4	32
		5	18·6	4	19
		9	19·3	4	34
1/1/34	27·0	0	1·3	5½	32
		5	1·2	5½	23
		0	11·7	3	43
		12	11·9	3	41
		0	3·0	4½	19
		7	3·4	4½	13
4/1/34	27·6	0	1·0	7	3
		4	1·0	7	2
		0	12·6	6	53
		5	13·1	6	51
		11	13·2	6	28
18/1/34	31·4	2	17·3	6	64
		7	22·4	6	67
23/4/34	20·4	0	17·6	10	70
		10	18·3	10	68
		0	18·0	10	73
		0	19·1	10	71
		6	19·0	10	71
		5	19·0	10	73
		0	19·4	10	75
		5	19·4	10	70
		0	19·6	10	78
		12	19·7	10	49
		0	20·1	10	79
		4	20·1	10	78
		0	18·5	10½	75
		6	18·9	10½	79
		0	18·7	10½	79
		9	18·7	10½	75
		0	20·6	10½	81
		7	20·6	10½	82
		0	19·9	10½	81
		7	20·1	10½	83
		0	18·3	10½	77
		7	18·3	10½	78
		0	17·4	10½	77
		8	15·8	10½	73
24/4/34	21·2	10	25·4	10	88
		12	25·2	9½	85
		10	25·7	9½	82
		13	25·9	10	86
		19	25·8	10	84
		30	26·2	10	79
1/5/34	28·0	0	3·1	13	10
		0	2·6	14	3
		0	9·1	14	14
		0	17·1	12	32
		9	21·0	11	34
		0	20·4	11½	45
		11	23·3	11	42
		11	23·0	11	42
		15	26·4	11	61
		15	26·8	10½	63
		19	28·0	10½	74
		33	28·9	10	81
		27	29·2	10	81
8/5/34	24·3	0	31·4	10	98
		20	31·4	10½	100
		39	31·5	10½	101
9/5/34	25·4	0	29·0	11	82
		37	29·7	11	86
		68	30·1	11	88
		0	29·4	11½	91
		17	30·5	11½	96
		0	29·8	11	88
		22	30·5	11	97
		0	30·6	11	95
		46	30·7	11	98
6/6/34	25·1	2	28·7	14½	66
		42	28·5	15	67
		2	28·7	15	68
		24	29·0	15	66
		48	28·7	15	66
		2	28·3	15	61
		18	28·3	15	59
		36	28·5	15	61
		2	28·5	15	63
		38	28·5	15	60
		2	28·5	15	64
		18	28·5	15	63

TABLE 12—*continued*

Date.	Height of high water (ft.).	Depth of sample (ft.).	Salinity (gm. per 1,000 gm.).	Temperature (°C.).	Dissolved oxygen concentration (per cent. of saturation value).
6/6/34 (contd.)	25·1	36	28·3	15	61
		2	28·3	15	63
		18	28·3	15	62
		36	28·3	15	61
		2	28·5	15	69
		21	28·5	15	68
		42	28·0	15	69
		2	28·3	15	67
		26	28·2	15	66
		52	28·5	15	66
		0	27·8	15	65
		63	28·5	15	67
		20	28·6	15	74
		2	28·2	15	71
		38	28·3	15	66
14/6/34	25·4	2	29·4	16	72
		28	29·4	16	72
		2	29·0	16	68
		38	29·2	16	67
		2	29·8	16	75
		30	30·1	16	79
		60	29·7	16	75
		2	29·6	16	73
		70	30·1	16	76
		30	29·6	16	74
		2	30·6	16	93
		40	31·9	16	99
		2	30·6	16	92
		36	31·3	16	93
		2	29·7	16	75
		30	29·9	16	81
		60	30·3	16	82
		2	30·5	16	85
		20	30·8	16	89
14/6/34 (contd.)	25·4	35	30·8	16	90
		2	29·7	16	81
		38	30·1	16	88
		2	30·3	16	88
		45	31·0	16	88
		2	29·0	16	65
		38	29·0	16½	65
		2	28·5	16½	56
		40	28·3	16½	54
		2	27·5	16½	51
		40	27·7	16½	51
18/6/34	23·7	2	31·7	17	107
		12	32·1	16½	105
		2	31·9	17	112
		26	32·0	16½	107
		2	31·4	17½	113
		27	31·9	17	110
		2	32·1	17	107
		20	32·2	17½	110
		2	32·2	17	110
		40	32·0	17	110
		2	31·9	17	112
		17	32·1	17	110
2/7/34	29·1	2	31·4	17	92
		16	31·4	17	91
		2	31·7	17	95
		23	31·4	17	95
		2	31·4	17	95
		20	31·2	17½	92
		2	31·2	17	90
		20	31·2	17½	90
		43	31·4	17½	92
4/7/34	26·6	2	28·4	18	54
		26	28·3	18	54
		2	28·0	18	54
		28	28·7	18	61
		2	28·5	18	57
		30	28·7	18	60
		2	29·0	18	60
		2	29·0	18	66
		34	28·9	18	63
		2	29·6	18	71
		39	29·7	18	71
		2	29·7	18	75
		41	29·6	18	72
		2	29·9	18	77
		44	30·1	18	77
		2	30·3	18	81
		45	30·5	18	80
		2	30·6	18	82
		47	30·2	18	84
		2	30·1	18	82
		47	30·5	18	83
25/3/36	31·7	0	22·2	7	65
		10	22·4	7	69
		20	22·8	7	64
		0	22·4	7	65
		10	22·6	7	57
		20	23·0	7	65
		0	22·2	7	55
		0	22·2	8	53
		10	22·2	8	51
		5	22·2	8	51
		0	22·2	7½	54

25/3/36 (contd.)	31·7	10	22·2	7½	54
		5	22·2	7½	51
		0	22·2	7½	54
		10	22·2	7½	53
		5	22·2	7½	54
		0	22·4	7½	62
		10	22·4	7½	55
		5	22·4	7½	55
		0	21·9	7½	49
		10	21·9	7½	51
		5	21·9	7½	55
28/2/36	27·2	0	19·2	5	54
		10	19·4	5	55
		20	19·4	5	55
		0	20·2	4	55
		10	20·6	4	55
		20	20·8	4	55
		0	21·1	4½	55
		10	21·2	4½	55
		20	21·2	4½	53
		0	20·9	4	55
		10	20·8	4	55
		20	20·8	4	54
20/11/33	29·8	0	28·1	8	79
21/11/33	29·0	0	28·5	8	77
22/11/33	27·9	0	28·6	8	75
23/11/33	25·6	0	24·4	7½	55
23/11/33	26·7	0	28·8	8	74
24/11/33	24·2	0	24·5	7½	66
24/11/33	25·6	0	28·3	7½	76
27/11/33	23·6	0	24·7	6½	59
28/11/33	23·6	0	25·3	6½	62
29/11/33	26·5	0	27·9	6½	77
29/11/33	26·5	0	25·8	6½	81
30/11/33	27·0	0	28·4	6½	84
30/11/33	27·0	0	26·5	6	85
1/12/33	27·5	0	29·5	6	86
2/12/33	27·5	0	29·5	5½	89
4/12/33	27·2	0	29·9	5	92
5/12/33	26·8	0	29·9	5	87
6/12/33	26·3	0	29·2	4½	87
7/12/33	25·8	0	29·2	4½	84
8/12/33	25·3	0	29·2	4½	85
9/12/33	23·8	0	26·7	4	79
11/12/33	22·9	0	27·4	3½	79
12/12/33	23·3	0	27·5	3½	79

13/12/33	24·2	0	23·7	3½	81
14/12/33	25·6	0	26·1	4½	82
15/12/33	27·1	0	29·2	4	90
15/12/33	27·1	0	26·2	3½	81
16/12/33	28·5	0	29·4	4	96
18/12/33	30·2	0	29·2	4	84
20/12/33	30·3	0	30·1	5	88
21/12/33	29·6	0	29·9	5	93
22/12/33	26·9	0	26·9	5	72
22/12/33	25·7	0	26·4	5	64
1/1/34	27·0	0	30·2	4	93
2/1/34	27·4	0	29·5	4	95
3/1/34	27·5	0	29·7	4½	90
4/1/34	27·6	0	29·7	5	93
5/1/34	27·4	0	30·1	7½	101
6/1/34	26·1	0	27·2	4½	76
8/1/34	24·9	0	27·8	6	83
8/1/34	25·6	0	31·0	6	92
9/1/34	24·2	0	26·9	5½	83
9/1/34	24·2	0	30·1	6½	89
10/1/34	23·4	0	27·1	5½	85
11/1/34	23·4	0	27·8	6	89
12/1/34	24·2	0	27·4	5½	86
13/1/34	25·8	0	31·3	6	98
15/1/34	29·2	0	30·1	7	91
16/1/34	30·6	0	30·8	7½	97
22/1/34	25·1	0	23·3	5	66
22/1/34	25·8	0	29·4	5½	85
23/1/34	23·5	0	24·2	5	70
24/1/34	22·2	0	25·3	5	76
25/1/34	21·8	0	26·0	5	83
26/1/34	22·3	0	25·9	5	85
27/1/34	23·6	0	29·5	5	93
29/1/34	26·1	0	24·7	4½	78
30/1/34	27·1	0	29·6	5	91
31/1/34	27·7	0	29·6	5	91
1/2/34	28·2	0	29·3	5	88
2/2/34	28·5	0	28·6	4½	85
5/2/34	27·0	0	24·5	4½	66
5/2/34	27·6	0	29·2	5	87
6/2/34	25·2	0	24·2	4½	65
6/2/34	26·3	0	28·3	5	81
7/2/34	24·8	0	25·3	5	70
8/2/34	23·4	0	25·8	5	82
9/2/34	22·6	0	26·3	5	83
12/2/34	27·2	0	29·4	5½	90
12/2/34	27·2	0	24·2	5½	79

13/2/34	29·5	0	30·3	5	96
14/2/34	31·0	0	29·1	5½	85
15/2/34	31·8	0	30·8	5	88
16/2/34	31·9	0	30·6	5	88
17/2/34	31·1	0	30·8	6	81
19/2/34	27·8	0	30·3	5½	82
20/2/34	25·5	0	27·2	5½	71
20/2/34	25·4	0	30·1	5½	82
21/2/34	23·2	0	27·7	5½	77
21/2/34	22·9	0	29·6	5½	86
22/2/34	21·5	0	28·1	6	81
24/2/34	20·9	0	28·1	6	83
26/2/34	24·5	0	29·4	5	82
26/2/34	24·1	0	27·8	5	83
27/2/34	26·1	0	29·7	4½	87
28/2/34	27·1	0	30·1	4½	88
1/3/34	27·8	0	30·1	5	88
2/3/34	28·5	0	29·8	5	85
3/3/34	28·8	0	29·5	5	87
5/3/34	28·5	0	29·8	6½	91
6/3/34	27·7	0	26·0	5½	73
6/3/34	27·7	0	30·9	5	88
7/3/34	26·6	0	26·8	5	75
7/3/34	26·1	0	29·5	5	90
8/3/34	25·0	0	27·2	5½	77
8/3/34	24·0	0	29·5	5½	90
9/3/34	23·3	0	27·6	6	80
10/3/34	22·0	0	27·6	5	79
12/3/34	24·7	0	27·0	5½	78
13/3/34	27·1	0	29·7	5	85
14/3/34	29·3	0	29·9	5	85
17/3/34	31·0	0	29·6	5	86
19/3/34	28·6	0	29·2	5	92
20/3/34	26·7	0	30·3	5	88
21/3/34	24·9	0	24·9	5½	73
21/3/34	24·4	0	29·7	6	90
22/3/34	23·2	0	25·1	5½	72
23/3/34	21·4	0	25·3	6	76
23/3/34	20·4	0	29·2	6	89
27/3/34	23·3	0	28·1	6½	90
27/3/34	23·3	0	25·6	7½	83
3/4/34	28·6	0	28·8	7½	85
4/4/34	26·9	0	29·0	6½	83
5/4/34	26·5	0	25·2	6½	67
5/4/34	25·2	0	28·9	7	84
6/4/34	24·9	0	25·1	5½	71
6/4/34	23·2	0	28·5	8	88

TABLE 12—*continued*

Date.	Height of high water (ft.).	Depth of sample (ft.).	Salinity (gm. per 1,000 gm.).	Tem-pera-ture (°C.).	Dissolved oxygen concentra-tion (per cent. of saturation value).	Date.	Height of high water (ft.).	Depth of sample (ft.).	Salinity (gm. per 1,000 gm.).	Tem-pera-ture (°C.).	Dissolved oxygen concentra-tion (per cent. of saturation value).	Date.	Height of high water (ft.).	Depth of sample (ft.).	Salinity (gm. per 1,000 gm.).	Tem-pera-ture (°C.).	Dissolved oxygen concentra-tion (per cent. of saturation value).
7/4/34	23·3	0	25·6	7	77	13/4/34	29·7	0	28·6	8½	87	21/4/34	22·1	0	27·1	10½	82
9/4/34	23·3	0	25·6	7	76	14/4/34	29·9	0	28·8	8½	89	24/4/34	21·2	0	26·9	10½	85
10/4/34	25·1	0	25·4	7	74	16/4/34	28·4	0	28·5	10	88	25/4/34	22·6	0	28·9	9½	81
11/4/34	27·1	0	25·1	8	76	17/4/34	27·0	0	29·4	10½	95	26/4/34	24·3	0	29·7	10	95
12/4/34	28·7	0	28·6	7½	86	18/4/34	25·6	0	28·8	10½	87						
12/4/34	28·7	0	24·4	8	76	19/4/34	23·9	0	28·8	10	83						

TABLE 13—*Salinity at High and Low Water in the Mersey Estuary at Different Ranges of Tide*

Date.	Height of high water (ft.).	Depth (ft.).	Salinity at high water (gm. per 1,000 gm.).	Depth (ft.).	Salinity at low water (gm. per 1,000 gm.).	Distance below Warrington Bridge (miles).
30/5/33	23·4	0	25·6	0	21·8	
		16	27·0	9	21·8	
		32	27·3	18	22·2	19½
		46	25·4	26	22·1	
6/6/33	26·4	0	23·1			
		9	23·7			
		18	23·5			15½
		29	23·9			
12/6/33	26·3	0	23·1	0	5·8	
		7	23·4	5	6·3	10½
		14	23·5	9	6·5	
12/6/33	26·3			0	0·8	5½
15/6/33	23·4	0	28·8	0	17·5	
		17	28·7	11	17·5	
		34	28·8	22	17·5	22½
		51	28·8	33	17·5	
21/6/33	25·1	0	3·6	0	0·4	
		5	3·4	5	0·4	6½
		10	3·5			
26/6/33	25·5	0	11·4	0	0·8	
		8	11·6			6½
27/6/33	25·4			0	26·0	
				10	26·2	
				20	26·4	27½
				30	26·8	
5/7/33	25·3	0	24·4	0	10·3	
		18	24·7			15½
10/7/33	28·0			3	0·4	5½
17/7/33	22·6	0	25·6	0	22·8	
		9	26·3	5	22·8	19½
		18	26·6			
18/7/33	22·7	0	26·9	0	17·8	
		12	27·3	5	17·8	19½
		24	27·5	9	18·0	
19/7/33	23·3	0	21·5			15½
21/7/33	24·8	0	29·1			
		8	29·2			22½

Date.	Height of high water (ft.).	Depth (ft.).	Salinity at high water (gm. per 1,000 gm.).	Depth (ft.).	Salinity at low water (gm. per 1,000 gm.).	Distance below Warrington Bridge (miles).
24/7/33	26·6	0	26·0			19½
		8	27·1			
24/7/33	26·6			0	26·7	25½
				8	26·9	
25/7/33	26·9			0	27·6	
				19	27·7	28½
				37	27·7	
25/7/33	26·9	0	26·3			
		11	27·0			16½
		22	26·8			
26/7/33	27·0			0	26·7	
				11	27·2	27½
				21	27·7	
26/7/33	27·0	0	26·6			
		11	27·0			16½
		21	27·2			
27/7/33	26·9			0	24·8	
				8	25·2	25½
				54	26·2	
27/7/33	26·9	0	25·9			
		8	25·9			15½
		13	26·1			
30/7/33	24·5			8	26·3	25½
30/7/33	24·5	8	26·9			18½
1/8/33	23·4			8	26·2	25½
1/8/33	23·4	8	26·1			19½
4/8/33	25·9			8	28·1	28½
4/8/33	25·9	8	27·1			16½
8/8/33	28·9			4	26·0	25½
8/8/33	28·9	8	25·3			12½
9/8/33	28·3	8	24·7			11½
11/8/33	25·9	8	29·0	8	25·8	21½
14/8/33	21·5			8	27·8	22½
14/8/33	21·5	8	27·5			17½
23/8/33	28·5			4	26·4	25½
				52	27·6	
23/8/33	28·5	13	25·3			13½

TABLE 13—*continued.*

Date.	Height of high water (ft.).	Depth (ft.).	Salinity at high water (gm. per 1,000 gm.).	Depth (ft.).	Salinity at low water (gm. per 1,000 gm.).	Distance below Warrington Bridge. (miles).
24/8/33	28·6			4 53	26·2 27·1	25½
24/8/33	28·6			4 28	27·4 27·8	26½
24/8/33	28·6	4 8	26·0 26·7			14½
25/8/33	28·3	4 29 54	32·3 32·3 32·6			27½
28/8/35	26·7	3 9	28·5 28·3			15½
28/8/35	26·7			3 27	28·5 29·0	27½
29/8/35	27·3	3 11	27·9 27·8			15½
29/8/35	27·3			3 53	28·1 28·5	25½
30/8/35	27·6	2 11	27·9 27·9			16½
31/8/35	27·5	3 12	28·2 28·1			15½
31/8/35	27·5			3 18	29·3 29·5	27½
1/9/35	27·3			3 38	28·6 29·0	28½
1/9/35	27·3	2 8	27·7 27·6			14½
2/9/35	26·6			3 48	28·8 29·1	28½
2/9/35	26·6	3 14	28·1 27·9			15½
3/9/35	25·6	2 13	29·5 29·4			18½
4/9/35	24·5	3 8	28·9 29·1			17½
5/9/35	23·5	3 35	30·6 30·4			21½

Date.	Height of high water (ft.).	Depth (ft.).	Salinity at high water (gm. per 1,000 gm.).	Depth (ft.).	Salinity at low water (gm. per 1,000 gm.).	Distance below Warrington Bridge (miles).
6/9/35	22·4			3 44	30·3 30·3	31½
6/9/35	22·4	3 22	30·2 30·2			20½
7/9/35	22·1	3 64	30·9 29·5			25½
8/9/35	22·8			3 61	31·5 31·5	36½
10/9/35	26·1	3 50	30·6 30·6			21½
30/7/33	24·5			8	26·9	18½
4/8/33	25·9	8	27·1			28½
9/8/35	22·0			3 12 18	25·0 21·0 19·7	25½
26/8/35	24·7	4 23	30·4 30·3			19½
11/8/33	25·9	8	29·0			21½
26/9/33	24·4	1	25·5			15½
27/9/33	22·9	1	24·4			15½
25/9/33	26·3	3	27·3			17½
11/11/35	29·9	21 40 69	32·7 32·7 32·7	0 21 40	27·9 28·5 28·8	39½
11/11/35	29·9	0 21 43 68	32·9 32·6 32·7 32·7	0 24 45	32·1 32·1 33·0	45½
25/3/36	31·7	0	22·2			16½
3/6/33	30·4	0 33 66	31·3 31·8 31·6	0 19 38	29·6 29·9 29·9	32½
4/10/33	29·4			0 22 43	29·9 30·0 29·8	32½

5/10/33	28·4	0	32·7	0	28·6	
		24	32·0	16	28·7	27½
		48	32·6	32	28·1	
20/9/33	29·1	2	29·8			
		29	29·8			16½
10/10/33	23·6	0	0·9			
		6	0·9			9½
10/11/33	22·4			0	24·2	
				15	24·9	22½
				30	24·7	
11/12/33	23·7	2	28·1	2	23·5	
		12	28·1	10	24·1	19½
		24	28·1			
15/11/33	27·1	2	27·2	0	19·8	
		16	27·7	5	20·0	19½
		33	27·9	10	20·8	
20/12/33	30·3	0	16·0	2	0·6	
		5	18·6			4½
		9	19·3			
1/1/34	27·0	0	11·7			
		12	11·9			5½
4/1/34	27·6	0	12·6	0	1·0	
		5	13·1	4	1·0	4½
		11	13·2			
23/4/34	20·5	0	17·6			
		10	18·3			12½
23/4/34	20·5			0	20·1	
				4	20·1	18½
23/4/34	20·5	0	17·4			
		8	15·8			11½
24/4/34	21·2	10	25·4			16½
24/4/34	21·2			30	26·2	33½
9/5/34	25·4	0	29·0			
		37	29·7			25½
		68	30·1			
9/5/34	25·4			0	29·4	
				17	30·5	37½
9/5/34	25·4	0	30·6			
		46	30·7			33½
6/6/34	25·1			2	28·7	
				18	28·3	31½
				36	28·7	
6/6/34	25·1	2	28·2			
		38	28·3			20½
7/6/34	25·3			0	22·3	
				14	22·2	17½
				27	21·9	

14/6/34	25·4	2	29·6			30½
		70	30·1			
20/11/33	29·8	0	28·1			25½
21/11/33	29·0	0	28·5			..
22/11/33	27·9	0	28·6			..
23/11/33	26·7	0	28·8	0	24·4	..
24/11/33	25·6	0	28·3	0	24·5	..
27/11/33	24·5			0	24·7	..
28/11/33	25·6			0	25·3	..
29/11/33	26·5	0	27·9	0	25·8	..
30/11/33	27·0	0	28·4	0	26·5	..
1/12/33	27·5	0	29·5			..
2/12/33	27·5	0	29·5			..
4/12/33	27·2	0	29·9			..
5/12/33	26·8	0	29·9			..
6/12/33	26·3	0	29·2			..
7/12/33	25·8	0	29·2			..
8/12/33	25·3	0	29·2			..
9/12/33	24·5			0	26·7	..
11/12/33	22·9			0	27·4	..
12/12/33	23·3			0	27·5	..
13/12/33	24·2			0	26·7	..
14/12/33	25·6			0	26·1	..
15/12/33	27·1	0	29·2	0	26·2	..
16/12/33	28·5	0	29·4			..
18/12/33	30·2	0	29·2			..
20/12/33	30·3	0	30·1			..
21/12/33	29·6	0	29·9			..
22/12/33	28·4	0	30·2	0	26·9	..
23/12/33	27·0			0	26·4	..
1/1/34	27·0	0	30·2			..
2/1/34	27·4	0	29·5			..
3/1/34	27·5	0	29·7			..
4/1/34	26·6	0	29·7			..
5/1/34	27·4	0	30·1			..
6/1/34	27·0			0	27·2	..
8/1/34	24·9	0	31·0	0	27·8	..
9/1/34	24·2	0	30·1	0	26·9	..
10/1/34	23·4			0	27·1	..
11/1/34	23·4			0	27·8	..
12/1/34	24·2			0	27·4	..
13/1/34	25·8	0	31·3			..
15/1/34	29·2	0	30·1			..
16/1/34	30·6	0	30·8			..
17/1/34	31·3	0	30·3			..
18/1/34	31·4	0	29·9			..
19/1/34	29·1	0	30·3	0	22·0	..
20/1/34	28·2			0	21·7	..

TABLE 13—*continued*

Date.	Height of high water (ft.).	Depth (ft.).	Salinity at high water (gm. per 1,000 gm.).	Depth (ft.).	Salinity at low water (gm. per 1,000 gm.).	Distance below Warrington Bridge (miles).
21/1/34	27·9	0	29·9			25½
22/1/34	25·1	0	29·4	0	23·3	,,
23/1/34	23·5			0	24·2	,,
24/1/34	22·2			0	25·3	,,
25/1/34	21·8			0	26·0	,,
26/1/34	22·3			0	25·9	,,
27/1/34	23·6	0	29·5			,,
29/1/34	26·1			0	24·7	,,
30/1/34	27·0	0	29·6			,,
31/1/34	27·7	0	29·6			,,
1/2/34	28·2	0	29·3			,,
2/2/34	28·5	0	28·6			,,
5/2/34	27·0	0	29·2	0	24·5	,,
6/2/34	26·2	0	28·3	0	24·2	,,
7/2/34	24·8			0	25·3	,,
8/2/34	23·4			0	25·8	,,
9/2/34	22·6			0	26·3	,,
12/2/34	27·2	0	29·4	0	24·2	,,
13/2/34	29·5	0	30·3			,,
14/2/34	31·0	0	29·1			,,
15/2/34	31·8	0	30·8			,,
16/2/34	31·9	0	30·6			,,
17/2/34	31·1	0	30·8			,,
19/2/34	27·8	0	30·3			,,
20/2/34	25·3	0	30·1	0	27·2	,,
21/2/34	23·2	0	29·6	0	27·7	,,
22/2/34	21·5			0	28·1	,,
24/2/34	20·9			0	28·1	,,
26/2/34	24·1	0	29·4	0	27·8	,,
27/2/34	25·8	0	29·1			,,
28/2/34	27·2	0	30·1			,,
1/3/34	27·9	0	30·1			,,
2/3/34	28·5	0	29·8			,,
3/3/34	28·8	0	29·5			,,
5/3/34	28·5	0	29·8			,,

Date.	Height of high water (ft.).	Depth (ft.).	Salinity at high water (gm. per 1,000 gm.).	Depth (ft.).	Salinity at low water (gm. per 1,000 gm.).	Distance below Warrington Bridge (miles).
6/3/34	27·7	0	30·9	0	26·0	25½
7/3/34	26·6	0	29·5	0	26·8	,,
8/3/34	25·0	0	29·5	0	27·2	,,
9/3/34	23·3			0	27·6	,,
10/3/34	22·0			0	27·6	,,
12/3/34	24·7			0	27·0	,,
13/3/34	27·1	0	29·7			,,
14/3/34	29·3	0	29·9			,,
17/3/34	31·0	0	29·6			,,
19/3/34	28·6	0	29·2			,,
20/3/34	26·7	0	30·3			,,
21/3/34	24·9	0	29·7	0	24·9	,,
22/3/34	23·2			0	25·1	,,
23/3/34	21·4	0	29·2	0	25·3	,,
27/3/34	23·3	0	28·1	0	25·6	,,
3/4/34	28·0	0	28·8			,,
4/4/34	26·9	0	29·0			,,
5/4/34	26·5	0	28·9	0	25·2	,,
6/4/34	24·9	0	28·5	0	25·1	,,
7/4/34	23·3			0	25·6	,,
9/4/34	23·3			0	25·6	,,
10/4/34	25·1			0	25·4	,,
11/4/34	27·1			0	25·1	,,
12/4/34	28·7	0	28·6	0	24·4	,,
13/4/34	29·7	0	28·6			,,
14/4/34	29·9	0	28·8			,,
16/4/34	28·4	0	28·5			,,
17/4/34	27·0	0	29·4			,,
18/4/34	25·6	0	28·8			,,
19/4/34	23·9	0	28·8			,,
21/4/34	22·1			0	27·1	,,
24/4/34	21·2			0	26·9	,,
25/4/34	22·6			0	28·9	,,
26/4/34	24·3	0	29·7			,,

TABLE 20—*Observations taken during a Series of Float Drifts, 28th August to 10th September, 1935*

Draught of Float: 3 ft.

Float Run 28.8.35

Fix No.	Time (B.S.T.).	Interval (min.).	Distance travelled (ft.).	Speed (knots).
		FLOOD.		
1	0813			
2	30	17	5,200	3·02
3	45	15	5,040	3·32
4	0900	,,	5,150	3·39
5	15	,,	4,480	2·95
6	30	,,	5,150	3·39
7	45	,,	5,100	3·36
8	1000	,,	5,230	3·44
9	15	,,	4,380	2·88
10	30	,,	3,640	2·40
11	45	,,	4,100	2·70
12	1100	,,	4,160	2·74
13	15	,,	3,260	2·15
14	30	,,	2,560	1·68
15	45	,,	1,900	1·25
16	1200	,,	1,600	1·05
17	15	,,	1,200	0·79
18	30	,,	540	0·36
		EBB.		
19	45	15		
20	1300	,,	860	0·57
21	15	,,	1,950	1·28
22	30	,,	2,250	1·48
23	45	,,	2,650	1·74
24	1400	,,	2,620	1·83
25	15	,,	3,030	1·99
26	30	,,	3,690	2·36
27	45	,,	3,170	2·09
28	1500	15	3,530	2·32
29	15	,,	2,850	1·88
30	30	,,	3,070	2·02
31	45	,,	2,730	1·80
32	1600	,,	2,420	1·59
33	15	,,	2,860	1·88
34	30	,,	3,850	2·54
35	45	,,	2,980	1·96
36	1700	,,	3,300	1·51
37	15	,,	2,960	1·95
38	30	,,	2,680	1·76
39	45	,,	2,530	1·67
40	1800	,,	2,110	1·39
41	15	,,	1,730	1·14
42	30	,,	1,520	1·00
43	45	,,	680	0·22
44	50			
		FLOOD.		
45	1900	10	360	0·36
46	01			
47	15			
48	20	20	1,500	
49	30	10	950	0·94
50	45	15	2,140	1·41
51	2000	,,	2,140	1·41
52	15	,,	2,490	1·64

FLOOD .. .. 72,270 feet
EBB .. .. 62,020 ,,

Float Run 29.8.35.

Fix No.	Time (B.S.T.).	Interval (min.).	Distance travelled (ft.).	Speed (knots).
		FLOOD.		
1	0800			
2	15	15	1,200	0·79
3	30	,,	2,490	1·64
4	45	,,	4,250	2·80
5	0900	,,	2,730	1·80
6	15	,,	4,000	2·63
7	30	,,	4,410	2·90
8	45	,,	4,840	3·19
9	1000	,,	3,800	2·50
10	15	,,	5,740	3·78
11	30	,,	3,560	2·34
12	45	,,		
13	1100	,,	5,230	1·72
14	15	,,	4,200	2·76
15	30	,,	2,620	1·73
16	45	,,	1,950	1·28
	Engine trouble; lost float			
17	1200	New float streamed.		
18	15	15	670	0·44
19	30	,,	1,280	0·84
20	45	,,	1,320	0·87
21	1300	,,	990	0·65
22	15	,,	300	0·20
		EBB.		
23	30	15	500	0·33
24	45	,,	1,130	0·74
25	1400	,,	1,480	0·97
26	15	,,	1,430	0·94
27	1430	15	1,500	0·99
28	45	,,	1,600	1·05
29	1500	,,	2,910	1·92
30	15	,,	4,220	2·78
31	30	,,	3,680	2·42
32	45	,,	3,430	2·26
33	1600	,,	2,180	1·44
34	15	,,	3,630	2·39
35	30	,,	3,660	2·41
36	45	,,	3,230	2·13
37	1700	,,	4,100	2·70
38	15	,,	2,220	1·46
39	30	,,	2,680	1·76
40	45	,,	3,050	2·01
41	1800	,,	1,600	1·05
42	15	,,	1,920	1·26
				Picked up
43	24	Float streamed.		
44	30	6	560	0·92
45	45	15	970	0·64
				Picked up
46	50	Float streamed.		
47	1900	10	730	0·72
48	15	15	800	0·53
				Picked up
49	20	Float streamed.		
50	30	10	280	0·28
51	45	15	780	0·51
52	2000	,,	380	0·25

FLOOD .. .. 55,580 feet.
EBB .. .. 54,650 ,,

TABLE 20—*continued*

Float Run 30.8.35

Fix No.	Time (B.S.T.).	Interval (min.).	Distance travelled (ft.).	Speed (knots).
1	0800			
2	15	15	140	0·09
		FLOOD.		
3	30	15	440	0·29
4	45	,,	1,180	0·78
5	0900	,,	2,180	1·43
6	15	,,	3,350	2·21
7	30	,,	4,630	3·05
8	45	,,	3,840	2·53
9	1000	,,	4,120	2·71
10	15	,,	3,900	2·57
11	30	,,	4,670	3·07
12	45	,,	4,330	2·85
13	1100	,,	3,950	2·60
14	15	,,	4,210	2·77
15	30	,,	3,670	2·41
16	45	,,	3,400	2·24
17	1203	18	2,500	1·37
18	15	12	1,580	1·30
19	30	15	1,140	0·75
20	45	,,	1,260	0·83
21	1300	,,	1,310	0·86
22	15	,,	630	0·41
23	30	,,	300	0·20
		EBB.		
24	1345	15	740	0·49
25	1400	,,	1,200	0·79
26	15	,,	2,220	1·46
27	30	,,	2,730	1·80
28	45	,,	3,750	2·47
29	1500	,,	3,540	2·33
30	15	,,	3,320	2·19
31	30	,,	3,530	2·32
32	45	,,	4,220	2·78
33	1600	,,	4,300	2·83
34	15	,,	4,790	3·16
35	30	,,	4,800	3·16
36	45	,,	4,430	2·92
37	1703	18	6,160	3·37
38	15	12	4,080	3·35
39	30	15	4,180	2·75
40	45	,,	4,040	2·66
41	1800	,,	3,455	2·26
42	15	,,	2,980	1·96
43	30	,,	3,150	2·07
44	45	,,	2,660	1·75
45	1900	,,	2,265	1·49
46	15	,,	1,475	0·97
47	30	,,	1,430	0·94

FLOOD .. .. 56,280 feet.
EBB .. .. 80,855 ,,

Float Run 31.8.35

1	0826			
		FLOOD.		
2	31	5	80	0·16
3	45	14	190	0·13
4	0900	15	840	0·55
5	15	,,	1,860	1·22
6	30	,,	2,720	1·79
7	45	,,	3,550	2·34
8	1000	,,	3,810	2·51
9	15	,,	4,000	2·64
10	30	,,	3,580	2·36
11	45	,,	3,870	2·54
12	1100	,,	4,990	3·28
13	15	,,	3,720	2·45
14	30	,,	3,800	2·50
15	45	,,	3,820	2·51
16	1200	,,	3,740	2·46
17	15	,,	3,040	2·00
18	30	,,	3,360	2·21
19	45	,,	3,750	2·47
20	1300	,,	2,560	1·69
21	15	,,	2,520	1·66
22	30	,,	1,970	1·30
23	45	,,	1,600	1·05
24	1400	,,	830	0·55
		EBB.		
25	15	15	170	0·11
26	30	,,	910	0·60
27	1445	15	2,210	1·45
28	1500	,,	1,870	1·23
29	15	,,	3,250	2·07
30	30	,,	3,540	2·33
31	45	,,	3,900	2·56
32	1600	,,	3,590	2·36
33	15	,,	3,480	2·29
34	30	,,	3,020	1·99
35	45	,,	3,240	2·13
36	1700	,,	3,520	2·32
37	15	,,	3,640	2·40
38	30	,,	3,910	2·57
39	45	,,	4,110	2·70
40	1800	,,	3,600	2·37
41	15	,,	3,440	2·26
				Picked up
42	16			Streamed
43	30	14	3,800	2·67
44	45	15	4,110	2·70
45	1900	,,	3,230	2·12
46	15	,,	2,180	1·43
47	30	,,	1,820	1·20
48	45	,,	1,490	0·98
49	2000	,,	920	0·61

FLOOD .. .. 64,200 feet.
EBB .. .. 68,960 ,,

Table 20—*continued*

Float Run 1.9.35

Fix No.	Time (B.S.T.).	Interval (min.).	Distance travelled (ft.).	Speed (knots).	Fix No.	Time (B.S.T.).	Interval (min.).	Distance travelled (ft.).	Speed (knots).
		Ebb.					Ebb.		
1	0800								
2	15	15	1,630	1·07	29	1445	15	720	0·47
3	30	,,	1,140	0·75	30	1500	,,	1,360	0·89
4	45	,,	1,320	0·87	31	15	,,	2,270	1·50
5	0900	,,	580	0·38	32	30	,,	2,750	1·81
6	15		0		33	45	,,	3,080	2·63
					34	1600	,,	3,960	2·61
					35	15	,,	4,330	2·86
		Flood.			36	30	,,	4,140	2·76
7	30	15	540	0·36	37	45	,,	3,720	2·45
8	32	Shifted Float			38	1700	,,	4,000	2·63
9	45	13	820	0·54	39	15	,,	4,430	2·92
10	1000	15	2,010	1·32	40	30	,,	3,990	2·63
11	15	,,	3,100	2·04	41	45	,,	4,650	3·06
12	30	,,	4,100	2·70	42	1800	,,	4,320	2·84
13	45	,,	4,570	3·63	43	15	,,	4,560	3·00
14	1100	,,	3,690	2·43	44	30	,,	4,040	2·66
15	15	,,	4,380	2·89	45	45	,,	3,820	2·51
16	30	,,	4,780	3·15	46	1900	,,	2,850	1·88
17	45	,,	5,530	3·64	47	15	,,	2,390	1·57
18	1200	,,	4,770	3·14	48	17	2	Shifted Float.	
19	15	,,	4,960	3·27	49	30	13	1,520	1·00
20	30	,,	4,000	2·64	50	45	15	1,885	1·24
21	45	,,	3,990	2·63	51	2000	,,	1,200	0·79
22	1300	,,	4,730	3·11					
23	15	,,	3,960	2·61					
24	30	,,	3,960	2·61					
25	45	,,	2,280	1·50					
26	1400	,,	1,210	0·80		Flood		67,140 feet.	
27	15	,,	950	0·63		Ebb		74,655 ,,	
28	30	,,	0						

Float Run 2.9.35.

Fix No.	Time (B.S.T.).	Interval (min.).	Distance travelled (ft.).	Speed (knots).	Fix No.	Time (B.S.T.).	Interval (min.).	Distance travelled (ft.).	Speed (knots).
		Ebb.			27	1430	15	2,700	1·78
1	0800				28	45	,,	1,510	0·99
2	15	15	1,730	1·14	29	1500	,,	680	0·45
3	30	,,	1,900	1·25					
4	45	,,	1,240	0·82					
5	0900	,,	760	0·50			Ebb.		
6	15	,,	430	0·28	30	15	15	0	
7	30	,,	100	0·07	31	30	,,	870	0·57
					32	45	,,	1,680	1·11
		Flood.			33	1600	,,	2,620	1·72
					34	15	,,	3,190	2·10
8	45	15	380	0·25	35	30	,,	3,540	2·33
9	1000	,,	970	0·64	36	45	,,	4,040	2·66
10	15	,,	1,430	0·94	37	1700	,,	2,920	1·92
11	30	,,	2,430	1·60	38	15	,,	3,440	2·26
12	45	,,	3,760	2·48	39	30	,,	2,380	1·57
13	1100	,,	4,870	3·21	40	45	,,	2,630	1·73
14	15	,,	5,090	3·35	41	1800	,,	2,980	1·96
15	30	,,	5,130	3·38	42	15	,,	2,850	1·88
16	45	,,	5,160	3·40	43	30	,,	3,120	2·05
17	1200	,,	4,340	2·85	44	45	,,	3,380	2·22
18	15	,,	4,400	2·90	45	1900	,,	3,130	2·06
19	31	16	3,880	2·55	46	15	,,	3,680	2·42
20	45	14	3,120	2·06	47	30	,,	3,740	2·46
21	1300	15	3,090	2·03	48	45	,,	3,740	1·62
22	16	16	2,170	1·43	49	2000	,,	3,740	
23	30	14	2,070	1·36					
24	45	15	2,800	1·84					
25	1400	,,	2,960	1·95		Flood		66,040 feet.	
26	15	,,	3,100	2·04		Ebb		63,930 ,,	

TABLE 20—*continued*

Float Run 3.9.35

Fix No.	Time (B.S.T.).	Interval (min.).	Distance travelled (ft.).	Speed (knots).
		EBB.		
1	0800			
2	15	15	2,760	1·82
3	30	,,	2,720	1·79
4	45	,,	2,280	1·50
5	0900	,,	1,770	1·17
6	15	,,	1,340	0·88
7	30	,,	836	0·55
8	45	,,	593	0·39
		FLOOD.		
9	1000	15	669	0·44
		Picked up.		
10	03	3 Streamed.		
11	15	12	669	0·55
12	30	15	1,080	0·71
13	45	,,	1,410	0·93
14	1100	,,	1,740	1·14
15	15	,,	1,740	1·14
16	30	,,	2,700	1·78
17	45	,,	3,710	2·44
18	1200	,,	5,200	3·42
19	15	,,	4,460	2·93
20	30	,,	4,890	3·22
21	45	,,	4,950	3·26
22	1300	,,	4,730	3·12
23	15	,,	3,910	2·58
24	30	,,	3,820	2·51
25	45	,,	3,000	1·97
26	1400	,,	2,180	1·44
27	15	,,	1,620	1·07
28	30	,,	1,270	0·84
29	45	,,	1,230	0·81
30	1500	,,	890	0·59
		EBB.		
31	1515	15	260	0·17
32	30	,,	240	0·16
33	45	,,	1,030	0·68
34	1600	,,	1,600	1·05
35	13	13	1,430	1·08
36	19	6	Shifted Float.	
37	30	11	2,500	2·24
38	45	15	3,300	2·18
39	1700	15	3,230	2·13
40	10	10	1,360	1·34
41	15	5	Shifted Float.	
42	30	15	3,410	2·24
43	45	,,	4,560	3·00
44	1800	,,	4,170	2·74
45	15	,,	4,580	3·02
46	30	,,	4,740	3·12
47	45	,,	4,860	3·20
48	1900	,,	4,520	2·98
49	15	,,	3,540	2·33
50	30	,,	3,025	1·99
51	45	,,	2,645	1·74
52	2000	,,	2,890	1·90

FLOOD .. .. 54,868 feet.
EBB .. .. 70,189 ,,

Float Run 4.9.35

Fix No.	Time (B.S.T.).	Interval (min.).	Distance travelled (ft.).	Speed (knots).
		EBB.		
1	0800			
2	15	15	2,870	1·89
3	30	,,	2,480	1·80
4	45	,,	1,642	1·08
5	0900	,,	2,310	1·52
6	15	,,	1,780	1·17
7	30	,,	1,294	0·85
8	45	,,	609	0·40
9	1000	,,	0	
		FLOOD.		
10	15	15	1,368	0·90
11	32	17	570	0·33
12	45	13	554	0·42
13	49	4	Shifted Float.	
14	1100	11	501	0·45
15	15	15	1,580	1·04
16	20	5	Shifted Float.	
17	30	10	1,043	1·63
18	45	15	2,810	1·85
19	1200	,,	2,810	1·85
20	15	,,	4,020	2·65
21	30	,,	4,790	3·15
22	45	,,	5,570	3·67
23	1300	,,	5,280	3·47
24	15	,,	4,730	3·12
25	30	,,	4,440	2·92
26	45	,,	3,600	2·37
27	1400	,,	3,340	2·20
28	1415	15	2,520	1·66
29	30	,,	2,700	1·78
30	45	,,	2,620	1·72
31	1500	,,	2,000	1·32
32	15	,,	2,070	1·36
33	30	,,	1,180	0·78
34	45	,,	540	0·36
35	1600	,,	0	
		EBB.		
36	15	15	680	0·45
37	30	,,	1,320	0·87
38	45	,,	1,630	1·07
39	1700	,,	2,120	1·40
40	15	,,	1,790	1·18
41	30	,,	3,540	2·33
42	45	,,	2,740	1·80
43	1800	,,	3,330	2·19
44	15	,,	1,540	1·01
45	30	,,	1,600	1·05
46	45	,,	1,580	1·04
47	1900	,,	2,210	1·45
48	15	,,	2,730	1·80
49	30	,,	2,970	1·95
50	45	,,	3,210	2·11

FLOOD .. .. 60,236 feet.
EBB .. .. 49,155 ,,

TABLE 20—*continued*

Float Run 5.9.35

Fix No.	Time (B.S.T.).	Interval (min.).	Distance travelled (ft.).	Speed (knots).	Fix No.	Time (B.S.T.).	Interval (min.).	Distance travelled (ft.).	Speed (knots).
		EBB.			29	1400	15	3,450	2·27
1	0800				30	15	,,	3,700	2·44
2	15	15	3,880	2·55	31	30	,,	3,040	2·00
3	30	,,	3,050	2·01	32	45	,,	3,410	2·24
4	45	,,	2,340	1·54	33	1500	,,	3,550	2·34
5	0900	,,	2,420	1·59	34	15	,,	3,590	2·36
6	15	,,	2,065	1·36	35	30	,,	3,250	2·14
7	30	,,	2,065	1·36	36	45	,,	2,390	1·57
8	45	,,	1,565	1·03	37	1600	,,	2,260	1·49
9	52	7	Shifted Float.		38	15	,,	1,470	0·97
10	1000	8	851	1·05	39	30	,,	1,050	0·69
11	15	15	973	0·64	40	45	,,	270	0·18
12	30	,,	532	0·35					
13	40	10	228	0·23					
							EBB.		
		FLOOD.			41	1700	15	480	0·31
14	45	—	Shifted Float.		42	15	,,	850	0·56
15	1100	15	471	0·31	43	30	,,	1,500	0·99
16	15	,,	775	0·51	44	45	,,	1,800	1·18
17	30	,,	1,125	0·74	45	1800	,,	2,960	1·95
18	45	,,	1,400	0·92	46	15	,,	2,510	1·65
19	1200	,,	1,642	1·08	47	30	,,	3,330	2·19
20	15	,,	1,658	1·09	48	45	,,	3,760	2·48
21	30	,,	1,325	0·87	49	1900	,,	2,680	1·76
22	35	5	Shifted Float.		50	15	,,	2,060	1·36
23	47	12	1,628	1·34	51	30	,,	1,930	1·27
24	53	6	Shifted Float.		52	45	,,	2,750	1·81
25	1300	7	1,140	1·61					
26	15	15	2,160	1·42					
27	30	,,	2,200	1·45		FLOOD		50,384 feet.	
28	45	,,	3,430	2·26		EBB		49,329 ,,	

Float Run 6.9.35

Fix No.	Time (B.S.T.).	Interval (min.).	Distance travelled (ft.).	Speed (knots).	Fix No.	Time (B.S.T.).	Interval (min.).	Distance travelled (ft.).	Speed (knots).
		EBB.			21	1600	15	2,940	1·95
1	1100				22	15	,,	2,260	1·50
2	15	15	502	0·33	23	30	,,	2,260	1·50
3	30	,,	243	0·16	24	45	,,	2,100	1·39
					25	1700	,,	1,240	0·82
		FLOOD.			26	15	,,	900	0·59
4	45	15	152	0·10	27	30	,,	400	0·27
5	1200	,,	577	0·38	28	45	,,	0	
6	15	,,	820	0·54					
7	30	,,	1,325	0·87			EBB.		
8	45	,,	1,370	0·90	29	1800	15	680	0·44
9	1300	,,	1,580	1·04	30	15	,,	960	0·62
10	15	,,	1,900	1·25	31	30	,,	1,270	0·84
11	30	,,	2,705	1·78	32	45	,,	1,910	1·25
12	45	,,	2,615	1·72	33	1900	,,	2,160	1·42
13	1400	,,	3,040	2·00	34	15	,,	2,530	1·67
14	15	,,	3,390	2·22	35	30	,,	2,610	1·72
15	30	,,	3,990	2·61	36	45	,,	4,430	1·92
16	45	,,	5,120	3·36	37	2000	,,	2,010	1·33
17	1500	,,	4,590	3·02					
18	15	,,	2,790	1·84		FLOOD		54,224 feet.	
19	30	,,	3,000	1·98		EBB		18,560 ,,	
20	45	,,	3,160	2·08		EBB		45,500 estimated.	

TABLE 20—*continued*

Float Run 7.9.35

Fix No.	Time (B.S.T.).	Interval (min.).	Distance travelled (ft.).	Speed (knots).
		EBB.		
1	0815			
2	30	15	2,750	1·83
3	45	,,	3,090	2·04
4	0900	,,	2,340	1·54
5	15	,,	2,190	1·44
6	30	,,	2,080	1·37
7	45	,,	1,945	1·28
8	1000	,,	1,900	1·25
9	15	,,	1,885	1·24
10	30	,,	2,130	1·40
11	42	12	1,385	1·14
12	45	Shifted Float.		
13	1100	15	2,035	1·34
14	12	12	1,550	1·28
15	15	Shifted Float.		
16	30	15	1,825	1·20
17	47	17	1,795	1·04
18	1223	Float foul of screw.		
19	30	7	350	0·49
20	45	15	395	0·26
21	1300	,,	334	0·22
22	15	,,	137	0·09
		FLOOD.		
23	30	15	137	0·09
24	45	,,	517	0·34
25	1400	,,	1,048	0·69
26	15	,,	1,080	0·71
27	1430	15	1,550	1·02
28	45	,,	2,220	1·46
29	1504	19	3,300	1·71
30	15	11	2,220	1·99
31	30	15	2,675	1·76
32	45	,,	2,980	1·96
33	1600	,,	2,840	1·87
34	15	,,	2,950	1·94
35	30	,,	2,630	1·73
36	45	,,	2,600	1·72
37	1700	,,	2,310	1·52
38	15	,,	2,590	1·71
39	30	,,	2,620	1·73
40	42	12	1,750	1·15
41	1800	18	1,770	1·17
42	15	15	1,210	0·80
43	30	,,	920	0·61
44	45	,,	400	0·37
		EBB.		
45	1900	15	1,220	0·80
46	15	,,	1,210	0·80
47	30	,,	1,600	1·05
48	45	,,	2,600	1·71
49	2000	,,	2,870	1·89

FLOOD .. .. 42,317 feet.
EBB .. .. 42,366 ,,

Float Run 8.9.35

Fix No.	Time (B.S.T.).	Interval (min.).	Distance travelled (ft.).	Speed (knots).
		EBB.		
1	0800			
2	15	15	1,570	1·03
3	30	,,	1,720	1·17
4	45	,,	2,350	1·55
5	0900	,,	2,410	1·59
6	15	,,	2,935	1·93
7	30	,,	1,915	1·26
8	1045	Float foul.		
9	1100	15	2,780	1·83
10	15	,,	2,310	1·52
11	30	,,	2,400	1·58
12	45	,,	3,010	1·98
13	1200	,,	2,980	1·96
14	05	Shifted Float.		
15	15	10	2,995	1·46
16	30	15	2,815	1·85
17	45	,,	2,525	1·66
18	1300	,,	2,555	1·68
19	15	,,	2,265	1·49
20	30	,,	1,735	1·14
21	45	,,	1,565	1·03
22	1400	,,	897	0·59
23	15	,,	745	0·49
24	30	,,	699	0·46
25	34	Shifted Float.		
26	45	11	426	0·38
27	1500	15	380	0·25
28	15	,,	243	0·16
		FLOOD.		
29	1530	15	289	0·19
30	34	Shifted Float.		
31	45	11	258	0·23
32	1600	15	609	0·40
33	15	,,	851	0·56
34	30	,,	1,004	0·66
35	45	,,	1,156	0·76
36	1700	,,	1,110	0·73
37	15	,,	1,310	0·86
38	30	,,	1,430	0·94
39	45	,,	1,560	1·05
40	1800	,,	1,340	0·88
41	15	,,	1,885	1·24
42	20	Shifted Float.		
43	30	10	609	0·60
44	45	15	760	0·50
45	1900	,,	699	0·46
46	15	,,	532	0·35
	Too dark to fix.			

FLOOD .. .. 15,401 feet.
EBB .. .. 46,285 ,,

TABLE 20—*continued*

Float Run 9.9.35

Fix No.	Time (B.S.T.).	Interval (min.).	Distance travelled (ft.).	Speed (knots).	Fix No.	Time (B.S.T.).	Interval (min.).	Distance travelled (ft.).	Speed (knots).
1	0808				12	1042	13	2,385	1·81
2	15	7	870	1·23	13	53	Shifted Float.		
3	55	40	3,180	0·78	14	1100	7	1,065	1·50
4	57	Shifted Float.			15	10	10	2,630	2·60
5	0915		0		16	30	20	3,880	1·91
6	30	15	1,170	0·77	17	57	27	5,590	2·04
7	52	22	3,280	1·47					
8	1000	8	1,430	1·77					
9	15				Insufficient readings.				
10	24	24	4,440	1·83	Distance travelled taken as mean between 8.9.35 and 10.9.35.				
11	29	5	1,095	2·16					

Float Run 10.9.35

Fix No.	Time (B.S.T.).	Interval (min.).	Distance travelled (ft.).	Speed (knots).	Fix No.	Time (B.S.T.).	Interval (min.).	Distance travelled (ft.).	Speed (knots).
		FLOOD.			29	1500	15	2,690	1·80
1	0800				30	15	,,	2,550	1·67
2	15	15	4,700	3·08	31	20	Shifted Float.		
3	30	,,	4,480	2·95	32	30	10	1,400	1·38
4	45	,,	3,790	2·50	33	43	13	2,130	1·67
5	0900	,,	2,390	1·59	34	47	Shifted Float.		
6	15	,,	3,060	2·02	35	1600	13	1,370	0·93
7	30	,,	2,430	1·60	36	15	15	1,915	1·28
8	45	,,	1,880	1·25	37	30	,,	990	0·64
9	1000	,,	1,430	0·95	38	34	Shifted Float.		
10	15	,,	770	0·51	39	45	11	1,310	1·00
11	30	,,	160	0·11	40	1700	15	760	0·50
		EBB.					FLOOD.		
12	45	15	670	0·44	41	15	15	0	
13	1100	,,	1,540	1·02	42	27	12	425	0·35
14	15	,,	2,460	1·62	43	31	Shifted Float.		
15	30	,,	3,070	2·01	44	45	14	1,370	0·97
16	45	,,	4,600	3·02	45	1800	15	1,810	1·20
17	1200	,,	5,030	3·31	46	15	,,	2,370	1·56
18	15	,,	5,620	3·70	47	30	,,	2,960	1·95
19	30	,,	5,440	3·58	48	45	,,	3,470	2·28
20	45	,,	5,090	3·35	49	1900	,,	3,280	2·18
21	1300	,,	4,075	2·68	50	15	,,	3,410	2·26
22	15	,,	3,620	2·30	51	30	,,	3,620	2·40
23	30	,,	3,880	2·55	52	45	,,	3,880	2·57
24	45	,,	3,780	2·49	53	2000	,,	3,840	2·54
25	1400	,,	3,530	2·32					
26	15	,,	3,090	2·03					
27	30	,,	3,150	2·03	FLOOD .. .. 55,525 feet.				
28	45	,,	3,010	1·98	EBB .. .. 76,770 ,,				

TABLE 26—*Composition of Surface Samples from Inter-Tidal Deposits in the Upper Mersey Estuary*

Sample No. S	Moisture (per cent.)	Percentage of dry weight			C/N ratio	Sample No. S	Moisture (per cent.)	Percentage of dry weight			C/N ratio
		Loss on ignition	Organic carbon	Kjeldahl nitrogen				Loss on ignition	Organic carbon	Kjeldahl nitrogen	
1	18·9	1·9	0·11	0·00	—	27	38·4	11·2	1·89	0·18	10·5
2	29·1	3·1	0·28	0·02	14·0	28	40·3	9·5	1·55	0·14	11·1
3	17·3	1·2	0·09	0·01	9·0	29	21·2	3·8	0·93	0·02	46·5
4	32·4	7·1	1·57	0·08	19·6	30	34·6	8·8	1·33	0·12	11·1
5	33·1	5·9	1·32	0·08	16·5	31	52·4	13·2	2·66	0·23	11·6
6	48·6	21·4	3·00	0·24	12·5	32	45·6	15·1	3·03	0·28	10·8
8	47·8	13·0	3·32	0·29	11·4	33	38·6	12·6	1·51	0·23	6·6
9	47·8	12·8	2·77	0·27	10·3	34	43·1	12·6	2·28	0·20	11·4
10	47·4	12·4	3·09	0·29	10·6	35	27·9	7·0	0·90	0·08	11·3
11	51·3	11·6	2·31	0·27	8·6	36	26·2	5·7	0·75	0·05	15·0
12	42·6	10·8	2·87	0·20	14·4	37	28·8	6·9	0·94	0·07	13·4
13	47·2	10·6	2·45	0·21	11·7	38	40·9	11·0	0·83	0·09	9·2
14	43·6	9·7	1·99	0·16	12·4	39	34·6	8·1	1·53	0·10	15·3
15	36·5	8·1	1·73	0·13	13·3	40	20·2	—	0·41	0·01	41·0
16	59·4	13·9	3·36	0·27	12·4	41	10·8	2·7	0·38	0·00	—
17	41·3	11·9	2·97	0·24	12·4	42	25·2	5·1	0·81	0·05	16·2
18	42·8	12·2	2·81	0·23	12·2	43	43·7	13·5	2·43	0·23	10·6
19	43·9	10·5	2·31	0·19	12·1	44	16·8	0·9	0·10	0·01	10·0
20	38·9	9·0	1·99	0·16	12·4	45	19·1	2·3	0·45	0·02	22·5
21	50·0	9·4	0·67	0·18	3·7	46	55·6	13·7	2·41	0·25	9·6
22	50·0	11·0	2·34	0·21	11·1	47	33·5	7·7	0·91	0·08	11·4
23	43·4	12·3	2·97	0·26	11·4	48	53·1	12·0	2·48	0·25	9·9
24	43·8	14·8	2·96	0·25	11·8	49	37·4	8·4	1·08	0·11	9·8
25	34·6	11·6	2·23	0·18	12·4	50	25·2	4·4	0·34	0·04	8·5
26	59·8	15·2	2·90	0·30	9·7						

Sample No. S	Moisture (per cent.)	Percentage of dry weight			C/N ratio	Percentage of dry weight					
		Loss on ignition	Organic carbon	Kjeldahl nitrogen		SiO_2	Fe_2O_3	Al_2O_3	"Sesqui-oxides"	CaO	MgO
51	29·2	6·6	0·98	0·09	10·9	76·1	2·3	7·4	9·7	4·2	1·0
52	39·0	10·6	2·34	0·21	11·1	58·7	4·8	13·0	17·8	—	—
53	37·8	8·6	1·51	0·11	13·7	66·5	3·4	10·6	14·0	—	—
54	41·9	11·8	2·52	0·21	12·0	56·4	5·5	15·7	21·2	—	—
55	40·4	11·0	2·02	0·19	10·6	61·9	4·3	14·1	18·4	—	—
56	28·3	6·5	0·98	0·09	10·9	71·8	5·0	10·5	15·5	—	—
57	42·5	8·4	1·72	0·16	10·7	69·2	3·3	8·8	12·1	—	—
58	37·9	13·6	2·86	0·25	11·4	54·0	5·9	14·8	20·7	4·7	—
59	41·0	13·5	2·02	0·29	7·0	52·2	6·4	16·0	22·4	4·7	1·6
60	40·2	10·8	2·47	0·20	12·4	59·4	4·5	15·7	20·2	—	—
61	39·4	11·3	1·88	0·20	9·4	61·5	5·2	14·6	19·8	4·8	1·1
62	58·3	13·3	2·71	0·31	8·7	56·0	5·4	13·7	19·1	5·0	2·3
63	40·9	11·9	1·99	0·18	11·0	60·1	4·2	15·2	19·4	—	—
64	59·6	13·1	3·49	0·29	11·3	53·9	4·9	14·6	19·5	—	—
65	46·7	13·7	2·91	0·27	10·8	52·5	6·1	14·9	21·0	5·1	1·7
66	44·4	13·2	2·82	0·26	10·8	53·9	5·6	13·2	18·8	—	—
67	41·8	11·7	2·44	0·22	11·1	57·9	5·3	13·3	18·6	5·6	0·5
68	49·8	11·7	2·55	0·25	10·2	59·7	4·6	10·8	15·4	—	—
69	40·0	9·0	1·23	0·12	10·2	68·2	3·5	10·9	14·4	4·6	0·7
70	46·5	12·1	2·09	0·23	9·1	57·9	5·1	14·6	19·7	—	—
71	43·2	12·2	2·32	0·20	11·6	57·9	5·3	13·3	18·6	6·1	0·5
72	41·5	14·4	3·49	0·30	11·6	50·8	6·6	14·8	21·4	—	—
73	45·3	13·4	3·29	0·30	11·0	53·8	6·0	13·3	19·3	4·4	0·4
74	45·6	12·5	3·13	0·24	13·0	54·1	5·6	15·1	20·7	—	—
75	43·8	11·6	2·83	0·23	12·3	58·3	5·1	14·6	19·7	5·3	1·7
76	40·0	10·2	2·25	0·16	14·1	63·2	4·0	13·4	17·4	—	—
77	39·5	8·0	1·45	0·12	12·1	76·9	3·0	9·8	12·8	4·2	0·8
78	49·0	13·5	3·32	0·31	10·7	55·1	5·3	14·5	19·8	—	—

TABLE 26—*continued*

Sample No. S	Moisture (per cent.)	Percentage of dry weight: Loss on ignition	Organic carbon	Kjeldahl nitrogen	C/N ratio	Percentage of dry weight: SiO_2	Fe_2O_3	Al_2O_3	"Sesqui-oxides"	CaO	MgO
79	48·3	13·3	3·48	0·28	12·4	54·6	5·3	14·3	19·6	4·5	1·4
80	42·6	12·7	2·55	0·20	12·8	58·8	4·6	12·3	16·9	—	—
81	29·8	7·5	1·61	0·10	16·1	73·3	2·9	6·4	9·3	4·1	0·2
82	37·4	9·1	1·68	0·13	12·9	66·1	3·3	9·9	13·2	5·2	0·9
83	45·1	8·3	1·69	0·14	12·1	69·9	2·9	9·1	12·0	4·2	0·0
84	39·8	7·3	1·23	0·12	10·3	66·9	2·8	7·9	10·7	4·2	1·3
85	38·1	12·7	2·99	0·26	11·5	55·5	6·0	14·0	20·0	4·6	1·3
86	35·8	10·4	2·16	0·20	10·8	61·9	4·7	13·7	18·4	4·8	0·7
87	40·0	10·8	2·52	0·20	12·6	59·0	5·3	15·6	20·9	4·4	1·9
88	36·2	9·0	2·02	0·09	22·4	66·2	4·5	11·2	15·7	4·5	1·7
89	39·1	11·0	1·98	0·21	9·4	60·3	5·0	13·6	18·6	4·5	1·8
90	37·3	11·7	2·87	0·24	12·0	57·4	5·7	15·4	21·1	4·2	—
91	42·2	10·3	2·16	0·18	12·0	63·7	4·4	23·5	27·9	4·6	1·6
92	56·6	12·1	2·30	0·23	10·0	61·2	4·6	13·2	17·8	4·3	2·1
93	42·7	11·2	2·53	0·21	12·0	60·0	5·1	13·1	18·2	5·0	2·4
94	42·1	11·3	2·82	0·20	14·1	61·0	5·4	12·9	18·3	4·5	2·2
95	51·1	10·9	2·35	0·21	11·2	61·0	4·4	10·8	15·2	4·4	1·9
96	38·6	9·4	2·04	0·18	11·3	65·7	4·5	11·7	16·2	4·7	1·7
97	51·0	13·8	3·65	0·13	20·4	50·2	6·4	11·3	17·7	5·0	2·2
98	42·2	12·4	2·91	0·27	10·8	54·9	5·8	14·5	20·3	4·7	2·6
99	41·7	11·9	2·86	0·21	13·6	57·7	5·4	16·8	22·2	4·6	2·7
100	42·7	11·0	2·65	0·21	12·6	60·1	4·8	12·6	17·4	4·5	2·1
101	40·8	9·2	1·74	0·15	11·6	64·9	3·7	10·3	14·0	4·8	1·8
102	47·0	12·9	3·21	0·32	10·0	57·1	5·3	14·6	19·9	4·9	2·3
103	42·7	13·3	3·33	0·23	14·5	54·2	6·0	14·2	20·2	4·7	2·7
104	51·5	13·9	2·97	0·27	11·0	52·7	6·4	13·9	20·3	4·6	2·9
105	42·5	13·1	2·63	0·29	9·1	53·8	6·4	14·4	20·8	4·6	2·8
106	44·5	12·9	2·38	0·27	8·8	55·2	5·7	13·7	19·4	4·7	2·6
107	40·0	11·0	2·12	0·25	8·5	62·6	4·4	10·8	15·2	5·2	2·0
108	29·0	7·9	1·13	0·17	6·5	71·6	3·2	8·0	11·2	4·3	1·5
109	36·0	8·5	1·48	0·13	11·4	69·0	3·4	8·8	12·2	4·4	1·7
110	36·0	8·5	1·50	0·17	8·8	68·3	3·4	19·0	12·4	4·4	1·3
111	22·5	5·0	0·59	0·06	9·8	80·0	2·1	6·1	8·2	3·7	2·3
112	41·4	14·4	1·62	0·14	11·6	50·3	7·0	16·5	23·5	4·3	2·8
113	40·3	13·5	3·03	0·26	11·7	52·6	6·8	15·3	22·1	4·4	3·8
114	45·9	16·1	3·23	0·31	10·4	53·5	5·3	13·0	18·3	4·1	2·6
115	45·0	10·2	2·91	0·27	10·8	55·8	5·5	13·0	18·5	5·3	2·4
116	40·2	12·8	2·32	0·18	12·9	61·0	4·7	11·3	16·0	5·1	2·1
117	26·3	5·5	1·27	0·07	18·1	76·1	—	—	19·7	3·8	1·2
118	27·1	3·3	0·66	0·06	11·0	82·5	2·5	4·8	7·3	3·0	0·8
119	18·7	1·6	0·31	0·02	15·5	90·4	1·2	2·9	4·1	1·9	0·4
120	53·2	14·4	3·65	0·33	11·1	52·1	6·4	14·3	20·7	4·7	2·4
121	44·8	11·7	3·24	0·27	12·0	54·6	6·1	14·9	21·0	5·3	2·7
122	43·0	11·5	3·30	0·27	12·2	57·2	5·9	13·5	19·4	4·6	2·5
123	41·6	10·3	2·81	0·22	12·8	61·2	5·1	12·3	17·4	4·5	—
124	37·0	6·2	1·33	0·14	9·5	70·9	3·4	9·1	12·5	4·4	—
125	54·4	11·0	3·42	0·30	11·4	56·4	5·2	12·1	17·3	5·2	—
126	46·4	7·6	2·76	0·23	12·0	61·5	4·2	12·3	16·5	5·0	—
127	48·1	7·7	2·56	0·22	11·6	59·8	4·3	12·0	16·3	5·0	—
128	46·8	11·3	2·03	0·27	7·5	67·5	6·5	5·0	11·5	5·0	—
129	37·0	11·4	2·94	0·27	10·9	54·7	6·0	13·8	19·8	4·5	—
130	41·8	9·7	2·94	0·27	10·9	58·3	5·5	12·7	18·2	4·6	—
131	37·6	12·2	1·32	0·19	6·9	59·8	4·6	11·3	15·9	4·6	—
132	27·5	5·2	1·28	0·10	12·8	70·5	3·5	8·7	12·2	4·9	—
133	33·4	7·9	1·31	0·16	8·2	65·1	4·1	10·8	14·9	4·2	—
134	24·8	5·7	1·26	0·12	10·5	74·6	3·1	8·2	11·3	3·7	—
135	57·8	12·4	2·63	0·26	10·1	62·2	4·0	10·0	14·0	4·9	—
136	20·9	3·2	0·37	0·02	18·5	85·9	1·3	4·2	5·5	2·7	—
137	23·8	5·7	0·06	0·07	0·9	76·0	2·9	7·7	10·6	3·3	—
138	32·5	7·6	1·39	0·09	15·5	70·1	3·3	8·7	12·0	5·2	—
139	27·6	7·0	0·98	0·09	10·9	73·4	2·8	7·5	10·3	4·8	—
140	24·0	5·6	0·76	0·09	8·4	77·2	3·0	6·0	9·0	3·9	—
141	30·5	6·9	1·05	0·05	21·0	74·8	3·1	5·4	8·5	4·0	—
142	23·1	4·0	0·79	0·06	13·2	80·1	2·1	7·3	9·4	2·5	—
143	49·4	18·1	0·97	0·30	3·2	51·8	5·5	13·4	18·9	4·4	—

TABLE 26—*continued*

Sample No. S	Moisture (per cent.)	Percentage of dry weight			C/N ratio	Percentage of dry weight				
		Loss on ignition	Organic carbon	Kjeldahl nitrogen		SiO_2	Fe_2O_3	Al_2O_3	"Sesqui-oxides"	CaO
144	31·4	6·9	1·44	0·10	14·4	75·1	2·9	6·9	9·8	4·0
145	32·2	8·4	1·17	0·17	6·9	73·9	3·4	7·4	10·8	5·2
146	44·7	16·6	1·73	0·15	11·5	58·6	4·6	11·0	15·6	4·0
147	35·4	10·5	1·83	0·15	12·2	66·4	3·6	9·6	13·2	4·8
148	34·8	8·6	0·57	0·16	3·6	69·4	3·4	8·6	12·0	4·6
149	45·6	10·6	1·58	0·20	7·9	67·2	3·6	9·1	12·7	4·5
150	39·1	10·0	1·07	0·10	10·7	68·7	3·5	8·3	11·8	4·3
151	51·2	17·5	2·72	0·18	15·1	52·9	5·5	9·5	15·0	4·6
152	39·2	15·2	1·75	0·15	11·7	64·4	3·8	9·4	13·2	4·4
153	39·7	13·4	1·76	0·18	9·8	58·0	5·4	13·0	18·4	4·3
154	48·4	11·2	2·45	0·24	10·2	61·6	4·6	10·8	15·4	4·9
155	42·9	9·8	1·61	0·20	8·1	66·8	4·0	9·2	13·2	4·9
156	52·7	11·5	2·44	0·24	10·2	60·1	4·6	11·4	16·0	4·2
157	56·1	12·2	2·50	0·25	10·0	58·2	4·7	11·9	16·6	4·8
158	42·7	13·4	3·27	0·27	12·1	53·7	6·2	14·2	20·4	4·6
159	36·8	11·6	2·58	0·21	12·3	58·9	5·3	12·2	17·5	4·6
160	24·0	4·1	0·46	0·03	15·3	82·8	1·6	5·0	6·6	3·4
161	14·9	9·0	0·36	0·04	9·0	58·7	5·1	14·0	19·1	5·0
162	21·2	3·9	0·27	0·03	9·0	84·2	1·4	4·6	6·0	3·2
163	29·3	6·7	0·89	0·07	12·7	73·4	2·8	7·0	9·8	4·9
164	42·3	11·8	2·06	0·19	10·8	58·1	5·7	13·3	19·0	4·4
165	35·1	9·5	1·42	0·14	10·1	64·3	4·4	10·9	15·3	4·6
166	35·9	10·4	2·05	0·21	9·8	62·7	4·3	11·4	15·7	4·9
167	33·6	8·1	1·08	0·10	10·8	70·3	3·7	9·0	12·7	4·3
168	23·3	4·5	0·42	0·03	14·0	81·7	2·1	4·8	6·9	3·9
169	27·6	6·5	0·58	0·06	9·7	77·3	2·2	6·4	8·6	4·3
170	31·3	7·7	0·73	0·10	7·3	74·7	2·4	6·8	9·2	4·7
171	34·0	8·8	1·00	0·10	1·0	69·9	2·8	7·4	10·2	5·4
172	30·5	6·6	0·79	0·11	7·2	76·5	2·4	6·4	8·8	4·2
173	29·5	10·8	2·06	0·15	13·7	64·2	4·3	10·5	14·8	5·0
173A	31·9	10·2	—	—	—	—	—	—	—	—
173B	31·6	11·2	—	—	—	—	—	—	—	—
174	33·2	10·7	1·60	0·16	10·0	63·3	4·8	11·1	15·9	4·4
174A	34·4	9·1	—	—	—	—	—	—	—	—
174B[1]	36·8	10·9	—	—	—	—	—	—	—	—
174B[2]	39·4	11·8	—	—	—	—	—	—	—	—
175	30·1	9·8	1·76	0·13	13·5	67·2	4·4	9·5	13·9	4·2
176	36·3	9·2	1·57	0·11	14·3	66·4	4·3	9·8	14·1	4·2
176A	36·6	10·7	—	—	—	—	—	—	—	—
176B	31·8	9·3	—	—	—	—	—	—	—	—
177	35·2	9·5	2·19	0·17	12·9	66·1	4·3	9·9	14·2	4·6
177A	30·5	9·4	—	—	—	—	—	—	—	—
177B[1]	35·0	10·5	—	—	—	—	—	—	—	—
177B[2]	40·4	10·9	—	—	—	—	—	—	—	—
178	28·7	7·6	1·08	0·11	9·8	68·7	3·8	9·2	13·0	4·6
178A	30·9	8·9	—	—	—	—	—	—	—	—
179	30·4	5·1	0·49	0·07	7·0	77·6	2·7	6·2	8·9	3·5
180	46·5	13·4	1·93	0·21	9·2	52·8	6·7	14·7	21·4	4·5
181	37·3	9·5	2·28	0·25	9·1	68·8	3·6	8·5	12·1	4·8
182	34·8	15·7	2·82	0·25	11·3	54·0	6·0	12·2	18·2	4·5
183	38·2	13·9	2·52	0·19	13·3	59·7	5·0	11·7	16·7	4·6
184	37·5	11·5	2·43	0·17	14·3	61·5	5·0	11·2	16·2	4·3
185	35·4	10·8	1·86	0·16	11·6	63·2	4·9	10·9	15·8	4·3
186	36·3	11·0	2·39	0·16	14·9	64·3	4·3	10·3	14·6	4·5
187	51·9	12·4	2·85	0·26	11·0	59·6	4·8	11·6	16·4	5·0
188	52·6	11·3	2·36	0·20	11·8	60·5	4·5	11·3	15·8	5·0
193	50·2	14·0	3·41	0·32	10·6	54·6	3·7	15·3	19·0	5·0
194	45·6	12·7	3·45	—	—	56·2	4·6	15·7	20·3	3·9
195	45·0	11·2	2·57	0·17	15·1	61·5	3·7	14·1	17·8	4·1
196	60·0	13·7	3·13	—	—	55·1	4·0	14·9	18·9	5·1
197	41·1	11·0	2·97	—	—	60·6	3·8	13·9	17·7	3·6
197A	49·1	13·6	—	—	—	—	—	—	—	—
197B	62·0	15·6	—	—	—	—	—	—	—	—
198	53·9	14·6	3·41	0·36	9·5	53·2	4·1	15·1	19·2	5·0
198A	57·8	15·0	—	—	—	—	—	—	—	—

TABLE 26—*continued*

Sample No. S	Moisture (per cent.)	Percentage of dry weight			C/N ratio	Percentage of dry weight				
		Loss on ignition	Organic carbon	Kjeldahl nitrogen		SiO_2	Fe_2O_3	Al_2O_3	"Sesqui-oxides"	CaO
199	53·4	14·6	3·70	0·40	9·3	53·2	5·6	13·1	18·7	5·3
200	46·9	11·8	2·81	0·26	10·8	59·9	4·6	14·3	15·9	5·0
200A	40·5	9·8	—	—	—	—	—	—	—	—
201	39·3	8·1	2·10	0·22	9·5	68·6	3·1	13·0	13·0	4·7
202	46·2	11·3	2·59	0·33	7·9	60·2	4·7	10·6	15·3	5·2
203	50·4	12·0	2·77	0·27	10·3	59·9	4·3	11·0	15·3	5·2
204	55·3	14·7	3·87	0·53	5·4	52·8	5·8	13·6	19·4	5·1
205	33·7	6·7	1·34	0·10	13·4	73·2	3·5	9·3	12·8	3·6
205A	31·1	6·3	—	—	—	—	—	—	—	—
206	58·6	15·1	3·55	0·37	9·6	51·9	5·9	13·6	19·5	5·0
207	56·9	13·6	3·60	0·46	7·8	53·6	5·9	14·5	20·4	4·5
207A	48·4	10·9	—	—	—	—	—	—	—	—
208	58·1	12·7	3·14	0·33	9·5	54·5	5·6	13·1	18·7	5·2
209	50·0	11·7	2·73	0·24	11·4	59·5	5·3	13·1	18·4	4·3
209A	48·4	12·1	—	—	—	—	—	—	—	—
210	62·8	15·6	3·67	0·37	9·9	50·7	6·2	13·4	19·6	5·2
211	57·9	15·1	3·50	0·41	8·5	51·9	6·1	13·6	19·7	3·6
212	41·5	10·7	2·06	0·16	12·9	52·5	5·3	12·1	17·4	2·6
213	62·5	14·8	3·43	0·37	9·3	51·6	5·8	13·9	19·7	5·0
214	71·6	16·0	3·57	0·43	8·3	47·8	6·0	12·9	18·9	5·2
215	38·1	12·2	2·73	0·25	10·9	53·8	5·8	13·4	19·2	4·9
216	62·5	11·9	3·37	0·39	8·6	49·1	5·9	14·8	20·7	5·1
217	52·0	11·5	3·00	0·25	12·0	59·9	4·9	12·3	17·2	5·0
218	41·7	8·8	2·11	0·20	10·6	68·1	3·5	9·5	13·0	4·7
219	39·8	8·5	1·79	0·17	10·5	68·4	3·5	9·4	12·9	4·9
220	50·6	12·3	3·27	0·31	10·5	59·1	5·1	11·5	16·6	4·9
221	55·4	13·6	3·72	0·38	9·8	56·3	5·6	12·9	18·5	5·1
222	56·2	13·0	3·06	0·34	9·0	55·6	5·4	13·1	18·5	5·1
223	35·8	6·7	1·46	0·15	9·7	74·2	2·9	8·0	10·9	4·2
224	30·1	4·9	0·76	0·08	9·5	79·6	2·0	5·7	7·7	3·6
225	38·7	6·3	1·44	0·10	14·4	76·0	2·5	6·8	9·3	4·2
226	21·2	2·9	0·04	0·01	4·0	87·1	1·4	4·2	5·6	2·4
227	40·3	8·9	1·83	0·20	9·2	69·3	3·3	7·6	10·9	4·8
228	38·3	9·4	1·60	0·18	8·9	72·9	3·2	8·2	11·4	5·5
229	38·3	9·0	1·56	0·12	13·0	71·7	2·8	8·0	10·8	5·0
230	31·2	7·2	1·16	0·10	11·6	74·9	2·4	7·0	9·4	4·3
231	35·3	7·7	1·22	0·13	9·4	68·5	2·6	7·6	10·2	4·6
232	28·1	4·9	0·77	0·06	12·8	80·9	1·8	5·6	7·4	3·8
233	21·5	3·5	0·15	0·02	7·5	85·0	1·4	4·5	5·9	3·3
234	21·3	3·6	0·03	0·05	0·6	88·2	1·1	4·1	5·2	2·4
235	44·3	12·8	—	0·25	—	55·1	6·0	13·6	19·6	4·4
236	43·0	15·4	3·09	0·30	10·3	53·2	—	—	18·8	4·4
237	45·2	13·0	2·76	0·29	9·5	56·5	—	—	16·4	5·1

TABLE 26—*continued*

Sample No. S	Moisture (per cent.)	Percentage of dry weight: Loss on ignition	Organic carbon	Kjeldahl nitrogen	C/N ratio	Percentage of dry weight: SiO_2
250	35·0	—	1·63	0·20	8·2	—
251	40·9	—	2·28	0·22	10·4	—
253	40·8	—	3·09	0·23	13·4	—
254	35·1	—	2·60	0·25	10·4	—
255	58·8	—	2·65	0·25	10·6	—
256	37·8	—	2·01	0·17	11·8	—
257	33·1	—	1·15	0·13	8·8	—
258	31·5	—	0·98	0·11	9·0	—
259	26·1	—	0·77	0·06	12·8	—
260	40·8	—	2·64	0·20	13·2	—
261	35·5	—	1·49	0·13	11·5	—
262	33·8	—	1·13	0·17	6·7	—
263	41·2	—	2·38	0·18	13·2	—
264	33·5	—	1·08	0·19	5·7	—
265	32·7	—	1·86	0·21	8·9	—
266	25·5	—	0·19	0·08	2·4	—
267	33·3	—	0·39	0·16	2·4	—
268	38·2	—	0·41	0·08	5·1	—
269	59·0	—	2·24	0·31	7·2	—
270	35·1	—	1·62	0·09	18·0	—
271	22·3	—	0·71	0·08	8·9	—
272	85·3	—	2·68	0·27	9·9	—
273	17·9	—	0·12	0·01	12·0	—
274	16·0	—	0·00	0·00	—	—
275	6·2	—	0·00	0·01	—	—
276	17·6	—	0·01	0·01	1·0	—
277	18·8	—	0·23	0·01	2·3	—
278	3·9	—	0·02	0·00	—	—
279	15·9	—	0·05	0·01	5·0	—
280	18·6	—	0·06	0·00	—	—
281	17·6	—	0·01	0·00	—	—
282	18·0	—	0·01	0·00	—	—
283	20·0	—	0·11	0·04	2·8	—
284	60·0	—	3·45	0·35	9·9	—
285	64·3	—	3·89	0·34	11·4	—
286	64·7	—	1·95	0·39	5·0	—
287	65·6	—	1·25	0·30	4·2	—
288	61·5	—	3·09	0·26	11·9	—
289	65·1	—	3·09	0·30	10·3	—
290	57·7	—	1·13	0·18	6·3	—
291	71·9	—	3·45	0·29	11·9	—
307	58·4	—	3·37	0·32	10·5	—
308	48·7	—	2·65	0·20	13·3	—
309	36·5	—	1·45	0·18	8·1	—
310	33·3	—	3·01	0·21	14·3	—
311	33·8	—	1·22	0·13	9·4	—
312	60·7	—	3·64	0·32	11·4	—
314	66·6	—	2·28	0·31	7·4	—
315	52·7	—	3·34	0·31	10·8	51·9
316	39·5	—	2·17	0·19	11·4	64·7
317	49·0	—	2·71	0·28	9·7	55·6
318	49·8	—	2·32	0·20	11·6	64·9
319	26·5	—	1·01	0·10	10·1	75·5
320	21·5	—	0·62	0·05	12·4	81·3
321	26·3	—	1·11	0·08	13·9	73·3
322	30·4	—	1·46	0·10	14·6	72·1
323	36·5	—	2·35	0·19	12·4	52·2
324	42·9	—	2·26	0·19	11·9	61·3
325	66·6	—	3·15	0·41	7·7	56·0
326A	40·9	—	2·15	0·19	11·3	62·8
326B	39·9	—	1·90	0·18	10·6	—
326C	40·3	—	2·07	0·18	11·5	64·3
326D	40·1	—	2·01	0·16	12·5	64·9
326E	37·7	—	1·88	0·16	11·8	65·6
327	43·0	—	2·96	0·26	11·4	53·2
328	53·4	—	3·71	0·32	8·5	52·9
329	57·4	—	3·34	0·40	8·4	50·1
330	54·8	—	2·98	0·35	8·5	49·1
331	30·7	—	1·48	0·14	10·5	60·8
332	50·7	—	2·20	0·21	10·5	63·7
333	33·4	—	1·39	0·12	11·6	69·3
334	39·5	—	1·71	0·15	11·4	67·3
335	47·1	—	2·76	0·24	11·5	52·8
336	51·8	—	2·81	0·29	9·7	57·1
337	37·7	—	2·80	0·24	11·7	55·3
338	42·1	—	2·12	0·19	11·2	63·1
339	47·3	—	1·84	0·20	9·2	64·2
340	50·4	—	2·66	0·27	9·9	52·4
341	51·1	—	3·10	0·27	11·5	49·1
342	51·2	—	3·28	0·29	11·3	48·8
343A	64·4	—	4·25	0·42	10·1	—
343B	62·2	—	3·72	0·41	9·1	49·3
343C	65·6	—	4·21	0·47	9·0	48·8
343D	65·8	—	4·13	0·47	8·8	48·4
344	42·5	—	2·25	0·22	10·2	57·9
345	42·4	—	2·26	0·24	9·4	56·5
346	39·4	—	2·00	0·25	8·0	54·4
347	37·3	—	2·29	0·19	12·0	57·2
348	32·9	—	2·27	0·22	10·3	54·5
349	58·5	—	3·18	0·39	8·2	52·6
350	54·7	—	3·22	0·40	8·1	51·4
351	57·0	—	3·70	0·35	10·6	48·6
352	56·5	—	3·40	0·39	8·7	48·7
353	54·2	—	3·53	0·33	10·7	51·0
354	38·6	—	2·79	0·26	10·7	53·9
355	72·8	16·4	—	—	—	48·5
356	70·1	16·3	—	—	—	50·1
357	37·8	7·5	—	—	—	72·2
358	44·3	11·0	—	—	—	65·6
359	25·8	14·9	2·64	0·25	10·6	52·3
360	26·7	14·6	2·95	0·23	12·8	64·8
361	31·4	11·7	2·62	0·26	10·1	59·2
362	30·7	12·9	2·73	0·26	10·5	58·7
363	25·9	9·9	1·74	0·16	10·9	67·7
364	44·0	13·5	3·14	0·27	11·6	64·8
365	36·5	9·3	2·39	0·25	9·6	55·0
366	36·8	9·2	2·50	0·23	10·9	69·8
367	45·7	8·5	2·21	0·17	13·0	72·8
368	64·4	16·1	3·93	0·41	9·6	55·9
369	68·9	16·1	3·47	0·37	9·4	50·1
370	50·2	10·9	2·05	0·22	9·3	59·8
371	54·1	13·6	2·75	0·29	9·5	54·3
372	43·7	11·3	2·81	0·23	12·2	62·3
373	38·0	8·9	2·00	0·16	12·5	65·9
374	60·3	15·4	3·55	0·34	10·4	50·7
375	47·6	—	2·88	0·26	11·1	—
376	55·3	—	3·32	0·27	12·3	—
377	59·2	—	3·17	0·28	11·3	—
378	54·6	—	3·40	0·28	12·1	—
379	53·8	—	3·02	0·27	11·2	—
380	57·3	—	2·81	0·27	10·4	—
381	46·8	—	3·10	0·28	11·1	—
382	48·0	—	2·98	0·30	9·9	—
383	34·1	—	1·97	0·16	12·3	—
384	31·2	—	1·38	0·11	12·5	—
385	29·5	—	1·28	0·12	10·7	—
386	32·5	—	1·12	0·15	7·5	—
387	35·7	—	2·27	0·16	14·2	—
388	28·1	—	1·52	0·14	10·9	—
389	42·1	—	2·72	0·21	13·0	—
390	40·1	—	2·46	0·19	13·0	—
391	42·3	—	2·94	0·21	14·0	—
392	55·1	—	4·34	0·39	11·1	—
393	58·0	—	3·69	0·39	9·5	—

TABLE 26—*continued*

Sample No. S	Moisture (per cent.)	Percentage of dry weight: Loss on ignition	Organic carbon	Kjeldahl nitrogen	C/N ratio	Sample No. S	Moisture (per cent.)	Percentage of dry weight: Loss on ignition	Organic carbon	Kjeldahl nitrogen	C/N ratio
394	58·7	—	3·90	0·36	10·8	410	33·7	—	1·64	0·14	11·7
395	38·3	—	2·23	0·19	11·7	411	30·7	—	1·40	0·13	10·8
396	42·6	—	3·25	0·26	12·5	412	28·7	—	1·27	0·10	12·7
397	56·6	—	3·77	0·35	10·8	413	39·6	—	2·46	0·18	13·7
398	38·3	—	1·94	0·14	13·9	414	30·7	—	1·69	0·15	11·3
399	38·5	—	2·43	0·20	12·2	415	34·5	—	2·35	0·18	13·1
400	30·5	—	1·40	0·13	10·8	416	34·2	—	2·96	0·28	10·6
401	38·2	—	2·06	0·14	14·7	417	51·1	—	3·39	0·30	11·3
402	31·4	—	2·40	0·18	13·3	418	31·2	—	2·77	0·22	12·6
403	44·5	—	2·81	0·23	12·2	419	53·7	—	3·10	0·28	11·1
404	51·3	—	3·57	0·29	12·3	420	44·6	—	2·62	0·23	11·4
405	42·1	—	2·26	0·19	11·9	421	41·0	—	2·13	0·20	10·7
406	41·2	—	2·02	0·16	12·6	422	40·2	—	2·27	0·17	13·4
407	39·7	—	1·82	0·17	10·7	423	61·8	—	3·17	0·33	9·6
408	44·3	—	2·57	0·23	11·2	424	45·1	—	2·22	0·18	12·3
409	42·4	—	1·93	0·18	10·7	425	35·3	—	2·29	0·12	19·1

TABLE 33—*Composition of Surface and Sub-Surface Samples from the Stanlow Bank*

Sample No.	Depth below surface of bank (ft.).	Approximate height of sample above Liverpool Bay Datum (ft.).	Estimated date of deposition.	Moisture (per cent.).	Percentage of dry weight.			C/N ratio.	Percentage of dry weight.				
					Loss on ignition.	Organic carbon.	Kjeldahl nitrogen.		SiO_2	Fe_2O_3	Al_2O_3	Sesqui-oxides.	CaO
S 214	0	27·0		71·6	16·0	3·57	0·43	8·3	47·8	6·0	12·9	18·9	5·2
	3	24·0		54·1	13·5	2·61	0·27	9·7	52·8	6·1	10·2	16·3	5·2
	6	21·0		43·1	11·5	2·11	0·18	11·7	59·2	4·9	15·3	20·2	5·4
	10	17·0	1901–1906	27·6	6·3	1·00	0·10	10·0	74·7	2·6	7·6	10·2	4·1
	16·5	10·5		21·3	4·8	0·59	0·05	11·8	80·5	1·7	5·8	7·5	3·8
	16·5	10·5	1886–1901	24·8	4·3	0·41	0·04	10·3	81·7	2·0	5·1	7·1	3·3
S 215	0	27·5		38·1	12·2	2·73	0·25	10·9	53·8	5·8	13·4	19·2	4·9
	3	24·5		27·9	6·9	1·35	0·08	16·9	72·5	3·2	8·6	11·8	4·0
	6	21·5		29·7	6·3	1·03	0·08	12·9	74·5	3·3	8·3	11·6	3·3
	8	19·5	1871–1881	26·8	5·4	0·83	0·06	13·8	77·1	2·7	7·2	9·9	3·5
S 216	0	28·0		62·5	11·9	3·37	0·39	8·7	49·1	5·9	14·8	20·7	5·1
	2·5	25·5		40·6	12·0	2·11	0·20	10·6	56·4	6·1	13·6	19·7	4·8
	4·5	23·5		49·0	12·9	2·76	0·25	11·0	53·9	6·2	14·2	20·4	4·6
	6·5	21·5		46·0	12·4	1·67	0·24	7·0	55·5	6·2	14·7	20·9	4·1
	9·5	18·5	1881–1886	45·7	12·4	3·01	0·28	10·8	55·7	6·3	15·0	21·3	3·6
	12·5	15·5	1861–1871	45·3	11·9	2·53	0·22	11·5	57·3	5·9	13·6	19·5	4·3
S 235	0	26·5		44·3	12·8	—	0·25	—	55·1	6·0	13·6	19·6	4·4
	3	23·5		48·5	13·3	2·56	0·23	11·1	53·5	5·9	13·4	19·3	5·2
	6	20·5	1906–1911	37·9	10·6	2·01	0·16	12·6	63·0	4·2	10·2	14·4	5·3
	9	17·5		30·7	8·2	0·35	0·12	29·2	70·5	3·4	8·0	11·4	5·0
	11	15·5	1886–1891	25·8	4·2	0·44	0·03	14·7	82·8	1·8	5·8	7·6	3·3
S 236	0	25·2		43·0	15·4	3·09	0·30	10·3	53·2	—	—	18·8	4·4
	3	22·2	1906–1911	41·9	11·0	1·96	0·18	10·9	60·6	—	—	15·7	5·3
	6	19·2		31·8	8·0	1·36	0·11	12·4	69·3	—	—	12·0	5·0
	9	16·2	1896–1901	25·3	5·1	0·59	0·05	11·8	79·5	—	—	8·7	3·5
S 237	0	25·3		45·2	13·0	2·76	0·29	9·5	56·5	—	—	16·4	5·1
	3	22·3	1911–1916	43·4	12·0	2·54	0·20	12·7	52·2	—	—	16·5	5·3
	5·5	19·8		33·6	8·6	1·49	0·13	11·5	72·9	—	—	12·2	5·0
	7·5	17·8		25·6	5·1	0·79	0·07	11·3	80·2	—	—	8·7	3·2
	10	15·3	1906–1911	25·7	5·5	0·79	0·06	13·2	77·6	—	—	9·5	3·8

TABLE 35—*Composition of Mud from Salt Marshes on the Shores of the Mersey Estuary*

Sample No.	Moisture (per cent.).	Percentage of dry weight.			Ratio : Carbon / Nitrogen.	Percentage of dry weight.	
		Loss on ignition.	Organic carbon.	Kjeldahl nitrogen.		Silica.	Sesqui-oxides.
U 11	29·0	9·5	1·20	0·13	9·2	60·6	16·8
,, 22	35·9	—	1·90	0·17	11·2	—	—
,, 23	32·7	—	1·40	0·13	10·8	—	—
,, 25D1 ..	24·0	—	2·25	0·15	15·0	—	—
,, 25D1A ..	35·1	—	3·27	0·23	14·2	—	—
,, 25D1B ..	24·5	—	0·34	—	—	—	—
,, 25D1C ..	31·4	—	1·52	0·15	10·1	—	—
,, 25D1D ..	29·5	—	1·58	0·14	11·3	—	—
,, 25D1E ..	18·8	—	0·17	—	—	—	—
,, 26	31·7	10·3	2·28	0·24	9·5	65·2	19·9
,, 27	23·8	12·0	1·67	0·16	10·4	64·4	19·1
,, 28	14·8	4·9	0·48	0·12	4·0	77·1	12·3
,, 29	16·2	8·6	0·31	0·05	6·2	69·1	15·5
,, 30	23·8	8·7	1·78	0·07	25·4	70·1	12·2

TABLE 36—*Composition of Boulder Clay from Cliffs on the Shores of the Mersey Estuary*

Sample No.	Moisture (per cent.).	Percentage of dry weight.			Ratio : Carbon / Nitrogen.	Percentage of dry weight.	
		Loss on ignition.	Organic carbon.	Kjeldahl nitrogen.		Silica.	Sesqui-oxides.
U 5	23·2	7·5	—	0·05	—	64·6	18·2
,, 6	26·5	8·7	—	0·05	—	60·6	16·3
,, 12	8·8	6·4	0·12	0·01	12·0	67·7	15·5
,, 13	24·3	6·1	1·50	0·10	15·0	69·3	15·1
,, 16	7·8	—	0·47	0·06	7·8	—	—
,, 18	6·6	—	0·33	0·02	16·5	—	—
,, 19	5·0	—	0·27	0·02	13·5	—	—
,, 20	11·6	—	0·60	0·07	8·6	—	—
,, 21	9·6	—	0·38	0·02	19·0	—	—
,, 24	7·3	—	0·17	0·01	17·0	—	—
,, 51	41·3	—	0·17	0·03	5·7	—	—

TABLE 39—*Composition of Suspended Matter in Fresh-Water Streams discharging into the Mersey Estuary*

Stream from which suspended matter was taken.	Percentage of dry weight.			Ratio: Carbon / Nitrogen.	Percentage of dry weight.	
	Loss on ignition.	Organic carbon.	Kjeldahl nitrogen.		Silica.	Sesqui-oxides.
River Mersey	—	9·2	0·82	8·9	—	—
,, ...	—	8·9	1·08	8·2	—	—
,, ...	50·2	28·1	2·78	10·1	21·5	23·0
,, ...	38·5	19·5	1·56	12·5	31·3	25·9
,, ...	41·3	31·8	2·41	13·2	25·6	25·4
,, ...	44·9	24·0	3·00	8·0	21·7	30·0
,, ...	25·7	20·5	1·47	14·0	36·7	31·8
,, ...	40·5	21·8	1·85	11·8	24·3	28·6
Sankey Brook	—	36·5	1·58	23·1	—	—
,, ...	—	7·1	0·83	8·6	—	—
,, ...	—	4·7	0·51	9·2	—	—

TABLE 40—*Composition of Samples dredged from the Bed of the Manchester Ship Canal*

Sample No.	Distance above Eastham Locks (miles).	Moisture (per cent.)	Percentage of dry weight.			Ratio: Carbon / Nitrogen.	Percentage of dry weight.	
			Loss on ignition.	Organic carbon.	Kjeldahl nitrogen.		Silica.	Sesqui-oxides.
M.S.C. 1	0	67·1	16·3	2·43	0·33	7·3	50·6	19·5
2	3	58·3	12·1	2·01	0·23	8·8	61·7	17·1
4	7	61·1	13·3	1·93	0·25	7·7	58·9	17·1
5	9	63·4	13·7	2·13	0·27	7·9	58·0	18·0
6	13	64·8	14·0	3·44	0·32	10·7	57·8	16·8
7	17	18·6	—	0·63	0·04	15·7	—	—
9	20	54·6	10·0	3·52	0·27	13·0	71·1	14·3
10	23	67·0	16·4	5·36	0·50	10·7	62·8	17·1
11	26	70·8	20·4	9·76	0·71	13·7	46·8	23·0
14	31	85·7	35·8	15·10	1·25	12·1	36·4	24·1
15	34	56·7	17·4	8·57	0·43	19·9	63·3	15·8
16	0	59·5	—	3·16	0·48	6·6	—	—
17	3	68·4	—	3·58	0·59	6·1	—	—
18	20	66·0	—	5·59	0·29	19·2	—	—
19	7	62·3	—	2·65	0·28	9·5	—	—
20	9	46·2	—	2·30	0·13	17·7	—	—
21	13	45·0	—	3·36	0·12	28·0	—	—
22	17	22·4	—	2·38	0·03	79·0	—	—
23	18	23·2	—	0·82	0·05	16·4	—	—
24	23	58·7	—	9·49	0·45	21·1	—	—
25	26	66·1	—	10·68	0·86	12·4	—	—
26	29	20·9	—	0·94	0·09	10·5	—	—
27	30	29·8	—	3·99	0·33	12·1	—	—
28	31	62·5	—	6·96	0·45	15·5	—	—
29	34	55·3	—	8·61	0·30	28·7	—	—

Table 42—*Organic Content of Samples dredged from the Channels and Submerged Banks in Liverpool Bay*

Sample No.	Moisture (per cent.).	Organic carbon (per cent. of dry weight).	Kjeldahl nitrogen (per cent. of dry weight).	Sample No.	Moisture (per cent.).	Organic carbon (per cent. of dry weight).	Kjeldahl nitrogen (per cent. of dry weight).
B 19	18·2	0·25	0·05	B 156	30·3	0·80	0·09
20	46·4	1·55	0·17	157	24·1	0·25	0·05
39	20·9	0·19	0·03	158	23·7	0·71	0·05
40	17·0	0·45	0·03	159	27·3	0·94	0·06
50	17·0	0·39	0·04	160	22·7	0·72	0·05
51	20·5	0·31	0·02	161	21·9	0·68	0·04
52	19·3	0·50	0·04	171	24·5	0·13	0·05
55	21·4	0·47	0·05	172	33·6	0·59	0·07
57	45·6	1·80	0·18	173	28·8	0·97	0·06
58	28·9	0·90	0·07	176	23·3	0·43	0·03
65	39·0	0·89	0·09	177	21·5	0·37	0·05
66	22·9	0·36	0·03	178	20·6	0·19	0·06
67	12·9	1·44	0·06	183	17·0	0·22	0·02
68	41·1	1·02	0·13	187	18·7	0·10	0·02
68A	15·3	0·40	0·03	192	20·9	0·29	0·02
70	21·8	0·38	0·03	193	17·8	0·24	0·01
71	33·1	1·57	0·12	194	17·6	0·19	0·01
73	7·1	0·27	0·05	197	26·3	0·76	0·07
74	18·0	0·40	0·04	199	30·5	0·52	0·05
79	36·6	1·42	0·11	216	20·7	0·57	0·03
80	26·2	0·52	0·05	217	23·1	0·36	0·05
82	37·9	1·51	0·16	218	22·7	0·60	0·03
85	20·1	0·69	0·07	229	19·2	0·50	0·01
88	9·9	0·60	0·05	232	32·1	0·66	0·07
95	27·0	0·55	0·04	237	21·6	0·27	0·04
98	37·8	0·31	0·10	238	23·5	0·37	0·05
99	28·8	0·62	0·05	239	20·8	0·16	0·04
102	19·0	0·14	0·01	240	18·2	—	0·01
103	23·9	0·85	—	241	17·2	0·05	0·01
107	50·5	1·37	0·14	242	18·0	0·01	0·01
108	45·3	1·28	0·09	243	17·7	0·05	0·01
109	38·4	1·95	0·13	244	18·2	0·01	0·01
110	29·6	0·64	0·06	245	17·8	0·01	0·01
112	23·7	0·45	0·03	246	17·0	0·00	0·00
113	38·3	0·94	0·10	247	17·3	0·05	0·00
114	24·2	0·45	0·04	248	29·3	0·51	0·08
123	17·6	0·19	0·01	249	18·5	0·16	0·03
124	18·5	0·17	0·02	250	31·1	0·71	0·09
126	20·9	0·33	0·02	251	17·6	1·77	0·04
138	17·4	0·16	0·01	258	26·9	0·77	0·08
152	21·9	0·54	0·04	260	42·8	2·03	0·20
153	22·1	0·35	0·03	263	62·8	2·18	0·25
154	22·4	0·45	0·05	264	46·4	2·28	0·24
155	36·8	0·54	0·10	265	25·8	0·42	0·04

TABLE 44—*Composition of Mud (separated from Sand by Sedimentation) in Samples from the Bed of Liverpool Bay*

Sample No.	Percentage of dry weight.				
	Organic carbon.	Kjeldahl nitrogen.	Loss on ignition.	Silica.	Sesquioxides.
B 1	2·89	0·25	12·2	56·1	—
2	2·63	0·16	11·6	59·1	—
3	1·12	0·10	7·3	72·2	—
4	1·21	0·18	11·7	58·9	—
5	—	0·10	9·1	63·9	—
6	2·01	0·13	8·8	66·5	—
7	3·43	0·19	10·9	60·8	—
8	1·24	0·04	4·7	82·1	—
9	2·61	0·20	10·5	69·4	—
10	2·10	0·13	8·5	69·0	—
11	1·47	0·05	6·8	73·6	—
12	1·24	0·04	6·3	75·5	—
85	2·67	0·27	14·9	51·2	24·3
89	1·68	0·15	9·0	68·6	13·6
101	1·60	0·17	10·5	62·6	15·8
122	1·17	0·15	—	—	—
140	1·67	0·16	6·2	63·1	13·8
151	2·47	0·26	15·3	54·2	20·9
153	1·80	0·22	13·0	58·8	17·0
155	2·31	0·25	14·1	55·6	19·3
158	2·54	0·27	13·9	54·0	29·2
161	1·66	0·23	13·6	54·1	22·0
172	2·44	0·30	14·4	54·1	21·6
176	3·02	0·31	17·1	52·1	20·4
193	0·90	0·26	15·9	52·0	22·1
194	1·55	0·27	15·2	54·9	20·6
197	2·38	0·27	14·4	54·6	21·8
199	1·03	0·27	14·6	55·0	20·0
201	2·31	0·28	16·9	51·0	19·9
207	2·30	0·51	16·2	63·7	13·5
209	1·72	0·22	14·7	53·0	21·8
215	1·65	0·22	13·3	55·0	20·0
216	1·80	0·21	12·7	56·7	18·5
217	2·25	0·29	14·4	53·3	21·5
218	2·07	0·27	14·1	51·6	22·5
229	2·33	0·19	13·3	55·7	20·0
232	2·03	0·22	13·4	56·6	18·8
237	0·88	0·21	12·7	56·5	19·9
238	1·60	0·15	11·8	57·4	18·6
239	1·30	0·23	12·9	53·5	21·3
240	2·40	0·29	14·0	52·3	21·3
248	1·98	0·25	12·7	57·9	18·3
249	2·09	0·25	11·5	59·9	17·9
250	1·96	0·22	12·0	57·5	19·0
251	2·09	0·22	12·1	57·9	19·6

TABLE 45—*Composition of Mud (separated from Sand by Sedimentation) in Surface Samples from the Stanlow Bank, Upper Mersey Estuary*

Sample No.	Percentage of dry weight.				
	Organic carbon.	Kjeldahl nitrogen.	Loss on ignition.	Silica.	Sesquioxides.
S 250	3·54	0·30	15·9	51·0	22·0
251	2·74	0·28	14·4	52·1	23·0
253	3·18	0·30	13·9	53·6	23·6
254	3·29	0·24	14·3	51·4	23·3
255	3·36	0·29	14·2	53·5	20·7
256	2·75	0·24	14·5	54·5	21·6
257	3·14	0·28	14·6	45·6	20·6
258	1·70	0·25	12·0	60·0	16·6
259	2·41	0·29	14·7	54·8	19·0
260	1·92	0·25	14·6	55·0	21·3
261	2·53	0·26	14·8	56·9	17·7
262	2·49	0·23	15·9	56·0	18·4
263	2·92	0·26	13·1	54·4	21·5
264	1·79	0·24	13·5	57·2	18·4
265	2·07	0·20	11·6	60·3	17·3
266	2·72	0·32	15·6	53·3	18·8
267	2·78	0·37	14·2	54·1	20·6
268	1·74	0·35	13·9	—	19·8
269	3·86	0·29	14·1	54·6	19·6
270	3·33	0·25	12·0	58·7	19·3
271	2·06	0·17	9·9	60·2	22·0
272	3·21	0·38	14·9	51·0	22·8
273	—	—	13·8	53·6	21·8
274	2·58	0·30	—	—	—
275	3·08	0·39	—	—	—
276	3·02	0·39	15·5	50·0	24·9
277	3·01	0·36	15·9	51·0	21·9
278	1·78	0·18	—	—	—
279	2·00	0·25	—	—	—
280	2·53	0·32	15·2	52·6	21·6
281	1·39	0·18	—	—	—
282	0·85	0·15	9·5	63·9	15·6
283	1·37	0·13	—	—	—
284	2·59	0·33	14·4	52·2	21·7
285	3·48	0·42	14·7	51·9	21·7
286	3·49	0·42	15·5	52·3	22·3
287	2·97	0·46	16·2	56·9	23·4
288	3·58	0·29	13·3	55·5	20·0
289	3·17	0·34	13·4	56·0	19·2
290	2·78	0·30	13·5	57·0	22·4
291	3·46	0·40	16·2	50·2	23·9

TABLE 46—*Organic Content of Samples from the Bed of the Irish Sea*

Sample No.	Moisture (per cent.).	Organic carbon (per cent. of dry weight).	Kjeldahl nitrogen (per cent. of dry weight).
I.S. 12	39·0	0·64	0·09
13	28·6	0·41	0·05
14	24·7	0·37	0·06
15	29·4	0·41	0·06
16	32·5	0·65	0·06
17	18·5	0·22	0·03
18	16·1	0·17	0·01
19	16·1	0·04	0·01
20	16·7	0·17	0·01
21	16·7	0·18	0·02
22	13·1	0·12	0·02
23	15·6	0·24	0·02
24	15·4	0·20	0·01

TABLE 47—*Composition of Mud (separated from Sand by Sedimentation) in Samples from the Bed of the Irish Sea*

Sample No.	Percentage of dry weight.				
	Organic carbon.	Kjeldahl nitrogen.	Loss on ignition.	Silica.	Sesquioxides.
I.S. 2	1·43	0·24	14·6	51·9	18·1
3	1·79	0·28	16·7	47·7	19·3
4	1·81	0·26	15·3	50·8	19·3
7	4·83	0·93	23·1	42·5	18·7
8	2·72	0·42	19·4	42·8	20·4
9	1·71	0·26	16·6	46·8	19·7
10	1·13	0·18	12·7	53·9	23·8
11	1·22	0·18	12·4	57·0	16·6
13	0·70	0·17	12·2	55·4	20·1
14	1·11	0·15	11·5	57·3	21·8
15	1·65	0·17	11·8	56·2	21·8
16	1·49	0·14	10·5	58·4	20·9
17	1·38	0·14	10·6	59·0	19·1
18	1·58	0·19	11·3	57·3	19·9
19	2·26	0·20	12·7	54·7	20·4
20	0·79	0·10	12·7	54·4	19·4
21	1·68	0·21	12·5	55·7	19·7
22	1·57	0·19	12·3	56·1	20·4
23	1·85	0·20	12·5	56·5	20·3
24	0·99	0·23	14·0	53·8	19·2

TABLE 48—*Composition of Suspended Matter from the Mersey Estuary*

Sample No.	Concentration of suspended matter (parts per 100,000).	Percentage of dry weight.			Ratio : Carbon / Nitrogen.	Percentage of dry weight.	
		Loss on ignition.	Organic carbon.	Kjeldahl nitrogen.		Silica.	Sesquioxides.
S.M. 2	9·7	21·9	4·40	0·37	11·9	43·4	22·5
3	0·8	21·5	5·00	0·54	9·3	44·6	24·4
4	1·7	20·0	4·43	0·41	10·8	42·6	20·5
5	22·1	20·2	3·72	0·43	8·7	47·8	21·3
6	4·4	18·6	2·00	0·26	7·7	50·0	19·4
7	13·2	20·0	3·40	0·39	8·7	49·9	22·6
8	17·1	18·7	3·04	0·40	7·6	51·6	20·4
9	17·9	20·3	3·50	0·38	9·2	49·0	20·4
10	6·1	21·6	3·86	0·38	10·2	48·0	21·8
11	11·6	19·9	2·63	0·31	8·5	50·2	20·4
12	3·2	23·8	4·93	0·46	10·7	45·6	21·2
13	3·3	21·9	3·29	0·41	8·0	47·0	21·2
14	14·2	19·5	2·56	0·43	6·0	50·0	—
18	—	19·6	3·90	0·55	7·1	48·5	—
23	—	19·5	3·40	0·52	6·5	45·6	—

TABLE 49—*Concentration of Dissolved Oxygen in some Estuaries from which Samples of Inter-Tidal Deposits were taken*

Estuaries.	Temperature (° C.).	Salinity (gm. per 1,000 gm.).	Dissolved oxygen (percentage of saturation value).
River Stour, Essex	13½	2·1	122
River Orwell, Suffolk	3½	0·7	100
	16	29·6	106
Hamford Marshes, Essex	14	29·0	92
River Deben, Suffolk	9½	14·7	84
	12	26·7	108
	12	31·0	80
	2	22·6	96
River Crouch, Essex	2½	20·4	98
	13	25·2	97
	14	31·0	105
River Blackwater, Essex	15½	33·3	113
	3½	25·4	101
River Roach, Essex	5	22·4	99
	14	31·7	97
River Ribble, Lancashire	14½	26·2	85
	14½	29·0	87
	18	33·0	86
River Tay, Perthshire, Scotland ..	13 to 17	0 to 34·0	85 to 104

TABLE 50—*Composition of Inter-Tidal Deposits from various Estuaries and Salt Marshes in the British Isles*

Locality from which the deposit was taken.	Sample No.	Moisture (percent.).	Percentage of dry weight.			Ratio: Carbon / Nitrogen.	Percentage of dry weight.	
			Loss on ignition.	Organic carbon.	Kjeldahl nitrogen.		Silica.	Sesqui-oxides.
Norfolk salt marshes, between Blakeney and Wells-on-Sea.	U 1	53·4	12·7	1·91	0·20	9·6	53·3	17·9
	2	45·8	10·1	1·13	0·18	6·3	64·2	14·4
	3	44·6	13·1	1·59	0·20	8·0	58·6	17·5
	4	36·2	8·0	2·11	0·15	14·1	73·1	11·2
Tamar Estuary, Devonshire.	U 8	58·4	14·9	4·20	0·31	13·5	55·1	22·3
	9	53·2	12·7	2·26	0·28	8·1	54·3	20·8
	Tamar 3	55·3	—	3·40	0·27	12·6	—	—
	4	62·8	—	4·70	0·37	12·7	—	—
Beach at Burnham - on - Sea, Somerset.	U 14	30·8	13·3	2·06	0·14	14·7	51·0	18·5
Dee Estuary, Cheshire and Flintshire.	Dee 1	26·4	—	0·66	0·05	13·2	75·5	—
	2	28·4	—	1·08	0·07	15·4	74·6	—
	3	20·8	—	0·50	0·05	10·0	—	—
	4	30·7	—	1·13	0·05	22·6	71·0	—
	5	28·6	—	0·98	0·09	10·9	72·7	—
	6	22·8	—	0·62	0·05	12·4	79·6	—
	7	24·0	—	0·46	0·08	5·8	—	—
	8	25·4	—	0·74	0·05	14·8	78·0	—
	9	20·8	—	0·38	0·02	19·0	—	—
	10	23·8	—	0·73	0·05	14·6	77·2	—
	11	23·9	—	0·33	0·04	8·3	—	—
	12	22·5	—	0·40	0·05	8·0	—	—
	17	20·3	—	0·29	0·05	5·8	—	—
	18	20·4	—	0·33	0·04	8·3	—	—
	19	19·2	—	0·26	0·03	8·7	—	—
	20	22·6	—	0·31	0·04	7·8	—	—
	21	23·4	—	0·59	0·06	9·8	80·0	—
	24	20·3	—	0·40	0·03	13·3	—	—
	25	23·3	—	0·34	0·03	11·3	—	—
	26	23·1	—	0·31	0·03	10·3	—	—
	27	24·8	—	0·46	0·04	11·5	—	—
	28	25·9	—	0·54	0·05	10·8	73·6	—
Ribble Estuary, Lancashire.	R 1	27·3	—	0·66	0·07	9·4	74·7	—
	2	21·8	—	0·43	0·07	6·1	79·6	—
	3	23·3	—	0·52	0·04	13·0	79·6	—
	4	19·9	—	0·14	0·01	14·0	85·4	—
	5	24·0	—	0·36	0·05	7·2	79·0	—
	6	18·4	—	0·10	0·01	10·0	91·7	—
	7	25·5	—	0·63	0·05	12·6	76·9	—
	8	27·2	—	1·22	0·10	12·2	74·0	—
	9	22·8	—	0·53	0·04	13·3	79·6	—
	10	34·7	—	1·10	0·12	9·2	67·3	—
	11	33·3	—	0·99	0·09	11·0	74·8	—
	12	31·4	—	1·38	0·11	12·5	67·9	—
	13	35·6	—	2·03	0·20	10·2	61·1	—
Morecambe Bay, Lancashire.	L 1	20·8	—	0·24	0·02	12·0	—	—
	2	22·0	—	0·21	0·02	10·5	—	—
	3	23·0	—	0·29	0·03	9·7	—	—
	4	21·6	—	0·20	0·01	20·0	—	—
	5	21·9	—	0·15	0·02	7·5	—	—
	6	21·8	—	0·17	0·01	17·0	—	—
	7	23·7	—	0·31	0·02	15·5	—	—
	8	20·9	—	0·20	0·02	10·0	—	—
	9	20·9	—	0·15	0·01	15·0	—	—
	10	20·4	—	0·23	0·01	23·0	—	—
	11	25·3	—	0·41	0·02	20·5	—	—
	12	21·1	—	0·33	0·03	11·0	—	—
	13	17·6	—	0·15	0·01	15·0	—	—
	14	18·7	—	0·27	0·01	27·0	—	—
	15	18·6	—	0·28	0·01	28·0	—	—
	16	17·3	—	0·07	0·00	—	—	—
	17	18·9	—	0·20	0·02	10·0	—	—
Tay Estuary, Perthshire, Scotland.	Tay 1	69·5	17·4	5·48	0·46	11·9	53·5	21·5
	2	51·9	9·4	2·83	0·23	12·3	62·7	20·9
	3	55·6	11·5	3·33	0·28	11·9	61·3	20·8
	4	56·4	10·4	3·49	0·27	12·9	62·0	22·0
	5	45·7	7·6	2·08	0·17	12·2	65·9	19·1

TABLE 50—*continued*

Locality from which the deposit was taken.	Sample No.	Moisture (per cent.).	Percentage of dry weight.			Ratio: Carbon / Nitrogen.	Percentage of dry weight.	
			Loss on ignition.	Organic carbon.	Kjeldahl nitrogen.		Silica.	Sesqui-oxides.
Tay Estuary, Perthshire, Scotland (*contd.*)	Tay 6	41·0	5·3	1·51	0·13	11·6	69·7	18·1
	7	34·7	3·8	1·09	0·09	12·1	73·8	16·8
	8	34·8	4·1	1·06	0·09	11·8	73·8	16·4
	9	45·2	6·7	1·92	0·15	12·8	71·6	15·2
	10	41·7	5·1	1·49	0·13	11·5	73·6	15·6
	11	35·3	3·7	0·94	0·08	11·7	75·4	14·5
	12	32·4	4·2	0·87	0·06	14·5	74·7	15·3
	13	33·8	4·0	1·04	0·08	13·0	75·3	14·8
	14	58·0	11·7	3·88	0·33	11·8	60·8	18·8
	15	66·4	15·1	4·97	0·40	12·4	55·2	21·8
	16	57·6	11·1	3·61	0·27	13·4	62·6	18·9
	17	35·7	4·3	1·34	0·12	11·2	73·9	14·9
	18	31·3	3·4	1·09	0·09	12·1	77·4	14·6
	19	46·1	9·5	—	0·17	—	64·7	17·7
Deben Estuary, Suffolk.	Deben 1	70·4	19·1	4·29	0·46	9·3	50·0	—
	2	62·8	15·6	3·79	0·38	10·0	54·9	—
	3	64·7	18·4	5·10	0·49	10·4	52·1	—
	4	60·1	12·7	2·00	0·21	9·5	52·4	—
	5	63·4	12·4	2·32	0·26	8·9	53·4	—
	6	63·6	13·4	2·17	0·23	9·4	53·2	—
	7	58·5	12·0	1·69	0·20	8·5	56·0	—
	8	57·5	13·3	2·21	0·24	9·2	50·6	—
	9	69·8	—	4·17	0·45	9·3	—	—
	10	72·5	—	5·53	0·52	10·6	—	—
	11	71·4	—	4·51	0·49	9·2	—	—
	12	49·6	—	1·67	0·18	9·3	—	—
	13	40·0	—	1·20	0·14	8·6	—	—
	14	54·3	—	2·80	0·30	9·3	—	—
	15	41·9	—	1·24	0·12	10·3	—	—
	16	50·9	—	2·08	0·21	9·9	—	—
	17	54·9	—	2·11	0·22	9·6	—	—
	18	44·0	—	1·23	0·10	12·3	—	—
	19	47·0	—	1·55	0·15	10·3	—	—
	20	48·0	—	1·42	0·14	10·1	—	—
Orwell Estuary, Suffolk.	Orwell 1	23·6	2·3	0·29	0·05	5·8	92·0	—
	2	61·4	11·2	2·10	0·31	6·8	62·9	—
	3	48·6	6·8	1·54	0·24	6·4	78·7	—
Stour Estuary, Essex.	Stour 1	73·0	16·0	4·37	0·47	9·3	54·4	—
	2	77·3	17·7	5·37	0·56	9·6	49·7	—
	3	57·6	8·2	1·98	0·24	8·2	72·7	—
	4	75·1	14·2	3·98	0·43	9·3	53·7	—
	5	72·5	—	4·38	0·47	9·3	43·5	—
	6	73·2	—	4·33	0·51	8·5	45·3	—
	7	62·7	—	2·92	0·30	9·7	62·3	—
	8	70·0	—	4·20	0·41	10·2	49·9	—
	9	43·4	—	1·55	0·18	8·6	73·0	—
	10	40·1	—	1·17	0·13	9·0	83·3	—
Hamford water (salt marsh), Essex.	Hamford 1	71·6	13·8	1·79	0·32	5·6	51·2	—
	2	74·8	14·8	3·45	0·39	8·9	48·5	—
	3	68·4	13·2	3·01	0·32	9·4	57·3	—
	4	67·2	13·2	2·71	0·30	9·0	56·9	—
	5	62·2	—	3·07	0·28	11·0	54·3	—
	6	65·7	—	3·53	0·34	10·4	47·8	—
	7	58·0	—	2·05	0·22	9·3	55·8	—
	8	62·3	—	2·55	0·27	9·5	50·8	—
	9	60·3	—	2·67	0·29	9·2	51·8	—
	10	59·6	—	2·57	0·28	9·2	53·0	—
Colne Estuary, Essex.	Colne 1	60·0	10·2	1·80	0·23	7·8	63·5	—
	2	59·1	11·7	1·91	0·24	8·0	59·8	—
	3	52·7	9·1	1·42	0·20	7·1	64·9	—
	4	51·3	9·3	1·44	0·18	8·0	64·1	—
	5	48·6	11·8	1·58	0·15	10·5	58·5	—
	6	43·1	8·6	1·58	0·16	9·9	63·5	—
	7	58·0	15·5	2·07	0·19	10·9	52·5	—
	8	55·7	—	1·96	0·17	11·5	54·0	—
Mersea Island, Blackwater Estuary, Essex.	Mersea 1	42·9	6·8	1·14	0·14	8·1	72·3	—
	2	49·9	9·4	1·40	0·18	7·8	64·1	—
	3	36·9	5·4	0·90	0·11	8·2	76·1	—
	4	38·5	6·5	0·89	0·11	8·1	73·3	—
	5	41·2	7·8	1·28	0·15	8·5	67·0	—
	6	60·8	12·1	1·66	0·21	7·9	56·3	—
	7	59·8	10·5	1·62	0·21	7·7	60·3	—
	8	64·3	13·5	2·16	0·28	7·7	51·3	—

TABLE 50—*continued*

Locality from which the deposit was taken.	Sample No.	Moisture (per cent.).	Percentage of dry weight.			Ratio : Carbon / Nitrogen.	Percentage of dry weight.
			Loss on ignition.	Organic carbon.	Kjeldahl nitrogen.		Silica.
Blackwater Estuary, Essex.	Black-water 1	50·2	7·2	1·95	0·23	8·5	75·3
	2	50·3	9·6	1·43	0·18	8·0	62·7
	3	47·9	8·5	1·32	0·14	9·4	66·4
	4	53·1	10·1	1·19	0·15	7·9	63·8
	5	53·6	10·2	1·27	0·15	8·5	64·9
Crouch Estuary, Essex.	Crouch 1	47·3	9·2	1·27	0·15	8·5	64·9
	2	41·7	7·9	0·98	0·12	8·2	70·2
	3	58·8	12·2	2·82	0·32	8·8	55·6
	4	60·2	10·8	2·46	0·30	8·2	56·0
	5	48·4	10·9	1·10	0·13	8·5	58·6
	6	40·8	9·4	0·91	0·11	8·3	66·3
	7	47·2	—	1·82	0·22	8·3	63·4
	8	53·8	—	1·73	0·23	7·5	55·3
	9	57·3	—	2·86	0·24	11·9	51·5
	10	59·3	—	1·87	0·19	9·9	53·3
Roach Estuary, Essex.	Roach 1	43·0	8·9	1·07	0·12	8·9	68·7
	2	34·6	7·3	0·73	0·09	8·1	72·3
Wye Estuary, Monmouthshire.	Wye 1	41·5	—	3·98	0·18	22·1	—
	2	46·1	15·0	4·03	0·17	23·7	53·1
	3	50·5	15·7	4·67	0·15	31·1	53·1
	4	45·7	14·5	4·79	0·14	34·2	55·1
	5	36·8	—	3·69	0·13	28·4	—
	6	40·9	14·5	3·94	0·14	27·1	57·1
Severn Estuary, Monmouthshire.	Severn 1	55·7	—	4·45	0·18	24·7	—
	2	49·6	16·5	4·11	0·19	21·6	50·8
	3	31·3	—	3·11	0·13	24·0	—
	4	46·8	16·8	5·28	0·17	31·0	52·2
Lough Foyle, North of Ireland.	F 1	39·8	—	1·81	0·15	12·1	—
	2	68·8	—	6·51	0·52	12·5	—
	3	40·2	—	1·09	0·12	9·1	—
	4	36·6	—	1·42	0·10	14·2	—
	5	60·0	—	4·38	0·30	14·6	—
	6	47·4	—	2·68	0·18	14·9	—
	7	43·4	—	2·81	0·24	11·7	—
	8	48·9	—	2·43	0·21	11·6	—
	9	52·7	—	3·74	0·30	12·5	—
	10	53·5	—	4·49	0·36	12·5	—
	11	45·2	—	1·88	0·35	5·4	—
	12	51·9	—	2·14	0·25	8·6	—
	13	39·8	—	1·56	0·11	14·2	—
	14	46·6	—	3·63	0·19	19·1	—
	15	36·1	—	2·33	0·13	17·9	—
	16	43·3	—	2·49	0·20	12·5	—
	17	32·2	—	0·94	0·06	15·7	—
	18	42·1	—	2·40	0·30	8·0	—
	19	58·7	—	5·21	0·38	13·7	—
	20	44·4	—	2·23	0·17	13·1	—
	21	64·9	—	5·24	0·41	12·8	—
	22	54·5	—	3·27	0·26	12·6	—
	23	59·1	—	4·01	0·36	11·1	—
	24	48·4	—	2·89	0·23	12·6	—
	25	54·0	—	4·11	0·28	14·7	—
	26	63·0	—	5·32	0·39	13·7	—
	27	52·0	—	3·42	0·25	13·7	—
	28	43·3	—	1·94	0·20	9·7	—
	29	42·3	—	2·29	0·22	10·4	—
	30	64·9	—	4·81	0·39	12·3	—
	31	44·7	—	2·59	0·17	15·2	—
	32	65·6	—	5·20	0·46	11·3	—
	33	64·9	—	5·24	0·38	13·8	—
Suir Estuary, Co. Waterford, Irish Free State.	Suir 1	45·2	—	2·51	0·25	10·0	—
	2	42·8	—	2·19	0·21	10·4	—
	3	45·3	—	2·60	0·22	11·8	—
	4	51·2	—	2·41	0·22	11·0	—
	5	57·5	—	2·88	0·27	10·7	—
	6	48·6	—	2·54	0·24	10·6	—
Barrow Estuary, Co. Waterford, Irish Free State.	Bar-row 1	61·7	—	3·16	0·32	9·9	—

TABLE 51—*Composition of Mud (separated from Sand by Sedimentation) in Inter-Tidal Deposits from Various Estuaries in the British Isles*

Localities from which samples were taken.	Sample No.	Percentage of dry weight.			Ratio: Carbon / Nitrogen.	Percentage of dry weight.	
		Loss on ignition.	Organic carbon.	Kjeldahl nitrogen.		Silica.	Sesqui-oxides.
Dee Estuary, Cheshire and Flintshire.	Dee 1	12·6	1·93	0·19	10·2	57·1	18·2
	2	13·9	1·63	0·25	6·5	56·5	18·9
	3	14·1	1·79	—	—	53·6	21·0
	4	13·1	1·23	0·23	5·3	55·6	20·8
	5	13·0	1·71	0·25	6·8	56·9	19·6
	6	12·7	2·05	0·22	9·3	58·3	17·5
	7	13·7	2·09	0·28	7·5	56·4	20·0
	8	13·1	2·19	0·24	9·1	58·1	17·7
	9	13·5	2·36	0·26	9·1	51·7	20·5
	10	11·7	1·86	0·28	6·6	62·9	15·9
	11	13·1	1·93	0·23	8·4	56·6	19·8
	12	14·6	1·45	0·29	5·0	54·7	18·9
	17	15·3	2·06	0·26	7·9	54·7	18·1
	18	14·1	1·86	0·18	10·3	55·3	20·2
	19	13·0	2·13	0·32	6·7	57·4	18·3
	20	12·7	1·91	0·23	8·3	58·4	17·4
	21	13·6	2·16	0·29	7·5	56·8	17·9
	24	—	2·25	0·31	6·9	—	—
	25	—	1·43	0·19	7·5	—	—
	26	11·1	1·65	0·21	7·9	63·4	17·1
	27	10·5	1·35	0·16	8·4	64·8	15·2
	28	10·2	1·34	0·14	9·6	65·1	11·7
Ribble Estuary, Lancashire.	R 1	12·2	1·55	0·19	8·2	59·2	18·5
	2	12·2	1·58	0·19	8·3	59·3	19·3
	3	12·8	1·18	0·25	4·7	57·1	19·0
	4	12·1	1·92	0·20	9·6	61·3	16·7
	5	12·5	1·64	0·23	7·1	58·1	18·2
	6	—	1·84	0·23	8·0	—	—
	7	13·3	1·25	0·14	8·9	62·6	16·1
	8	13·1	2·51	0·24	10·5	57·9	18·5
	9	12·0	2·04	0·18	11·3	57·6	17·9
	10	13·3	2·10	0·22	9·6	56·7	20·3
	11	12·3	1·93	0·21	9·2	62·0	18·5
	12	11·4	1·43	0·18	8·0	60·1	17·7
	13	13·4	3·08	0·27	11·4	55·7	20·9
Morecambe Bay, Lancashire.	L 11	—	1·93	0·15	12·9	—	—
	12	—	1·66	0·18	9·2	—	—
	17	—	2·37	0·26	9·1	—	—
Tay Estuary, Perthshire, Scotland.	Tay 1	16·2	5·56	0·45	12·4	54·9	22·2
	2	5·6	2·72	0·21	12·9	66·0	21·4
	3	10·6	3·70	0·28	13·2	60·9	21·1
	4	10·9	3·90	0·31	12·6	59·6	19·9
	5	8·1	2·47	0·18	13·7	64·0	19·3
	6	7·5	2·42	0·18	13·5	64·3	19·8
	7	5·8	1·94	0·16	12·1	65·6	21·2
	8	6·0	1·73	0·12	14·4	65·5	20·9
	9	12·1	4·39	0·36	12·2	59·5	20·6
	10	7·9	2·67	0·20	13·4	66·7	18·2
	11	7·6	2·50	0·18	13·9	67·0	17·8
	12	7·9	2·42	0·18	13·4	65·8	19·4
	13	7·3	2·25	0·19	11·8	64·6	19·3
	14	11·6	4·00	0·36	11·1	61·0	20·0
	15	14·9	3·83	0·37	10·3	55·7	21·5
	16	13·6	4·67	0·36	13·0	58·1	20·6
	17	8·6	3·30	0·24	13·7	63·3	19·8
	18	9·7	3·19	0·26	12·3	61·6	21·0
	19	10·4	3·37	0·26	13·0	61·7	19·3
Lough Foyle, North of Ireland.	F 1	—	3·31	0·25	13·2	—	—
	2	—	10·63	0·82	13·0	—	—
	3	—	3·47	0·32	10·8	—	—

TABLE 51—*continued*

Localities from which samples were taken.	Sample No.	Percentage of dry weight.			Ratio: Carbon Nitrogen.	Percentage of dry weight.	
		Loss on ignition.	Organic carbon.	Kjeldahl nitrogen.		Silica.	Sesqui-oxides.
Lough Foyle, North of Ireland —*contd.*	F 4	—	2·24	0·17	14·2	—	—
	5	—	4·37	0·28	15·6	—	—
	6	—	1·98	0·14	14·2	—	—
	7	—	1·73	0·12	14·4	—	—
	8	—	2·98	0·22	13·5	—	—
	9	—	3·12	0·20	15·6	—	—
	10	—	2·39	0·17	14·1	—	—
	11	—	3·66	0·31	11·8	—	—
	12	—	3·92	0·34	11·5	—	—
	13	—	1·49	0·11	13·5	—	—
	14	—	4·41	0·29	15·2	—	—
	15	—	3·72	0·24	15·5	—	—
	16	—	3·24	0·21	15·4	—	—
	17	—	1·59	0·11	14·5	—	—
	18	—	2·43	0·20	12·4	—	—
	19	—	5·60	0·30	18·7	—	—
	20	—	3·51	0·24	14·6	—	—
	21	—	5·16	0·40	12·9	—	—
	22	—	3·65	0·26	14·0	—	—
	23	—	4·66	0·39	11·9	—	—
	24	—	2·72	0·22	12·4	—	—
	25	—	4·21	0·34	12·4	—	—
	26	—	5·50	0·28	19·6	—	—
	27	—	2·74	0·25	11·0	—	—
	28	—	2·77	0·22	12·6	—	—
	29	—	2·66	0·22	12·1	—	—
	30	—	5·84	0·48	12·2	—	—
	31	—	2·78	0·24	11·6	—	—
	32	—	5·38	0·41	13·1	—	—
	33	—	5·24	0·41	12·8	—	—

TABLE 52—*Organic Content of Mersey Mud, Estuarine Suspended Matter, and Boulder Clay after Stirring with Different Concentrations of Settled Sewage*

S.M. = Estuarine suspended matter collected in Estuary water.

Experiment No. T	Sample and treatment.	Period of stirring (days).	Total of amounts of sewage added (per cent. of volume of suspension).	Analysis of mud after treatment. Percentage of dry weight. Organic carbon.	Kjeldahl nitrogen.	Ratio: Carbon / Nitrogen.
102	S.M. 80, without sewage	12½	0	4·23	0·58	7·3
103	,, with one addition of sewage ..		0·25	4·89	0·63	7·8
104	,, ,, ,, ,, ,, ..		0·5	5·67	0·67	8·5
105	,, ,, ,, ,, ,, ..		1·0	5·85	0·67	8·7
106	,, ,, ,, ,, ,, ..		2·0	6·47	0·78	8·3
107	,, ,, ,, ,, ,, ..		5·0	9·04	1·11	8·1
108	S.M. 83, without sewage	11¾	0	3·96	0·52	7·6
109	,, with one addition of sewage ..		0·25	4·05	0·52	7·8
110	,, ,, ,, ,, ,, ..		0·5	4·55	0·58	7·8
111	,, ,, ,, ,, ,, ..		1·0	4·53	0·60	7·6
112	,, ,, ,, ,, ,, ..		2·0	5·04	0·67	7·5
113	,, ,, ,, ,, ,, ..		5·0	6·03	0·83	7·3
114	U. 51, suspension of boulder clay in tap water and sea salt	6	0	0·37	0·10	3·7
115	,, with one addition of sewage ..		0·5	0·56	0·15	3·7
116	,, ,, ,, ,, ,, ..		1·0	0·94	0·21	4·5
117	,, ,, ,, ,, ,, ..		5·0	1·44	0·30	4·8
120	S.M. 90, without sewage	3½	0	3·91	0·46	8·5
121	,, with one addition of sewage ..		0·25	3·77	0·44	8·6
122	,, ,, ,, ,, ,, ..		0·5	4·24	0·49	8·7
123	,, ,, ,, ,, ,, ..		1·0	4·19	0·49	8·6
124	,, ,, ,, ,, ,, ..		2·0	5·00	0·62	8·1
125	,, ,, ,, ,, ,, ..		5·0	5·74	0·73	7·9
126	S.M. 95, without sewage	6	0	4·68	0·58	8·1
127	,, with one addition of sewage ..		0·25	4·87	0·58	8·4
128	,, ,, ,, ,, ,, ..		0·5	5·24	0·64	8·2
129	,, ,, ,, ,, ,, ..		1·0	5·39	0·67	8·0
130	,, ,, ,, ,, ,, ..		2·0	5·57	0·73	7·6
131	,, ,, ,, ,, ,, ..		5·0	6·62	0·88	7·5
132	U. 51, suspension of boulder clay in tap water and sea salt	13	0	0·51	0·06	8·5
133	,, with one addition of sewage ..		0·5	0·62	0·08	7·8
134	,, ,, ,, ,, ,, ..		1·0	0·76	0·09	8·5
135	,, ,, ,, ,, ,, ..		2·0	0·89	0·11	8·1
136	,, ,, ,, ,, ,, ..		5·0	1·60	0·23	7·0

TABLE 53—*Petroleum Ether Extractives and Organic Carbon in Mud from Various Localities and in Digested Sewage Sludges*

Locality from which sample was taken.	Sample No.	Percentage of dry weight.		Weight of ether extractives (gm. per 100 gm. of organic carbon).
		Petroleum ether extractives.	Organic carbon.	
Mud separated from samples from the bed of the Manchester Ship Canal.	M.S.C. 4	0·018	0·85	2·1
	5	0·019	0·96	2·0
	6	0·170	1·52	11·2
	9	0·430	2·24	19·2
	10	0·731	3·21	22·8
Mud separated from samples from the bed of Liverpool Bay.	B 197	0·003	2·38	0·1
	199	0·035	1·03	3·4
	217	0·002	2·25	0·1
	218	0·014	2·07	0·7
	238	0·090	1·60	5·6
	248	0·007	1·98	0·4
Mud separated from samples from the bed of the Irish Sea.	I.S. 10	0·007	1·13	0·6
	12	0·008	0·64	1·3
	13	0·005	0·70	0·7
	14	0·009	1·11	0·8
	15	0·008	1·65	0·5
	16	0·004	1·49	0·3
	17	0·003	1·38	0·2
	18	0·002	1·58	0·1
	22	0·030	1·57	1·9
Lough Foyle, North of Ireland.	F 1	0·006	1·81	0·3
	13	0·011	1·56	0·7
	19	0·020	5·21	0·4
	25	0·029	4·11	0·7
	31	0·013	2·59	0·5
Mud separated from samples from the Ribble Estuary, Lancashire.	R 1	0·006	1·55	0·4
	2	0·005	1·58	0·3
	3	0·008	1·18	0·7
	5	0·008	1·64	0·5
	11	0·007	1·93	0·4
Dee Estuary, Cheshire and Flintshire.	Dee 1	0·001	0·66	0·2
	2	0·005	1·08	0·5
	26	0·007	0·31	2·3
Mud separated from Dee samples.	7	0·008	2·09	0·4
,, ,, ,,	8	0·007	2·19	0·3
Orwell Estuary, Suffolk.	Orwell 2	0·010	2·10	0·5
Deben Estuary, Suffolk.	Deben 3	0·035	5·10	0·7
Hamford Marshes, Essex.	Hamford 2	0·003	3·45	0·1
,, ,,	Hamford 3	0·004	3·01	0·1
Stour Estuary, ,,	Stour 1	0·003	4·37	0·1
,, ,,	Stour 2	0·009	5·37	0·2
Digested sewage sludges from Birmingham. (Age of sludge in years given in brackets)	No. 1 (21)	2·136	18·5	11·5
	2 (17)	1·167	19·0	6·2
	3 (12)	2·434	22·9	10·6
	4 (6)	1·882	21·5	8·8
	5 (1)	2·627	25·9	10·1

TABLE 55.—*Composition of Digested Sewage Sludges from Birmingham*

Sample No.	Age of sludge (years).	Moisture (per cent.).	Percentage of dry weight.			Ratio: Carbon / Nitrogen.
			Loss on ignition.	Organic carbon.	Kjeldahl nitrogen.	
1 A	21	41·2	44·7	—	1·87	—
B	,,	54·0	40·3	21·7	1·71	12·7
C	,,	51·8	39·1	12·4	1·35	9·2
D	,,	50·9	39·7	20·5	1·34	15·3
E	,,	53·6	38·5	19·6	1·49	13·2
F	,,	54·2	41·7	18·4	1·47	12·5
2 A	17	55·4	42·4	19·9	2·01	9·9
B	,,	48·6	42·3	15·1	1·83	8·3
C	,,	51·8	46·6	15·1	1·72	8·8
D	,,	47·3	43·3	18·0	1·55	11·6
E	,,	50·0	44·8	23·5	1·94	12·1
F	,,	54·0	43·5	22·6	1·60	14·1
3 A	12	48·3	45·3	22·1	1·99	11·1
B	,,	51·7	45·4	26·7	1·80	14·8
C	,,	48·1	46·1	20·7	1·93	10·7
D	,,	50·0	44·7	23·3	1·72	13·5
E	,,	50·0	43·5	25·1	2·08	12·1
F	,,	49·2	44·5	19·2	1·85	10·4
4 A	6	54·3	44·1	18·6	2·17	8·6
B	,,	55·3	44·9	24·8	1·81	13·7
C	,,	52·3	44·8	18·2	1·84	9·9
D	,,	59·0	45·5	23·4	1·62	14·4
E	,,	55·6	43·7	21·5	1·56	13·8
F	,,	54·5	45·8	22·4	1·94	11·5
5 A	1	49·3	53·9	25·8	2·50	10·3
B	,,	53·4	49·6	24·2	2·91	8·3
C	,,	55·6	49·5	25·5	2·08	12·3
D	,,	48·2	50·9	26·3	1·53	17·2
E	,,	48·0	47·9	29·4	2·70	10·9
F	,,	52·9	47·8	24·0	2·33	10·3

TABLE 56—*Change in the Composition of Mud from the Stanlow Bank on Storing under Sea Water at Laboratory Temperature*

Samples S 316—354 stored 189 days
,, 375—386 ,, 365 ,,
,, 387—401 ,, 351 ,,
,, 402—413 ,, 339 ,,
,, 414—425 ,, 338 ,,

Sample No.	Original composition (per cent. of dry weight).		Final composition (per cent. of dry weight).		Final carbon × 100	Final nitrogen × 100
	Organic carbon.	Kjeldahl nitrogen.	Organic carbon.	Kjeldahl nitrogen.	Original carbon.	Original nitrogen.
S 315	3·44	0·34	3·06	0·29	89	85
,,	3·33	0·28	2·98	0·26	90	93
,,	3·25	0·31	2·92	0·27	90	87
316	2·04	0·20	1·93	0·15	95	75
,,	2·16	0·20	1·88	0·14	87	70
,,	2·32	0·17	1·94	0·15	83	88
317	2·85	0·28	3·10	0·28	109	100
,,	2·74	0·29	2·76	0·24	101	83
,,	3·17	0·28	2·82	0·25	89	89
318	2·40	0·19	2·14	0·17	89	90
,,	2·35	0·21	2·25	0·18	96	86
,,	2·20	0·20	2·18	0·17	99	85
319	0·78	0·09	1·06	0·09	136	100
,,	1·10	0·10	1·04	0·09	95	90
,,	1·14	0·10	1·08	0·09	95	90
320	0·60	0·05	0·56	0·05	93	100
,,	0·63	0·05	0·54	0·04	86	80
321	1·08	0·08	0·81	0·08	74	100
,,	1·21	0·09	0·79	0·08	65	89
,,	1·04	0·08	0·90	0·08	87	100
322	1·56	0·09	1·22	0·11	78	122
,,	1·44	0·12	1·22	0·11	85	92
,,	1·38	0·10	4·20	0·11	87	110
323	2·42	0·19	2·17	0·17	90	90
,,	1·55	0·19	2·33	0·17	150	90
,,	2·28	0·19	2·08	0·17	91	90
324	2·35	0·21	2·15	0·19	92	91
,,	2·18	0·17	2·16	0·19	99	112
325	3·32	0·40	3·06	0·29	92	73
,,	2·99	0·38	2·56	0·26	86	68
,,	3·14	0·45	2·67	0·27	85	60

Sample No.	Original composition (per cent. of dry weight).		Final composition (per cent. of dry weight).		Final carbon × 100	Final nitrogen × 100
	Organic carbon.	Kjeldahl nitrogen.	Organic carbon.	Kjeldahl nitrogen.	Original carbon.	Original nitrogen.
S 326A	2·18	0·19	2·05	0·18	94	95
,,	2·10	0·17	1·86	0·17	89	100
,,	2·17	0·19	1·99	0·18	92	95
326B	1·89	0·19	1·78	0·18	94	95
,,	1·86	0·18	1·82	0·19	98	105
,,	1·95	0·17	1·85	0·18	95	106
326C	2·08	0·18	2·21	0·18	106	100
,,	2·03	0·18	2·19	0·17	108	95
,,	2·11	0·19	2·18	0·17	103	90
326D	2·03	0·15	2·10	0·15	103	100
,,	1·98	0·17	2·18	0·15	110	88
,,	2·01	0·16	1·99	0·15	99	94
326E	1·81	0·17	1·94	0·16	107	94
,,	1·89	0·13	1·96	0·16	104	123
,,	1·95	0·16	2·00	0·17	102	106
327	3·05	0·30	2·86	0·26	94	87
,,	2·81	0·29	2·92	0·27	104	93
,,	3·03	0·19	2·90	0·26	96	137
328	3·65	0·37	2·36	0·30	65	81
,,	3·99	0·33	2·31	0·31	58	94
,,	3·48	0·30	3·06	0·29	88	97
329	3·30	0·39	3·08	0·28	93	72
,,	3·42	0·39	3·19	0·28	93	72
,,	3·29	0·41	2·92	0·26	89	63
330	2·95	0·33	3·23	0·28	110	85
331	1·62	0·15	1·59	0·17	98	113
,,	1·50	0·18	1·64	0·16	109	89
,,	1·50	0·16	1·53	0·16	102	100
332	2·17	0·20	2·06	0·18	95	90
,,	2·31	0·21	2·08	0·18	90	86
,,	2·11	0·22	2·12	0·18	100	82

Sample No.	Original composition (per cent. of dry weight).		Final composition (per cent. of dry weight).		Final carbon × 100	Final nitrogen × 100
	Organic carbon.	Kjeldahl nitrogen.	Organic carbon.	Kjeldahl nitrogen.	Original carbon.	Original nitrogen.
S 333	1·42	0·11	1·23	0·11	87	100
,,	1·35	0·12	1·25	0·11	93	92
,,	1·41	0·12	1·25	0·11	89	92
334	1·77	0·15	1·63	0·13	92	87
,,	1·73	0·15	1·62	0·13	94	87
,,	1·63	0·15	1·79	0·13	110	87
335	2·66	0·23	2·62	0·22	99	96
,,	2·93	0·22	3·07	0·25	105	113
,,	2·69	0·29	2·60	0·23	97	79
336	2·80	0·30	2·71	0·27	97	90
,,	2·76	0·28	2·46	0·25	89	89
,,	2·88	0·28	2·47	0·25	86	89
337	2·89	0·24	2·84	0·25	98	104
,,	2·75	0·26	2·49	0·21	91	81
,,	2·75	0·24	2·62	0·24	95	100
338	2·16	0·21	2·00	0·17	93	81
,,	2·12	0·17	1·95	0·18	92	106
,,	2·09	0·20	1·93	0·17	92	85
339	1·97	0·19	1·70	0·20	86	105
,,	1·82	0·19	1·64	0·20	90	105
340	2·71	0·28	2·52	0·24	93	86
,,	2·60	0·28	3·13	0·30	120	107
,,	2·67	0·27	2·38	0·22	89	81
341	3·10	0·26	3·16	0·25	102	96
,,	2·84	0·29	3·05	0·24	107	83
,,	3·09	0·28	3·02	0·25	98	89
342	3·21	0·24	3·18	0·27	99	112
,,	3·37	0·32	3·17	0·27	94	85
,,	3·27	0·31	3·55	0·29	108	93
343A	4·53	0·40	3·37	0·38	74	95
,,	4·20	0·49	3·29	0·36	78	73

S 343A	4·01	0·37	3·29	0·36	82	97
343B	3·85	0·38	3·60	0·35	94	92
,,	3·48	0·38	3·73	0·35	107	92
,,	3·84	0·47	3·69	0·34	96	72
343C	4·31	0·51	3·82	0·35	89	69
,,	4·10	0·45	3·87	0·37	94	82
,,	4·23	0·43	3·59	0·36	85	84
343D	4·08	0·46	3·59	0·36	88	78
,,	3·97	0·45	3·86	0·39	97	87
,,	4·35	0·48	3·63	0·35	83	73
344	2·56	0·21	2·34	0·20	91	95
,,	2·61	0·22	2·33	0·21	89	96
,,	1·59	0·21	2·18	0·18	137	86
345	2·26	0·24	2·56	0·23	113	96
,,	2·34	0·25	2·17	0·22	93	88
,,	2·18	0·24	2·46	0·23	113	96
346	1·90	0·24	2·55	0·22	134	92
,,	1·61	0·22	2·73	0·23	170	104
,,	2·49	0·27	3·23	0·21	130	78
347	2·34	0·19	2·20	0·19	94	100
,,	2·35	0·19	2·40	0·21	102	110
,,	2·18	0·19	2·36	0·20	108	105
348	1·75	0·20	2·56	0·20	146	100
,,	2·54	0·25	2·50	0·21	98	84
,,	2·53	0·21	2·28	0·19	90	90
349	3·37	0·36	3·10	0·29	92	81
,,	3·12	0·37	2·99	0·28	96	76
,,	3·04	0·43	2·95	0·27	97	63
350	3·18	0·44	3·18	0·31	100	70
,,	3·13	0·34	3·14	0·31	100	91
,,	3·35	0·42	3·11	0·31	93	74
351	3·58	0·30	3·32	0·31	93	103
,,	3·81	0·36	3·33	0·31	87	86

S 351	3·72	0·38	3·05	0·28	82	74
352	3·33	0·39	3·16	0·32	95	82
,,	3·14	0·39	3·11	0·32	99	82
,,	3·72	0·40	3·08	0·33	83	83
353	3·74	0·38	3·54	0·33	95	87
,,	3·35	0·25	3·17	0·31	95	124
,,	3·50	0·36	3·48	0·30	99	81
354	2·78	0·26	2·70	0·25	94	96
,,	2·85	0·26	2·74	0·23	96	88
,,	2·75	0·24	2·82	0·24	102	100
375	2·88	0·26	2·45	0·22	85	85
376	3·32	0·27	2·85	0·27	86	100
377	3·17	0·28	3·16	0·26	100	93
378	3·40	0·28	2·92	0·25	86	89
379	3·02	0·27	3·33	0·25	110	93
380	2·81	0·27	2·93	0·23	104	85
381	3·10	0·28	2·84	0·19	92	68
382	2·98	0·30	3·02	0·25	101	83
383	1·97	0·16	2·11	0·17	107	106
384	1·38	0·11	1·68	0·13	122	118
385	1·28	0·12	1·52	0·12	119	100
386	1·12	0·15	1·30	0·10	116	67
387	2·27	0·16	2·16	0·15	95	94
388	1·52	0·14	1·70	0·11	112	79
389	2·72	0·21	2·40	0·17	88	81
390	2·46	0·19	2·50	0·18	102	95
391	2·94	0·21	2·37	0·18	81	86
392	4·34	0·38	3·32	0·31	76	80
393	3·69	0·39	3·18	0·28	86	72
394	3·90	0·36	3·13	0·30	80	83
395	2·23	0·19	2·15	0·16	96	84

S 396	3·25	0·26	2·81	0·25	86	96
397	3·77	0·36	3·40	0·30	90	83
398	1·94	0·14	1·80	0·14	93	100
399	2·43	0·20	2·37	0·19	98	95
400	1·40	0·13	1·35	0·10	97	77
401	2·06	0·14	1·81	0·13	88	93
402	2·40	0·18	2·62	0·18	109	100
403	2·81	0·23	2·94	0·20	105	87
404	3·57	0·29	3·18	0·26	89	90
405	2·26	0·19	2·18	0·17	97	90
406	2·02	0·26	2·33	0·15	115	94
407	1·82	0·17	1·73	0·16	95	94
408	2·57	0·23	2·50	0·20	97	87
409	1·93	0·18	1·86	0·16	96	89
410	1·64	0·14	1·61	0·13	98	93
411	1·50	0·13	1·48	0·13	106	100
412	1·27	0·10	1·37	0·11	108	110
413	2·46	0·18	2·76	0·20	112	111
414	1·69	0·15	2·16	0·16	128	107
415	2·35	0·18	2·47	0·19	105	105
416	2·96	0·28	2·93	0·22	99	79
417	3·39	0·30	3·09	0·24	91	80
418	2·77	0·22	2·78	0·22	100	100
419	3·10	0·28	2·78	0·24	90	86
420	2·62	0·23	2·68	0·18	102	78
421	2·13	0·20	2·15	0·17	101	85
422	2·27	0·17	2·11	0·17	93	100
423	3·17	0·33	2·55	0·24	80	73
424	2·22	0·18	2·55	0·21	115	117
425	2·29	0·12	2·34	0·17	102	142

TABLE 57—*Change in the Composition of Mud from the Stanlow Bank on Storing under Sea Water at 37° C.*

Samples 389 to 400 stored 350 days
,, 402 ,, 425 ,, 338 ,,

Sample No.	Original composition (per cent. of dry weight).		Final composition (per cent. of dry weight).		Final carbon × 100 / Original carbon.	Final nitrogen × 100 / Original nitrogen.
	Organic carbon.	Kjeldahl nitrogen.	Organic carbon.	Kjeldahl nitrogen.		
S 389	2·72	0·21	3·70	0·26	136	124
390	2·46	0·19	2·31	0·16	94	84
392	4·34	0·39	3·08	0·28	71	72
393	3·69	0·39	2·98	0·25	81	64
394	3·90	0·36	3·21	0·24	82	67
395	2·23	0·19	2·23	0·15	100	79
397	3·77	0·36	3·37	0·27	89	75
398	1·94	0·14	1·90	0·11	98	79
400	1·40	0·13	1·44	0·08	103	62
402	2·40	0·18	2·34	0·17	98	95
403	2·81	0·23	2·73	0·20	97	87
404	3·57	0·29	2·60	0·20	73	69
405	2·26	0·19	2·22	0·15	98	79
406	2·02	0·16	2·11	0·14	104	88
407	1·82	0·17	1·86	0·14	102	82
408	2·57	0·23	2·63	0·20	102	87
409	1·93	0·18	1·93	0·12	100	67
410	1·64	0·14	1·68	0·11	102	79
411	1·40	0·13	1·39	0·08	99	62
412	1·27	0·10	1·18	0·08	93	80
413	2·46	0·18	2·46	0·17	100	95
414	1·69	0·15	2·03	0·13	120	87
415	2·35	0·18	2·09	0·15	89	83
416	2·96	0·28	2·89	0·24	98	86
417	3·39	0·30	3·12	0·26	92	87
418	2·77	0·22	2·77	0·21	100	96
420	2·62	0·23	2·41	0·17	92	74
421	2·13	0·20	2·33	0·17	109	85
422	2·27	0·17	2·12	0·16	93	94
423	3·17	0·33	2·66	0·25	84	76
424	2·22	0·18	2·50	0·21	113	117
425	2·29	0·12	1·98	0·11	86	92

TABLE 58—*Effect of Storage under Sea Water on the Composition of Mud dredged from the Manchester Ship Canal*

Stored 318 days

Sample No.	Original composition (per cent. of dry weight).		Final composition (per cent. of dry weight).		Loss of carbon and nitrogen (per cent. of dry weight).		Final carbon × 100 / Original carbon.	Final nitrogen × 100 / Original nitrogen.	Temperature of storage (° C.).
	Organic carbon.	Kjeldahl nitrogen.	Organic carbon.	Kjeldahl nitrogen.	Organic carbon.	Kjeldahl nitrogen.			
M.S.C. 16	3·16	0·48	2·88	0·26	0·28	0·22	91	54	Laboratory temp.
17	3·58	0·59	3·15	0·28	0·43	0·31	88	47	,,
18	5·59	0·29	4·68	0·34	0·91	0·05*	84	117	,,
25	10·7	0·86	10·3	0·67	0·4	0·19	96	78	,,
18	5·59	0·29	3·98	0·14	1·61	0·15	71	48	37
24	9·49	0·45	4·50	0·24	4·99	0·21	47	53	,,
25	10·7	0·86	3·32	0·28	7·36	0·58	31	33	,,
28	6·96	0·45	5·55	0·27	1·41	0·18	80	60	,,

* Gain.

TABLE 59—*Effect of Storage under Sea Water on the Composition of Estuarine Suspended Matter previously stirred with Settled Sewage*

Stored at 37° C.

Period of storage.	Composition of sample (per cent. of dry weight).	Sample No.				
		T. 108.	T. 110.	T. 111.	T. 112.	T. 113.
None	Organic carbon	3·96	4·55	4·53	5·04	6·03
	Kjeldahl nitrogen	0·52	0·58	0·60	0·67	0·83
2 weeks	Organic carbon	3·63	3·49	4·43	4·80	5·89
	Kjeldahl nitrogen	0·49	0·53	0·60	0·62	0·83
2 months	Organic carbon	3·68	4·21	4·46	4·90	5·65
	Kjeldahl nitrogen	0·35	0·50	0·49	0·55	0·71
10 months	Organic carbon	3·35	3·61	4·07	—	—
	Kjeldahl nitrogen	0·30	0·32	0·40	—	—
2 weeks	Organic carbon lost	0·33	1·06	0·10	0·24	0·14
2 months		0·28	0·34	0·07	0·14	0·38
10 months		0·61	0·94	0·46	—	—
2 weeks	Kjeldahl nitrogen lost	0·03	0·05	0	0·05	0
2 months		0·17	0·08	0·11	0·12	0·12
10 months		0·22	0·26	0·20	—	—
2 weeks	Final carbon × 100 / Original carbon	92	77	98	95	98
2 months		93	92	98	97	94
10 months		85	79	90	—	—
2 weeks	Final nitrogen × 100 / Original nitrogen	94	91	100	93	100
2 months		67	86	82	82	86
10 months		58	55	67	—	—

The samples consisted of suspended matter from the Mersey Estuary previously stirred with the following concentrations of settled sewage :—

T. 108 0 per cent.
T. 110 0·5 ,,
T. 111 1 ,,
T. 112 2 ,,
T. 113 5 ,,

TABLE 61—*Rate of Fall of Mud Particles through a Column of Water 9 ft. in Length*

Suspended Matter from Mersey Estuary used in all cases
Salinity of Water 25 gm. per 1,000 gm.

Depth of particle observed (ft.).	Time after beginning of sedimentation (min.).	Rate of fall of particle (ft. per min.).
Experiment 1		
1	13·5	0
	17·5	0
	20·5	0
	52	0
	62	0
	83·5	0
	131	0
2	13·5	0
	17·5	0
	20·5	0
	24	0
	36	0
	47	0
	52	0
	62	0
	83·5	0
	131	0
3	13·5	0
	17·5	0
	20·5	0
	24	0
	35	0
	46·5	0
	52	0
	62	0
	83·5	0
	131	0
4	13·5	0
	17·5	0
	20·5	0
	24	0
	29	0·31
	32	0·36
	34·5	0·32
	45·5	0·47
	51	0·46
	51·5	0·47
	60·5	0·38
	61	0·31
	82	0·32
	131	0
5	10	0·42
	13	0·98
	13	0·81
	17	0·72
	20	0·76
	24	0·85
	28·5	0·75
	45	0·73
	55	0·53
	60	0·76
	77	0·27
	130	0·19
6	16·5	0·66
	19	0·79
	23	0·88
	28	0·84
	45	0·89
	49	0·94
	54·5	0·70
	59	0·53
	75	0·45
	129	0·31
7	7	1·20
	8	1·20
	8	1·40
	8	1·51
	8·5	1·51
	8·5	1·16
	10	0·53
	11·5	1·16
	16	0·91
	19	0·70
	23	0·72
	27	0·88
	40·5	0·85
	44·5	0·98
	48	0·71
	53·5	1·23
	53·5	0·65
	58·5	0·89
	73	0·47
	127·5	0·16
8	12	1·16
	12	0·94
	12·5	0·82
	15	0·70
	15	0·82
	15·5	1·51
	16	0·98
	18	0·70
	22·5	0·89
	26·5	0·85
	36	0·79
	40	0·94
	44	0·81
	47·5	0·98
	52·5	0·66
	53	0·88
	58	1·40
	72	0·81
	126·5	0·21
Experiment 2		
1	17·5	0
	22	0
	25	0
	34	0
2	17·5	0·44
	21·5	0·44
	25	0·55
	29·5	0
	34	0
	38·5	0
3	17	0·76
	21	0·82
	25	0·65
	29	0
	38	0·40
	47·5	0·52
	48	0·49
4	16·5	0·82
	20·5	0·82
	24·5	0·69
	34·5	0·70
	39·5	0·82
	48·5	0·67
	49	0·44
5	16	0·87
	20	1·61
	24	1·09
	28	1·51
	32	0·65
	35	0·73
	43	0·55
	50	0·43
6	15·5	1·47
	18·5	1·04
	23·5	1·24
	27·5	1·00
	32·5	0·88
	35·5	0·69
	44	0·85
	44·5	0·60
	50·5	0·49
	60	0·50
7	15	1·21
	18	1·23
	23	1·33
	27	1·16
	33	1·17
	36	0·88
	36·5	1·07
	45	0·70
	52·5	0·82
	58·5	0·45
8	12·5	0·81
	18	1·29
	22·5	1·26
	26	0·94
	26·5	1·06
	33	1·31
	37	1·00
	37	0·97
	45·5	0·63
	46	0·85
	53	0·50
	53·5	0·47
	54	0·66
	58	0·50
Experiment 3		
1	17	0·25
	22·5	0·18
	30	0
	38	0
	58·5	0
2	16	0·38
	21·5	0·32
	29	0·28
	38	0
	58·5	0

TABLE 61—*continued*

Depth of particle observed (ft.).	Time after beginning of sedimentation (min.).	Rate of fall of particle (ft. per min.).
Experiment 3 —*contd.*		
3	15·5	0·43
	20·5	0·40
	28·5	0·35
	36·5	0
	38	0
	48	0
	58·5	0
4	15	0·43
	19·5	0·54
	27	0·32
	27·5	0·41
	36	0·37
	37·5	0·39
	46	0·29
	46·5	0·25
	57·5	0·19
5	14	0·94
	19	1·16
	19	0·81
	26	0·80
	26·5	0·66
	34·5	0·54
	35	0·58
	44	0·40
	44·5	0·45
	45	0·41
	55	0·41
	55·5	0·34
	56	0·38
6	14	0·77
	18·5	0·83
	25	0·68
	25·5	0·91
	25·5	0·71
	33·5	0·69
	34	0·59
	42	0·50
	42·5	0·47
	43	0·55
	53	0·34
	53·5	0·31
	54·5	0·37
7	12	0
	13·5	0·66
	18	0·79
	24	0·92
	32·5	0·61
	33	0·85
	33	0·60
	40	0·46
	40·5	0·41
	41·5	0·39
	51	0·40
	52	0·38
	52·5	0·41
	60	0·22

Depth of particle observed (ft.).	Time after beginning of sedimentation (min.).	Rate of fall of particle (ft. per min.).
8	12	0·47
	13	0·92
	17·5	0·68
	23	0·57
	24·5	0·92
	25	0·71
	31	0·57
	31	0·56
	31·5	0·66
	32	0·64
	38	0·64
	38·5	0·47
	39	0·57
	49·5	0·51
	50	0·45
	50·5	0·42
	58·5	0·29
	59·5	0·33
Experiment 4		
1	19	0·23
2	16	0·44
	16	0·55
	17	0·60
3	13	0·79
	14	0·58
	14	0·44
	15	0·50
4	10	1·21
	10	0·77
	32·5	0·38
	34·5	0·35
	35	0·33
5	8·5	1·20
	9	1·00
	9	1·04
	28	0·61
	28	0·73
	29	0·76
6	7	1·69
	7·5	1·29
	8	1·47
	26	0·81
	27	0·50
	27	0·59
	39·5	0·56

Depth of particle observed (ft.).	Time after beginning of sedimentation (min.).	Rate of fall of particle (ft. per min.).
7	7	1·96
	7	2·28
	25	0·53
	25	0·56
	25·5	0·73
	38	0·49
	38·5	0·49
	39	0·47
8	23	0·58
	23	0·58
	24	0·49
	36	0·49
	37	0·57
	37·5	0·54
Experiment 5		
4	3	3·28
	3	4·92
	3·5	2·46
	3·5	2·46
	9·5	2·59
	9·5	2·18
	11·5	2·14
5	9	3·51
	9	3·07
6	6·5	3·28
	7	4·47
	19·5	1·26
	19·5	1·26
	20	1·64
7	4	3·28
	5	3·28
	5	2·46
	6	3·78
	6	3·07
	6	3·93
	16·5	2·18
	16·5	1·64
	17	1·73
	18·5	2·46
	18·5	1·97
	19	1·79
8	5·5	3·39
	5·5	3·28
	5·5	3·78
	6	3·64
	17	1·79
	17·5	2·59
	18	1·89
	18	1·70
	18	1·47

Table 62—*Effect of Salinity on Rate of Sedimentation of Mud*

Length of Sedimentation Column 9 ft.
S.M. = Suspended Matter from Mersey Estuary. S = Mersey mud

Sample.	Period of sedimentation (min.).	Percentage of mud originally present settled through 9 ft. Salinity of suspension ($S^{\circ}/_{oo}$) shown at head of each column.					
S.M. 111. Concentration of mud 18·0 parts per 100,000.		$S^{\circ}/_{oo}=0{\cdot}4$	$S^{\circ}/_{oo}=9{\cdot}8$	$S^{\circ}/_{oo}=18{\cdot}4$	$S^{\circ}/_{oo}=27{\cdot}1$	$S^{\circ}/_{oo}=31{\cdot}4$	
	10	8	9	11	8	7	
	20	15	17	18	16	13	
	30	23	24	24	23	22	
	50	39	56	50	50	50	
	70	61	83	85	78	69	
	90	77	96	102	92	70	
S.M. 117. Concentration of mud 20·0 parts per 100,000.		$S^{\circ}/_{oo}=0{\cdot}4$	$S^{\circ}/_{oo}=11{\cdot}3$	$S^{\circ}/_{oo}=18{\cdot}0$	$S^{\circ}/_{oo}=22{\cdot}0$	$S^{\circ}/_{oo}=25{\cdot}7$	$S^{\circ}/_{oo}=32{\cdot}6$
	90	61	92	73	109	85	81
S.M. 116. Concentration of mud 18·6 parts per 100,000.		$S^{\circ}/_{oo}=0{\cdot}4$	$S^{\circ}/_{oo}=11{\cdot}3$	$S^{\circ}/_{oo}=18{\cdot}3$	$S^{\circ}/_{oo}=22{\cdot}3$	$S^{\circ}/_{oo}=25{\cdot}8$	$S^{\circ}/_{oo}=32{\cdot}5$
	90	46	92	88	90	78	89
S.M. 113. Concentration of mud 20·8 parts per 100,000.		$S^{\circ}/_{oo}=0{\cdot}4$	$S^{\circ}/_{oo}=11{\cdot}4$	$S^{\circ}/_{oo}=18{\cdot}4$	$S^{\circ}/_{oo}=22{\cdot}4$	$S^{\circ}/_{oo}=26{\cdot}0$	$S^{\circ}/_{oo}=32{\cdot}7$
	90	64	96	78	76	74	68
Suspended matter from Estuary of R. Blackwater, Essex. Concentration of mud 19·1 parts per 100,000.		$S^{\circ}/_{oo}=3{\cdot}3$	$S^{\circ}/_{oo}=13{\cdot}4$	$S^{\circ}/_{oo}=19{\cdot}5$	$S^{\circ}/_{oo}=23{\cdot}5$	$S^{\circ}/_{oo}=25{\cdot}0$	$S^{\circ}/_{oo}=32{\cdot}5$
	90	42	51	53	69	78	60
S. 457. Concentration 24·0 parts per 100,000.		$S^{\circ}/_{oo}=0{\cdot}4$	$S^{\circ}/_{oo}=7{\cdot}8$	$S^{\circ}/_{oo}=16{\cdot}1$	$S^{\circ}/_{oo}=23{\cdot}7$	$S^{\circ}/_{oo}=31{\cdot}9$	
	10	13	11	8	5	9	
	20	26	17	15	15	24	
	30	33	26	27	27	49	
	50	44	44	46	47	82	
	70	50	55	54	58	98	
	90	55	62	61	66	107	
	10	11	12	12	5	11	
	20	22	24	22	14	25	
	30	34	39	34	26	50	
	50	47	51	47	38	71	
	70	51	60	56	48	84	
	90	57	62	62	56	92	
S. 459. Concentration 16·0 parts per 100,000.		$S^{\circ}/_{oo}=0{\cdot}4$	$S^{\circ}/_{oo}=10{\cdot}0$	$S^{\circ}/_{oo}=20{\cdot}0$	$S^{\circ}/_{oo}=30{\cdot}0$		
	10	5	5	6	6		
	20	11	11	12	13		
	30	16	17	20	21		
	50	21	30	38	40		
	70	26	45	58	60		
	90	30	55	71	73		
S. 459. Concentration 27·0 parts per 100,000.	10	5	6	6	5		
	20	10	12	14	11		
	30	16	21	22	19		
	50	24	44	46	37		
	70	30	62	63	49		
	90	35	73	72	57		

TABLE 63—*Rate of Sedimentation of Mud from the Upper Mersey Estuary, Liverpool Bay, the Manchester Ship Canal and Various Estuaries*

Sedimentation in a mixture of sea and tap water of salinity 25·0 gm. per 1,000 gm. in columns 9 ft. in depth. All determinations at approximately 18° C. Sand removed from mud before sedimentation in each case

Sample.	Original concentration of mud (dry weight in gm. per 100 litres).	Percentage of mud settled after :					
		10 min.	20 min.	30 min.	50 min.	70 min.	90 min.
Muds from Upper Mersey Estuary.							
S 426	20·4	5	11	18	53	78	92
427	21·0	6	12	18	39	64	81
428	20·1	5	12	21	45	66	80
429	23·7	7	15	25	58	80	93
430	20·0	5	11	19	47	68	83
431	20·9	5	11	19	53	75	90
444	17·6	5	12	18	36	58	74
444	18·3	6	13	20	36	49	61
444	18·2	5	10	16	40	56	68
445	28·2	2	7	12	27	48	65
445	27·8	5	10	15	28	46	60
445	27·6	3	8	13	28	48	63
446	29·8	4	9	16	36	57	70
446	30·1	3	9	16	36	54	67
446	29·8	4	10	18	40	61	75
447	19·8	7	15	22	33	53	65
447	19·5	9	17	24	45	66	79
447	19·7	8	16	24	45	68	84
448	22·8	5	11	18	31	50	69
448	15·1	5	9	13	22	42	65
448	24·3	4	9	16	40	65	80
448	16·2	4	8	12	22	39	58
448	29·3	3	7	12	27	44	57
449	24·7	4	9	23	65	83	97
449	18·1	6	10	15	33	49	61
449	21·5	4	8	13	31	50	62
449	29·7	5	11	23	55	77	88
449	29·7	5	10	18	47	71	84
449	29·0	4	11	16	40	64	77
449	29·0	3	8	13	36	60	73
450	17·3	2	5	9	21	41	57
450	18·0	2	4	7	19	36	51
450	17·4	2	4	8	27	49	64

Sample.	Original concentration of mud (dry weight in gm. per 100 litres).	Percentage of mud settled after :					
		10 min.	20 min.	30 min.	50 min.	70 min.	90 min.
S 450	25·8	5	9	16	34	56	72
450	25·8	4	8	13	29	50	67
450	25·8	5	11	16	28	49	66
450	25·8	5	9	14	26	46	63
450	20·6	2	6	13	21	36	51
450	20·6	3	7	9	16	32	51
453	27·0	3	10	18	42	57	68
455	27·5	4	8	14	42	64	78
457	30·3	3	10	23	45	58	66
457	30·4	3	12	29	49	61	67
457	29·7	2	8	23	45	56	62
457	30·5	5	14	30	51	63	69
457	20·7	13	26	33	44	50	55
457	20·7	11	22	34	47	51	57
457	25·4	5	15	27	47	58	66
457	25·4	5	14	26	38	48	56
457	30·8	5	11	24	61	79	90
457	30·8	5	10	21	55	72	83
457	30·8	5	11	22	58	77	88
458	29·2	3	7	11	36	60	74
458	29·2	3	6	12	36	64	79
459	28·6	6	12	18	37	56	66
459	16·7	6	13	21	40	60	73
459	28·5	5	11	19	37	49	57
459	27·9	5	11	19	41	59	70
459	29·2	4	10	18	44	63	74
461	27·4	7	13	25	60	75	87
461	31·0	5	10	17	52	75	88
461	31·0	4	9	17	49	72	84
462	30·0	5	9	14	36	53	64
462	25·8	10	20	29	48	61	73
462	34·3	6	13	23	48	67	78
462	28·6	4	9	16	37	58	72
462	31·4	5	10	19	53	78	92
462	31·4	4	9	17	41	60	70

TABLE 63—*continued*

Sample.	Original concentration of mud (dry weight in gm. per 100 litres).	Percentage of mud settled after: 10 min.	20 min.	30 min.	50 min.	70 min.	90 min.
S 462	18·0	7	13	18	30	47	62
462	20·0	5	9	14	28	47	62
462	20·0	5	10	15	27	44	59
462	28·2	4	9	16	36	54	64
462	28·2	4	9	14	34	51	60
462	22·3	4	9	15	28	43	53
462	22·3	5	8	14	29	45	55
462	22·4	4	7	13	26	40	50
462	21·9	4	7	14	26	42	53
462	28·8	4	9	26	53	64	72
462	30·0	4	8	29	65	80	92
462	27·4	4	8	18	39	51	59
462	27·4	3	9	20	47	63	74
462	17·6	4	8	12	22	38	51
462	17·6	4	7	11	22	38	52
462	32·7	3	9	28	63	78	85
462	32·7	4	8	26	64	79	88
462	19·2	4	7	11	19	34	47
462	28·5	2	5	10	20	47	60
462	26·7	3	6	9	23	44	59
524	20·7	4	8	14	35	59	72
525	21·0	2	5	9	18	36	51
526	20·9	4	7	11	29	51	64
527	22·3	3	7	11	19	34	47
528	22·3	4	7	13	29	46	65
529	22·8	4	6	11	29	50	68
530	22·9	5	15	38	62	73	81
531	32·2	4	21	48	74	86	95
Liverpool Bay samples.							
B 258	20·7	6	11	19	39	63	81
260	20·5	7	13	19	37	64	83
263	22·2	9	16	22	39	64	82
264	21·9	12	19	27	38	59	79
265	20·8	24	31	39	61	—	78

Sample.	Original concentration of mud (dry weight in gm. per 100 litres).	Percentage of mud settled after: 10 min.	20 min.	30 min.	50 min.	70 min.	90 min.
Suspended matter in Mersey Estuary.							
S.M. 97	19·5	15	20	30	57	71	81
105	19·7	12	24	38	67	84	93
106	19·8	12	22	34	65	87	98
107	18·3	7	14	24	51	74	88
108	17·2	13	23	32	51	72	85
109	21·9	12	26	43	77	92	100
110	20·1	8	17	27	61	83	96
114	19·9	8	15	23	40	56	71
115	21·2	8	14	22	45	66	78
118	19·1	6	11	19	49	81	100
130	15·8	6	12	17	33	40	53
Mud dredged from the bed of the Manchester Ship Canal.							
M.S.C. 17	21·9	7	14	21	52	82	99
18	22·1	5	14	34	59	73	82
19	21·1	5	10	18	44	64	76
20	22·2	6	13	27	74	98	112
25	16·9	7	18	37	68	85	99
26	19·9	22	98	115	—	—	—
27	18·2	24	104	—	—	—	—
28	19·6	8	64	88	102	—	—
29	19·6	14	75	96	110	—	—
Samples from Estuaries in Suffolk and Essex.							
Deben 9	20·4	5	13	37	76	96	109
10	30·9	5	14	47	83	99	—
11	20·6	6	12	22	54	75	89
12	20·1	7	13	19	58	45	63

Deben	13	16·6	5	11	16	26	36	51
(*contd.*)	14	20·2	6	15	20	34	55	75
	15	20·5	5	11	20	27	37	55
	16	21·0	5	10	17	28	50	70
	17	20·1	4	11	22	51	82	100
	18	20·7	6	13	—	32	57	75
	19	20·4	5	10	15	26	45	49
	20	20·9	4	8	11	17	26	40
	21	22·6	3	7	11	30	50	63
Stour	5	19·6	7	13	22	56	85	99
	5	21·2	3	6	12	39	62	78
	5	20·9	2	6	13	38	59	75
	5	20·9	3	6	12	32	49	62
	6	19·8	4	9	18	56	84	100
	7	19·4	7	12	20	41	59	70
	8	20·4	9	17	33	69	90	103
	9	21·2	7	16	41	75	92	103
	10	19·7	7	14	34	63	78	87
	11	22·0	4	8	14	42	65	77
	12	22·2	4	8	15	43	64	75
Hamford	5	19·8	7	19	45	80	102	119
	6	19·7	4	10	20	24	78	95
	7	19·2	7	13	24	57	81	99
	8	19·6	6	12	22	53	78	95
	8	23·7	3	6	11	40	70	87
	8	24·0	3	6	11	38	67	85
	8	24·7	3	6	12	36	64	80
	9	19·8	6	13	25	58	82	98
	10	19·6	6	12	19	35	56	71
	11	21·0	6	12	20	42	57	69
	12	22·0	3	5	8	17	27	43
Colne	5	20·2	4	9	19	51	78	93
	6	19·1	5	10	22	62	88	101
	7	19·2	5	9	18	40	64	80
	8	19·2	5	10	17	42	66	84
Blackwater	2	19·2	6	12	22	52	76	91
	3	19·1	9	11	18	45	70	89
	4	18·8	4	9	17	39	57	68

Blackwater	4	21·8	4	8	14	35	58	74
(*contd.*)	4	22·7	4	8	12	25	44	56
	4	22·2	3	7	12	27	47	61
	5	19·6	5	11	19	48	77	94
	6	21·5	3	6	11	31	54	68
	7	22·2	3	7	10	17	32	47
Crouch	7	19·3	5	10	18	42	60	72
	8	20·3	7	12	19	41	69	87
	9	19·7	7	13	27	62	86	100
	10	19·6	6	14	30	62	78	88
	11	22·1	4	7	13	45	67	81
	12	21·0	4	8	15	43	64	75
Roach	3	21·0	5	8	11	18	30	43
Tamar Estuary, Devonshire.								
	3	20·4	4	10	22	52	67	76
	4	19·7	5	12	23	54	75	87
Firth of Forth, Scotland.								
	1	21·1	2	5	9	22	49	68
	1	21·1	3	6	10	25	52	72
	2	21·4	6	12	21	40	56	65
	2	21·4	11	18	25	47	62	72
	3	21·0	10	17	28	58	79	91
	3	21·0	8	14	24	51	71	85
	4	20·4	3	9	13	28	50	63
	4	20·4	4	8	13	29	56	73
	5	20·7	7	13	25	69	95	109
	5	20·7	7	13	24	64	89	102
	6	19·2	6	11	17	45	67	81
	6	19·2	5	10	17	54	85	102
Suspended matter from Forth Estuary.								
	1	19·4	4	11	31	70	89	100
	1	19·4	4	11	32	73	92	103
Suspended matter, Dee Estuary, Cheshire		17·9	3	8	13	31	48	58
,, ,,		18·1	4	9	14	30	48	60

TABLE 64—*Rate of Sedimentation of Muds from the Estuaries of the Severn and the Wye, Monmouthshire*

Length of Sedimentation Column 9 ft.

Sample.		Concentration of mud (gm. dry weight per 100 litres).	Salinity of water (gm. per 1,000 gm.).	Percentage of mud settled after :					
				10 min.	20 min.	30 min.	50 min.	70 min.	90 min.
Severn Estuary, Monmouthshire.									
Suspended matter as taken	SM 1	94·5	11·4	2	7	25	61	80	91
	SM 1	94·5	11·4	3	8	25	63	83	92
	SM 1	94·5	11·4	4	18	42	70	85	94
	SM 1	94·5	11·4	3	13	36	65	80	91
,, ,,	SM 2	158·6	14·0	4	21	53	98	114	120
	SM 2	158·6	14·0	3	22	53	108	124	129
	SM 2	158·6	14·0	7	32	60	90	100	104
	SM 2	158·6	14·0	8	32	50	94	106	110
Suspended matter diluted	SM 1	19·3	25·3	3	7	10	17	27	40
	SM 1	19·3	25·3	3	6	9	15	21	34
	SM 1	19·3	25·3	3	8	12	21	33	55
	SM 1	19·3	25·3	3	6	10	18	29	49
,, ,,	SM 2	19·6	25·1	3	6	9	15	22	35
	SM 2	19·6	25·1	3	6	10	16	24	37
	SM 2	19·6	25·1	2	5	9	17	31	47
	SM 2	19·6	25·1	2	5	9	16	28	42
Severn muds	Nos. 1	19·0	25·0	3	7	11	18	27	39
	1	30·6	25·0	4	7	11	26	49	65
	2	18·0	25·0	4	8	11	19	30	45
	2	28·7	25·0	2	6	10	21	37	51
	2	18·7	25·0	3	5	8	13	21	35
	4	19·2	25·0	2	5	9	16	28	43
Wye Estuary, Monmouthshire.									
Wye muds	Nos. 2	20·0	25·0	2	4	8	15	24	37
	3	20·0	25·0	3	6	10	19	30	44
	4	20·4	25·0	3	6	11	19	30	40
	6	19·7	25·0	2	6	10	17	27	40

TABLE 65—*Effect of Settled Sewage on Rate of Sedimentation of Mersey Mud through a Depth of 10 cm.*

S = Mersey mud. S.M. = Suspended Matter in Estuary Water

Sample.	Salinity of water (gm. per 1,000 gm.).	Concentration of suspended matter (gm. dry weight per 100 litres).	Settled sewage added (per cent.).	Percentage of mud remaining in suspension at a depth of 10 cm. after :					
				10 min.	30 min.	1 hour.	2 hours.	3 hours.	4 hours.
S 255	25·0	8·6	0	59	49	42	33	—	34
,,	,,	9·6	5	56	59	53	44	—	36
,,	,,	19·4	0	49	42	40	34	—	24
,,	,,	20·5	5	52	47	46	37	—	30
,,	,,	26·4	0	47	35	29	25	—	—
,,	,,	27·1	5	47	40	34	31	—	—
,,	,,	52·8	0	45	—	23	14	—	—
,,	,,	53·6	5	48	—	26	22	—	—
,,	,,	102·8	0	50	28	17	10	—	—
,,	,,	104·4	5	53	30	20	13	—	—
,,	,,	214·0	0	36	15	8	6	—	—
,,	,,	216·0	5	42	17	8	6	—	—
,,	,,	23·1	0	47	44	36	29	—	—
,,	,,	23·1	1	48	48	40	34	—	—
,,	,,	23·1	2	53	47	39	33	—	—
,,	,,	23·1	5	49	44	—	37	—	—
,,	,,	24·6	0	41	36	33	28	—	—
,,	,,	24·6	1	43	39	34	29	—	—
,,	,,	24·6	2	42	44	35	30	—	—
,,	,,	24·6	5	51	41	39	30	—	—
,,	15·8	24·4	0	58	49	43	35	—	—
,,	15·8	24·4	2	43	44	41	34	—	—
,,	17·8	24·4	0	53	50	40	35	—	—
,,	17·8	24·4	2	45	43	41	32	—	—
S.M. 17	26·2	9·1	0	89	79	70	58	—	33
,,	26·2	10·5	1	77	76	64	55	—	41
,,	26·2	10·3	2	75	71	59	50	—	39
,,	26·2	11·7	5	87	80	73	60	—	44
S 255	Tap water	24·0	0	51	48	44	39	—	35
,,	,,	24·0	5	53	51	50	43	—	42
,,	15·7	24·0	0	47	45	44	40	—	27
,,	15·7	24·0	5	52	48	43	39	—	28
S.M. 19+S 255	23·7	26·8	0	57	49	43	35	—	—
,,	23·7	28·7	5	56	50	46	16	—	—
S.M. 20+S 255	19·7	26·8	0	53	47	43	37	—	—
,,	19·7	28·7	5	55	53	46	39	—	—
S.M. 21	27·0	13·4	0	87	76	62	44	—	—
,,	27·0	14·1	2	88	71	64	40	—	—
,,	27·0	14·6	5	83	73	64	42	—	—
,,	27·0	15·8	10	90	80	68	53	—	—
S.M. 23+S 255	23·3	26·0	0	53	39	32	30	—	—
,,	23·3	26·9	2	50	41	32	25	—	—
,,	23·3	27·5	5	54	42	32	24	—	—
,,	23·3	28·4	10	—	47	40	32	—	—
S 255	25·0	24·3	0	56	42	32	25	31	—
,,	,,	24·3	0·1	50	45	39	28	23	—
,,	,,	24·3	0·2	51	42	38	30	26	—
,,	,,	24·3	0·5	53	49	41	31	27	—
,,	,,	25·0	0	49	39	30	22	—	16
,,	,,	26·8	5	53	42	30	24	—	20
Mud from Liverpool Bay.	,,	24·0	0	64	55	43	31	—	14
,,	,,	25·1	5	61	56	42	31	—	20
S.M. 24	26·4	5·9	0	75	47	41	22	22	—
,,	26·4	7·5	5	82	57	54	40	34	—
26	28·0	7·4	0	82	64	43	39	—	23
,,	28·0	8·9	5	90	71	61	50	—	52
27	14·6	21·1	0	88	68	53	35	—	—
,,	14·6	23·9	5	87	67	48	44	—	—
28	24·8	37·6	0	71	54	41	29	22	—
,,	24·8	41·7	5	66	46	34	23	16	—
29	27·5	20·6	0	79	55	47	29	—	—
,,	27·5	20·6	5	86	56	44	28	—	—
30	12·4	13·9	0	89	76	63	48	—	35
,,	12·4	14·5	5	98	81	66	39	—	28

TABLE 65—*continued*

Sample.	Salinity of water (gm. per 1,000 gm.).	Concentration of suspended matter (gm. dry weight per 100 litres).	Settled sewage added (per cent.).	Percentage of mud remaining in suspension at a depth of 10 cm. after :					
				10 min.	30 min.	1 hour.	2 hours.	3 hours.	4 hours.
S.M. 31	24·8	23·2	0	89	69	41	29	—	—
,,	24·8	24·5	5	92	70	40	29	—	—
32	29·4	9·8	0	95	76	59	49	37	—
,,	29·4	11·8	5	92	76	66	52	43	—
34	29·6	15·4	0	86	78	66	43	30	—
,,	29·6	16·4	5	98	78	62	52	41	—
35	30·0	18·8	0	93	77	56	37	25	—
,,	30·0	20·5	5	91	67	48	33	30	—
36	30·0	23·7	0	84	72	53	32	18	—
,,	30·0	25·9	5	87	67	44	32	20	—
39	14·3	60·0	0	73	48	29	19	15	—
,,	14·3	61·5	5	72	37	25	16	13	—
41	27·7	21·2	0	75	52	37	25	—	—
,,	27·7	20·6	5	74	57	37	30	—	—
46	16·2	12·5	0	—	70	62	50	33	—
,,	16·2	15·0	5	83	79	57	42	39	—
61	21·0	11·9	0	74	55	57	40	29	—
,,	21·0	14·0	5	78	58	50	40	31	—
50	1·2	17·8	0	67	28	23	18	16	—
,,	1·2	22·3	5	69	40	28	30	22	—
53	24·0	9·8	0	83	73	44	19	13	—
,,	24·0	12·8	5	79	59	40	23	26	—
S 335	Tap water	12·7	0	65	59	50	41	31	—
,,	,,	12·7	0·2	64	52	46	43	33	—
,,	,,	13·9	0·5	61	49	46	34	33	—
,,	,,	14·0	1	60	49	45	34	36	—
,,	,,	13·0	2	68	55	46	43	38	—
,,	,,	14·5	5	66	55	49	40	37	—
S.M. 88	23·0	13·1	0	80	39	36	28	17	—
,,	23·0	14·0	5	79	35	42	26	20	—

TABLE 66—*Effect of Sewage on Rate of Sedimentation of Mersey Mud in Columns of Various Depths*

SM = Estuary Water containing Suspended Matter. S = Mersey Mud

* indicates Unsettled Sewage; otherwise Settled Sewage

Salinity of Water 25 gm. per 1,000 gm.

Sample.	Length of sedimentation column (ft.).	Concentration of mud (gm. dry weight per 100 litres).	Concentration of sewage added *(per cent.).	Percentage of mud settled after:					
				10 min.	20 min.	30 min.	50 min.	70 min.	90 min.
S 444	9	17·6	0	5	12	18	36	58	74
..	..	18·3	0	6	13	20	36	49	61
..	..	18·2	0	5	10	16	40	56	68
..	..	19·2	5·0	5	12	28	61	77	90
..	..	19·7	5·0	5	12	26	54	69	79
..	..	14·7	0	—	—	16	—	46	69
..	..	14·3	0·1	—	—	12	—	37	53
..	..	13·9	0·2	—	—	12	—	35	55
..	..	13·8	0·3	—	—	14	—	47	70
..	..	14·1	0·5	—	—	13	—	42	65
..	..	14·1	1·0	—	—	14	—	51	76
S 445	..	28·2	0	2	7	12	27	48	65
..	..	27·8	0	5	10	15	28	46	60
..	..	27·6	0	3	8	13	28	48	63
..	..	31·3	5·0	2	6	20	58	77	88
..	..	32·4	5·0	2	6	14	45	59	68
..	..	31·4	5·0	3	7	18	49	65	74
S 446	..	29·0	0	4	9	16	36	57	70
..	..	30·1	0	3	9	16	36	54	67
..	..	29·8	0	4	10	18	40	61	75
..	..	33·3	5·0	3	8	28	65	83	92
..	..	35·5	5·0	3	8	23	57	74	83
..	..	33·0	5·0	3	9	25	64	81	91
S 447	..	19·8	0	7	15	22	33	53	65
..	..	19·5	0	9	17	24	45	66	79
..	..	19·7	0	8	16	24	45	68	85
..	..	21·4	5·0	4	11	22	46	56	70
..	..	21·6	5·0	6	13	26	58	74	85
..	..	24·8	0	—	6	—	50	—	78
..	..	25·7	0·1	—	12	—	53	—	75
..	..	26·2	1·0	—	7	—	51	—	70
S 448	..	22·8	0	5	11	18	31	50	69
..	..	20·5	5·0	5	8	14	29	50	68
..	..	15·1	0	5	9	13	22	42	65

Sample.	Length of sedimentation column (ft.).	Concentration of mud (gm. dry weight per 100 litres).	Concentration of sewage added (per cent.).	Percentage of mud settled after:					
				10 min.	20 min.	30 min.	50 min.	70 min.	90 min.
S 448	9	15·2	0·25	3	7	10	19	33	49
..	..	15·4	0·5	3	8	10	14	25	50
..	..	15·5	1·0	2	8	12	26	41	60
..	..	16·2	2·0	5	12	17	35	55	75
..	..	16·9	5·0	6	12	19	35	58	76
..	..	24·3	0	4	9	16	40	65	80
..	..	22·0	0·1	3	7	14	37	57	70
..	..	23·5	0·2	3	8	15	38	56	67
..	..	24·5	1·0	3	4	20	57	68	89
..	..	29·3	0	3	7	12	27	44	57
..	..	29·3	5·0	4	11	21	52	72	84
SM121 + S448	..	18·9	0	3	6	8	18	42	67
..	..	18·3	0·1	2	5	10	18	42	64
..	..	18·6	0·2	3	5	7	20	45	66
..	..	18·0	0·5	4	7	12	32	56	75
SM124 + S448	..	16·2	0	4	8	12	22	39	58
..	..	16·5	0·25	4	7	12	22	35	48
..	..	17·1	1·0	4	8	14	33	49	64
..	..	20·0	5·0	4	10	22	46	60	72
..	..	16·2	0	4	8	12	22	39	58
..	..	16·8	0·25	4	8	13	26	45	63
..	..	17·7	5·0	3	6	31	37	56	72
S 449	..	44·3	0	4	14	36	79	94	105
..	..	44·8	3·0	3	—	35	72	87	97
..	..	24·7	0	4	9	23	65	83	97
..	..	25·1	3·0	4	9	19	51	70	82
..	..	18·1	0	6	10	15	33	49	61
..	..	18·2	3·0	16	24	32	57	77	90
..	..	43·7	0	3	10	35	77	96	104
..	..	41·4	2·5	4	14	40	79	97	105
..	..	33·8	0	3	7	19	67	96	111
..	..	32·6	2·0	4	11	30	76	103	115
..	..	21·5	0	4	8	13	31	50	62
..	..	22·6	1·0	2	7	12	31	47	57

TABLE 66—*continued*

Sample.	Length of sedimentation column (ft.).	Concentration of mud (gm. dry weight per 100 litres).	Concentration of sewage added (per cent.).	Percentage of mud settled after:					
				10 min.	20 min.	30 min.	50 min.	70 min.	90 min.
S 449	9	29·7	0	5	11	23	55	77	88
,,	,,	29·7	0	5	10	18	47	71	84
,,	,,	29·7	5·0	6	14	27	67	89	101
,,	,,	29·7	5·0	6	14	24	60	81	93
,,	,,	29·0	0	4	11	16	40	64	77
,,	,,	29·0	0	4	8	13	36	60	73
,,	,,	29·0	5·0	2	8	22	58	79	88
,,	,,	29·0	5·0	3	7	19	53	72	82
S 450	,,	17·3	0	2	5	9	21	41	57
,,	,,	18·0	0	2	4	7	19	36	51
,,	,,	17·4	0	2	4	8	27	49	64
,,	,,	19·1	5·0	3	6	10	25	44	59
,,	,,	18·5	5·0	3	6	10	24	42	57
,,	,,	19·6	5·0	2	4	7	19	23	45
,,	,,	25·8	0	5	9	16	24	56	72
,,	,,	25·8	0	4	8	13	29	50	67
,,	,,	25·8	5·0	5	9	15	31	46	55
,,	,,	25·8	5·0	5	7	14	39	64	80
,,	,,	25·8	0	5	11	16	28	49	66

Sample.	Length of sedimentation column (ft.).	Concentration of mud (gm. dry weight per 100 litres).	Concentration of sewage added (per cent.).	Percentage of mud settled after:					
				10 min.	20 min.	30 min.	50 min.	70 min.	90 min.
S 450	9	25·8	0	5	9	14	26	46	63
,,	,,	25·8	5·0	5	10	17	40	63	78
,,	,,	25·8	5·0	5	9	14	34	54	67
,,	,,	20·6	0	2	6	13	21	36	51
,,	,,	20·6	0	3	7	9	16	32	51
,,	,,	20·6	5·0	3	7	13	32	54	69
,,	,,	20·6	5·0	2	7	13	27	46	63
S 455	,,	27·5	0	4	8	14	42	64	78
,,	,,	27·5	0·2	3	6	13	42	65	79
,,	,,	27·5	0·5	5	9	16	40	60	72
,,	,,	27·5	1·0	5	9	16	45	67	80
,,	,,	27·5	2·0	4	9	19	51	72	85
,,	,,	27·5	5·0	4	9	19	55	78	91
S 459	40	28·6	0	0	3	6	16	34	54
,,	,,	30·8	5·0	1	4	6	17	34	52
,,	9	28·6	0	6	12	18	37	56	66
,,	,,	30·8	5·0	7	15	25	54	71	82
S 461	,,	27·4	0	7	13	25	60	75	87
,,	,,	27·4	5·0	6	12	21	54	69	82

TABLE 66—*continued*

Sample.	Length of sedimentation column (ft.).	Concentration of mud (gm. dry weight per 100 litres).	Concentration of sewage added (per cent.).	Percentage of mud settled after: 10 min.	20 min.	30 min.	50 min.	70 min.	90 min.	2 hrs.
SM144+S462	9	43·3	0	5	10	20	50	66	75	83
,,	,,	44·3	5·0	4	13	34	63	75	—	86
,,	4	43·3	0	9	16	29	54	67	77	86
,,	,,	44·3	5·0	8	20	41	66	76	—	87
SM145+S462	40	30·0	0	3	7	12	24	40	58	74
,,	,,	30·5	5·0	2	4	7	18	33	56	74
,,	9	30·0	0	5	9	14	36	53	64	77
,,	,,	30·5	5·0	4	8	15	39	57	68	81
,,	4	30·0	0	9	18	27	48	61	71	80
,,	,,	30·5	5·0	10	21	32	54	70	80	89
SM146+S462	40	37·4	0	3	7	12	24	42	62	78
,,	,,	36·4	*5·0	1	4	9	22	39	57	74
,,	9	37·4	0	4	10	21	47	66	78	88
,,	,,	36·4	*5·0	6	15	35	68	84	92	100
,,	4	37·4	0	9	21	35	60	75	85	93
,,	,,	38·4	*5·0	11	23	42	62	72	79	84
SM147+S462	40	25·8	0	2	3	5	10	18	29	45
,,	,,	27·0	*5·0	1	3	5	11	20	31	46
,,	9	25·8	0	10	20	29	48	61	73	84
,,	,,	27·0	*5·0	8	16	23	41	58	68	79
,,	4	25·8	0	20	36	47	62	75	86	94
,,	,,	27·0	*5·0	13	23	34	49	63	73	83
SM148+S462	9	34·3	0	6	13	23	48	67	78	89

Sample.	Length of sedimentation column (ft.).	Concentration of mud (gm. dry weight per 100 litres).	Concentration of sewage added (per cent.).	Percentage of mud settled after: 10 min.	20 min.	30 min.	50 min.	70 min.	90 min.	2 hrs.
SM148+S462	9	36·9	*5·0	5	12	18	52	72	83	93
,,	4	34·3	0	16	33	47	69	83	92	101
,,	,,	36·9	*5·0	14	25	49	71	85	95	102
SM149+S462	40	28·6	0	3	6	10	19	30	46	64
,,	,,	28·6	*5·0	1	4	6	15	30	47	64
,,	9	28·6	0	4	9	16	37	58	72	84
,,	,,	28·6	*5·0	4	9	16	48	71	83	94
,,	4	28·6	0	7	18	28	49	66	78	88
,,	,,	28·6	*5·0	9	19	31	57	73	83	92
SM150+S462	40	48·4	0	4	7	12	25	41	57	68
,,	,,	48·4	*5·0	3	5	10	21	38	54	69
,,	9	48·4	0	7	22	44	72	87	95	103
,,	,,	48·4	*5·0	10	27	61	92	105	112	119
,,	4	48·4	0	12	24	40	61	74	81	88
,,	,,	48·4	*5·0	16	42	69	93	104	111	118
SM151+S462	40	18·0	0	3	5	8	13	22	32	51
,,	,,	18·0	*5·0	2	4	6	13	22	33	51
,,	9	18·0	0	7	13	18	30	47	62	76
,,	,,	18·0	*5·0	9	16	24	44	70	86	101
,,	4	18·0	0	10	17	27	39	51	62	72
,,	,,	18·0	*5·0	13	23	36	56	76	87	98
S 531	9	32·2	0	4	21	48	74	86	95	—
,,	,,	33·4	*2·0	4	22	46	68	80	88	—

Table 67—*Effect of Sewage on Rate of Sedimentation of Mersey Mud at Various Temperatures*

S = Mersey Mud

Length of Sedimentation Column 9 ft.
Salinity of Water approximately 25 gm. per 1,000 gm.

Sample.	Concentration of mud (gm. dry weight per 100 litres).	Concentration of sewage (per cent.).	Mean temperature during sedimentation (° C.).	Percentage of mud settled after :					
				10 min.	20 min.	30 min.	50 min.	70 min.	90 min.
S 450	25·8	0	5·0	2	5	8	12	19	30
,,	,,	0	5·0	3	5	8	13	23	39
,,	,,	5·0	5·5	3	5	11	18	35	48
,,	,,	5·0	5·5	3	6	9	16	29	43
,,	,,	0	16·0	5	9	16	34	56	72
,,	,,	0	16·0	4	8	13	29	50	67
,,	,,	5·0	16·0	5	9	15	31	46	55
,,	,,	5·0	16·0	5	7	16	39	64	80
,,	,,	0	24·0	3	6	15	50	72	84
,,	,,	0	24·0	3	6	16	50	70	81
,,	,,	5·0	24·0	4	10	27	64	78	90
,,	,,	5·0	24·0	4	10	27	68	86	97
S 449	29·0	0	7·0	2	5	7	14	29	50
,,	,,	0	7·5	3	5	9	15	27	44
,,	,,	5·0	7·5	1	5	9	25	41	51
,,	,,	5·0	7·0	2	5	8	22	40	52
,,	,,	0	17·5	4	11	16	40	64	77
,,	,,	0	17·5	3	7	15	36	60	73
,,	,,	5·0	17·5	2	8	22	58	79	88
,,	,,	5·0	17·5	3	7	19	53	72	82
,,	,,	0	24·0	1	7	21	61	80	92
,,	,,	0	24·0	1	7	22	55	69	76
,,	,,	5·0	24·0	2	11	42	70	82	88
,,	,,	5·0	24·0	2	11	42	69	80	87
S 450	20·6	0	9·0	2	7	10	14	21	32
,,	,,	0	9·0	3	5	8	12	19	27
,,	,,	5·0	8·0	2	5	9	14	21	31
,,	,,	5·0	8·0	3	5	9	12	22	30
,,	,,	0	17·5	2	6	13	21	36	51
,,	,,	0	17·5	3	7	9	16	32	51
,,	,,	5·0	17·5	3	7	13	32	54	69
,,	,,	5·0	17·5	2	7	13	27	46	63
,,	,,	0	23·5	4	11	17	39	61	74
,,	,,	0	24·0	3	5	12	31	52	63
,,	,,	5·0	23·5	3	8	19	45	62	72
,,	,,	5·0	24·0	3	8	18	45	64	74

TABLE 68—*Effect of Sewage on Rate of Sedimentation of Muds from Various Estuaries*

Salinity of Water approximately 25 gm. per 1,000 gm.

Sample.	Concentration of mud (gm. dry weight per 100 litres).	Concentration of settled sewage (per cent.).	Percentage of mud settled through 9 ft. after :					
			10 min.	20 min.	30 min.	50 min.	70 min.	90 min.
Samples from estuaries in Essex :								
Stour 5	21·2	0	2	6	12	39	62	78
,, ...	20·9	0	2	6	13	38	59	75
,, ...	20·9	0	3	6	12	32	49	62
,, ...	21·7	5·0	3	7	17	50	69	83
,, ...	20·5	5·0	2	6	17	51	70	84
,, ...	21·4	5·0	2	7	19	55	76	92
Blackwater 4 ..	22·7	0	4	8	12	25	44	56
,, ..	22·2	0	3	7	12	27	47	61
,, ..	25·1	5·0	3	9	26	54	63	67
,, ..	24·8	5·0	5	11	34	63	72	76
Hamford Water 8	23·7	0	3	6	11	40	70	87
,, ..	24·0	0	3	6	11	38	67	85
,, ..	24·7	0	3	6	12	36	64	80
,, ..	26·6	5·0	2	6	26	64	77	84
,, ..	26·8	5·0	2	5	24	61	75	83
,, ..	26·6	5·0	3	8	30	77	95	104
Severn Estuary, Monmouthshire :								
Severn 1.. ..	30·0	0	6	11	17	40	58	75
,, ...	30·0	5·0	6	11	18	53	72	86

TABLE 69—*Effect of the Addition of Mixed Living Sewage Bacteria on Rate of Sedimentation of Mersey Mud*

SM = Suspended matter from Estuary
S = Mersey mud

Salinity of Water approximately 25 gm. per 1,000 gm.

Sample.	Volume of bacterial suspension added (per cent. of volume of mud suspension).	Concentration of mud (gm. dry weight per 100 litres).	Percentage of mud settled through a depth of 9 ft. after :					
			10 min.	20 min.	30 min.	50 min.	70 min.	90 min.
SM 130	0	15·8	6	12	17	33	40	53
,,	0·1	,,	6	10	15	24	34	46
,,	0·5	,,	6	10	16	22	31	41
,,	1·0	,,	5	9	14	24	35	49
,,	2·0	,,	8	13	18	28	40	52
,,	5·0	,,	5	10	15	25	38	53
,,	10·0	,,	7	13	18	33	48	60
,,	20·0	,,	5	9	14	30	45	59
S 455	0	27·5	4	8	13	34	56	72
,,	0·2	,,	3	7	11	29	52	67
,,	0·5	,,	4	9	13	35	—	—
,,	1·0	,,	4	9	14	36	62	76
,,	2·0	,,	4	8	12	31	56	69
,,	5·0	,,	2	5	10	32	57	70
,,	7·5	,,	2	6	12	36	60	72
,,	10·0	,,	2	6	12	35	57	70

TABLE 70—*Effect of Vigorous Stirring on Rate of Sedimentation of Mud through 10 cm.*

SM = Estuarine Suspended Matter

Salinity of Water approximately 25 gm. per 1,000 gm.

Sample.	Concentration of mud (gm. dry weight per 100 litres).	Period of stirring.	Percentage of mud remaining in suspension at a depth of 10 cm. after:				
			10 min.	30 min.	1 hr.	2 hrs.	3 hrs.
SM 46	12·5	0	—	69	62	50	33
,,	16·1	4 hrs.	78	58	26	20	14
SM 47	8·3	0	80	63	43	40	20
,,	,,	3 hrs.	79	—	46	31	26
SM 48	14·5	0	78	61	38	23	15
,,	,,	3 hrs.	75	—	41	21	17
SM 50	17·8	0	67	28	23	18	16
,,	,,	2½ hrs.	72	27	16	21	13
,,	,,	1 day	76	41	32	19	18
,,	,,	2 days	76	38	25	18	13
,,	,,	4 ,,	81	46	36	29	13
,,	,,	6 ,,	71	61	42	26	21
,,	,,	9 ,,	74	51	20	23	17
,,	,,	14 ,,	84	56	39	21	20
,,	,,	16 ,,	89	59	39	27	25
,,	,,	26 ,,	85	60	31	16	18
,,	,,	33 ,,	79	44	25	20	16
SM 53	9·8	0	82	72	44	19	13
,,	,,	1 day	77	50	26	27	18
,,	,,	5 days	84	49	23	10	6
,,	,,	8 ,,	72	24	12	8	5
,,	,,	13 ,,	57	17	4	3	3
,,	,,	25 ,,	71	7	3	5	6
SM 58	15·4	0	64	34	20	12	13
,,	,,	1 day	73	61	42	29	19
,,	,,	7 days	70	21	16	7	3
,,	,,	15 ,,	64	9	7	4	3
,,	,,	22 ,,	30	8	6	3	4
SM 84	16·1	0	62	45	34	28	25
,,	,,	1 day	68	53	46	34	25
,,	,,	2 days	69	63	51	36	25
,,	,,	4 ,,	69	43	26	18	15
,,	,,	5 ,,	55	38	33	28	16
,,	28·2	0	64	45	31	23	22
,,	,,	1 day	70	41	33	24	18
,,	,,	2 days	65	54	38	25	19
,,	,,	4 ,,	67	43	15	10	9
,,	,,	5 ,,	66	30	16	12	8
SM 88	13·1	0	80	39	36	27	17
,,	,,	4 days	75	34	29	21	5
SM 100	16·8	0	84	37	14	12	9
,,	,,	1 day	77	28	21	10	4

TABLE 71—*Effect of Vigorous Stirring on Rate of Sedimentation of Mersey Mud through Various Depths*

SM = Mersey Estuary Water containing Mud
S = Mersey Mud

Salinity of Water approximately 25 gm. per 1,000 gm.

Sample.	Length of column through which mud was settled (ft.).	Length of time stirred (days).	Concentration of mud (gm. dry weight per 100 litres).	Percentage of mud settled after :						
				10 min.	20 min.	30 min.	50 min.	70 min.	90 min.	2 hours.
S448	9	0	22·8	5	11	18	31	50	69	
,,	,,	5	,,	5	12	25	49	61	68	
,,	,,	6	,,	7	15	33	68	85	97	
S448	,,	0	15·1	5	9	13	22	42	65	
,,	,,	6	,,	8	21	50	100	125	138	
S448	,,	0	24·3	4	9	16	40	65	80	
,,	,,	3	,,	4	11	20	52	79	94	
SM121 + S448	,,	0	18·9	3	6	8	—	42	67	
,,	,,	3	,,	4	9	13	30	50	66	
,,	,,	8	,,	4	8	18	54	74	85	
,,	,,	10	,,	7	15	31	67	86	98	
,,	,,	15	,,	4	10	18	48	74	90	
SM124 + S448	,,	0	16·2	4	8	12	22	39	58	
,,	,,	4	,,	3	6	13	37	61	78	
S450	,,	0	25·8	5	11	16	28	49	66	
,,	,,	0	,,	5	9	14	26	46	63	
,,	,,	5	,,	5	11	20	53	78	92	
,,	,,	5	,,	4	8	15	42	69	85	
S457	,,	0	30·8	5	11	24	61	79	90	
,,	,,	0	,,	5	10	21	55	72	83	
,,	,,	0	,,	5	11	22	58	77	88	
,,	,,	9	,,	5	13	24	56	80	92	
,,	,,	9	,,	4	10	20	53	73	86	
,,	,,	9	,,	6	13	22	54	76	90	
SM141 + S457	,,	0	30·3	3	10	23	45	58	66	
,,	,,	9	,,	3	7	16	48	64	73	
SM141 + S457	,,	0	30·3	3	10	23	45	58	66	
,,	,,	7	,,	6	45	62	76	83	87	
S458	,,	0	29·2	3	7	12	40	62	76	
,,	,,	7	,,	2	5	10	35	62	75	
S459	,,	0	29·2	4	10	18	44	63	74	
,,	,,	8	,,	7	16	27	59	80	91	
S461	,,	0	27·4	7	13	25	60	75	87	
,,	,,	5	,,	6	13	22	53	73	88	
S461	,,	0	31·0	5	10	17	52	74	86	
,,	,,	8	,,	3	7	13	37	61	73	
S462	,,	0	30·8	3	7	15	43	63	73	
,,	,,	0	,,	4	8	13	31	46	53	
,,	,,	7	,,	4	9	22	54	72	82	
,,	,,	7	,,	4	12	29	57	73	82	
SM156 + S462	40	0	20·0	2	4	7	14	27	44	62
,,	,,	7	,,	3	8	13	31	69	80	84
,,	9	0	,,	5	9	14	28	47	62	79
,,	,,	0	,,	5	10	15	27	44	59	74
,,	,,	7	,,	3	9	26	63	78	89	100
,,	,,	7	,,	3	9	27	63	79	89	101

TABLE 71—*continued*

Sample.	Length of column through which mud was settled (ft.).	Length of time stirred (days).	Concentration of mud (gm. dry weight per 100 litres).	Percentage of mud settled after :						
				10 min.	20 min.	30 min.	50 min.	70 min.	90 min.	2 hours.
SM156 + S462	4	0	20·0	8	19	27	41	56	67	77
,,	,,	0	,,	9	17	25	40	57	68	81
,,	,,	7	,,	5	16	28	54	66	74	81
,,	,,	7	,,	4	11	22	49	61	69	76
SM157 + S462	40	0	28·2	2	5	9	19	37	58	71
,,	,,	7	,,	3	6	12	37	68	79	84
,,	9	0	,,	4	9	16	36	54	64	74
,,	,,	0	,,	4	9	14	34	51	60	70
,,	,,	7	,,	5	14	39	67	81	90	97
,,	,,	7	,,	5	15	37	67	82	91	99
,,	4	0	,,	7	15	22	34	43	52	58
,,	,,	0	,,	10	19	26	39	51	58	65
,,	,,	7	,,	12	27	42	62	73	80	85
,,	,,	7	,,	8	21	37	57	68	73	79
SM159 + S462	40	0	32·7	3	7	11	25	41	57	72
,,	,,	6	,,	5	11	18	34	55	72	81
,,	20	0	,,	4	8	16	40	62	72	79
,,	,,	6	,,	5	10	18	46	66	75	81
,,	9	0	,,	4	9	15	35	50	59	68
,,	,,	6	,,	3	8	22	48	61	68	74
,,	4	0	,,	8	16	24	37	48	56	63
,,	,,	6	,,	6	17	32	51	61	67	71

TABLE 72—*Effect of Stirring at Different Speeds on Rate of Sedimentation of Mersey Mud* (S 462)

Suspensions carefully sucked into 9-ft. Tube and settled

Salinity of Water approximately 25 gm. per 1,000 gm.

Concentration of mud (gm. dry weight per 100 litres).	Time of stirring (days).	Speed of stirring (revs. per min.).	Percentage of mud settled through 9 ft. after:					
			10 min.	20 min.	30 min.	50 min.	70 min.	90 min.
22·4	0	—	4	7	13	26	40	50
21·9	0	—	4	7	14	26	42	53
22·2	2	28	18	65	83	97	104	107
22·2	2	55	3	11	34	63	75	81
22·2	2	85	3	5	10	42	64	76
22·2	2	132	2	5	11	45	74	90
28·8	0	—	4	9	26	53	64	72
30·0	0	—	4	8	29	65	80	92
29·4	3	28	51	96	105	113	117	120
29·4	3	85	3	14	44	70	80	86
27·4	0	—	4	8	18	39	51	59
27·4	0	—	3	9	20	47	63	74
27·4	4	28	30	79	91	101	106	109
27·4	4	85	3	9	26	47	56	61
17·6	0	—	4	8	12	22	38	51
17·6	0	—	4	7	11	22	38	52
17·6	3½	28	25	70	87	103	109	113
17·6	3½	85	6	21	46	72	83	89
27·4	0	—	4	8	18	39	51	59
27·4	0	—	3	9	20	47	63	74
27·0	1	28	11	51	68	78	83	85
27·0	1	28	29	83	101	111	116	119
27·0	1	85	2	6	17	57	72	80
27·0	1	85	2	7	33	66	77	83
27·0	1 then 2 hrs.	85 } 28 }	11	57	74	85	90	93
27·0	1 then 2 hrs.	85 } 28 }	5	48	75	94	101	106

TABLE 73—*Rate of Sedimentation through a Depth of 9 ft. of Mud from the Mersey and from Estuaries in Suffolk and Essex, after stirring slowly for Different Periods*

Speed of Stirring 28 r.p.m.

Salinity of Water approximately 25 gm. per 1,000 gm.

Sample.	Concentration of mud (gm. dry weight per 100 litres).	Time of stirring (min.).	Percentage of mud settled through 9 ft. after:					
			10 min.	20 min.	30 min.	50 min.	70 min.	90 min.
Samples from Mersey Estuary.								
S524	20·7	0	4	8	14	35	59	72
	,,	15	10	39	59	79	88	93
	,,	30	17	47	65	80	87	92
	,,	120	8	106	118	126	130	132
S525	21·0	0	2	5	9	18	36	51
	,,	15	10	29	52	71	81	87
	,,	30	10	44	64	79	86	91
	,,	120	16	55	74	88	93	97
S526	20·9	0	4	7	11	29	51	64
	,,	15	6	28	55	77	87	92
	,,	30	16	58	76	88	94	96
	,,	120	54	99	110	116	120	121
S527	22·3	0	3	7	11	19	34	47
	,,	15	8	14	23	45	62	72
	,,	30	4	12	25	50	64	73
	,,	120	12	36	49	60	64	66
S528	22·3	0	4	7	13	29	46	65
	,,	15	7	28	57	82	93	102
	,,	30	8	32	53	70	77	83
	,,	120	25	72	88	98	102	105
S528	30·9	0	6	14	33	61	75	84
	,,	15	16	53	69	80	84	87
	,,	30	29	73	84	90	92	93
	,,	120	43	80	87	93	95	95
S529	22·8	0	4	6	11	29	50	68
	,,	15	10	34	62	84	94	101
	,,	30	12	48	67	82	89	95
	,,	120	9	38	57	71	79	84
S529	28·4	0	4	9	26	59	76	88
	,,	15	14	60	82	97	101	104
	,,	30	33	83	92	99	102	103
	,,	120	46	88	93	97	99	100
Samples from Suffolk and Essex Estuaries.								
Hamford 2	21·0	0	6	12	20	42	57	69
	,,	15	7	19	35	54	65	74
	,,	30	21	54	65	74	78	81
	,,	120	51	93	104	112	117	118
Hamford 12	22·0	0	3	5	8	17	27	43
	,,	15	6	5	36	56	66	73
	,,	30	8	19	58	76	85	90
	,,	120	20	66	81	92	97	99
Deben 21	22·6	0	3	7	11	30	50	63
	,,	15	6	35	55	71	79	84
	,,	120	39	78	89	98	101	102

TABLE 73—*continued*

Sample.	Concentration of mud (gm. dry weight per 100 litres).	Time of stirring (min.).	Percentage of mud settled through 9 ft. after :					
			10 min.	20 min.	30 min.	50 min.	70 min.	90 min.
Stour 11	22·0	0	4	8	14	42	65	77
	,,	15	9	36	62	79	85	88
	,,	30	13	43	72	89	97	102
	,,	120	10	43	68	83	90	94
Stour 12	22·2	0	4	8	15	43	64	75
	,,	15	17	64	87	97	101	104
	,,	30	18	56	76	86	90	92
	,,	120	16	58	80	89	94	96
Blackwater 6	21·5	0	3	6	11	31	54	68
	,,	30	8	34	66	86	91	94
	,,	120	11	45	77	94	99	101
Blackwater 7	22·2	0	3	7	10	17	32	47
	,,	15	5	16	30	53	67	75
	,,	30	8	30	50	67	76	82
	,,	120	30	83	100	111	114	116
Roach 3	21·0	0	5	8	11	18	30	43
	,,	15	6	14	30	55	66	73
	,,	30	8	36	60	81	90	95
	,,	120	21	61	74	85	89	92
Crouch 11	22·1	0	6	11	16	34	53	65
	,,	15	8	40	66	81	88	91
	,,	30	7	36	61	76	82	84
	,,	120	9	42	65	79	84	86
Crouch 12	21·0	0	4	7	13	45	67	81
	,,	15	14	56	80	90	95	97
	,,	30	18	64	92	103	107	109
	,,	120	12	55	85	97	102	105

TABLE 74—*Stability of the Aggregates formed by stirring Mersey Mud at 28 r.p.m.*

S.462, Concentration 32·7 parts per 100,000.

Salinity of Water approximately 25 gm. per 1,000 gm.

Time of stirring (hrs.).	Method of introducing suspension into sedimentation tube.	Percentage of mud settled through 9 ft. after :					
		10 min.	20 min.	30 min.	50 min.	70 min.	90 min.
0	Poured	3	9	28	63	78	85
0	,,	4	8	26	64	79	88
4	Sucked	30	81	96	103	106	107
4	,,	32	83	98	105	107	109
4	Poured	2	7	24	59	72	81
4	,,	3	8	21	54	68	76

TABLE 75—*Effect of Vigorous Stirring with Sewage on Rate of Sedimentation of Mersey Muds*

Salinity of Water approximately 25 gm. per 1,000 gm.
Muds settled through a Depth of 10 cm.
S = Mersey Mud
SM = Mersey Suspended Matter

Sample.	Concentration of mud (gm. dry weight per 100 litres).	Length of time stirred (days).	Concentration of settled sewage added (per cent.).	Percentage of mud remaining in suspension at a depth of 10 cm. after :				
				10 min.	30 min.	1 hr.	2 hrs.	3 hrs.
SM41 ..	15·0	2	0	80	43	27	10	3
,, ..	,,	2	5·0	24	11	3	5	3
SM42 ..	12·8	1	0	94	74	63	39	30
,, ..	,,	1	5·0	70	26	16	8	5
SM44 ..	14·3	1	0	71	48	38	22	14
,, ..	,,	1	5·0	78	46	24	13	6
SM46 ..	12·5	4	0	78	58	26	20	14
,, ..	,,	4	5·0	76	15	7	5	4
SM50 ..	17·8	1	0	76	41	32	19	18
,, ..	,,	1	5·0	82	51	28	20	14
,, ..	,,	2	0	77	38	25	18	13
,, ..	,,	2	5·0	32	18	16	15	18
,, ..	,,	7	0	71	51	39	22	18
,, ..	,,	7	5·0	33	18	11	6	8
,, ..	,,	14	0	84	56	29	21	20
,, ..	,,	14	5·0	—	18	10	8	7
,, ..	,,	19	0	89	59	39	27	25
,, ..	,,	19	5·0	67	22	14	10	8
,, ..	,,	26	0	85	60	31	16	18
,, ..	,,	26	5·0	77	29	8	6	0
SM52 ..	13·1	4	0	85	47	13	3	6
,, ..	,,	4	5·0	44	5	3	3	1
SM53 ..	9·8	1	0	78	50	27	28	18
,, ..	,,	1	5·0	76	26	10	10	9
,, ..	,,	5	0	84	49	23	10	6
,, ..	,,	5	5·0	33	23	10	0	0
,, ..	,,	13	0	56	17	0	0	0
,, ..	,,	13	5·0	51	1	1	0	0
,, ..	,,	18	0	66	12	1	1	1
,, ..	,,	18	5·0	60	14	9	1	0
,, ..	,,	25	0	65	1	0	0	0
,, ..	,,	25	5·0	76	1	1	1	1
SM65 ..	33·9	2	0	61	19	16	11	8
,, ..	,,	2	0·25	63	21	13	11	7
,, ..	,,	2	0·5	53	19	12	9	8
,, ..	,,	2	1·0	59	14	10	7	5
,, ..	,,	2	2·0	38	10	6	4	3
,, ..	,,	2	5·0	40	12	8	4	3
SM69 ..	10·7	1	0	69	51	15	13	11
,, ..	,,	1	0·25	76	35	9	9	3
,, ..	,,	1	0·5	54	28	7	6	7
,, ..	,,	1	1·0	74	53	30	16	9
,, ..	,,	1	2·0	67	54	31	16	11
,, ..	,,	1	5·0	77	51	32	27	16
,, ..	,,	2	0	82	50	18	11	10
,, ..	,,	2	0·25	86	34	17	8	9
,, ..	,,	2	0·5	85	35	21	8	2
,, ..	,,	2	1·0	83	23	16	7	7
,, ..	,,	2	2·0	70	17	9	6	4
,, ..	,,	2	5·0	73	21	8	6	3

TABLE 75—*continued*

Sample.	Concentration of mud (gm. dry weight per 100 litres).	Length of time stirred (days).	Concentration of settled sewage added (per cent.).	Percentage of mud remaining in suspension at a depth of 10 cm. after :				
				10 min.	30 min.	1 hr.	2 hrs.	3 hrs.
SM69 ..	10·7	3	0	86	46	35	11	11
,, ..	,,	3	0·25	72	48	30	14	7
,, ..	,,	3	0·5	80	47	30	16	10
,, ..	,,	3	1·0	77	42	32	—	8
,, ..	,,	3	2·0	84	29	28	7	6
,, ..	,,	3	5·0	83	27	18	3	2
,, ..	,,	4	0	74	67	32	19	19
,, ..	,,	4	0·25	68	41	21	17	17
,, ..	,,	4	0·5	78	50	26	20	13
,, ..	,,	4	1·0	81	40	21	23	16
,, ..	,,	4	2·0	76	34	21	20	15
,, ..	,,	4	5·0	81	28	8	11	8
SM94 ..	20·7	2	0	87	47	38	25	18
,, ..	,,	2	5·0	81	27	21	13	9
SM100 ..	16·8	1	0	72	28	21	10	4
,, ..	,,	1	5·0	67	20	18	6	6
S355 ..	34·8	1	0	44	19	9	6	3
,, ..	,,	1	0·25	38	18	11	5	3
,, ..	,,	1	0·5	34	—	8	4	2
,, ..	,,	1	1·0	31	13	8	4	0
,, ..	,,	1	2·0	36	12	7	4	3
,, ..	,,	1	5·0	32	12	6	2	3
,, ..	17·6	3	0	38	27	19	9	4
,, ..	,,	3	0·25	36	29	11	5	2
,, ..	,,	3	0·5	30	24	11	3	3
,, ..	,,	3	1·0	35	22	18	2	2
,, ..	,,	3	2·0	43	21	7	3	4
,, ..	,,	3	5·0	25	10	5	1	2

TABLE 76—*Effect of Vigorous Stirring with Sewage on Rate of Sedimentation of Mersey Mud through Columns of Different Lengths*

Salinity of Water approximately 25 gm. per 1,000 gm.
SM = Mersey Suspended Matter
S = Mersey Mud

Sample.	Length of column through which mud was settled (ft.).	Concentration of mud (gm. dry weight per 100 litres).	Length of time stirred (days).	Concentration of sewage (per cent.).	Percentage of mud settled after:						
					10 min.	20 min.	30 min.	50 min.	70 min.	90 min.	120 min.
SM120	9	18·7	4	0	3	7	15	53	78	92	
,,	,,	,,	4	0·5	5	14	42	84	100	110	
,,	,,	,,	4	5·0	12	55	85	107	116	122	
S448	,,	22·8	5	0	5	12	25	49	61	68	
,,	,,	,,	5	5·0	15	50	83	112	123	130	
,,	,,	,,	6	0	7	15	33	68	85	97	
,,	,,	,,	6	5·0	5	12	31	63	77	86	
,,	,,	,,	6	0	8	21	50	100	125	138	
,,	,,	,,	6	0·25	5	12	33	68	86	98	
,,	,,	,,	6	0·5	6	19	47	75	89	97	
,,	,,	,,	6	1·0	6	26	57	85	98	106	
,,	,,	,,	6	2·0	6	18	39	74	96	110	
S448	,,	24·3	3	0	4	11	20	52	79	94	
,,	,,	,,	3	0·1	4	10	22	60	81	93	
,,	,,	,,	3	0·2	3	8	16	49	73	86	
,,	,,	,,	3	1·0	5	11	28	75	95	106	
SM121 + S448	,,	18·9	3	0	4	9	13	30	50	66	
,,	,,	,,	3	0·2	4	8	12	36	54	65	
,,	,,	,,	3	0·4	3	7	14	44	63	74	
,,	,,	,,	3	1·0	3	8	21	60	79	91	
,,	,,	,,	8	0	4	8	18	54	74	85	
,,	,,	,,	8	0·6	4	11	24	60	79	90	
,,	,,	,,	8	1·2	4	14	37	79	99	109	
,,	,,	,,	8	3·0	3	28	46	67	78	83	
,,	,,	,,	10	0	7	15	31	67	86	98	
,,	,,	,,	10	0·8	7	17	35	63	75	84	
,,	,,	,,	10	1·6	9	27	56	89	104	113	
,,	,,	,,	10	4·0	14	55	80	106	119	128	
,,	,,	,,	15	0	4	10	18	48	74	90	
,,	,,	,,	15	1·0	5	16	45	87	106	119	
,,	,,	,,	15	2·0	7	32	57	76	83	88	
,,	,,	,,	15	5·0	10	78	108	129	138	144	
SM123	,,	41·0	3	0	5	14	73	99	109	117	
,,	,,	,,	3	0·1	5	38	67	91	103	110	
,,	,,	,,	5	0	6	22	59	88	101	108	
,,	,,	,,	5	0·2	4	22	65	100	114	122	
SM124 + S448	,,	16·2	4	0	3	6	13	37	61	78	
,,	,,	,,	4	0·25	3	6	11	30	49	61	
,,	,,	,,	4	1·0	3	7	15	44	66	81	
,,	,,	,,	4	5·0	5	29	58	88	104	115	
SM124 + S448	,,	16·8	4	0	3	6	13	37	61	78	
,,	,,	,,	4	0·25	3	7	14	40	68	83	
,,	,,	,,	4	5·0	3	13	40	74	93	105	
S450	,,	25·8	5	0	5	11	20	53	78	92	
,,	,,	,,	5	0	4	8	15	42	69	85	
,,	,,	,,	5	5·0	5	16	52	92	109	118	
,,	,,	,,	5	5·0	3	10	30	68	92	102	
S457	,,	30·8	9	0	5	13	24	56	80	92	
,,	,,	,,	9	0	4	10	20	53	73	86	
,,	,,	,,	9	0	6	13	22	54	76	90	
,,	,,	,,	9	0·2	5	11	23	55	75	87	
,,	,,	,,	9	0·2	5	11	20	47	67	81	
,,	,,	,,	9	0·2	2	7	17	48	73	87	
S457	,,	30·3	7	0	6	45	62	76	83	87	
,,	,,	,,	7	1·4	12	62	83	98	106	111	
,,	,,	,,	7	3·5	32	95	109	120	126	130	
,,	,,	,,	7	7·0	21	80	96	106	112	114	

TABLE 76—*continued*

Sample.	Length of column through which mud was settled (ft.).	Concentration of mud (gm. dry weight per 100 litres).	Length of time stirred (days).	Concentration of sewage (per cent.).	Percentage of mud settled after :						
					10 min.	20 min.	30 min.	50 min.	70 min.	90 min.	120 min.
SM141 + S457	9	32·7	9	0	3	7	16	48	64	73	
,,	,,	,,	9	0·6	4	10	21	54	68	74	
,,	,,	,,	9	1·2	4	9	18	47	63	71	
,,	,,	,,	9	3·0	5	21	49	80	91	98	
S458 . .	,,	30·0	8	0	2	5	10	35	62	75	
,, . .	,,	,,	8	0·25	2	5	10	30	55	69	
S459 . .	,,	31·9	8	0	7	16	27	59	80	91	
,, . .	,,	,,	8	1·0	7	15	32	65	82	91	
,, . .	,,	,,	8	2·0	6	14	31	61	77	88	
,, . .	,,	,,	8	4·0	7	17	43	75	90	98	
S461 . .	,,	27·4	5	0	6	13	22	53	73	88	
,, . .	,,	,,	5	5·0	4	10	27	71	90	101	
S461 . .	,,	32·3	8	0	3	7	13	37	61	73	
,, . .	,,	,,	8	0·25	3	7	15	45	69	82	
S462 . .	,,	31·6	5	0	3	8	21	58	78	88	
,, . .	,,	,,	5	1·0	3	8	28	69	88	98	
,, . .	,,	,,	5	2·5	2	8	29	58	71	79	
,, . .	,,	,,	5	5·0	3	11	35	61	72	79	
SM155 + S462	40	21·7	6	0	3	8	14	33	63	75	80
,,	9	,,	6	0	6	16	38	69	86	96	104
,,	9	,,	6	0	5	14	34	65	82	92	101
,,	4	,,	6	0	12	27	42	63	76	85	92
,,	40	,,	6	5·0	2	6	12	38	65	69	71
,,	9	,,	6	5·0	5	18	40	66	78	85	92
,,	9	,,	6	5·0	5	22	46	72	84	91	99
,,	4	,,	6	5·0	11	32	50	72	82	88	94
,,	4	,,	6	5·0	9	31	53	77	88	96	103
SM155 + S462	40	29·9	6	0	8	13	22	43	70	79	82
,,	9	,,	6	0	6	17	41	72	87	96	104
,,	9	,,	6	0	7	20	47	77	92	100	108
,,	4	,,	6	0	12	30	51	75	83	96	103
,,	4	,,	6	0	14	33	56	83	97	106	114
,,	40	,,	6	5·0	2	7	17	41	63	69	71
,,	9	,,	6	5·0	6	28	56	83	97	107	115
,,	9	,,	6	5·0	5	25	54	81	94	103	111
,,	4	,,	6	5·0	9	29	51	73	86	94	101
SM157 + S462	40	27·4	7	0	3	6	12	37	68	79	84
,,	9	,,	7	0	5	14	39	67	81	90	97
,,	9	,,	7	0	5	15	37	67	82	91	99
,,	4	,,	7	0	12	26	42	62	73	80	85
,,	4	,,	7	0	8	21	37	57	68	73	78
,,	40	,,	7	5·0	2	6	12	38	68	81	85
,,	9	,,	7	5·0	8	50	73	93	103	109	114
,,	9	,,	7	5·0	8	47	73	94	103	110	115
,,	4	,,	7	5·0	13	44	63	81	88	93	97
,,	4	,,	7	5·0	16	48	65	80	88	92	97
SM159 + S462	40	29·7	6	0	5	11	18	34	55	72	81
,,	20	,,	6	0	5	10	18	46	66	75	81
,,	9	,,	6	0	3	8	22	48	61	68	74
,,	4	,,	6	0	6	17	32	51	61	67	71
,,	40	,,	6	5·0	5	11	17	34	52	68	75
,,	20	,,	6	5·0	3	10	19	53	70	79	84
,,	9	,,	6	5·0	3	13	34	58	69	75	81
,,	4	,,	6	5·0	7	30	58	83	94	100	105

Table 77—*Effect of Vigorous Stirring with Sewage on Rate of Sedimentation of Muds from Estuaries in Essex and Monmouthshire*

Salinity of Water approximately 25 gm. per 1,000 gm.

Sample.	Concentration of mud (gm. dry weight per 100 litres).	Period of stirring (days).	Concentration of sewage added (per cent.).	Percentage of mud settled through 9 ft. after :					
				10 min.	20 min.	30 min.	50 min.	70 min.	90 min.
Hamford 8	23·7	0	0	3	6	11	40	70	87
,,	,,	0	0	3	6	11	38	67	85
,,	,,	0	0	3	6	12	36	64	80
,,	,,	0	5	2	6	26	64	77	84
,,	,,	0	5	2	5	24	61	75	83
,,	,,	0	5	3	8	30	77	95	104
,,	,,	2	0	3	6	11	30	53	69
,,	,,	2	0	3	6	11	34	56	69
,,	,,	2	0	3	6	10	29	49	60
,,	,,	2	5	3	22	78	104	117	126
,,	,,	2	5	7	43	82	111	123	131
,,	,,	2	5	5	22	67	104	119	128
Severn 1	30·0	0	0	6	11	17	40	58	75
,,	,,	0	5	6	11	18	53	72	86
,,	,,	5	0	5	11	18	36	61	80
,,	,,	5	5	5	11	20	57	80	94

Table 78—*Effect of Vigorous Stirring with Ultra-Filtered Sewage on Rate of Sedimentation of Mersey Mud*

Salinity of Water approximately 25 gm. per 1,000 gm.

SM = Mersey Estuary water containing Mud

Sample.	Length of time stirred (days).	Concentration of mud (gm. per 100 litres).	Ultra-filtered sewage added (per cent.).	Percentage of mud remaining in suspension at 10 cm. depth after :				
				10 min.	30 min.	1 hr.	2 hrs.	3 hrs.
SM 52	4	13·1	0	85	47	13	0	1
,,	4	,,	5·0	66	23	15	1	1
SM 57	4	12·2	0	84	56	30	21	17
,,	4	,,	10·0	64	18	1	1	0
SM 66	2	25·6	0	84	33	21	16	11
,,	2	,,	2·0	37	31	20	14	1
SM 67	3	15·3	0	75	55	39	24	16
,,	3	,,	1·0	77	57	32	20	14
,,	3	,,	2·0	70	50	35	22	17
,,	3	,,	5·0	80	53	37	24	18
,,	3	,,	10·0	61	34	25	16	11
,,	3	,,	20·0	73	46	26	20	12
SM 68	4	48·3	0	72	40	18	9	4
,,	4	,,	3·0	64	26	10	3	3

TABLE 79—*Rate of Sedimentation of Suspensions of Mersey Mud* (S 462) *with or without Addition of Sewage, after Slow Stirring at Different Speeds*

Salinity of Water approximately 25 gm. per 1,000 gm.

Clots unbroken before Sedimentation

Concentration of mud (gm. dry weight per 100 litres).	Period of stirring (days).	Speed of stirring (r.p.m.).	Concentration of sewage (per cent.).	Percentage of mud settled through 9 ft. after :					
				10 min.	20 min.	30 min.	50 min.	70 min.	90 min.
22·4	0	—	0	4	7	13	26	40	50
21·9	0	—	0	4	7	14	26	42	53
22·2	2	28	0	18	65	83	97	104	107
,,	2	55	0	3	11	34	63	75	81
,,	2	85	0	3	5	10	42	64	76
,,	2	132	0	2	5	11	45	74	90
,,	2	28	3·0	33	71	82	90	94	97
,,	2	55	3·0	6	38	65	81	87	91
,,	2	85	3·0	4	9	35	71	84	91
,,	2	132	3·0	2	7	22	62	80	90
28·8	0	—	0	4	9	26	53	64	72
30·0	0	—	0	4	8	29	65	80	92
29·4	3	28	0	51	96	105	113	117	120
,,	3	28	0·6	47	92	102	110	114	116
,,	3	28	3·0	60	91	98	104	107	109
,,	3	85	0	3	14	44	70	80	86
,,	3	85	0·6	5	25	61	87	97	103
,,	3	85	3·0	8	54	75	90	96	100
27·4	0	—	0	4	8	18	39	51	59
,,	0	—	0	3	9	20	47	63	74
,,	4	28	0	30	79	91	101	106	109
,,	4	28	0·6	41	88	98	108	112	115
,,	4	28	3·0	37	72	81	88	91	93
,,	4	85	0	3	9	26	47	56	61
,,	4	85	0·6	5	26	54	73	82	88
,,	4	85	3·0	20	78	98	113	119	123
17·6	0	—	0	4	8	12	22	38	51
,,	0	—	0	4	7	11	22	38	52
,,	3·5	28	0	25	70	87	103	109	113
,,	3·5	28	0·8	25	68	84	98	105	108
,,	3·5	28	4·0	44	73	82	90	94	96
,,	3·5	85	0	6	21	46	72	83	89
,,	3·5	85	0·8	10	53	79	100	108	113
,,	3·5	85	4·0	43	96	114	128	134	137

TABLE 80—*Effect of Unsettled Sewage on Rate of Sedimentation of Mersey Mud* (S 530) *previously stirred slowly for Different Periods*

Clots Unbroken before Sedimentation
Temperature of Sedimentation between 14° C. and 21° C.
Salinity of Water approximately 25 gm. per 1,000 gm.

Concentration of mud (gm. dry weight per 100 litres).	Time stirred before addition of sewage (min.).	Time stirred after addition of sewage (hrs.).	Concentration of unsettled sewage (per cent.).	Percentage of mud settled through 9 ft. after:					
				10 min.	20 min.	30 min.	50 min.	70 min.	90 min.
25·1*	0	2	0	8	32	56	79	89	94
,,	15	2	0	6	26	52	74	83	88
,,	30	2	0	6	25	50	71	80	84
,,	60	2	0	6	31	60	85	96	101
,,	0	2	5	11	43	72	93	101	106
,,	15	2	5	12	49	73	90	97	100
,,	30	2	5	10	36	53	65	71	74
,,	60	2	5	9	31	45	56	61	63
21·4	0	2	0	11	52	75	92	100	103
,,	15	2	0	12	54	77	95	103	107
,,	30	2	0	12	47	67	82	88	91
,,	60	2	0	11	50	76	94	102	106
,,	0	2	5	18	73	97	115	120	124
,,	15	2	5	10	53	77	94	101	104
,,	30	2	5	14	49	66	78	83	85
,,	60	2	5	9	40	61	74	81	84
25·3	0	2	0	4	29	54	73	83	88
,,	15	2	0	18	62	82	91	94	96
,,	30	2	0	20	59	78	86	88	89
,,	60	2	0	16	60	82	92	96	98
,,	0	2	2	20	68	90	101	105	107
,,	15	2	2	17	57	76	84	87	88
,,	60	2	2	13	50	64	76	79	81
23·5	0	1	0	18	50	61	68	70	71
,,	30	1	0	14	46	61	69	72	73
,,	60	1	0	12	48	66	76	80	82
,,	0	1	5	18	56	77	85	87	89
,,	30	1	5	17	53	70	79	82	84
,,	60	1	5	17	53	72	83	86	88
27·4	0	1	0	16	42	53	58	60	61
,,	30	1	0	10	40	54	61	64	66
,,	60	1	0	16	51	67	75	78	80
,,	0	1	5	19	50	65	73	76	78
,,	30	1	5	20	54	68	75	78	80
,,	60	1	5	13	53	74	83	86	88
23·8	0	1	0	9	30	46	57	61	62
,,	30	1	0	8	29	48	60	65	67
22·7	0	1	1	6	26	50	68	73	76
,,	30	1	1	4	24	49	67	73	77
,,	60	1	1	6	34	59	74	78	81
23·4	0	1	0	25	56	65	71	73	74
,,	30	1	0	18	56	65	76	80	81
,,	60	1	0	4	33	56	72	77	81
,,	0	1	5	24	66	80	86	88	88
,,	30	1	5	30	72	85	91	94	95
,,	60	1	5	23	70	84	92	95	96

* S.M. 165.

TABLE 80—*continued*

Concentration of mud (gm. dry weight per 100 litres).	Time stirred before addition of sewage (min.).	Time stirred after addition of sewage (hrs.).	Concentration of unsettled sewage (per cent.).	Percentage of mud settled through 9 ft. after : 10 min.	20 min.	30 min.	50 min.	70 min.	90 min.
34·2	0	1	0	27	42	47	51	53	53
,,	30	1	0	25	47	58	63	65	66
,,	60	1	0	6	28	40	49	53	56
36·7	0	1	5	19	49	56	61	63	64
,,	30	1	5	25	57	64	68	70	71
,,	60	1	5	10	38	47	51	53	54
33·2	0	1	0	38	67	75	80	83	85
,,	30	1	0	32	72	83	90	94	96
,,	60	1	0	29	71	82	90	93	95
33·9	0	1	1	24	60	73	79	82	83
,,	30	1	1	25	70	84	92	95	97
,,	60	1	1	22	73	86	95	98	100
35·5	0	1	0	17	39	44	49	52	53
,,	30	1	0	9	35	43	50	54	56
,,	60	1	0	21	53	61	67	71	73
36·3	0	1	1	14	39	58	64	68	70
,,	30	1	1	4	27	42	52	59	61
,,	60	1	1	9	36	54	61	66	68
26·4	0	1	0	25	64	75	82	85	87
28·5	60	1	0	25	74	90	100	103	105
28·1	120	1	0	33	92	107	117	121	123
28·0	0	1	1	18	66	89	103	107	110
27·0	60	1	1	21	75	100	115	119	122
28·2	120	1	1	27	81	100	109	122	114
22·7	0	1	0	5	34	60	81	89	93
23·2	60	1	0	6	31	59	82	91	96
23·4	120	1	0	6	43	75	99	109	114
23·1	0	1	1	5	23	55	81	91	97
22·6	60	1	1	6	38	77	100	111	116
23·4	120	1	1	4	16	55	92	109	116
31·1	0	1	0	5	29	57	72	79	83
29·7	60	1	0	5	33	59	80	87	92
30·6	0	1	1	7	49	74	87	92	95
30·3	30	1	1	5	31	66	98	106	110
29·8	60	1	1	4	28	62	79	84	87
29·3	0	1	0	14	56	73	81	84	87
28·8	30	1	0	20	70	93	103	107	110
27·3	60	1	0	19	72	99	112	117	120
28·4	0	1	2	12	58	77	87	92	94
27·9	30	1	2	10	48	74	85	91	94
28·1	60	1	2	18	64	82	92	95	97

TABLE 81—*Rate of Sedimentation of Mersey Mud eroded from the Bottom of 5-litre Beakers into Water or into Water containing Unsettled Sewage*

Salinity of Water approximately 25 gm. per 1,000 gm.

Mixture stirred slowly for Various Lengths of Time and the Suspensions sucked into 9-ft. Sedimentation Tubes

S = Mersey Mud

Sample.	Concentration of mud (gm. dry weight per 100 litres).	Temperature during sedimentation (° C.).		Concentration of unsettled sewage added (per cent.).	Length of time stirred (hrs.).	Percentage of mud settled through 9 ft. after:					
		Initial.	Final.			10 min.	20 min.	30 min.	50 min.	70 min.	90 min.
S 531	36·0	4·5	7·5	0	1	36	87	97	103	105	106
,,	,,	,,	,,	0	,,	81	94	101	101	103	105
,,	,,	,,	,,	0	,,	33	87	101	108	111	112
,,	,,	,,	,,	2	,,	25	79	100	109	113	115
,,	,,	,,	,,	2	,,	18	59	75	85	84	91
,,	,,	21·5	22·5	0	,,	76	105	108	110	112	112
,,	,,	,,	,,	0	,,	73	99	102	105	107	107
,,	,,	,,	,,	0	,,	71	108	113	116	118	119
,,	,,	,,	,,	2	,,	59	91	96	94	101	102
,,	,,	,,	,,	2	,,	59	88	93	96	98	99
S 531	32·9	5·0	7·0	0	1½	47	93	101	106	108	109
,,	,,	,,	,,	0	,,	42	92	102	108	110	111
,,	,,	,,	,,	0	,,	46	102	113	120	123	125
,,	,,	,,	,,	3	,,	24	75	95	107	111	114
,,	,,	,,	,,	3	,,	29	77	90	98	101	103
,,	,,	,,	,,	3	,,	28	71	83	91	94	95
,,	,,	22·0	22·5	0	,,	91	117	119	122	123	124
,,	,,	,,	,,	0	,,	97	108	113	116	117	118
,,	,,	,,	,,	0	,,	83	118	122	125	126	127
,,	,,	,,	,,	3	,,	61	89	95	100	102	103
,,	,,	,,	,,	3	,,	45	80	87	93	95	97
,,	,,	,,	,,	3	,,	27	63	74	83	87	89
S 531	37·7	4·5	6·0	0	1½	48	85	93	97	99	100
,,	36·2	,,	,,	0	,,	44	83	91	96	98	99
,,	35·6	,,	,,	3	,,	29	85	99	108	112	114
,,	34·4	,,	,,	3	,,	25	79	93	101	105	107
,,	37·1	23·0	23·0	0	,,	71	—	—	—	—	—
,,	37·5	,,	,,	0	,,	—	88	91	93	94	94
,,	37·5	,,	,,	0	,,	67	99	103	107	109	110
,,	34·7	,,	,,	3	,,	52	85	91	96	99	101
,,	34·4	,,	,,	3	,,	58	92	97	101	103	105
,,	34·7	,,	,,	3	,,	37	90	102	110	115	118
S 531	36·0	4·0	6·5	5	1½	13	63	81	92	96	99
,,	36·3	,,	6·0	5	,,	6	18	47	65	72	75
,,	35·4	,,	,,	5	,,	4	27	59	79	87	91
,,	36·1	,,	,,	0	,,	32	85	97	104	107	109
,,	36·7	,,	,,	0	,,	32	78	87	93	96	—
,,	34·9	,,	,,	0	,,	22	69	83	90	93	95
,,	35·6	21·0	22·0	5	,,	38	64	68	71	73	73
,,	35·7	,,	,,	5	,,	41	75	80	85	87	89
,,	35·2	,,	,,	5	,,	31	77	88	97	102	104
,,	35·7	,,	23·0	0	,,	52	85	90	94	97	98
,,	34·6	,,	22·0	0	,,	51	93	99	104	106	107
,,	35·2	,,	,,	0	,,	50	87	92	96	97	—
S 531	32·0	4·0	6·0	5	1½	51	94	104	112	115	116
,,	33·0	,,	,,	5	,,	38	83	94	100	103	105
,,	31·7	,,	,,	5	,,	35	78	94	105	111	113
,,	33·0	,,	,,	0	,,	60	104	113	119	122	123
,,	33·4	,,	,,	0	,,	77	113	122	127	129	130
,,	32·9	,,	,,	0	,,	49	92	100	105	108	109
,,	30·4	22·0	23·0	5	,,	104	119	123	125	128	128
,,	32·2	,,	,,	5	,,	100	116	120	122	124	124
,,	33·3	,,	,,	0	,,	89	98	100	102	103	104
,,	32·2	,,	,,	0	,,	96	109	113	116	117	118
,,	31·3	,,	,,	0	,,	91	107	110	113	114	115

TABLE 81—*continued*

Sample.	Concentration of mud. (gm. dry weight per 100 litres).	Temperature during sedimentation (° C.).		Concentration of unsettled sewage added (per cent.).	Length of time stirred (hrs.).	Percentage of mud settled through 9 ft. after :					
		Initial.	Final.			10 min.	20 min.	30 min.	50 min.	70 min.	90 min.
S 532	27·5	4·0	6·5	5	3½	12	67	87	99	104	106
,,	27·9	,,	,,	5	,,	8	47	71	86	92	96
,,	26·0	,,	,,	5	,,	7	45	78	99	106	111
,,	27·6	,,	,,	0	,,	8	49	80	98	105	110
,,	26·8	,,	,,	0	,,	9	52	77	92	98	101
,,	27·7	,,	,,	0	,,	9	50	68	79	85	88
,,	28·1	23·0	23·0	0	,,	53	92	98	102	104	105
,,	27·9	,,	,,	0	,,	62	108	116	121	124	125
,,	26·9	,,	,,	0	,,	51	100	107	114	117	119
,,	27·1	,,	,,	5	,,	37	67	72	76	78	79
,,	27·3	,,	,,	5	,,	39	90	100	108	112	114
,,	27·2	,,	,,	5	,,	36	88	96	103	106	107
S 533	26·4	3·0	6·0	5	3	5	35	73	99	106	109
,,	28·0	,,	,,	5	,,	4	24	51	73	80	83
,,	26·3	,,	5·5	5	,,	6	33	75	104	112	117
,,	27·2	,,	,,	0	,,	4	11	43	79	92	99
,,	27·7	,,	,,	0	,,	4	21	51	82	93	100
,,	27·4	,,	,,	0	,,	4	15	49	70	78	83
,,	29·0	22·5	23·0	5	,,	37	82	90	95	—	98
,,	29·1	,,	,,	5	,,	24	74	85	93	—	98
,,	28·3	,,	,,	5	,,	30	86	101	110	—	115
,,	27·5	,,	,,	0	,,	10	65	85	97	—	106
,,	29·5	,,	,,	0	,,	20	76	90	98	—	104
,,	28·9	,,	,,	0	,,	23	82	96	106	—	112
S 534	37·0	3·5	6·0	0	3	3	9	32	53	67	74
,,	35·1	,,	,,	0	,,	3	7	17	57	73	80
,,	36·3	,,	,,	0	,,	3	9	26	68	83	89
,,	36·5	,,	,,	5	,,	3	23	67	102	111	116
,,	36·3	,,	,,	5	,,	4	17	49	82	91	96
,,	36·5	,,	,,	5	,,	4	20	55	86	95	99
,,	34·5	22·0	23·0	0	,,	7	50	69	80	85	88
,,	39·2	,,	,,	0	,,	9	50	71	80	84	87
,,	36·1	,,	,,	0	,,	6	45	76	90	97	100
,,	35·2	,,	23·5	5	,,	25	79	95	102	106	108
,,	36·7	,,	,,	5	,,	27	86	102	110	113	115
,,	37·4	,,	,,	5	,,	11	71	96	106	111	114
S 534	32·3	4·0	6·0	0	3	4	15	46	72	82	88
,,	29·9	,,	,,	0	,,	4	12	37	65	75	82
,,	28·4	,,	,,	0	,,	4	10	32	66	80	87
,,	30·9	,,	,,	5	,,	4	13	44	85	97	104
,,	28·9	,,	,,	5	,,	4	26	61	88	95	99
,,	31·3	,,	,,	5	,,	3	9	26	58	71	77
,,	30·2	22·0	23·0	0	,,	18	59	71	79	82	84
,,	30·6	,,	,,	0	,,	13	55	68	78	82	84
,,	29·6	,,	23·5	0	,,	19	71	89	99	104	107
,,	30·0	,,	,,	5	,,	22	71	84	93	96	98
,,	27·8	,,	,,	5	,,	21	83	101	112	117	119
,,	30·3	,,	,,	5	,,	25	84	103	112	116	118

TABLE 82—*Rate of Sedimentation of Suspended Matter in Mersey Estuary Water*

Sedimentations Carried out in the Field

Date.	Time from nearest high water E = Ebb F = Flood.	Temperature of water (° C.).	Method of filling sedimentation tube: S = Filled without breaking clots. P = Poured into tube, clots broken.	Weight of mud (gm.) settled through 9 ft. after:						
				10 min.	20 min.	30 min.	40 min.	50 min.	70 min.	90 min.
	hrs.min.									
26/2/36	F 3.05	4	S	0·0666	0·2328	0·3636	—	0·4709	0·5104	0·5337
,,	F 2.53	4	S	0·0831	0·2689	0·4806	—	0·6448	0·6991	0·7261
,,	F 2.34	4	S	0·0458	0·0991	0·1711	—	0·2735	0·3177	0·3418
,,	F 2.08	4	S	0·1537	0·3389	0·4589	—	0·5587	0·6002	0·6138
27/2/36	F 3.23	5	S	0·2469	—	0·8343	—	1·0050	1·0489	1·0805
,,	F 3.06	4	S	0·1154	0·3437	0·5184	—	0·6345	0·6998	0·7272
,,	F 2.40	4	S	0·2682	0·5420	0·6999	—	0·8288	0·8757	0·9045
,,	F 2.08	4	S	0·0720	0·1820	0·2926	—	0·3924	0·4248	0·4504
,,	F 1.24	4	S	0·0127	0·3202	0·4566	—	0·5336	—	—
,,	F 1.13	4	S	0·1082	0·3599	0·4848	—	0·6012	—	—
,,	F 0.54	4·5	S	0·3074	0·6266	0·7766	—	—	—	—
5/3/36	E 2.01	4	S	0·0109	0·0244	0·0391	—	0·0678	0·0883	0·0981
,,	E 2.39	4	S	0·0101	0·0249	0·0434	—	0·0933	0·1402	0·1665
,,	E 3.41	4	S	0·0575	0·1390	0·2043	—	0·2414	0·2805	0·3006
6/3/36	E 1.38	4	S	0·0295	0·0833	0·1227	—	0·1594	0·1783	0.1870
,,	E 2.18	4	S	0·0537	0·1332	0·1753	—	0·2069	0·2247	0·2353
,,	E 2.54	4·5	S	0·0672	0·1604	0·2321	—	0·2920	0·3179	0·3338
,,	E 3.22	4·5	S	0·1364	0·3469	0·4443	—	0·5096	—	—
9/3/36	E 0.11	5	S	0·2850	0·5733	0·7294	0·8132	—	—	—
,,	E 0.25	5	S	0·1537	0·4129	0·6260	0·7479	—	—	—
,,	E 1.16	5	S	0·0832	0·1833	0·2613	0·3211	—	—	—
,,	E 1.43	5	S	0·1246	0·3103	0·4707	0·5637	—	—	—
,,	E 2.10	5	S	0·1494	0·3681	0·5763	0·7038	—	—	—
,,	E 2.32	5	S	0·3782	0·7277	0·9594	1·0635	—	—	—
,,	E 2.48	5	S	0·1453	0·4276	0·5640	0·6382	—	—	—
,,	E 3.04	5	S	0·2095	0·6112	0·8364	0·9485	—	—	—
,,	E 3.19	5	S	0·3947	0·9332	1·1990	1·2957	—	—	—
,,	E 3.38	6	S	0·9736	1·3908	1·5564	—	—	—	—
10/3/36	F 1.46	5	S	0·0761	0·2190	0·3178	0·3688	—	—	—
,,	F 1.27	5	S	0·3971	1·0313	1·2766	1·3789	—	—	—
,,	F 0.57	5	S	0·0663	0·1595	0·2325	0·2745	—	—	—
,,	F 0·40	5	S	0·0376	0·0999	0·1677	0·2270	—	—	—
,,	F 0·30	5	S	0·0787	0·2138	0·2858	0·3227	—	—	—
,,	F 0·12	5	S	0·0830	0·1678	0·2174	0·2441	—	—	—
,,	E 0.19	5	S	0·0965	0·1484	0·1788	0·1980	—	—	—
,,	E 2.02	5	S	0·0104	0·0336	0·0602	0·0932	—	—	—
,,	E 2.25	5	S	0·0552	0·1359	0·2035	0·2474	—	—	—
13/3/36	F 3.06	4	S	0·1978	0·3451	0·4049	0·4512	—	—	—
,,	F 3.06	4	P	0·0128	0·0288	0·0627	—	0·1417	0·2144	0·2604
,,	F 2.37	4	S	0·0983	0·2670	0·3557	0·4009	—	—	—
,,	F 2.37	4	P	0·0589	0·0841	0·1212	—	0·2293	0·3082	0·3604
,,	F 2.08	4	S	0·0677	0·1779	0·2580	0·2990	—	—	—
,,	F 2.08	4	P	0·0274	0·0423	0·0577	—	0·0981	—	0·1871
,,	F 1.39	4	S	0·0805	0·1791	0·2344	0·2669	—	—	—
,,	F 1.39	4	P	0·0265	0·0417	0·0597	—	0·0933	0·1423	0·1891
,,	F 1·11	4	S	0·1520	0·2634	0·3201	0·3553	—	—	—
,,	F 1.11	4	P	0·0651	0·0806	0·0979	—	0·1425	0·1982	0·2369
,,	F 0.44	4	S	0·0634	0·1471	0·2039	0·2399	—	—	—
,,	F 0·44	4	P	0·0230	0·0333	0·0462	—	0·0714	0·1086	0·1453
,,	F 0.18	4	S	0·1195	0·2145	0·2784	0·3172	—	—	—
,,	E 0.13	4	S	0·0634	0·1032	0·1308	0·1486	—	—	—
25/3/36	E 2.09	—	S	0·0589	0·1336	0·1870	—	0·2374	0·2613	—
,,	E 1·41	—	S	0·0323	0·0830	0·1344	—	0·1843	0·2077	0·2222
,,	E 1·41	—	P	0·0096	0·0186	0·0278	—	0·0416	0·0591	0·0767
26/3/36	F 3.23	7	S	0·0806	0·2380	0·3688	—	0·4718	0·5099	0·5317
,,	F 3.23	7	P	0·0532	0·0865	0·1451	—	0·2274	0·2829	0·3175
11/5/36	F 2.00	16	S	0·0565	0·0882	0·1218	—	0·1670	0·1924	0·2085
,,	F 2·00	16	P	0·0384	0·0588	0·0846	—	0·1466	0·2018	0·2425
12/5/36	F 2.48	15	S	0·0856	0·1877	0·2512	—	0·2973	0·3197	0·3363
,,	F 2·48	15	P	0·0283	0·0502	0·0797	—	0·1511	0·1932	0·2198
,,	F 2.37	15	S	0·0613	0·1505	0·2073	—	0·2573	0·2832	0·2988
,,	F 2.37	15	P	0·0549	0·0724	0·0887	—	0·1241	0·1472	0·1776
,,	F 2·28	15	S	0·0537	0·1337	0·2085	—	0·2737	0·3109	0·3293
,,	F 2.28	15	P	0·0412	0·0759	0·1221	—	0·2539	0·3353	0·3817
22/5/36	F 2.55	13·5	S	0·0645	0·1200	0·1715	—	0·2253	0·2486	0·2602
,,	F 2.55	13·5	P	0·0460	0·0614	0·0939	—	0·1684	0·2220	0·2577
,,	F 2.35	13·5	S	0·0434	0·0798	0·1176	—	0·1647	0·1853	0·1983
,,	F 2.35	13·5	P	0·0246	0·0460	0·0724	—	0·1376	0·1875	0·2217
,,	F 2.09	13·5	S	0·0427	0·0729	0·0939	—	0·1195	0·1334	0·1422
,,	F 2.09	13·5	P	0·0231	0·0387	0·0520	—	0·0718	0·0956	0·1143
,,	F 1.16	13·5	S	0·0624	0·1070	0·1573	—	0·2090	0·2300	0·2430
,,	F 1.16	13·5	P	0·0201	0·0368	0·0519	—	0·0824	0·1204	0·1449

TABLE 83—*Rate of Sedimentation of Suspended Matter in Water from the Estuaries of the Rivers Suir and Barrow, Irish Free State*

Sedimentations Carried out in the Field

Place of sampling.	Length of time from nearest high water F = Flood E = Ebb.	Temperature of water (° C.).	Method of filling sedimentation tube: S = Clots unbroken. P = Clots broken.	Weight of mud (gm.) settled through 9 ft. after:					
				10 min.	20 min.	30 min.	50 min.	70 min.	90 min.
	hrs.min.								
Estuary of the River Suir.	E 3.00	8	S	0·1048	0·1396	0·1621	0·1854	0·1999	0·2106
	E 3.00	8	P	0·0523	0·0821	0·1129	0·1571	0·1864	0·2036
	E 3.40	8	S	0·3763	0·4309	0·4556	0·4749	0·4852	0·4906
	E 3.40	8	P	0·1005	0·1525	0·2069	0·2548	0·2814	0·2983
	E 4.20	8	S	0·3061	0·3815	0·4198	0·4660	0·4795	0·4890
	E 4·20	8	P	0·1449	0·2389	0·3074	0·3834	0·4204	0·4227
	E 5·07	8	S	0·3790	0·4463	0·4695	0·4909	0·5021	0·5094
	E 5.07	8	P	0·1326	0·2103	0·2602	0·3105	0·3376	0·3546
	E 5.33	8	S	0·1204	0·1445	0·1557	0·1647	0·1700	0·1738
Estuary of River Barrow.	E 2.14	8·5	S	0·0640	0·0890	0·1058	0·1264	0·1397	0·1477
	E 2.14	8·5	P	0·0472	0·0625	0·0773	0·0949	0·1153	0·1296
	E 2.49	8·5	S	0·0390	0·0617	0·0771	0·0918	0·1011	0·1069
	E 2.49	8·5	P	0·0138	0·0273	0·0389	0·0559	0·0763	0·0883
	E 3.51	8·5	S	0·1002	0·1191	0·1265	0·1355	0·1410	0·1447
	E 3.51	8·5	P	0·0261	0·0418	0·0535	0·0705	0·0993	0·1074
	E 4.07	8·5	S	0·0386	0·0514	0·0593	0·0674	0·0718	0·0751
	E 4.07	8·5	P	0·0195	0·0316	0·0439	0·0617	0·0761	0·0874
	E 4.40	8·5	S	0·0859	0·1237	0·1453	0·1591	0·1665	0·1720
	E 4.40	8·5	P	0·0552	0·0916	0·1249	0·1775	0·2058	0·2251

TABLE 84—*Concentration and Composition of Suspended Matter in the Mersey Estuary at Different States of Spring and Neap Tides*

Date.	Height of high water above L.B.D. (ft.).	Time from predicted high water. EBB (E) after previous high water. FLOOD (F) before next high water.	Speed of float. Float moving upstream F. Float moving down-stream E. (knots).	Distance from Rock Light. + Above, − Below. (thousands of ft.).	Total depth of water. (ft.).	Depth of sample. (ft.).	Concentration of suspended matter. (parts per 100,000).	Composition of suspended matter. Loss on ignition (per cent. of dry weight)
		hrs.min.						
30/7/33	24·5	F 5·30	—	+16·1	—	8	0·9	52
Float Drift		F 4·30	F 2·0	+17·8	—	8	1·7	47
		F 3·00	F 1·0	+31·6	—	8	2·8	31
		F 2·00	F 1·9	+40·5	—	8	2·0	40
		F 1·00	F 1·2	+50·5	—	8	2·9	22
		F 0·30	F 1·0	+53·6	—	8	4·2	21
1/8/33	23·6	F 5·00	F 0·6	+19·7	—	8	0·8	25
Float Drift		F 4·00	F 0·9	+24·8	—	8	2·2	18
		F 3·00	F 0·8	+29·5	—	8	3·0	17
		F 2·00	F 1·1	+34·0	—	8	1·3	18
		F 1·00	F 1·1	+41·7	—	8	0·8	16
		HW	F 0·7	+47·2	—	8	0·4	0
4/8/33	25·9	E 0·15	—	+64·2	—	8	1·6	31
Float Drift		E 1·30	E 1·6	+59·1	—	8	1·4	23
		E 2·15	E 2·0	+48·3	—	8	6·5	16
		E 3·15	E 2·4	+36·3	—	8	4·0	16
		E 4·15	E 2·7	+21·1	—	8	1·3	34
8/8/33	28·9	F 5·00	F 0·0	+17·0	47	8	2·6	24
		F 4·30	F 0·8	+18·8	68	8	2·4	25
		F 3·30	F 2·7	+27·1	50	8	2·0	20
Float Drift		F 2·30	F 3·7	+41·8	33	8	25·4	14
		F 1·30	F 3·7	+62·0	8	4	27·3	14
		F 0·30	F 2·0	+80·0	19	4	23·4	15
		HW	F 1·5	+80·0	19	4	21·6	14
		E 0·30	F 0·4	+90·0	15	4	31·7	15
9/8/33	28·3	F 3·15	F 3·5	+51·5	12	8	28·8	13
Float Drift		F 2·15	F 2·6	+67·2	10	8	58·1	13
		F 1·15	F 0·7	+84·0	12	8	35·6	13
		F 0·15	F 0·6	+88·0	12	8	14·1	16
		E 0·15	F 1·0	+89·2	14	8	15·1	17
		E 0·45	E 0·1	+90·7	14	8	5·7	22
11/8/33	25·9	F 5·00	F 1·1	+38·0	—	8	2·8	17
Fixed Position		F 4·00	F 2·4	,,	26	8	7·4	17
		F 3·00	F 2·5	,,	32	8	8·2	16
		F 2·00	F 1·8	,,	44	8	11·6	14
		F 1·00	F 1·3	,,	49	8	2·0	18
		HW	F 0·4	,,	44	8	1·0	27
14/8/33	21·5	E 4·30	—	+34·0	22	8	1·2	0
Float Drift		E 5·00	E 0·8	+31·1	43	8	0·6	7
		E 5·30	E 0·5	+29·4	45	8	0·6	25
		E 6·00	E 0·4	+28·0	27	8	0·5	33
		F 6·00	E 0·3	+28·0	24	8	0·4	0
		F 5·30	F 0·2	+28·3	22	8	0·5	46
		F 5·00	F 0·2	+28·5	43	8	0·5	23
		F 4·30	F 0·6	+29·6	45	8	0·5	25
		F 4·00	F 0·7	+31·9	45	8	0·5	46
		F 3·36	F 1·1	+35·2	40	8	0·7	47
		F 3·00	F 1·3	+38·8	38	8	0·8	32
		F 2·30	F 1·6	+44·7	25	8	3·9	16
		F 2·00	F 1·4	+48·9	14	8	2·9	11
		F 1·30	F 1·2	+52·2	28	8	2·3	22
		F 1·00	F 1·0	+55·0	29	8	1·0	29
		F 0·30	F 1·1	+57·9	25	8	1·0	32
		HW	F 0·7	+60·1	20	8	0·9	27
22/8/33	28·1	F 4·15	—	+17·8	—	4	1·2	19
						57	12·4	13
Float Drift		F 3·45	F 1·8	+21·5	—	4	1·8	13
						40	14·3	11
		F 3·15	F 2·9	+30·0	—	4	12·0	12
						32	32·4	12
		F 2·45	F 2·4	+36·7	—	4	27·2	13
						16	32·4	13
		F 2·15	F 3·2	+44·8	—	4	20·2	14
						24	25·0	12
		F 1·45	F 3·9	+52·8	—	4	24·8	13
						15	20·6	13

TABLE 84—*continued*

Date.	Height of high water above L.B.D. (ft.).	Time from predicted high water. EBB (E) after previous high water. FLOOD (F) before next high water.	Speed of float. Float moving upstream F. Float moving down-stream E. (knots).	Distance from Rock Light. + Above, − Below. (thousands of ft.).	Total depth of water. (ft.).	Depth of sample. (ft.)	Concentration of suspended matter. (parts per 100,000).	Composition of suspended matter.
		hrs.min.						Loss on ignition (per cent. of dry weight)
23/8/33	28·5	F 5·00	E 0·3	+18·0	58	4	2·0	16
						52	2·4	15
Float Drift		F 4·30	F 0·5	+18·8	62	4	1·8	13
						53	4·0	14
		F 4·00	F 0·9	+21·2	74	4	1·7	23
						53	6·5	13
		F 3·30	F 2·4	+27·0	25	4	8·0	13
						23	10·9	12
		F 3·00	F 2·2	+34·6	15	4	35·4	9
						13	43·4	10
		F 2·30	F 2·2	+40·2	38	4	14·9	15
						36	23·4	13
		F 2·00	F 3·4	+48·5	18	4	17·5	11
						16	20·2	13
		HW	—	+83·3	15	4	22·1	13
						13	33·9	12
24/8/33	28·6	F 4·00	F 1·1	+ 8·5	61	4	1·7	5
						53	12·2	10
Float Drift		F 3·30	F 1·9	+23·0	56	4	1·4	6
						52	2·7	9
		F 3·00	F 2·6	+28·7	49	4	3·4	8
						45	34·2	12
		F 2·30	F 3·6	+39·0	33	4	26·6	12
						30	55·8	13
		F 2·00	F 3·1	+49·0	28	4	38·7	12
						25	38·4	10
		F 1·30	F 2·9	+57·0	26	4	35·4	11
						22	36·4	13
		F 1·00	F 2·4	+64·5	19	4	30·7	8
						15	34·2	12
		F 0·30	F 1·4	+70·5	12	4	25·0	9
						10	23·0	11
		HW	F 0·8	+73·8	9	4	12·2	10
						8	15·2	15
		E 0·30	F 0·4	+75·0	11	4	2·9	6
						8	4·5	4
		E 1·00	E 0·5	+74·8	10	4	1·8	35
						8	3·7	5
		E 1·30	E 1·2	+71·5	11	4	8·3	20
						8	34·9	19
		E 2·00	E 1·7	+65·2	15	4	18·5	14
						13	28·9	14
		E 2·30	E 2·1	+58·7	21	4	16·4	13
						19	16·0	15
		E 3·00	E 2·5	+53·5	22	4	22·2	13
						19	22·0	14
		E 3·30	E 2·0	+47·0	13	4	19·7	13
						11	18·6	14
		E 4·00	E 2·2	+41·0	29	4	16·0	14
						24	16·0	12
		E 4·30	E 2·3	+33·6	39	4	18·6	11
						40	23·8	14
		E 5·00	E 2·5	+26·5	69	4	5·5	20
						53	42·6	13
		E 5·30	E 2·0	+25·0	34	4	3·9	14
						30	5·3	21
		E 6·00	E 1·1	+16·4	14	4	2·3	2
						12	2·5	29
		E 6·30	E 0·8	+13·9	39	4	1·7	40
						36	2·0	37
		E 7·00	E 0·4	+13·0	37	4	4·4	21
						28	1·8	36
25/9/33	26·3	F 1·00	F 0·8	+60·4	2	1	15·2	16
		F 0·35	F 0·9	,,	5	3	10·9	18
Fixed Position.		F 0·15	F 0·7	,,	5	3	13·8	13
		E 0·05	F 0·7	,,	5	3	5·9	22
		E 0·25	—	,,	5	3	6·7	21
		E 0·45	—	,,	4	3	9·5	17
		E 1·05	—	,,	4	2	16·0	17
		E 1·25	E 0·6	,,	2	1	26·6	15
		E 1·45	E 0·6	,,	3	1	26·5	16
		E 2·05	E 0·6	,,	2	1	111·6	9

TABLE 84—*continued*

Date.	Height of high water above L.B.D. (ft.).	Time from predicted high water. EBB (E) after previous high water. FLOOD (F) before next high water.	Speed of float. Float moving upstream F. Float moving down-stream E. (knots).	Distance from Rock Light. + Above, − Below. (thousands of ft.).	Total depth of water. (ft.).	Depth of sample. (ft.).	Concen-tration of suspended matter. (parts per 100,000).	Composition of suspended matter.
		hrs. min.						Loss on ignition (per cent. of dry weight)
26/9/33	24·4	F 1·15	—	+66·7	2	1	19·9	19
		F 1·00	F 0·8	,,	3	1	16·0	18
Fixed Position		F 0·30	F 0·6	,,	4	1	9·2	19
		F 0·15	—	,,	4	1	4·7	21
		HW	—	,,	4	1	24·4	25
		E 0·30	E 0·6	,,	4	1	3·4	22
		E 0·45	E 0·7	,,	3	1	8·0	20
		E 1·00	E 0·6	,,	2	1	10·6	17
27/9/33	22·9	F 1·00	F 0·8	+67·5	2	1	13·7	17
		F 0·40	F 0·6	,,	3	1	10·2	18
Fixed Position.		F 0·20	—	,,	4	1	5·7	18
		HW	—	,,	4	1	2·9	19
		E 0·20	—	,,	4	1	3·0	28
		E 0·40	E 0·6	,,	4	1	3·0	31
		E 1·00	E 0·6	,,	3	1	7·0	19
2/10/33	28·3	E 0·15	0	−20·7	53	0	1·3	47
						40	1·8	29
Fixed Position.		E 0·40	0	,,	53	40	0·9	30
		E 1·10	0	,,	52	40	1·3	38
		E 1·40	E 1·9	,,	50	36	3·4	23
		E 2·10	E 2·1	,,	45	31	7·8	18
		E 2·40	E 2·5	,,	42	22	9·4	21
		E 3·10	E 2·6	,,	40	20	5·2	18
		E 3·40	E 2·6	,,	39	19	5·6	23
		E 4·10	E 2·4	,,	36	16	11·6	17
		E 4·40	E 2·4	,,	34	14	10·5	23
		E 5·10	E 2·2	,,	32	12	9·4	17
		E 5·40	E 1·9	,,	31	11	11·4	18
		E 6·10	E 1·2	,,	30	10	14·0	18
		E 6·40	E 0·6	,,	30	10	6·5	19
								Oxygen consumed (Adeney) (gm. oxygen per 100 gm. dry weight)
7/8/35	22·8	F 5·00	—	+34·1	30	3	2·2	14·3
Float Drift					30	12	2·5	12·9
					30	25	3·8	9·9
		F 3·40	F 1·0	+41·4	36	3	2·1	15·4
					36	12	5·7	2·8
					36	35	17·4	8·6
		F 3·00	F 2·1	+49·0	22	3	13·8	9·4
					22	12	13·6	6·6
					22	18	14·4	5·7
		F 2·00	F 1·7	+58·5	6	3	33·2	6·8
		F 1·00	F 1·1	+63·7	6	6	26·6	7·1
		F 0·20	F 0·7	+66·0	3	0	13·8	7·1
9/8/35	22·0	E 4·00	—	+37·7	20	3	2·6	10·9
Float Drift						12	2·7	12·7
						18	7·2	10·3
		E 5·30	E 0·9	+34·1	42	3	2·4	12·5
						12	2·6	14·6
						18	3·9	10·8
						30	4·8	11·1
		E 5·35	E 1·6	+26·4	49	3	1·4	19·1
						12	1·5	18·4
						18	2·0	13·2
						30	2·2	13·9
		E 6·33	E 0·8	+19·5	60	3	0·9	36·4
						12	1·4	22·0
						18	1·6	24·4
						30	2·0	19·6
		E 7·15	E 0·7	+16·6	60	3	1·0	25·0
						12	1·5	21·0
						18	1·3	19·7
14/8/35	28·3	F 0·15	—	+17·3	75	0	6·4	10·3
Float Drift						30	6·8	10·2
						60	6·8	10·5
		HW	—	+16·6	75	0	6·7	10·1
						30	5·4	10·4
						60	5·2	9·2

TABLE 84—*continued*

Date.	Height of high water above L.B.D. (ft.).	Time from predicted high water. EBB (E) after previous high water. FLOOD (F) before next high water.	Speed of float. Float moving upstream F. Float moving down-stream E. (knots).	Distance from Rock Light. + Above, — Below. (thousands of ft.).	Total depth of water. (ft.).	Depth of sample. (ft.).	Concen-tration of suspended matter. (parts per 100,000).	Composition of suspended matter. Oxygen consumed (Adeney) (gm. oxygen per 100 gm. dry weight).
		hrs.min.						
14/8/35	28·3	E 0·15	—	+13·8	72	0	7·6	8·9
						30	10·2	8·6
						66	10·9	8·6
Float Drift —*contd.*		E 0·30	—	+13·6	78	0	5·3	10·2
						30	6·0	9·4
						72	5·8	10·2
		E 0·45	—	+12·3	66	0	9·7	11·1
						30	17·8	7·5
						60	18·8	6·9
		E 1·00	—	+14·7	77,	0	4·8	18·6
						36	4·5	12·5
						72	5·5	10·5
		E 1·15	—	+13·7	82	0	5·2	10·7
						36	7·0	8·6
						78	8·0	9·1
		E 1·30	—	+14·7	90	0	5·0	10·9
						42	7·4	10·5
						84	8·1	9·2
		E 1·45	—	+15·2	78	0	4·5	10·9
						36	9·2	9·4
						72	9·6	8·8
16/8/35	30·2	HW	—	+18·0	78	0	3·8	12·5
						39	6·4	10·0
Float Drift						75	6·3	8·5
		E 0·12	—	+16·5	72	0	4·8	10·3
						36	6·0	9·3
						69	6·3	11·1
19/8/35	28·0	F 4·50	F 1·4	−46·4	6	0	13·6	6·2
						5	13·0	6·8
Float Drift		F 3·30	F 1·5	−32·5	38	0	15·8	7·0
						18	20·6	6·0
						36	28·4	5·4
		F 1·30	F 1·4	−13·4	21	0	17·2	6·4
						9	20·9	5·3
						21	18·8	6·8
		F 0·30	F 1·1	− 5·1	21	0	15·0	7·1
						10	27·2	6·0
						20	31·6	6·1
21/8/35	26·1	E 5·30	—	+ 0·9	56	0	4·4	11·0
						27	7·8	9·7
Float Drift						54	13·0	7·3
		E 6·05	—	− 5·0	54	0	3·4	13·7
						26	6·0	7·3
						52	11·8	8·0
		LW	—	− 9·1	45	0	2·3	14·9
						22	2·2	10·7
						43	2·9	11·1
26/8/35	24·7	F 2·30	—	+10·2	72	4	8·8	8·4
						69	22·6	7·4
Float Drift		F 1·30	F 3·4	+32·5	48	4	10·5	17·5
						45	13·6	8·1
		F 1·00	F 2·3	+39·6	27	4	11·0	8·0
						24	11·8	7·7
		F 0·30	F 1·7	+44·6	34	4	8·7	8·3
						30	12·4	9·1
		HW	F 1·3	+48·1	27	4	8·3	7·9
						23	5·2	21·3
		E 1·30	E 0·3	+46·6	21	4	5·2	10·5
						17	12·3	4·4
		E 3·00	E 2·9	+24·4	60	3	7·0	9·5
						56	11·8	8·3
		E 4·30	E 2·7	+ 0·3	48	4	6·2	9·4
						44	12·6	8·5
		E 5·00	E 1·9	− 5·0	36	4	3·8	10·0
						32	5·6	10·4
		E 5·30	E 1·2	− 8·4	15	4	10·1	4·1
						13	3·8	20·2

TABLE 84—*continued*

Date.	Height of high water above L.B.D. (ft.).	Time from predicted high water. EBB (E) after previous high water. FLOOD (F) before next high water.	Speed of float. Float moving upstream F. Float moving down-stream E. (knots).	Distance from Rock Light. + Above, − Below. (thousands of ft.).	Total depth of water. (ft.).	Depth of sample. (ft.).	Concentration of suspended matter. (parts per 100,000).	Composition of suspended matter. Oxygen consumed (Adeney) (gm. oxygen per 100 gm. dry weight).
		hrs. min.						
28/8/35	26·7	F 3·00	F 3·4	+24·7	68	3	11·7	8·6
						60	14·1	9·6
Float Drift		F 1·30	F 2·4	+52·0	28	3	23·7	8·9
						24	30·8	6·8
		F 1·00	F 2·7	+59·4	26	3	18·3	11·5
						22	32·2	9·0
		F 0·30	F 1·7	+66·2	21	3	22·5	9·4
						17	27·8	9·2
		HW	F 1·1	+68·6	73	3	13·1	10·3
						9	22·9	8·7
		E 0·30	F 0·4	+71·5	14	3	6·0	11·0
						13	8·2	10·2
		E 1·00	E 0·6	+70·3	12	3	3·4	13·5
						11	14·8	10·1
		E 1·30	E 1·5	+66·2	15	3	20·1	8·4
						14	25·9	9·8
		E 3·00	E 2·3	+48·2	15	3	16·1	7·7
						13	17·3	8·1
		E 5·00	E 1·5	+25·3	56	3	6·2	10·4
						52	19·5	8·7
		E 5·30	E 1·8	+19·7	69	3	4·1	12·2
						65	17·1	10·0
		E 6·00	E 1·4	+15·1	58	3	2·6	12·1
						54	20·6	8·5
		LW	E 1·0	+12·1	37	3	2·9	12·3
						27	3·4	10·0
		F 5·10	F 0·4	+12·1	9	1	6·2	26·0
						8	4·8	20·2
		F 4·40	F 0·9	+13·8	44	3	2·6	12·5
						34	6·3	10·7
29/8/35	27·3	F 4·30	—	+ 9·9	60	3	2·0	18·7
						56	13·9	8·6
Float Drift		F 3·00	F 2·9	+28·8	54	3	4·3	13·9
						50	31·7	6·6
		F 1·30	F 1·7	+52·2	21	3	53·5	4·4
						17	9·4	30·3
		F 1·00	F 1·7	+59·4	16	3	35·2	6·0
						12	55·8	4·8
		F 0·30	—	+64·5	21	3	33·6	6·4
						17	40·1	4·7
		HW	F 0·8	+66·6	15	3	18·6	8·1
						11	26·2	8·8
		E 0·30	F 0·7	+68·2	15	3	5·5	12·7
						11	8·3	10·8
		E 2·00	E 1·0	+63·0	24	3	14·3	8·0
						20	13·6	9·2
		E 3·30	E 1·4	+46·5	11	3	27·1	6·3
						7	27·0	7·4
		E 5·00	E 1·8	+27·6	43	3	8·1	11·7
						39	53·1	8·4
		E 5·30	E 1·1	+22·9	47	3	7·0	12·1
						43	42·3	8·3
		E 6·00	E 0·9	+20·1	55	3	3·1	17·7
						51	11·1	10·3
		LW	E 0·7	+18·8	57	3	2·4	17·0
						53	3·5	10·9
		F 5·10	E 0·3	+17·9	58	3	2·3	15·5
						54	4·2	13·9
		F 4·40	E 0·3	+17·2	52	3	2·3	16·7
						48	3·0	13·3
30/8/35	27·6	F 5·00	—	+ 9·8	57	3	2·2	22·1
						53	5·5	16·5
Float Drift		F 3·30	F 3·1	+21·5	75	3	1·9	18·9
						72	37·3	7·4
		F 2·00	F 2·6	+45·4	30	3	26·1	7·9
						26	26·3	10·6
		F 1·00	F 1·4	+57·6	15	3	16·3	9·8
						11	24·8	8·1
		F 0·30	F 0·8	+60·0	9	1	16·8	13·4
						7	24·4	12·1
		HW	F 0·9	+62·2	13	2	6·4	14·0
						11	13·3	13·9

TABLE 84—*continued*

Date.	Height of high water above L.B.D. (ft.).	Time from predicted high water. EBB (E) after previous high water. FLOOD (F) before next high water.	Speed of float. Float moving upstream F. Float moving downstream E. (knots).	Distance from Rock Light. + Above, — Below. (thousands of ft.).	Total depth of water. (ft.).	Depth of sample. (ft.).	Concentration of suspended matter. (parts per 100,000).	Composition of suspended matter. Oxygen consumed (Adeney) (gm. oxygen per 100 gm. dry weight).
		hrs.min.						
30/8/35	27·6	E 0·30	E 0·2	+62·9	10	2	6·7	11·9
						8	6·9	15·9
Float Drift —*contd.*		E 2·00	E 2·3	+49·0	14	2	39·1	4·1
						12	123·5	1·5
		E 3·30	E 3·2	+24·2	66	3	8·4	10·7
		E 3·00	E 2·3	— 2·0	42	3	12·4	12·5
						38	29·2	9·8
		E 5·30	E 2·1	— 8·0	45	3	3·8	11·8
						41	20·4	10·1
		E 6·00	E 1·5	—12·8	33	3	7·0	16·4
						29	10·9	11·5
		E 6·30	E 0·9	—15·8	26	3	4·7	11·3
						22	13·0	12·7
31/8/35	27·5	F 5·00	—	+ 9·6	54	3	2·4	15·9
						50	9·4	11·2
Float Drift		F 4·30	F 0·6	+ 9·5	66	3	2·1	16·7
						62	21·2	7·8
		F 4·00	F 1·8	+10·2	55	3	2·0	16·2
						51	41·0	6·5
		F 2·30	F 3·3	+14·6	27	3	35·6	4·5
						23	323·8	0·7
		F 1·30	F 2·5	+37·8	40	3	27·0	6·1
						36	137·0	2·6
		F 1·00	F 2·2	+51·5	32	3	70·8	5·4
						28	91·2	4·8
		F 0·30	F 1·7	+56·8	27	3	38·3	6·8
						23	87·7	4·8
		HW	F 1·3	+63·1	16	3	15·7	7·6
						12	50·8	5·5
		E 0·30	F 0·6	+67·8	13	3	3·5	14·3
						11	6·7	11·2
		E 1·00	E 0·6	+69·9	10	3	3·6	13·9
						8	20·9	8·4
		E 1·30	E 1·2	+68·8	24	3	9·4	9·0
						20	22·6	7·8
		E 5·00	E 2·7	+15·7	44	3	7·8	10·2
						40	19·3	7·0
		E 5·30	E 2·1	+ 8·6	52	3	11·6	7·8
						48	14·9	9·1
		E 6·00	E 1·2	+ 4·7	25	3	2·7	13·2
						21	5·7	11·4
		LW	E 0·6	+ 2·3	22	3	3·3	13·8
						18	4·2	16·7
1/9/35	27·3	E 6·20	—	+ 9·7	59	3	4·0	18·7
						55	8·9	12·9
Float Drift		LW	E 0·8	+ 7·0	42	3	2·9	20·7
						38	4·3	10·6
		F 5·00	—	+ 5·3	27	3	2·9	13·8
						23	2·5	14·3
		F 3·30	F 2·7	+15·6	46	3	6·0	11·7
						42	9·2	9·2
		F 2·00	F 3·1	+43·0	42	3	58·9	5·1
						38	160·0	2·5
		F 1·30	F 2·6	+51·4	18	3	33·1	7·7
						14	83·9	5·1
		F 1·00	F 3·1	+59·3	26	3	8·0	11·9
						22	39·4	6·5
		F 0·30	F 1·8	+67·0	21	3	25·9	8·5
						17	52·5	6·2
		HW	F 0·8	+70·4	10	2	16·1	7·8
						8	42·1	5·3
		E 0·30	—	+72·2	10	2	7·3	12·3
						8	7·8	11·5
		E 2·00	E 2·6	+56·3	26	3	32·7	6·9
						22	94·2	4·4
		E 3·30	E 2·6	+32·4	47	3	15·3	9·8
						43	32·5	6·0
		E 5·00	E 1·9	+ 8·2	31	3	7·6	10·5
						27	9·7	9·8
		E 5·30	E 1·0	+ 3·9	26	3	3·6	16·7
						22	7·5	12·0
		E 6·00	E 0·8	+ 1·0	35	3	4·9	14·3
						31	7·3	11·0

TABLE 84—*continued*

Date.	Height of high water above L.B.D. (ft.).	Time from predicted high water. EBB (E) after previous high water. FLOOD (F) before next high water.	Speed of float. Float moving upstream F. Float moving down-stream E. (knots).	Distance from Rock Light. + Above, − Below. (thousands of ft.).	Total depth of water. (ft.).	Depth of sample. (ft.).	Concen-tration of suspended matter. (parts per 100,000).	Composition of suspended matter. Oxygen consumed (Adeney) (gm. oxygen per 100 gm. dry weight).
		hrs.min.						
2/9/35	22·6	E 6·00	—	+ 9·7	53	3 49	2·8 21·3	21·4 11·3
Float Drift		E 6·30	E 1·2	+ 6·0	55	3 51	5·1 12·0	16·7 12·1
		LW	E 0·5	+ 4·1	52	3 48	3·1 5·2	14·0 12·0
		F 5·00	E 0·1	+ 3·6	56	3 52	2·4 3·8	18·1 22·4
		F 3·30	F 3·2	+17·2	68	3 64	2·2 28·1	18·2 7·8
		F 2·00	F 2·6	+45·8	11	0 9	48·8 111·5	6·6 3·2
		F 1·30	F 2·0	+51·9	11	1 9	37·2 57·0	7·9 5·8
		F 1·00	F 1·4	+56·3	22	3 18	18·4 41·2	9·5 7·4
		F 0·30	F 1·9	+62·4	27	3 23	12·5 47·1	12·4 5·8
		HW	F 1·8	+68·8	18	3 14	23·4 31·3	10·3 8·0
		E 0·30	F 0·4	+71·9	17	3 13	13·9 17·7	11·2 11·3
		E 2·00	E 2·3	+57·7	18	3 14	46·0 79·0	8·6 9·5
		E 3·30	E 2·0	+40·0	24	3 20	25·7 30·7	9·7 7·8
		E 5·00	E 2·5	+20·3	55	3 51	3·7 12·5	18·9 12·0
3/9/35	25·6	E 5·30	—	+ 9·4	59	3 55	6·4 37·8	12·5 8·7
Float Drift		E 6·00	E 1·8	+ 3·9	70	3 66	3·1 21·7	19·3 8·3
		E 6·30	E 1·2	− 0·1	46	3 39	2·8 5·9	14·5 13·6
		F 5·30	E 0·6	− 2·0	23	3 19	1·8 2·8	19·4 25·0
		F 5·00	F 0·4	− 2·1	50	3 46	1·7 2·1	22·7 16·7
		F 4·30	F 0·7	+ 0·5	48	3 44	1·6 2·5	23·4 18·4
		F 4·00	F 1·1	+ 3·8	49	3 46	1·3 5·2	26·9 19·2
		F 2·45	F 2·9	+24·7	83	3 79	6·8 20·4	10·3 7·8
		F 1·30	F 2·5	+44·9	27	3 23	14·8 23·3	8·4 5·6
		F 1·00	F 1·4	+48·7	11	2 9	19·4 22·9	9·3 6·6
		F 0·30	F 0·8	+51·3	14	2 12	10·8 18·1	10·2 8·8
		HW	F 0·6	+52·5	15	2 13	9·3 7·9	10·7 11·4
		E 0·30	E 0·2	+51·2	14	3 12	3·4 3·4	23·5 20·6
		E 1·00	E 1·0	+48·0	13	2 11	6·3 10·5	14·3 9·5
		E 1·30	E 2·2	+41·9	27	3 23	3·5 13·1	15·0 8·8
		E 3·30	E 3·1	+10·0	65	3 60	4·9 14·5	16·1 11·0
4/9/35	24·5	E 5·00	—	+ 9·5	63	3 59	10·9 19·2	11·0 9·4
Float Drift		E 5·30	E 1·8	+ 4·2	76	3 72	3·8 3·7	26·3 9·3
		E 6·00	E 1·5	− 0·7	46	3 42	3·8 8·6	23·7 12·8
		E 6·30	E 0·9	− 3·4	15	3 11	42·5 3·0	3·9 16·1
		F 4·30	F 0·5	− 0·9	48	3 44	4·1 4·0	10·5 11·9

TABLE 84—*continued*

Date.	Height of high water above L.B.D. (ft.).	Time from predicted high water. EBB (E) after previous high water. FLOOD (F) before next high water.	Speed of float. Float moving upstream F. Float moving down-stream E. (knots).	Distance from Rock Light. + Above, − Below. (thousands of ft.).	Total depth of water. (ft.).	Depth of sample. (ft.).	Concentration of suspended matter. (parts per 100,000).	Composition of suspended matter. Oxygen consumed (Adeney) (gm. oxygen per 100 gm. dry weight).
		hrs. min.						
4/9/35	24·5	F 3·00	F 3·2	+16·3	72	3	2·8	14·3
						68	22·5	9·8
Float Drift —*contd.*		F 1·30	F 2·2	+43·2	14	3	24·3	7·4
						10	33·7	6·2
		F 1·00	F 1·8	+48·4	34	3	20·1	9·7
						30	28·1	7·0
		F 0·30	F 1·3	+53·5	17	3	13·4	15·7
						13	15·1	8·3
		HW	F 0·8	+56·9	10	3	12·8	10·9
						8	16·5	10·3
		E 0·30	—	+57·4	13	3	4·5	20·0
						9	7·7	13·0
		E 2·00	E 2·3	+45·5	26	3	16·7	10·2
						22	3·8	10·5
		E 3·30	E 1·5	+32·8	28	3	3·8	10·5
						24	31·9	9·9
		E 4·30	E 2·1	+20·6	74	3	3·1	16·4
						70	26·3	9·5
5/9/35	23·5	E 4·20	—	+ 9·5	60	3	6·1	14·8
						56	11·2	10·3
Float Drift		E 5·35	E 1·4	− 4·2	42	3	2·9	19·0
						38	11·6	10·3
		E 6·05	E 1·0	− 7·6	21	3	2·4	16·0
						17	4·1	17·1
		E 6·35	E 0·6	− 9·6	41	3	2·2	24·4
						37	3·8	18·4
		F 5·30	E 0·4	−10·2	19	3	2·0	20·5
						15	1·9	18·9
		F 4·00	F 1·1	− 3·6	12	2	2·3	19·5
						10	3·4	26·4
		F 2·30	F 2·3	+ 8·2	30	3	6·5	10·7
						26	11·3	9·7
		F 1·00	F 2·4	+29·1	63	3	3·2	21·8
						59	14·5	10·7
		F 0·30	F 1·6	+34·7	54	3	5·2	13·5
						50	11·5	10·4
		HW	F 1·0	+38·5	45	3	3·6	18·1
						35	10·9	7·8
		E 0·15	F 0·7	+39·5	46	3	3·9	17·9
						40	25·3	10·5
		E 1·45	E 1·9	+32·2	48	3	1·4	23·2
						44	10·4	8·2
		E 3·15	E 1·3	+15·8	52	3	2·6	22·6
						48	26·1	8·8
6/9/35	22·4	E 6·30	—	−11·8	53	3	1·8	36·2
						49	5·2	16·3
Float Drift		LW	E 0·2	−12·2	48	3	1·7	20·6
						44	2·9	25·8
		F 5·15	F 0·4	−11·6	44	3	1·5	43·3
						40	1·8	30·6
		F 4·45	F 0·9	− 9·5	48	3	1·5	31·0
						44	3·1	21·0
		F 4·15	F 1·0	− 6·5	52	3	1·2	29·2
						48	6·1	14·7
		F 3·45	F 1·8	− 2·0	55	3	1·4	25·0
						51	6·3	19·1
		F 2·30	F 3·4	+15·6	69	3	2·9	19·0
						65	3·3	18·2
		F 1·30	F 2·1	+28·8	63	3	3·8	14·5
						59	4·6	13·0
		F 1·00	F 1·5	+34·0	47	3	4·3	15·1
						43	5·5	16·4
		F 0·30	F 1·4	+38·4	45	3	3·0	20·0
						41	5·3	13·2
		HW	F 0·6	+40·5	36	3	4·0	17·5
						32	5·2	14·4
		E 0·30	—	+40·8	30	3	2·0	27·5
						26	2·6	19·2
		E 1·00	E 0·6	+39·2	36	3	4·9	15·3
						32	1·6	21·0
		E 1·30	E 1·3	+36·1	36	3	1·1	28·6
						32	7·0	11·4
		E 2·30	E 1·9	+24·1	61	3	1·3	36·0
						57	5·9	11·8

TABLE 84—*continued*

Date.	Height of high water above L.B.D. (ft.).	Time from predicted high water. EBB (E) after previous high water. FLOOD (F) before next high water.	Speed of float. Float moving upstream F. Float moving downstream E. (knots).	Distance from Rock Light. + Above, − Below. (thousands of ft.).	Total depth of water. (ft.).	Depth of sample. (ft.).	Concentration of suspended matter. (parts per 100,000).	Composition of suspended matter. Oxygen consumed (Adeney) (gm. oxygen per 100 gm. dry weight).
		hrs.min.						
7/9/35	22·1	E 2·30	—	+ 7·9	62	3	1·9	26·4
						58	2·9	19·0
Float Drift		E 4·00	E 1·3	− 6·6	46	3	2·1	26·2
						42	8·3	10·2
		E 5·15	E 1·3	−15·8	48	3	1·4	32·1
						44	2·4	20·8
		E 5·45	E 1·2	−19·2	50	3	2·1	17·1
						46	1·9	23·7
		E 6·45	E 0·2	−21·7	43	3	1·1	28·6
						39	1·9	26·3
		F 5·50	E 0·2	−22·5	41	3	1·0	37·5
						36	2·3	26·1
		F 3·30	F 2·2	−13·0	38	3	1·1	33·3
						34	4·4	11·3
		F 2·00	F 1·7	+ 2·8	74	3	3·5	21·4
						70	5·0	11·0
		F 1·30	F 1·5	+ 7·6	69	3	1·7	25·0
						65	3·7	14·8
		F 1·00	F 1·7	+12·7	72	3	1·7	22·6
						60	2·1	28·5
		F 0·30	F 1·2	+16·2	51	3	0·7	54·0
						47	2·1	17·8
		HW	F 0·6	+18·2	68	3	2·5	18·0
						64	1·7	32·4
		E 0·15	F 0·4	+18·6	72	3	1·9	23·7
						68	1·7	17·6
		E 1·30	E 1·9	+ 9·9	56	3	1·7	19·7
						52	6·6	9·9
8/9/35	22·8	E 0·30	—	+ 9·8	76	3	2·4	15·6
						72	2·3	19·5
Float Drift		E 2·00	E 1·3	− 3·3	39	35	2·3	12·2
		E 3·15	—	−17·5	52	3	1·7	18·2
						48	3·0	13·3
		E 4·45	E 1·5	−19·5	45	3	1·3	18·0
						41	3·4	10·4
		E 5·15	E 1·7	−24·7	45	3	1·5	19·0
						41	2·3	16·3
		E 5·45	E 1·5	−29·5	39	3	1·2	25·0
						35	1·9	17·6
		E 6·15	E 1·0	−32·7	58	3	0·9	30·6
						54	1·6	24·2
		LW	E 0·5	−34·3	65	3	1·4	21·4
						61	1·1	34·0
		F 4·15	F 0·2	−34·8	55	3	1·3	17·3
						51	1·4	25·0
		F 2·45	F 0·9	−29·2	54	3	1·2	29·2
						50	2·2	15·9
		F 1·30	F 0·6	−22·1	57	3	1·2	29·2
						53	1·4	21·4
		F 1·00	F 0·5	−20·7	58	3	1·3	23·0
						54	1·6	21·9
		F 0·30	—	−20·0	65	3	1·0	29·0
						61	0·8	31·2
		F 0·15	—	−19·8	59	3	0·8	33·3
						55	1·3	21·2
9/9/35	24·8	F 0·30	F 1·2	+11·2	70	3	1·9	20·3
						66	2·5	13·0
Float Drift		E 0·15	—	+14·5	62	3	1·6	19·4
						58	2·0	19·2
		E 0·45	E 0·8	+13·5	60	3	1·3	26·0
						56	1·8	18·1
		E 1·15	E 1·8	+ 8·8	42	3	1·5	19·0
						38	1·5	22·4
		E 1·45	E 2·2	+ 2·9	37	3	1·5	21·6
						33	2·1	15·5
		E 3·15	E 2·0	− 4·4	54	3	1·2	25·0
						50	1·7	21·2

TABLE 84—*continued*

Date.	Height of high water above L.B.D. (ft.).	Time from predicted high water. EBB (E) after previous high water. FLOOD (F) before next high water.	Speed of float. Float moving upstream F. Float moving downstream E. (knots).	Distance from Rock Light. + Above, − Below. (thousands of ft.).	Total depth of water. (ft.).	Depth of sample. (ft.).	Concentration of suspended matter. (parts per 100,000).	Composition of suspended matter. Oxygen consumed (Adeney) (gm. oxygen per 100 gm. dry weight).
		hrs.min.						
10/9/35	25·1	F 2·00	—	+11·3	87	3	3·1	14·5
						78	10·3	14·5
Float Drift		F 1·30	F 3·0	+20·5	84	3	5·4	6·5
						80	8·2	7·3
		F 1·00	F 1·6	+26·3	81	3	3·7	13·5
						77	4·2	13·1
		F 0·30	F 1·6	+31·7	58	3	7·2	6·3
						54	5·7	8·8
		HW	F 1·0	+35·0	54	3	2·8	18·2
						50	4·7	10·6
		E 1·30	E 2·0	+28·2	63	3	1·3	26·0
						59	4·0	11·3
		E 3·00	E 2·7	+ 2·6	51	3	5·7	7·1
						47	10·0	4·0
		E 4·30	E 2·1	−22·1	40	3	6·8	9·6
						36	17·1	4·4
		E 5·30	E 0·9	−31·9	51	3	6·0	6·7
						47	17·9	6·7
		E 6·00	E 0·9	−35·7	48	3	5·2	10 6
						44	28·2	7·1
		F 3·45	F 2·4	−38·5	72	3	4·9	10·2
						68	4·6	9·8
		F 3·15	F 2·2	−40·2	62	3	1·8	20·0
						58	5·4	8·3
		F 2·45	F 2·4	−31·5	48	3	1·7	23·5
						44	22·6	3·3
		F 2·15	F 2·5	−10·3	57	3	2·3	15·2
						53	8·4	5·4
13/9/35	30·4	F 3·45	F 2·3	+18·4	66	3	3·7	—
						62	61·7	—
Float Drift		F 2·35	F 4·1	+44·2	27	3	32·7	—
						23	88·9	—
		F 1·05	F 2·2	+76·4	12	1	92·5	—
						10	180·6	—
		F 0·35	F 1·4	+81·0	18	1	13·6	—
						16	73·8	—
		HW	F 0·7	+83·2	22	3	6·7	—
						18	21·6	—
		E 0·30	F 0·5	+84·9	20	3	4·8	—
						17	8·5	—
		E 1·00	E 0·2	+85·1	17	3	3·4	—
						14	4·2	—
		E 2·15	E 2·8	+72·0	13	1	101·3	—
						11	103·9	—
		E 4·00	E 2·9	+39·2	27	3	50·3	—
						23	338·0	—
		E 5·30	E 1·3	+20·2	43	3	10·9	—
						39	53·3	—
		E 6·00	E 1·5	+16·9	54	3	4·6	—
						50	57·9	—
		E 6·30	E 1·5	+12·4	48	3	3·8	—
						44	11·5	—
		LW	E 1·0	+ 8·9	27	3	5·0	—
						23	4·2	—
27/9/35	27·5	E 2·10	—	−56·3	—	0	0·9	27·0
		E 2·18	—	−54·3	—	0	0·5	28·6
Float Drift		E 2·27	—	−50·3	—	0	1·1	21·0
		E 2·36	—	−45·2	—	0	1·3	18·0
		E 2·47	—	−41·6	—	0	0·9	30·8
		E 2·54	—	−38·6	—	0	1·2	16·5
		E 3·09	—	−32·6	—	0	1·2	14·5
		E 3·15	—	−30·7	—	0	1·4	15·2
		E 3·21	—	−28·9	—	0	1·4	14·0
11/11/35	29·9	LW	—	−45·4	42	0	10·1	6·9
						21	10·6	6·1
Formby Light Vessel						40	10·9	5·5
		F 5·00	—	,,	43	0	10·3	5·3
						21	10·6	5·7
						40	12·9	5·4
		F 4·45	—	,,	45	0	7·9	5·7
						21	10·1	5·5
						40	12·3	5·7

TABLE 84—*continued*

Date.	Height of high water above L.B.D. (ft.).	Time from predicted high water. EBB (E) after previous high water. FLOOD (F) before next high water.	Speed of float. Float moving upstream F. Float moving down-stream E. (knots).	Distance from Rock Light. + Above. − Below. (thousands of ft.).	Total depth of water. (ft.).	Depth of sample. (ft.).	Concentration of suspended matter. (parts per 100,000).	Composition of suspended matter. Oxygen consumed (Adeney) (gm. oxygen per 100 gm. dry weight).
		hrs.min.						
11/11/35 —*contd.*	29·9	F 4·30	—	−45·4	46	0	6·5	4·6
						21	7·0	6·4
						40	10·1	4·5
		F 4·15	—	,,	48	0	6·1	4·9
						21	8·6	2·9
						40	19·3	0
						45	14·8	—
		F 4·00	—	,,	50	0	4·9	5·1
						21	6·0	4·2
						40	4·5	5·6
						47	7·4	6·1
		F 3·45	—	,,	54	0	8·8	4·0
						21	6·0	5·0
						40	11·0	2·3
						51	12·4	2·4
		F 3·30	—	,,	55	0	8·9	8·4
						21	11·2	5·4
						40	20·0	2·5
						52	24·6	2·2
		F 3·15	—	,,	58	0	9·9	3·0
						21	12·2	2·9
						40	16·4	2·3
						55	14·8	2·7
		F 3·00	—	,,	63	0	9·4	5·3
						21	8·0	2·5
						40	8·9	3·9
						60	12·9	2·3
		F 2·45	—	,,	64	0	5·5	5·5
						21	7·0	2·9
						40	11·0	3·2
						61	10·1	3·0
		F 2·30	—	,,	66	0	5·7	5·3
						21	11·8	2·1
						40	9·4	2·7
						63	17·8	2·2
		F 2·15	—	,,	68	0	11·8	2·5
						21	15·7	1·3
						40	5·6	4·5
						65	16·5	1·2
		F 2·00	—	,,	69	0	6·0	4·2
						21	10·1	2·5
						40	8·3	4·2
		F 1·45	—	,,	69	0	7·8	3·2
						21	8·3	3·6
						40	8·7	3·4
						66	12·8	2·7
		F 1·30	—	,,	69	0	6·8	7·4
						40	6·2	8·1
						66	6·2	7·3
		F 1·15	—	,,	69	0	4·7	7·4
						21	4·4	8·0
						40	4·0	6·3
						66	5·4	13·0
		F 1·00	—	,,	70	0	4·1	8·5
						21	3·3	9·1
						40	4·2	9·5
						70	4·7	7·4
		F 0·45	—	,,	70	0	3·6	9·7
						21	3·8	5·3
						40	2·9	8·6
						67	3·4	5·9
		F 0·30	—	,,	70	0	2·0	10·0
						21	2·2	6·8
						40	2·5	4·0
						67	2·8	5·4
		F 0·15	—	,,	72	0	2·5	4·0
						21	1·8	2·6
						40	1·8	11·0
						69	1·9	7·9
		HW	—	,,	72	21	1·6	9·4
						40	1·5	6·7
						69	2·3	4·4

TABLE 84—*continued*

Date.	Height of high water above L.B.D. (ft.).	Time from predicted high water. EBB (E) after previous high water. FLOOD (F) before next high water. (hrs.min.)	Speed of float. Float moving upstream F. Float moving down-stream E. (knots).	Distance from Rock Light. + Above, − Below. (thousands of ft.).	Total depth of water. (ft.).	Depth of sample. (ft.).	Concen-tration of suspended matter. (parts per 100,000).	Composition of suspended matter. Oxygen consumed (Adeney) (gm. oxygen per 100 gm. dry weight).
11/11/35	29·2	E 6·15	—	−71·8	48	0	1·1	23·0
Bar Light Vessel.						24	1·5	30·0
						45	2·8	23·0
		E 6·30	—	,,	47	0	2·5	26·0
						45	2·1	12·0
		LW	—	,,	47	0	1·8	31·0
		F 5·15	—	,,	46	0	1·9	7·9
						21	0·9	16·7
						43	1·4	32·0
		F 5·00	—	,,	47	0	2·5	18·0
						21	2·1	7·1
						43	3·1	8·1
		F 4·45	—	,,	48	0	1·4	7·1
						21	2·1	24·0
						43	3·0	5·0
		F 4·30	—	,,	49	0	1·4	14·3
						21	2·6	17·7
						43	2·3	17·4
						46	3·1	8·1
		F 4·15	—	,,	49	0	0·6	8·3
						21	1·0	10·0
						43	1·4	10·7
						46	3·2	9·4
		F 4·00	—	,,	51	0	0·9	5·6
						21	1·1	18·2
						43	2·4	2·1
						48	3·0	8·3
		F 3·45	—	,,	53	0	1·4	14·3
						21	1·1	13·6
		F 3·30	—	,,	57	0	1·1	4·5
						21	0·9	5·6
						43	2·3	4·4
						54	2·9	15·5
		F 3·15	—	,,	60	0	2·2	4·5
						21	1·3	7·7
						43	3·3	7·6
						57	3·3	12·1
		F 3·00	—	,,	62	0	2·6	1·9
						21	4·0	5·0
						43	4·7	3·2
						59	5·1	4·9
		F 2·45	—	,,	64	0	4·8	8·3
						21	5·5	1·8
						43	6·1	4·9
						61	5·4	6·5
		F 2·30	—	,,	65	0	2·3	8·7
						21	3·7	4·1
						43	4·5	3·3
						62	4·6	5·4
		F 2·15	—	,,	67	0	2·0	10·0
						21	2·7	1·9
						43	2·3	8·7
						64	3·8	2·6
		F 2·00	—	,,	66	0	2·2	6·8
						21	1·9	5·3
						43	2·4	4·2
						63	2·8	5·4
		F 1·45	—	,,	68	0	1·9	5·3
						21	2·2	9·1
						43	2·3	8·7
						65	3·6	2·8
		F 1·30	—	,,	69	0	2·2	2·3
						21	2·3	4·3
						43	2·7	3·7
						66	2·4	4·2
		F 1·15	—	,,	72	0	2·3	2·2
						21	2·3	6·5
						43	2·2	4·5
						69	3·1	3·2
		F 1·00	—	,,	72	0	1·3	7·7
						21	2·3	4·4
						43	2·0	2·5
						69	3·0	1·7

TABLE 84—*continued*

Date.	Height of high water above L.B.D. (ft.).	Time from predicted high water. EBB (E) after previous high water. FLOOD (F) before next high water.	Speed of float. Float moving upstream F. Float moving downstream E. (knots).	Distance from Rock Light. + Above, — Below. (thousands of ft.)	Total depth of water. (ft.).	Depth of sample. (ft.).	Concentration of suspended matter. (parts per 100,000).	Composition of suspended matter. Oxygen consumed (Adeney) (gm. oxygen per 100 gm. dry weight).
		hrs. min.						
11/11/35 —*contd.*	29·2	F 0·45	—	−71·8	72	0	2·1	4·8
						21	1·9	0
						43	1·7	5·9
						69	1·5	3·3
		F 0·30	—	"	72	0	1·1	0
						21	1·9	0
						43	1·9	2·6
						69	1·8	5·6
		F 0·15	—	"	71	0	1·9	2·6
						21	0·8	6·8
						43	1·6	3·1
						68	1·8	2·8
15/11/35	26·6	F 2·40	—	+35·9	29	0	25·8	—
Float Drift						6	32·3	—
						12	46·6	—
						24	21·8	—
		F 2·20	F 1·9	+39·8	27	0	23·2	—
						6	35·7	—
						12	40·2	—
						24	75·7	—
		F 2·05	F 2·1	+42·8	31	0	10·9	—
						6	15·7	—
						12	17·0	—
						24	16·3	—
		F 1·55	F 1·5	+44·6	18	0	23·8	—
						6	27·9	—
						12	35·1	—
		F 1·40	F 1·6	+46·8	34	0	13·2	—
						6	21·8	—
						12	31·7	—
						24	37·5	—
		F 1·25	F 1·7	+48·9	42	0	11·8	—
						6	16·2	—
						12	14·2	—
						24	20·6	—
		F 1·10	—	+53·3	30	0	15·8	—
						6	20·7	—
						12	19·8	—
						24	25·8	—
		F 0·55	F 1·7	+53·8	19	0	18·1	—
						6	23·8	—
						12	26·1	—
		F 0·40	F 1·6	+54·4	28	0	11·2	—
						6	34·1	—
						12	49·2	—
						24	47·9	—
		F 0·25	F 1·1	+55·8	33	0	10·4	—
						12	11·8	—
						18	15·2	—
						24	28·2	—
		F 0·10	F 1·1	+57·3	28	0	10·9	—
						12	10·2	—
						18	12·7	—
						24	26·3	—
		E 0·05	F 0·8	+59·1	27	0	13·5	—
						12	17·2	—
						18	23·3	—
						24	22·2	—
		E 0·15	F 1·1	+60·1	29	0	5·7	—
						12	14·0	—
						18	18·0	—
						24	26·5	—
		E 0·25	F 1·0	+60·9	27	12	10·6	—
						18	17·3	—
						24	19·3	—
		E 0·35	F 0·2	+61·2	26	18	14·7	—
						24	78·4	—

TABLE 84—*continued*

Date.	Height of high water above L.B.D. (ft.).	Time from predicted high water. EBB (E) after previous high water. FLOOD (F) before next high water.	Speed of float. Float moving upstream F. Float moving down-stream E. (knots).	Distance from Rock Light. + Above, — Below. (thousands of ft.).	Total depth of water. (ft.).	Depth of sample. (ft.).	Concen-tration of suspended matter. (parts per 100,000).	Composition of suspended matter. Oxygen consumed (Adeney) (gm. oxygen per 100 gm. dry weight).
		hrs.min.						
28/2/36	27·2	F 5·20	—	+17·8	59	0	5·1	—
						10	8·1	—
Float Drift						20	9·8	—
		F 4·10	F 0·2	+18·5	—	0	5·6	—
						10	6·4	—
						20	7·2	—
		F 3·10	F 1·2	+24·3	—	0	5·3	—
						10	5·8	—
						20	5·5	—
		F 2·10	F 2·5	+39·1	—	0	131·7	—
						10	135·0	—
						20	127·9	—
		F 1·10	F 2·3	+53·8	—	0	53·8	—
						10	56·5	—
						20	60·6	—
		F 0·40	F 1·7	+59·3	—	0	56·3	—
						10	58·4	—
						20	56·0	—
		F 0·10	F 1·7	+66·4	—	0	34·0	—
						10	55·8	—
						20	72·5	—
		E 0·20	F 1·3	+69·9	—	0	14·7	—
						10	24·8	—
						20	76·0	—
		E 0·50	—	+72·0	—	0	13·2	—
						10	15·2	—
						20	20·3	—

TABLE 98—*Organic Carbon Content of Suspended Matter from the Mersey Estuary*

Sample No.	Concen-tration of suspended matter. (parts per 100,000).	Organic carbon. (per cent. of dry weight).	Sample No.	Concen-tration of suspended matter. (parts per 100,000).	Organic carbon. (per cent. of dry weight).	Sample No.	Concen-tration of suspended matter. (parts per 100,000).	Organic carbon. (per cent. of dry weight).
SM 2	9·7	4·40	SM 173	7·2	4·45	SM 192	2·6	9·85
3	0·8	5·00	174	4·3	6·45	193	3·2	8·75
4	1·7	4·43	175	5·0	6·20	194	3·1	9·90
5	22·1	3·72	176	4·2	6·40	195	3·4	7·70
6	4·4	2·00	177	5·3	6·05	196	2·1	10·75
7	13·2	3·40	178	4·2	6·45	197	3·3	9·25
8	17·1	3·04	179	9·6	4·45	198	4·3	7·60
9	17·9	3·50	180	11·0	4·30	199	2·9	9·25
10	6·1	3·86	181	7·2	4·55	200	6·5	5·20
11	11·6	2·63	182	16·7	4·15	201	8·2	4·95
12	3·2	4·93	183	16·0	4·05	202	9·9	4·45
13	3·3	3·29	184	11·5	4·45	203	15·3	4·25
14	14·2	2·56	185	4·2	6·20	204	9·3	4·60
88	13·8	3·65	186	15·3	4·15	205	10·5	4·35
89	28·8	3·43	187	9·8	4·65	206	29·4	3·75
92	27·0	3·37	188	3·6	7·50	207	3·2	14·60
170	11·6	4·20	189	4·8	6·20	208	9·2	4·45
171	11·1	4·15	190	21·3	3·90	209	16·3	4·00
172	17·5	4·20	191	5·5	6·00			

TABLE 99—*Erodibility of Mersey Muds*

Sample No.	Percentage of sample eroded in 10 mins.	Moisture (per cent.).	Percentage of dry weight.		
			Silica.	Organic carbon.	Loss on ignition.
S 193 ..	13·2	50·2	54·6	3·41	14·0
194 ..	6·4	45·5	56·2	3·45	12·7
195 ..	35·7	45·1	61·5	2·57	11·2
196 ..	78·6	60·0	55·1	3·13	13·7
197 ..	10·0	41·1	60·6	2·97	11·0
198 ..	22·1	53·9	53·2	3·41	14·6
199 ..	15·0	53·4	53·2	3·70	14·6
200 ..	22·5	46·9	59·9	2·81	11·8
201 ..	17·1	39·2	68·6	2·10	8·1
202 ..	26·8	46·2	60·2	2·59	11·3
203 ..	14·3	50·4	59·9	2·77	12·0
204 ..	7·1	55·3	52·3	3·87	14·7
205 ..	17·8	33·7	73·2	1·34	6·7
206 ..	18·6	58·6	51·8	3·55	15·1
207 ..	24·6	56·9	53·6	3·60	13·6
208 ..	58·9	58·1	54·5	3·14	12·7
209 ..	16·1	50·0	59·5	2·73	11·7
210 ..	33·9	62·8	50·7	3·67	15·6
211 ..	18·2	57·9	51·9	3·50	15·1
212 ..	10·4	41·5	52·5	2·06	10·7
213 ..	71·6	62·5	51·6	3·43	14·8
217 ..	18·2	52·0	59·9	3·00	11·5
218 ..	26·4	41·7	62·8	2·11	8·8
219 ..	17·1	39·8	68·4	1·79	8·5
220 ..	16·1	50·6	55·9	3·27	12·3
221 ..	16·1	55·4	55·6	3·72	13·6
222 ..	16·1	56·2	55·6	3·06	13·0
223 ..	25·7	35·8	74·2	1·46	6·7
224 ..	89·2	30·1	79·6	0·76	4·9
225 ..	92·8	38·7	76·0	1·44	6·3
226 ..	100	21·3	87·1	0·04	2·9
227 ..	33·2	40·3	69·3	1·83	8·9
228 ..	33·9	38·3	72·9	1·60	9·4
229 ..	62·5	38·3	71·7	1·56	9·0
230 ..	62·5	31·2	75·1	1·16	7·2
231 ..	58·9	35·3	68·5	1·22	7·7
232 ..	33·9	28·1	80·9	0·77	4·9
233 ..	100	21·5	85·0	0·15	3·5
234 ..	100	21·3	88·2	0·03	2·6
235 ..	6·1	44·3	55·1	—	—
236 ..	7·9	25·3	79·5	0·59	5·1
237 ..	5·7	45·2	56·5	2·76	13·0
355 ..	100	72·8	48·5	—	16·4
This and all subsequent samples dried for various periods in laboratory at air temperature.	92·2	71·3			
	93·8	69·7			
	58·4	66·6			
	38·8	65·3			
	24·7	61·3			
	0	40·3			
356 ..	100	70·1	50·1	—	16·3
	94·5	69·4			
	62·0	67·7			
	32·9	64·4			
	30·0	62·7			
	19·3	58·7			
	0	45·4			
357 ..	33·1	37·8	72·2	—	7·5
	25·0	34·8			
	17·0	31·4			
	6·5	27·0			
	7·3	25·8			
	3·6	18·5			
358 ..	40·2	44·3	65·6	—	11·0
	33·2	42·5			
	20·9	40·3			
	8·6	35·6			
	7·0	34·8			
	1·4	27·6			
S 359 ..	17·3	47·4	52·3	2·64	14·9
	12·1	42·5			
	0	33·9			
360 ..	11·8	48·9	64·8	2·95	14·6
	4·8	44·7			
	0	35·2			
361 ..	34·8	53·2	59·2	2·62	11·7
	23·9	49·2			
	7·6	40·1			
362 ..	23·2	53·5	58·7	2·73	12·9
	17·8	48·6			
	2·3	41·0			
363 ..	50·0	46·2	67·7	1·74	9·9
	33·0	41·8			
	8·1	32·6			
364 ..	66·0	66·2	64·8	3·14	13·5
	49·4	62·6			
	11·4	53·7			
365 ..	98·6	54·5	55·0	2·39	9·3
	42·7	51·7			
	12·1	40·3			
	7·5	38·3			
366 ..	40·6	39·8	69·8	2·50	9·2
	15·7	34·5			
	9·6	27·4			
	7·2	26·4			
367 ..	100	50·0	72·8	2·21	8·5
	92·9	44·3			
	35·0	40·8			
	21·8	37·6			
	9·7	31·1			
368 ..	38·6	64·4	59·9	3·93	16·1
	23·6	62·0			
	16·4	58·7			
	5·7	56·4			
369 ..	80·7	68·9	50·1	3·47	16·1
	58·9	66·2			
	33·6	62·6			
	11·4	53·7			
370 ..	41·1	50·2	59·8	2·05	10·9
	22·5	46·1			
	15·7	43·5			
	14·6	41·4			
	17·1	38·8			
371 ..	52·5	54·1	54·3	2·75	13·6
	27·5	49·6			
	16·4	47·3			
	11·8	45·3			
	7·2	42·5			
372 ..	10·0	43·7	62·3	2·81	11·3
	7·1	40·9			
	6·1	39·0			
373 ..	10·9	38·0	65·9	2·00	8·9
	6·1	34·6			
	5·4	33·0			
374 ..	19·6	60·3	50·7	3·55	15·4
	19·3	57·9			
	10·7	56·7			
	16·1	55·1			
	10·7	52·9			

TABLE 100—*Erodibility of Muds from the Estuaries of Rivers in Suffolk and Essex and of the Wye and Severn, Monmouthshire*

Samples Dried for Different Periods by Exposure at Room Temperature

Sample No.	Percentage of sample eroded in 10 min.	Moisture (per cent.).	Percentage of dry weight. Silica.	Percentage of dry weight. Organic carbon.	Percentage of dry weight. Loss on ignition.
Deben 1	33·9	69 6	50·0	4·29	19·1
	16·8	65·7			
	15·7	63·3			
	11·8	61·1			
Deben 2	25·0	61·9	54·9	3·79	15·6
	22·2	58·0			
	15·0	55·9			
	10·7	54·3			
Deben 3	23·2	62·4	52·1	5·10	18·4
	20·4	57·9			
	11·1	55·7			
	10·0	52·5			
Deben 4	15·3	58·2	52·4	2·00	12·7
	11·8	54·5			
	15·0	52·8			
	5·4	50·6			
Deben 5	23·2	60·4	53·4	2·30	12·4
	16·4	55·1			
	17·9	55·0			
	10·0	52·2			
Deben 6	22·8	61·1	53·2	2·17	13·4
	16·1	58·0			
	13·6	55·4			
	5·4	52·6			
Deben 7	25·0	55·6	56·0	1·69	12·0
	19·0	52·4			
	18·9	49·6			
	9·3	46·7			
Deben 8	18·6	57·5	50·6	2·21	13·3
	10·0	54·3			
	4·3	51·8			
Stour 1	29·6	71·7	54·4	4·37	16·0
	16·1	69·5			
	14·7	68·0			
	11·4	66·8			
Stour 2	46·4	75·1	49·7	5·37	17·7
	21·1	73·1			
	23·6	72·1			
	20·7	71·5			
Stour 3	39·3	56·6	72·7	1·98	8·2
	18·6	53·0			
	11·4	51·1			
	8·2	50·2			
Stour 4	32·9	71·1	53·7	3·98	14·2
	17·2	68·0			
	11·1	68·1			
	19·3	65·0			
Blackwater 1	20·0	48·9	75·3	1·95	7·2
	22·9	45·4			
	12·1	43·4			
	5·7	39·1			
Hamford 1	88·3	71·0	51·2	1·79	13·8
	58·5	70·8			
	52·1	69·4			
	25·7	68·0			

Sample No.	Percentage of sample eroded in 10 min.	Moisture (per cent.).	Percentage of dry weight. Silica.	Percentage of dry weight. Organic carbon.	Percentage of dry weight. Loss on ignition.
Hamford 2	58·2	72·4	48·5	3·45	14·8
	30·7	72·5			
	44·7	70·7			
	24·3	69·5			
Hamford 3	29·0	66·7	57·3	3·01	13·2
	34·3	66·4			
	30·4	65·2			
	18·6	63·0			
Hamford 4	34·6	65·6	56·9	2·71	13·2
	33·2	65·0			
	24·3	64·0			
	18·9	61·9			
Roach 1	25·4	42·4	68·7	1·07	8·9
	19·3	41·0			
	12·9	36·0			
	6·1	34·1			
Roach 2	18·2	35·9	72·3	0·73	7·3
	18·9	33·8			
	7·9	28·9			
	0	25·7			
Colne 1	57·8	57·2	63·5	1·80	10·2
	35·0	57·5			
	21·4	54·5			
	18·2	52·5			
Colne 2	22·8	54·0	59·8	1·91	11·7
	27·1	57·2			
	16·1	54·0			
	17·9	52·1			
Colne 3	26·4	52·5	64·9	1·42	9·1
	20·4	51·5			
	12·5	47·2			
	6·8	45·0			
Colne 4	20·0	51·0	64·1	1·44	9·3
	18·9	50·6			
	11·8	46·2			
	9·3	44·2			
Orwell 1	26·8	21·3	92·0	0·29	2·3
	32·2	22·2			
	29·0	20·8			
Orwell 2	60·4	59·0	62·9	2·10	11·2
	34·0	58·8			
	16·4	55·0			
	13·9	53·1			
Orwell 3	23·6	44·5	78·7	1·54	6·8
	19·7	44·2			
	10·7	40·4			
	9·3	36·7			
Mersea 1	16·4	43·4	72·3	1·14	6·8
	15·4	42·1			
	14·3	38·7			
	5·4	33·2			
Mersea 2	14·7	50·1	64·1	1·40	9·4
	12·5	48·4			
	6·4	45·4			

TABLE 100—*continued*

Sample No.	Percentage of sample eroded in 10 min.	Moisture (per cent.).	Percentage of dry weight. Silica.	Organic carbon.	Loss on ignition.
Mersea 3	11·4 7·9 10·0 3·6	36·4 34·0 30·6 27·4	76·1	0·90	5·4
Mersea 4	11·1 7·9 4·6	39·0 35·2 33·5	73·3	0·89	6·5
Mersea 5	4·3 3·6 0	43·0 40·5 39·8	67·0	1·28	7·8
Mersea 6	25·0 15·7 11·4 10·0	61·7 59·4 57·3 54·4	56·3	1·66	12·1
Mersea 7	34·3 23·9 16·4 10·0	60·5 58·0 55·8 53·0	60·3	1·62	10·5
Mersea 8	16·4 14·3 4·6	63·5 61·5 59·2	51·3	2·16	13·5
Crouch 1	25·4 14·3 9·3 6·4	47·2 44·2 42·1 39·6	64·9	1·27	9·2
Crouch 2	22·9 13·2 10·0 8·2	41·9 39·3 37·7 37·0	70·2	0·98	7·9
Crouch 3	10·7 8·6 3·2	58·8 55·8 54·1	55·6	2·82	12·2
Crouch 4	11·4 10·7 6·4 4·3	60·1 57·3 54·7 53·8	56·0	2·46	10·8
Crouch 5	13·9 5·4 0	47·1 44·6 42·2	58·6	1·10	10·9
Crouch 6	14·3 10·0 3·6	40·8 37·5 33·8	66·3	0·91	9·4
Severn 2	26·1 21·4 25·0 14·3 8·9 7·2	51·1 51·1 48·5 46·8 45·6 42·0	50·8	4·11	16·5
Severn 4	33·9 25·7 25·0 22·5 10·7	48·4 45·5 43·8 43·6 41·1	52·2	5·28	16·8
Wye 2	22·5 18·6 13·6 9·3 9·3 7·9	47·3 47·3 45·5 43·3 42·6 39·3	53·1	4·03	15·0
Wye 3	56·4 37·1 28·6 34·6 23·6 12·1	50·8 50·8 47·8 45·6 44·0 40·1	53·1	4·67	15·7
Wye 4	62·9 38·6 59·0 34·6 34·6 30·7 25·7 19·7 5·0	46·5 46·5 46·5 44·3 44·3 42·7 41·3 38·4 34·6	55·1	4·79	14·5
Wye 6	26·8 26·8 22·1 17·1 14·3 12·1 1·8	42·7 42·7 40·6 38·9 37·7 35·0 31·9	57·1	3·94	14·5

TABLE 101—*Composition and Erodibility of Mersey Muds and Suspended Matter stirred with Different Concentrations of Sewage in Saline Water and settled*

Sediment Dried for Different Periods at Room Temperature

Sample No.	Treatment.	Concentration of sewage (per cent.).	Organic carbon (per cent. of dry weight of sediment).	Silica (per cent. of dry weight of sediment).	Percentage of sediment eroded in 10 min.	Moisture (per cent.).
T 96 (Suspended Matter SM 76 in Estuary water).	Stirred 7 days	0	4·25	48·5	64·3	70·4
					27·9	64·0
					19·3	61·5
					10·7	57·8
					8·9	54·5
T 97 as T 96 ..	,,	0·25 (settled sewage)	4·60		100	73·9
					34·6	69·9
					24·7	68·6
					34·7	66·6
					23·2	65·0
					19·6	60·9
					6·4	52·6
T 98 as T 96 ..	,,	0·5 ,,	4·85		72·5	70·6
					43·9	71·0
					35·0	70·5
					38·2	70·0
					27·2	66·3
					25·7	66·0
					19·7	62·3
					19·3	59·2
T 99 as T 96 ..	,,	1·0 ,,	4·90		92·8	76·0
					35·7	72·8
					63·2	72·1
					53·6	71·7
					32·2	70·8
					27·5	67·9
					12·5	65·7
					15·4	63·7
					2·5	54·4

Sample No.	Treatment.	Concentration of sewage (per cent.).	Organic carbon (per cent. of dry weight of sediment).	Silica (per cent. of dry weight of sediment).	Percentage of sediment eroded in 10 min.	Moisture (per cent.).
T 100 as T 96	Stirred 7 days	1·96 (settled sewage)	6·10		100	79·4
					100	77·1
					62·2	77·0
					62·5	76·3
					45·4	75·6
					42·8	73·9
					36·4	71·0
					35·4	72·0
					19·3	69·0
					18·9	64·4
T 101 as T 96	,,	4·76 ,,	7·88		100	82·9
					100	81·5
					100	81·5
					100	80·5
					100	80·3
					62·5	79·7
					100	78·2
					58·6	76·8
					37·2	77·0
					28·2	76·2
					36·5	75·0
T 102 (Suspended matter SM 80 in Estuary water).	Stirred 12½ days	0	4·23	39·4	55·3	78·3
					34·6	75·7
					27·2	74·7
					39·6	74·9
					24·3	73·5
					22·9	72·1
					12·5	67·3

TABLE 101—*continued*

Sample No.	Treatment.	Concentration of sewage (per cent.).	Organic carbon (per cent. of dry weight of sediment).	Silica (per cent. of dry weight of sediment).	Percentage of sediment eroded in 10 min.	Moisture (per cent.).
T 103 as T 102	Stirred 12½ days	0·25	4·89		100	80·2
					60·0	77·7
					35·7	76·9
					34·6	76·4
					31·4	75·4
					30·8	74·1
					15·0	70·0
T 104 as T 102	,,	0·5	5·67		60·7	80·8
					44·6	79·0
					50·7	78·0
					46·5	76·8
					32·5	76·1
					32·2	75·0
					22·5	70·2
T 105 as T 102	,,	1·0	5·85		57·1	78·7
					30·4	75·2
					61·7	74·0
					23·2	73·5
					24·3	70·3
T 106 as T 102	,,	2·0	6·47		61·4	80·1
					46·5	78·6
					61·7	78·0
					51·8	77·3
					31·4	76·4
					37·2	75·6
					31·1	71·0
T 107 as T 102	,,	5·0	9·04		100	79·4
					38·2	77·6
					27·5	76·5
					31·4	75·6
					26·8	74·7
					27·5	71·3

Sample No.	Treatment.	Concentration of sewage (per cent.).	Organic carbon (per cent. of dry weight of sediment).	Silica (per cent. of dry weight of sediment).	Percentage of sediment eroded in 10 min.	Moisture (per cent.).
T 150–152 (Mersey Mud S 449 in Estuary water SM 137).	Stirred 10 days	0	—	—	89·3	69·1
					87·7	67·6
					61·8	65·5
					50·8	65·2
					37·1	64·2
					27·4	62·8
					30·3	60·0
					22·7	57·6
					13·0	53·7
					14·7	55·5
					13·3	52·3
					0	43·7
T 153–155 as T 150–152.	,,	5·0 (settled)	—		84·7	70·6
					89·0	69·8
					69·8	67·9
					53·4	66·6
					44·6	65·2
					31·7	62·5
					25·7	59·7
					16·3	55·2
					14·0	54·7
					7·9	51·5
					5·4	47·1
T 126 (Estuary water SM 95).	Stirred 6 days	0	4·68	—	28·6	71·8
		,,	,,		11·1	62·4
T 127 as T 126	,,	0·25	4·87		27·5	71·7
		,,	,,		12·9	63·6
		,,	,,		17·1	57·5
T 128 ,,	,,	0·5	5·24		52·5	74·5
		,,	,,		24·0	69·4
		,,	,,		17·8	66·1

T 129 as T. 126	Stirred 6 days	1·0	5·39		31·1	73·9
		,,	,,		21·4	69·4
		,,	,,		16·8	65·7
T 130 ,,	,,	2·0	5·57		100	79·1
		,,	,,		31·1	76·5
		,,	,,		21·4	72·4
T 131 ,,	,,	5·0	6·62		100	80·1
		,,	,,		28·6	76·9
		,,	,,		30·4	75·1
T 143 (Estuary water SM 120).	Stirred 4 days	0	2·36		34·3	66·5
		,,	,,		20·7	64·1
		,,	,,		11·4	60·8
		,,	,,		19·7	55·3
		,,	,,		5·0	51·8
T 142 as T 143	,,	0·25	2·50		100	68·9
		,,	,,		33·4	65·7
		,,	,,		13·9	58·9
		,,	,,		4·3	53·0
T 141 as T 143	,,	0·5	2·96	—	100	75·0
		,,	,,		100	73·0
		,,	,,		100	71·4
		,,	,,		28·6	66·0
		,,	,,		14·3	55·1
		,,	,,		5·0	51·2
T 140 as T 143	,,	1·0	2·98		100	70·5
		,,	,,		66·9	68·6
		,,	,,		25·4	67·0
		,,	,,		16·8	63·4
		,,	,,		21·8	61·1
		,,	,,		15·0	59·4
		,,	,,		14·3	56·8
		,,	,,		6·4	53·9
T 139 as T 143	,,	2·0	3·25		100	71·7
		,,	,,		35·0	69·3
		,,	,,		34·0	67·7
		,,	,,		27·2	64·4
		,,	,,		14·7	62·8
		,,	,,		11·4	61·4
		,,	,,		19·7	58·0
		,,	,,		10·4	56·3

T 138 as T 143	Stirred 4 days	5·0	3·54		17·9	71·2
		,,	,,		21·1	69·0
		,,	,,		26·8	67·2
		,,	,,		13·6	63·4
		,,	,,		15·4	62·2
		,,	,,		7·9	55·6
T 144 (Estuary water SM 121 containing Mersey mud S 448).	Stirred 51 days	0	—	—	62·5	73·7
		,,			78·2	70·5
		,,			81·9	70·5
		,,			35·4	70·5
		,,			44·6	69·7
		,,			22·1	64·7
		,,			18·2	62·4
		,,			10·4	58·6
T 145 as T 144	,,	3·0	—		24·3	73·4
		,,			44·6	73·4
		,,			25·4	71·7
		,,			21·4	67·9
		,,			21·1	67·4
		,,			15·4	65·5
		,,			12·9	64·3
		,,			17·1	63·1
		,,			12·5	63·1
		,,			6·1	55·2
T 146 as T 144	,,	6·0	—		61·5	78·2
		,,			60·4	76·6
		,,			59·3	76·2
		,,			62·5	75·8
		,,			44·3	75·0
		,,			25·4	73·1
		,,			24·3	71·0
		,,			18·6	69·0
		,,			10·0	64·2
T 147 as T 144	,,	15·0	—		53·6	83·0
		,,			42·9	82·8
		,,			50·0	81·7
		,,			42·9	80·6
		,,			32·2	80·0
		,,			26·1	77·5
		,,			17·1	74·0
		,,			12·4	71·8
		,,			10·0	69·9

TABLE 101—*continued*

Sample No.	Treatment.	Concentration of sewage (per cent.).	Organic carbon (per cent. of dry weight of sediment).	Silica (per cent. of dry weight of sediment).	Percentage of sediment eroded in 10 min.	Moisture (per cent.).	Sample No.	Treatment.	Concentration of sewage (per cent.).	Organic carbon (per cent. of dry weight of sediment).	Silica (per cent. of dry weight of sediment).	Percentage of sediment eroded in 10 min.	Moisture (per cent.).
T 148 (Estuary water SM 123).	Stirred 38 days	0	—	—	37·5	70·0	T 149 as T 148	Stirred 38 days	2·8	—		18·9	66·0
		,,			36·8	69·4			,,			23·2	66·0
		,,			26·1	66·8			,,			17·5	64·0
		,,			33·6	66·8			,,			11·4	59·6
		,,			29·3	64·8			,,			14·3	59·5
		,,			21·1	64·7			,,			12·1	57·7
		,,			16·1	61·6			,,			10·4	57·0
		,,			9·3	59·8			,,			12·1	55·5
		,,			9·7	58·9			,,			0	48·8
		,,			8·9	56·8							

TABLE 102—*Rate of Drying of Mersey Mud, previously settled from Saline Water with and without Addition of Unsettled Sewage*

Experiment No.	Sample.	Unsettled sewage added (per cent.).	Method of drying.	Organic carbon (per cent. of dry weight).	Period of drying.	Moisture (per cent.). A	B	C	Mean
1 (A, B, C)	Mersey mud S 462 in Estuary water SM 158. Concn. 30 parts per 100,000. Stirred 3 days.	0	Soxhlet thimbles.	3·9	0	81	81	81	81
					1½ hrs.	50	52	52	51
					3 ,,	48	50	49	49
					6 ,,	45	47	46	46
					23½ ,,	30	32	32	31
					30 ,,	23	25	26	25
					48 ,,	12	13	14	13
					54 ,,	8	10	11	10
					72 ,,	3	4	4	4
					78 ,,	2	1	2	2
2 (B, C)	As experiment 1 ..	1	Soxhlet thimbles.	4·2	0	—	81	81	81
					1½ hrs.	—	52	50	51
					3 ,,	—	50	48	49
					6 ,,	—	47	45	46
					23½ ,,	—	32	31	32
					30 ,,	—	25	24	25
					48 ,,	—	13	12	13
					54 ,,	—	10	9	10
					72 ,,	—	3	3	3
					78 ,,	—	1	2	2
3 (A, B, C)	As experiment 1 ..	5	Soxhlet thimbles.	4·9	0	81	81	81	81
					1½ hrs.	48	48	48	48
					3 ,,	46	46	46	46
					6 ,,	43	43	43	43
					23½ ,,	29	28	29	29
					30 ,,	23	22	23	23
					48 ,,	11	12	11	11
					54 ,,	7	7	6	7
					72 ,,	1	1	1	1
					78 ,,	0	0	0	0
6 (A, B, C)	Mersey mud S 462. 1 kg. wet mud in 60 litres sea water. 30 litres mud suspension with (6) 30 litres tap water (7) 30 litres sewage. Settled 2 days. Sludge filtered on Buchner funnel and transferred to crucibles.	0	In crucibles.	—	0	62	62	62	62
					7 hrs.	59	59	59	59
					24 ,,	55	56	55	55
					31 ,,	54	53	53	53
					48 ,,	50	50	50	50
					96 ,,	41	41	39	40
					144 ,,	36	35	32	34
					192 ,,	27	25	23	25
					240 ,,	17	19	15	17
7 (A, B, C)	As experiment 6 ..	Added	In crucibles.	—	0	65	63	64	64
					7 hrs.	61	61	61	61
					24 ,,	58	57	57	57
					31 ,,	56	55	55	55
					48 ,,	52	51	51	51
					96 ,,	42	41	41	41
					144 ,,	33	35	34	34
					192 ,,	25	25	25	25
					240 ,,	15	16	16	16
8 (A, B, C)	2 kg. Mersey mud S 462 in 80 litres sea water. 40 litres of suspension mixed with (8) 40 litres tap water (9) 40 litres sewage. Settled overnight. Sludge stood a further 3 days in a beaker, and water then removed. Transferred to Petri dishes.	0	In Petri dishes.	4·1	0	73	73	73	73
					1 day	67	68	68	68
					2 days	61	62	61	61
					3 ,,	55	56	55	55
					4 ,,	48	49	48	48
					5 ,,	40	42	40	41
					7 ,,	32	33	32	32
					9 ,,	23	25	24	24

TABLE 102—*continued*

Experiment No.	Sample.	Unsettled sewage added (per cent.).	Method of drying.	Organic carbon (per cent. of dry weight).	Period of drying.	Moisture (per cent.). A	B	C	Mean
9 (A, B, C)	As experiment 8 ..	Added	In Petri dishes.	6·8	0	73	73	73	73
					1 day	68	67	68	68
					2 days	61	62	61	61
					3 "	54	56	54	55
					4 "	47	49	47	48
					5 "	40	40	39	40
					7 "	32	33	31	32
					9 "	23	24	23	23
						Moisture lost (per cent. of original wet weight).			
4 (A, B, C)	Mersey mud S 462 in sea water, not stirred. 10 litres mud suspension added to (4) 10 litres tap water. (5) 10 litres unsettled sewage. Mixture settled 3 hrs. Water poured off. Sludge stood overnight, water poured off and mud put into Soxhlet thimbles.	0	Soxhlet thimbles.	3·9	0	0	0	0	0
					1½ hrs.	28	26	26	27
					3 "	32	30	30	31
					6 "	35	33	33	34
					24 "	52	51	50	51
					30 "	59	57	56	57
					48 "	72	71	70	71
5 (A, B, C)	As experiment 4 ..	Added	Soxhlet thimbles.	5·0	0	0	0	0	0
					1½ hrs.	27	26	24	26
					3 "	31	30	28	30
					6 "	35	34	32	34
					24 "	52	51	50	51
					30 "	58	57	56	57
					48 "	72	72	71	72

TABLE 103—*Erodibility of Mersey and Other Muds allowed to settle from Suspension in Water of Salinity 25 gm. per 1,000 gm. with and without Addition of Sewage*

Concentration of Mud 30 Parts per 100,000 unless otherwise stated

Experiment No.	Mud sample.	Concentration of unsettled sewage (per cent.).	Time after making up suspension.	Speed of stirring (Speed No.).	Speed (revs. per min.).	Time of stirring (min. sec.)	Remarks.
E. 2	Mersey S 530	0	19 hrs.	3 4	24·0 26·6	5 00 4 05	Not eroded. All ,,
				4 5	26·6 30·8	5 00 1 45	Not ,, All ,,
				4	26·6	1 40	,, ,,
				4	26·6	4 55	,, ,,
				4 5	26·6 30·8	5 00 0 10	Not ,, All ,,
				4	26·6	5 00	,, ,,
		5·0	19 hrs.	4	26·6	0 30	,, ,,
				4	26·6	0 40	,, ,,
				4	26·6	1 05	,, ,,
				4	26·6	0 35	,, ,,
				4	26·6	2 30	,, ,,
				4	26·6	0 25	,, ,,
E. 3	Mersey S 530	0	20 hrs.	4 5	26·6 30·8	5 00 0 36	Not ,, All ,,
				4 5 6 7	26·6 30·8 33·3 37·5	5 00 5 00 5 00 0 14	Not ,, ,, ,, ,, ,, All ,,
				4 5 6	26·6 30·8 33·3	5 00 5 00 0 35	Not ,, ,, ,, All ,,
				4 5 6	26·6 30·8 33·3	5 00 5 00 0 40	Not ,, ,, ,, All ,,
				4	26·6	1 40	,, ,,
				4 5	26·6 30·8	5 00 2 17	Not ,, All ,,
		1·0	20 hrs.	4	26·6	0 33	,, ,,
				4	26·6	0 45	,, ,,
				4 5	26·6 30·8	5 00 0 59	Not ,, All ,,
				4 5 6	26·6 30·8 33·3	5 00 5 00 0 20	Not ,, ,, ,, All ,,
				4 5 6 7 8	26·6 30·8 33·3 37·5 39·4	5 00 5 00 5 00 5 00 5 00	Not ,, ,, ,, ,, ,, ,, ,, ,, ,,
				4	26·6	1 50	All ,,

TABLE 103—*continued*

Experiment No.	Mud sample.	Concentration of unsettled sewage (per cent.).	Time after making up suspension.	Speed of stirring (Speed No.).	Speed (revs. per min.).	Time of stirring (min. sec.)	Remarks.
E. 4	Mersey S 530	0	20 hrs.	4	26·6	5 00	Not eroded
				5	30·8	1 06	All ,,
				4	26·6	5 00	Not ,,
				5	30·8	2 32	All ,,
				4	26·6	5 00	Not ,,
				5	30·8	0 37	All ,,
				4	26·6	5 00	Not ,,
				5	30·8	5 00	,, ,,
				6	33·3	5 00	,, ,,
				7	37·5	5 00	,, ,,
				8	39·4	1 40	All ,,
				4	26·6	5 00	Not ,,
				5	30·8	5 00	,, ,,
				6	33·3	5 00	,, ,,
				7	37·5	5 00	,, ,,
				8	39·4	5 00	,, ,,
				4	26·6	5 00	Not ,,
				5	30·8	5 00	,, ,,
				6	33·3	5 00	,, ,,
				7	37·5	0 42	All ,,
		0·25	20 hrs.	4	26·6	5 00	Not ,,
				5	30·8	5 00	,, ,,
				6	33·3	5 00	,, ,,
				7	37·5	5 00	,, ,,
				8	39·4	5 00	,, ,,
				4	26·6	0 25	All ,,
				4	26·6	1 25	,, ,,
				4	26·6	5 00	Not ,,
				5	30·8	5 00	,, ,,
				6	33·3	0 11	All ,,
				4	26·6	5 00	Not ,,
				5	30·8	0 18	All ,,
		1·0	20 hrs.	4	26·6	0 18	,, ,,
				4	26·6	0 22	,, ,,
				4	26·6	0 25	,, ,,
				4	26·6	0 28	,, ,,
				4	26·6	0 20	,, ,,
				4	26·6	0 23	,, ,,
		5·0	20 hrs.	4	26·6	0 26	,, ,,
				4	26·6	0 21	,, ,,
				4	26·6	0 19	,, ,,
				4	26·6	0 25	,, ,,
				4	26·6	0 22	,, ,,
				4	26·6	0 18	,, ,,
E. 5	Mersey S 530	0	4 days	6	33·3	5 00	Not ,,
				7	37·5	2 51	All ,,
				6	33·3	5 00	Not ,,
				7	37·5	5 00	,, ,,
				8	39·4	5 00	,, ,,
				9	41·0	5 00	,, ,,
				10	44·5	5 00	,, ,,

TABLE 103—*continued*

Experiment No.	Mud sample.	Concentration of unsettled sewage (per cent.).	Time after making up suspension.	Speed of stirring (Speed No.).	Speed (revs. per min.).	Time of stirring (min. sec.)	Remarks.
E. 5—*contd.*	Mersey S 530	0	4 days	6	33·3	0 29	All eroded
				6	33·3	5 00	Not ,,
				7	37·5	5 00	,, ,,
				8	39·4	2 41	All ,,
				6	33·3	5 00	Not ,,
				7	37·5	5 00	,, ,,
				8	39·4	5 00	,, ,,
				9	41·0	2 48	All ,,
				6	33·3	5 00	Not ,,
				7	37·5	5 00	,, ,,
				8	39·4	5 00	,, ,,
				9	41·0	5 00	,, ,,
				10	44·5	1 06	All ,,
		5·0	4 days	6	33·3	5 00	Not ,,
				7	37·5	5 00	,, ,,
				8	39·4	5 00	,, ,,
				9	41·0	5 00	,, ,,
				10	44·5	5 00	,, ,,
				6	33·3	5 00	,, ,,
				7	37·5	5 00	,, ,,
				8	39·4	5 00	,, ,,
				9	41·0	2 57	All ,,
				6	33·3	5 00	Not ,,
				7	37·5	5 00	,, ,,
				8	39·5	5 00	,, ,,
				9	41·0	5 00	,, ,,
				10	44·5	5 00	,, ,,
				6	33·3	5 00	,, ,,
				7	37·5	5 00	,, ,,
				8	39·5	5 00	,, ,,
				9	41·0	0 44	All ,,
				6	33·3	5 00	Not ,,
				7	37·5	0 15	All ,,
				6	33·3	5 00	Not ,,
				7	37·5	5 00	,, ,,
				8	39·5	0 28	All ,,
E. 6	Mersey S 527	0	22½ hrs.	6	33·3	0 48	,, ,,
	Mersey S 524	0	22½ hrs.	5	30·8	0 45	,, ,,
	Mersey S 528	0	22½ hrs.	4	26·6	2 34	,, ,,
	Mersey S 525	0	22½ hrs.	3	24·0	4 27	,, ,,
	Mersey S 529	0	22½ hrs.	3	24·0	0 28	,, ,,
	Mersey S 526	0	22½ hrs.	2	20·0	5 00	Not ,,
				3	24·0	3 20	All ,,
	Stour 11	0	22½ hrs.	2	20·0	5 00	Not ,,
				3	24·0	5 00	,, ,,
				4	26·6	5 00	,, ,,
				5	30·8	0 42	All ,,
	Crouch 12	0	22½ hrs.	3	24·0	5 00	Not ,,
				4	26·6	5 00	,, ,,
				5	30·8	1 55	All ,,

TABLE 103—*continued*

Experiment No.	Mud sample.	Concentration of unsettled sewage (per cent.).	Time after making up suspension.	Speed of stirring (Speed No.).	Speed (revs. per min.).	Time of stirring (min. sec.)	Remarks.
E. 6—*contd.*	Blackwater 6	0	22½ hrs.	3	24·0	5 00	Not eroded
				4	26·6	5 00	,, ,,
				5	30·8	2 30	All ,,
	Blackwater 7	0	22½ hrs.	3	24·0	5 00	Not ,,
				4	26·6	5 00	,, ,,
				5	30·8	0 34	All ,,
	Hamford 11	0	22½ hrs.	3	24·0	5 00	Not ,,
				4	26·6	1 09	All ,,
	Roach 3	0	22½ hrs.	3	24·0	5 00	Not ,,
				4	26·6	5 00	,, ,,
				5	30·8	2 02	All ,,
E. 7	Mersey S 530	0	3 days	6	33·3	1 35	,, ,,
				5	30·8	2 10	,, ,,
				4	26·6	5 00	Not ,,
				5	30·8	2 45	All ,,
				4	26·6	5 00	Not ,,
				5	30·8	5 00	,, ,,
				6	33·3	5 00	,, ,,
				7	37·5	5 00	,, ,,
				8	39·4	5 00	,, ,,
				9	41·0	5 00	,, ,,
				10	44·5	5 00	,, ,,
				4	26·6	5 00	,, ,,
				5	30·8	3 42	All ,,
				4	26·6	5 00	Not ,,
				5	30·8	5 00	,, ,,
				6	33·3	5 00	,, ,,
				7	37·5	1 05	All ,,
		5·0	3 days	4	26·6	5 00	Not ,,
				5	30·8	0 35	All ,,
				4	26·6	4 56	,, ,,
				4	26·6	4 30	,, ,,
				4	26·6	5 00	,, ,,
				4	26·6	2 55	,, ,,
				4	26·6	5 00	Not ,,
				5	30·8	5 00	,, ,,
				6	33·3	3 25	All ,,
E. 8	Crouch 11	0	17½ hrs.	3	24·0	1 02	,, ,,
	Deben 21	0	17½ hrs.	3	24·0	5 00	Not ,,
				4	26·6	4 08	All ,,
	Stour 12	0	17½ hrs.	3	24·0	5 00	Not ,,
				4	26·6	1 02	All ,,
	Hamford 12	0	17½ hrs.	3	24·0	5 00	Not ,,
				4	26·6	5 00	,, ,,
				5	30·8	0 55	All ,,
	Mersey S 524	0	17½ hrs.	3	24·0	0 55	,, ,,
	Mersey S 525	0	17½ hrs.	3	24·0	5 00	Not ,,
				4	26·6	2 20	All ,,

TABLE 103—*continued*

Experiment No.	Mud sample.	Concentration of unsettled sewage (per cent.).	Time after making up suspension.	Speed of stirring (Speed No.).	Speed (revs. per min.).	Time of stirring (min. sec.)	Remarks.
E 8—*contd.*	Mersey S 527	0	17½ hrs.	3	24·0	1 49	All eroded
	Mersey S 528	0	17½ hrs.	3	24·0	5 00	Not ,,
				4	26·6	3 25	All ,,
	Mersey S 529	0	17½ hrs.	3	24·0	0 46	All ,,
E. 11	Severn Estuary suspended matter SM 1	0 (Concn. of mud 94·5 pts. per 100,000)	20½ hrs.	3	24·0	5 00	Not ,,
				4	26·6	1 00	All ,,
			20½ hrs.	3	24·0	2 20	All ,,
		0 (Concn. of mud 30·0 pts. per 100,000)	20½ hrs.	2	20·0	5 00	Not ,,
				3	24·0	5 00	,, ,,
				4	26·6	1 45	All ,,
				3	24·0	5 00	Not ,,
				4	26·6	3 15	All ,,
	Severn Estuary suspended matter S.M.2	0 (Concn. of mud 158·6 pts. per 100,000)	20½ hrs.	3	24·0	5 00	Not ,,
				4	26·6	5 00	,, ,,
				5	30·8	5 00	,, ,,
				6	33·3	5 00	,, ,,
				7	37·5	5 00	,, ,,
				8	39·4	5 00	,, ,,
				9	41·0	1 35	All ,,
		0 (Concn. of mud 30·0 pts. per 100,000)	20½ hrs.	3	24·0	5 00	Not ,,
				4	26·6	5 00	,, ,,
				5	30·8	3 10	All ,,
				4	26·6	5 00	Not ,,
				5	30·8	1 48	All ,,
E. 13	Mersey S 530	0	9 days	6	33·3	5 00	Not ,,
				7	37·5	5 00	,, ,,
				8	39·4	5 00	,, ,,
				9	41·0	0 06	All ,,
				6	33·3	5 00	Not ,,
				7	37·5	3 40	All ,,
				6	33·3	5 00	Not ,,
				7	37·5	5 00	,, ,,
				8	39·4	5 00	,, ,,
				9	41·0	5 00	,, ,,
				10	44·5	5 00	,, ,,
				6	33·3	5 00	Not ,,
				7	37·5	1 08	All ,,
				6	33·3	5 00	Not ,,
				7	37·5	5 00	,, ,,
				8	39·4	5 00	,, ,,
				9	41·0	2 53	All ,,
				6	33·3	5 00	Not ,,
				7	37·5	1 05	All ,,
		5·0	9 days	6	33·3	5 00	Not ,,
				7	37·5	5 00	,, ,,
				8	39·4	2 35	All ,,
				6	33·3	5 00	Not ,,
				7	37·5	5 00	,, ,,
				8	39·4	5 00	,, ,,
				9	41·0	1 15	All ,,

TABLE 103—*continued*

Experiment No.	Mud sample.	Concentration of unsettled sewage (per cent.).	Time after making up suspension.	Speed of stirring (Speed No.).	Speed (revs. per min.).	Time of stirring (min. sec.)	Remarks.
E 13—*contd.*	Mersey S 530	5·0	9 days	6	33·3	5 00	Not eroded
				7	37·5	5 00	,, ,,
				8	39·4	5 00	,, ,,
				9	41·0	2 52	All ,,
				6	33·3	5 00	Not ,,
				7	37·5	5 00	,, ,,
				8	39·4	4 45	All ,,
				6	33·3	5 00	Not ,,
				7	37·5	5 00	,, ,,
				8	39·4	0 50	All ,,
				6	33·3	5 00	Not ,,
				7	37·5	5 00	,, ,,
				8	39·4	1 22	All ,,

TABLE 107—*Weight of Material dredged by the Mersey Docks and Harbour Board during the Period* 1890 *to* 1935

(Data supplied by the Mersey Docks and Harbour Board)

Vessel.	Dredging capacity (tons per load).	Date when working was begun.	Date when working was finished.	Weight of material dredged (tons).		
				Bar and Shoals (Liverpool Bay).	Upper Estuary, Brunswick Dock Entrance and other positions.	Total.
"No. 7" ..	500	Sep. 1890	Feb. 1907	2,050,860	7,412,080	9,462,940
"No. 5" ..	400	Apl. 1891	Oct. 1919	2,220,550	9,139,390	11,359,940
"Brancker" ..	2,900	Jly. 1893	Nov. 1928	106,837,100	16,719,850	123,556,950
"G.B. Crow" ..	3,000	Nov. 1895	Dec. 1932	102,808,840	31,023,575	133,832,415
"Laga" (hired) ..	650	Oct. 1901	Jun. 1902	625,600	13,000	638,600
"Coronation" ..	3,500	Sep. 1903	—	40,882,390	68,874,155	109,756,545
"Sea Lion" (hired)	1,150	Oct. 1906	Apl. 1907	Nil	356,250	356,250
"No. 16" ..	800	Jun. 1907	Jly. 1928	6,751,880	8,641,590	15,393,470
"Sexta" ..	No hoppers	Dec. 1907	Sep. 1917	Nil	1,040,386	1,040,386
"Leviathan" ..	10,000	Mar. 1909	—	179,512,400	2,404,600	181,917,000
"Prinses Juliana" (hired)	800	Sep. 1912	May 1913	Nil	540,550	540,550
"Lord Desborough" (hired)	3,500	Jan. 1915	Jun. 1918 Purchased by Board 1923 and name changed to "Burbo." Totals included in "Burbo" figures.			
"Burbo" ..	3,500	Mar. 1923	—	46,481,970	15,833,310	62,315,280
"Hilbre Island"	3,500	Feb. 1933	—	13,167,950	1,401,820	14,569,770
"Hoyle" ..	3,500	Feb. 1935	—	4,301,100	409,500	4,710,600
		Grand Totals	..	505,640,640	163,810,056	669,450,696

TABLE 108—*Average Monthly Rate of Dredging by the Sand Pump Dredger "Leviathan"*

Tons per hour

(Figures in brackets indicate number of loads during each month)

Month.	Dredged Cut.	Queen's Channel.	Crosby Channel.
1909			
April ..	2,645 (33)	5,819 (39)	2,991 (14)
May ..	2,143 (9)	4,914 (109)	3,692 (8)
June ..	3,279 (35)	5,538 (43)	3,233 (17)
July ..	3,301 (39)	5,255 (40)	3,147 (31)
August	2,936 (36)	5,682 (40)	4,009 (30)
September	2,095 (47)	5,088 (34)	3,946 (19)
October	2,114 (12)	4,616 (54)	3,745 (27)
November	2,443 (12)	4,641 (20)	3,464 (33)
December	2,544 (11)	5,344 (34)	3,295 (47)
1910			
January	2,272 (16)	5,885 (41)	3,302 (28)
February	2,848 (11)	5,753 (42)	3,192 (34)
March	2,837 (19)	5,105 (52)	4,156 (45)
April ..	2,812 (11)	4,544 (27)	3,185 (22)
July ..	3,514 (2)	4,779 (27)	2,626 (27)
August	2,992 (30)	4,568 (64)	3,002 (21)
September	2,412 (41)	4,449 (59)	4,294 (15)
October	2,431 (11)	4,440 (11)	4,752 (16)
November	1,930 (22)	4,661 (19)	4,716 (50)
December	2,434 (28)	3,736 (18)	4,242 (44)
1911			
January	2,633 (21)	4,690 (19)	3,685 (52)
February	2,738 (21)	4,696 (41)	5,144 (32)
March	2,234 (16)	4,338 (20)	5,157 (78)
April	2,165 (22)	4,138 (19)	4,056 (35)
May ..	2,214 (44)	4,232 (55)	4,114 (6)
June ..	2,879 (42)	4,501 (63)	—
July ..	2,807 (31)	4,821 (55)	4,582 (16)
August	2,135 (10)	3,971 (27)	3,927 (19)
1911—*contd.*			
September	2,337 (9)	4,846 (58)	3,636 (5)
October	2,125 (11)	5,082 (32)	4,923 (21)
November	2,838 (7)	5,511 (44)	4,919 (43)
December	3,852 (26)	5,748 (8)	5,394 (66)
1912			
January	3,593 (35)	6,335 (17)	4,943 (36)
February	3,462 (47)	6,070 (13)	4,737 (40)
March	3,218 (7)	—	4,570 (23)
April ..	3,490 (13)	6,069 (22)	—
May ..	3,696 (41)	6,115 (64)	4,121 (20)
June ..	3,932 (31)	6,432 (32)	4,442 (45)
July ..	3,625 (20)	6,133 (37)	4,641 (42)
August	3,684 (8)	5,927 (57)	3,770 (43)
September	3,844 (37)	6,067 (36)	3,642 (19)
October	3,429 (21)	5,950 (18)	5,060 (25)
November	4,145 (21)	6,265 (24)	5,086 (50)
December	3,661 (10)	6,378 (27)	4,810 (40)
1913			
January	2,333 (21)	5,723 (32)	4,334 (35)
February	2,914 (27)	5,792 (25)	4,758 (27)
March	3,524 (21)	5,532 (25)	5,064 (43)
April ..	3,609 (12)	5,072 (44)	6,057 (48)
May ..	3,016 (14)	5,217 (23)	4,423 (17)
June ..	3,119 (23)	5,112 (21)	4,415 (50)
July ..	3,266 (23)	5,148 (40)	4,439 (32)
August	3,345 (31)	4,922 (37)	4,005 (34)
September	2,940 (17)	4,654 (56)	5,187 (27)
October	2,808 (17)	3,639 (17)	3,717 (14)
November	2,422 (9)	3,868 (31)	3,567 (37)
December	2,824 (6)	4,322 (17)	4,418 (49)

TABLE 108—*continued*

Month.	Dredged Cut.	Queen's Channel.	Crosby Channel.	Askew Spit.	Taylor's Spit.
1914					
January ..	2,442 (7)	4,150 (37)	4,327 (35)	—	—
February ..	—	4,917 (5)	4,770 (19)	5,893 (33)	5,980 (30)
March ..	—	4,012 (23)	4,593 (16)	4,817 (11)	5,665 (49)
April ..	—	4,128 (30)	—	4,970 (21)	5,167 (30)
May ..	—	3,958 (38)	3,676 (17)	5,660 (15)	3,991 (30)
June ..	—	3,506 (22)	3,441 (27)	6,076 (16)	3,214 (21)
July ..	—	3,183 (10)	3,694 (29)	5,225 (10)	4,286 (7)
August ..	—	4,376 (31)	3,200 (6)	—	4,749 (15)
September ..	—	3,997 (40)	4,688 (5)	—	3,103 (27)
October ..	—	3,450 (36)	4,074 (25)	—	3,043 (25)
November ..	—	2,724 (33)	4,173 (9)	—	4,503 (11)
December ..	1,846 (5)	2,983 (24)	4,368 (16)	4,629 (3)	5,404 (10)
1915					
January ..	—	3,431 (29)	4,785 (13)	4,800 (6)	5,419 (14)
February ..	—	2,945 (4)	5,217 (2)	—	7,500 (2)
March ..	2,621 (20)	3,523 (17)	3,731 (32)	—	6,486 (2)
April ..	2,479 (15)	3,334 (23)	3,600 (35)	—	—
May ..	2,390 (14)	2,406 (48)	4,199 (19)	—	—
June ..	2,251 (15)	2,622 (33)	3,466 (16)	2,893 (2)	—
July ..	2,591 (3)	2,661 (9)	2,886 (4)	—	—
August ..	2,609 (10)	2,755 (49)	6,041 (11)	5,590 (2)	—
September ..	2,308 (2)	2,867 (68)	3,621 (7)	—	—
October ..	2,312 (18)	2,724 (40)	3,820 (11)	—	—
November ..	2,582 (17)	2,877 (38)	4,191 (17)	3,345 (8)	—
December ..	2,493 (22)	3,097 (31)	3,435 (12)	5,714 (1)	—
1916					
January ..	2,759 (6)	3,662 (33)	5,310 (15)	4,615 (1)	—
February ..	2,673 (9)	3,377 (34)	5,047 (33)	—	—
March ..	2,805 (14)	3,396 (45)	4,316 (30)	—	—
April ..	3,248 (17)	3,319 (38)	4,090 (36)	—	—
May ..	3,141 (20)	3,605 (42)	4,129 (32)	—	3,356 (19)
June ..	2,804 (10)	3,390 (40)	4,324 (36)	5,030 (14)	—
July ..	2,763 (20)	3,887 (69)	4,615 (31)	5,924 (16)	—
August ..	2,846 (19)	3,201 (41)	4,269 (18)	5,714 (6)	—
September ..	2,477 (9)	3,254 (8)	3,200 (2)	7,059 (1)	—
October ..	2,404 (9)	3,396 (36)	5,005 (27)	6,400 (4)	—
November ..	2,692 (9)	3,368 (48)	4,292 (14)	6,316 (2)	—
December ..	2,734 (28)	3,275 (50)	4,500 (12)	6,486 (4)	—

Month.	Dredged Cut.	Queen's Channel.	Crosby Channel.	Askew Spit.	Taylor's Spit.
1917					
January ..	2,590 (9)	3,165 (59)	4,615 (20)	—	—
February ..	2,766 (31)	3,715 (36)	4,401 (15)	—	—
March ..	2,625 (21)	4,073 (49)	4,160 (22)	6,154 (2)	—
April ..	—	3,247 (25)	3,780 (12)	—	—
May ..	—	3,237 (84)	3,983 (32)	—	—
June ..	—	3,171 (62)	4,142 (36)	—	5,000 (1)
July ..	—	3,383 (79)	4,683 (45)	—	—
August ..	—	3,309 (83)	3,937 (24)	—	—
September ..	—	3,267 (76)	3,597 (12)	—	—
October ..	—	3,349 (28)	4,305 (8)	—	—
November ..	2,366 (11)	3,295 (33)	4,104 (14)	—	3,088 (7)
December ..	—	2,222 (9)	3,509 (5)	—	—
1918					
November ..	—	3,926 (24)	2,426 (12)	—	—
December ..	—	3,623 (29)	3,460 (53)	5,391 (6)	—
1919					
January ..	—	3,798 (49)	3,862 (30)	5,074 (9)	—
February ..	2,487 (5)	3,333 (52)	3,619 (23)	4,345 (13)	—
March ..	2,708 (15)	3,323 (35)	3,389 (40)	—	—
April ..	—	3,249 (36)	3,956 (53)	—	—
May ..	—	3,532 (68)	3,695 (38)	—	—
June ..	—	3,859 (32)	3,544 (43)	—	—
July ..	—	3,304 (28)	3,440 (26)	—	—
August ..	—	3,179 (24)	4,854 (43)	—	—
September ..	—	3,243 (5)	3,822 (5)	—	—
1922					
January ..	4,285 (5)	5,156 (1)	4,595 (10)	—	—
March ..	2,611 (14)	2,832 (28)	3,489 (33)	5,333 (10)	—
April ..	2,787 (12)	3,547 (29)	4,437 (41)	5,902 (6)	—
May ..	4,256 (18)	4,432 (42)	5,042 (60)	—	—
June ..	4,749 (15)	5,260 (60)	5,276 (40)	—	—
July ..	4,789 (36)	5,169 (30)	5,600 (27)	5,455 (3)	5,756 (22)
August ..	4,800 (25)	4,149 (13)	5,117 (45)	5,950 (6)	5,554 (30)
September ..	4,845 (39)	4,476 (17)	5,338 (39)	6,545 (3)	5,000 (20)
October ..	4,766 (90)	5,051 (25)	5,131 (18)	6,487 (6)	5,172 (5)
November ..	4,322 (55)	4,948 (20)	5,379 (30)	5,607 (10)	5,148 (13)
December ..	4,596 (59)	4,954 (9)	5,204 (28)	5,941 (10)	5,341 (15)

1923					
January	4,487 (48)	5,522 (10)	5,762 (29)	6,316 (3)	5,870 (15)
February ..	4,733 (56)	5,000 (3)	5,703 (25)	—	4,457 (15)
March ..	4,898 (16)	—	5,132 (10)	—	6,675 (2)
April	3,941 (49)	4,417 (6)	5,255 (18)	5,838 (9)	5,118 (18)
May	3,993 (55)	4,683 (8)	5,460 (43)	5,902 (6)	4,032 (21)
June	3,883 (46)	4,800 (5)	4,860 (45)	6,000 (4)	4,810 (23)
July	4,060 (52)	4,640 (11)	5,046 (32)	5,370 (9)	4,429 (22)
August ..	4,005 (45)	5,275 (4)	5,195 (51)	5,189 (8)	4,891 (15)
September ..	3,996 (52)	4,897 (4)	5,159 (46)	—	4,264 (7)
October ..	4,189 (31)	5,455 (1)	5,420 (70)	6,300 (1)	5,128 (5)
November ..	3,485 (78)	6,000 (1)	4,427 (19)	—	4,800 (2)
December ..	3,481 (75)	—	4,790 (40)	5,217 (1)	4,242 (7)
1924					
January ..	3,645 (99)	—	4,926 (22)	6,109 (2)	3,896 (5)
February ..	3,502 (58)	4,615 (2)	4,960 (46)	—	3,249 (5)
March ..	3,704 (20)	—	5,350 (7)	4,800 (1)	4,571 (4)
April	3,556 (63)	—	5,456 (30)	—	4,286 (11)
May	2,813 (67)	—	5,179 (56)	3,478 (2)	5,000 (2)
June	3,204 (50)	4,285 (3)	4,995 (38)	4,472 (6)	4,478 (10)
July	3,339 (3)	4,444 (3)	4,906 (67)	7,059 (1)	6,227 (2)
August ..	3,226 (34)	4,643 (13)	4,561 (67)	5,714 (1)	3,429 (1)
September ..	3,223 (34)	4,626 (15)	4,574 (51)	—	3,750 (1)
October ..	3,225 (81)	4,022 (6)	4,266 (22)	—	—
November ..	3,169 (63)	4,557 (6)	4,793 (27)	—	—
December ..	3,079 (48)	—	4,605 (34)	—	3,810 (6)
1925					
January ..	3,239 (49)	4,555 (5)	4,805 (36)	—	—
February ..	3,025 (37)	—	4,297 (49)	—	—
March ..	3,004 (67)	—	4,350 (28)	—	—
April	2,673 (14)	—	4,149 (9)	—	—
May	2,582 (62)	—	4,029 (29)	—	—
June	2,724 (60)	—	4,067 (40)	—	—
July	2,871 (62)	—	4,244 (36)	—	—
August ..	2,647 (62)	3,561 (1)	3,705 (39)	—	—
September ..	1,906 (23)	—	3,613 (49)	—	—
October ..	1,802 (48)	—	3,801 (36)	—	—
November ..	1,730 (42)	—	3,758 (26)	—	—
December ..	1,838 (29)	—	3,718 (34)	—	—
1926					
January ..	1,862 (27)	—	3,489 (44)	—	3,410 (14)
February ..	1,843 (33)	4,082 (5)	3,451 (36)	—	—
March ..	1,548 (1)	—	3,628 (12)	—	—
April	1,889 (17)	3,399 (10)	4,456 (38)	—	—
May	1,839 (9)	4,027 (5)	3,257 (7)	—	—
1928					
May	2,971 (30)	3,429 (1)	3,681 (28)	—	—
June	3,066 (52)	—	4,033 (37)	—	—

1928—*contd.*					
July	2,537 (43)	—	3,885 (39)	—	—
August ..	2,692 (49)	—	3,400 (46)	—	—
September ..	2,419 (47)	2,915 (22)	3,404 (21)	—	—
October ..	2,692 (27)	2,893 (30)	3,298 (29)	—	—
November ..	2,792 (35)	2,996 (17)	3,111 (17)	—	—
December ..	2,529 (68)	2,325 (2)	3,150 (23)	—	—
1929					
January ..	2,688 (67)	3,750 (4)	3,558 (22)	—	—
February ..	2,545 (52)	4,000 (6)	3,816 (13)	—	—
March ..	2,245 (12)	2,346 (5)	3,352 (5)	—	—
April	3,049 (36)	4,789 (1)	3,334 (50)	—	4,800 (1)
May	3,523 (28)	—	3,565 (68)	—	—
June	3,574 (30)	—	3,447 (65)	—	—
July	3,901 (32)	4,845 (13)	3,545 (59)	—	—
August ..	2,439 (32)	4,312 (9)	2,661 (49)	—	—
September ..	2,767 (35)	4,586 (12)	3,525 (34)	—	—
October ..	2,474 (3)	3,772 (13)	3,851 (50)	—	—
November ..	2,050 (16)	3,868 (6)	2,888 (51)	—	—
December ..	1,993 (7)	3,163 (7)	2,560 (41)	—	—
1930					
January ..	2,966 (6)	3,150 (1)	4,591 (53)	—	4,285 (6)
February ..	1,616 (19)	4,210 (2)	2,670 (30)	—	3,924 (20)
March ..	1,668 (10)	3,617 (11)	2,434 (46)	—	4,080 (9)
April	1,571 (13)	3,554 (9)	4,941 (32)	—	3,806 (10)
May	2,167 (2)	3,706 (7)	3,838 (13)	3,840 (3)	—
June	4,053 (30)	3,819 (52)	3,819 (52)	4,140 (15)	—
July	—	4,191 (8)	3,809 (63)	4,582 (29)	—
August ..	1,773 (3)	3,684 (23)	4,183 (46)	4,586 (12)	—
September ..	2,724 (5)	3,602 (31)	3,840 (45)	—	—
October ..	1,644 (2)	3,900 (22)	3,855 (49)	—	—
November ..	1,949 (5)	3,944 (32)	3,251 (47)	—	—
December ..	2,278 (18)	3,706 (27)	3,659 (25)	—	—
1931					
January ..	2,021 (3)	3,801 (29)	3,449 (35)	—	—
February ..	1,924 (5)	3,382 (26)	3,423 (38)	5,130 (7)	—
March ..	2,348 (21)	3,391 (27)	3,380 (32)	5,454 (9)	—
April	2,481 (3)	3,448 (19)	3,720 (45)	4,923 (8)	—
May	2,908 (6)	3,824 (32)	3,433 (56)	5,091 (7)	—
June	2,658 (6)	3,845 (44)	3,111 (46)	—	—
July	2,400 (1)	4,005 (5)	3,351 (14)	5,714 (1)	—
August ..	1,824 (1)	3,826 (17)	3,358 (77)	—	—
September ..	1,820 (12)	3,751 (21)	3,747 (59)	—	—
October ..	1,740 (11)	4,125 (15)	3,679 (26)	—	—
1935					
October ..	—	—	2,556 (5)	—	4,842 (23)
November ..	—	—	—	—	4,552 (112)
December ..	—	—	—	—	4,669 (73)

TABLE 109—*Average Monthly Rate of Dredging by the Sand Pump Dredger "Coronation"*

Tons per Hour

(Figures in brackets indicate number of loads during each month)

Month.	Dredged Cut.	Queen's Channel.	Crosby Channel.	Askew Spit.	Taylor's Spit.
1909					
July	—	3,928 (15)	—	—	3,500 (26)
August ..	—	3,925 (13)	—	—	3,840 (32)
September ..	—	—	—	—	4,064 (15)
October ..	—	3,542 (4)	—	—	3,865 (25)
November ..	—	3,937 (3)	—	—	4,271 (24)
December ..	—	3,359 (2)	—	—	4,200 (8)
1910					
January ..	—	5,398 (2)	—	—	4,200 (4)
February ..	—	3,500 (1)	—	—	4,472 (4)
March ..	—	3,309 (4)	—	—	3,999 (16)
April	—	3,325 (4)	—	—	3,775 (16)
May	—	3,360 (2)	—	—	3,928 (13)
June	—	3,564 (6)	—	—	3,981 (31)
July	—	3,574 (8)	—	—	4,097 (20)
August ..	—	2,896 (10)	—	—	3,375 (31)
September ..	—	3,036 (33)	—	—	3,526 (11)
October ..	—	3,559 (5)	—	—	3,736 (25)
November ..	—	3,895 (14)	—	—	4,200 (8)
December ..	—	3,478 (28)	—	—	3,937 (3)
1911					
January ..	—	3,291 (9)	—	—	4,131 (12)
February ..	—	3,629 (7)	—	—	4,179 (20)
March ..	—	3,239 (12)	—	—	3,962 (25)
April	—	3,030 (14)	—	—	3,433 (16)
May	—	2,794 (27)	—	—	3,810 (22)
June	—	2,565 (7)	—	—	3,073 (32)
July	—	3,360 (4)	—	—	3,266 (43)
August ..	—	2,863 (15)	—	—	3,000 (1)
September ..	—	3,405 (6)	—	—	3,318 (32)
October ..	—	3,500 (1)	—	—	3,461 (22)
November ..	—	3,494 (9)	—	—	4,121 (20)
December ..	—	3,677 (4)	—	—	3,600 (24)

Month.	Dredged Cut.	Queen's Channel.	Crosby Channel.	Askew Spit.	Taylor's Spit.
1912					
January ..	—	—	—	—	3,750 (22)
February ..	—	3,500 (1)	—	—	3,328 (19)
March ..	—	—	—	—	3,999 (2)
May	—	—	—	—	3,518 (36)
June	—	3,652 (2)	—	—	3,523 (38)
July	—	3,230 (4)	—	—	3,619 (37)
August ..	—	2,722 (2)	—	—	3,955 (21)
September ..	—	—	—	—	3,885 (37)
October ..	—	2,878 (15)	—	—	3,561 (34)
November ..	—	3,134 (15)	—	4,285 (5)	3,850 (11)
1913					
February ..	—	—	—	—	2,992 (29)
July	—	—	—	—	3,043 (5)
August ..	—	—	—	—	3,069 (20)
September ..	—	—	—	—	3,009 (27)
October ..	—	—	—	—	1,734 (25)
November ..	—	—	—	—	2,692 (10)
December ..	—	—	—	—	3,030 (14)
1914					
January ..	—	—	—	3,500 (1)	2,866 (33)
February ..	—	—	—	2,947 (4)	2,852 (19)
March ..	—	—	—	—	2,804 (13)
April	—	—	—	—	2,470 (26)
May	—	—	—	—	1,850 (34)
June	—	—	—	—	1,579 (30)
July	—	—	—	—	1,784 (13)
August ..	—	—	—	—	2,032 (3)
September ..	—	—	—	—	1,995 (19)
October ..	—	2,117 (33)	—	—	1,624 (7)
November ..	—	2,010 (18)	—	—	2,345 (9)
December ..	—	2,333 (1)	—	—	2,081 (11)

1915					
January ..	—	1,992 (13)	—	—	2,571 (1)
February ..	—	1,816 (8)	—	—	1,900 (11)
March ..	—	1,932 (15)	—	—	1,570 (16)
April	—	1,721 (10)	—	—	1,802 (13)
May	—	1,786 (12)	—	—	1,750 (15)
June	—	1,977 (17)	—	—	1,652 (17)
July	—	1,931 (4)	—	—	1,680 (1)
September ..	—	1,928 (9)	—	—	1,662 (13)
October ..	812 (1)	1,025 (18)	—	1,105 (1)	1,918 (9)
December ..	988 (6)	1,068 (27)	1,392 (6)	1,362 (6)	—
1916					
January ..	—	1,252 (25)	1,448 (1)	1,760 (7)	—
February ..	—	1,079 (10)	—	2,330 (2)	—
April	1,354 (3)	1,499 (15)	—	—	—
May	993 (2)	1,716 (28)	—	1,736 (16)	—
June	—	1,303 (10)	—	1,552 (23)	1,280 (7)
July	619 (2)	1,589 (7)	—	1,604 (18)	978 (23)
August ..	—	1,664 (21)	—	1,829 (21)	1,045 (37)
September ..	—	1,216 (35)	1,008 (1)	1,400 (15)	1,362 (12)
October ..	—	1,312 (16)	—	1,553 (15)	1,089 (7)
November ..	—	1,415 (12)	—	1,484 (11)	1,363 (5)
December ..	—	1,659 (10)	—	1,710 (20)	1,226 (6)
1917					
January ..	—	1,468 (5)	—	1,891 (20)	1,288 (10)
February ..	—	1,455 (22)	—	1,968 (15)	1,191 (30)
April	—	2,075 (9)	—	2,074 (4)	1,576 (22)
May	—	1,290 (53)	—	2,672 (14)	—
June	—	1,309 (49)	—	2,189 (22)	—
July	—	1,794 (1)	—	1,763 (17)	—
August ..	—	1,491 (23)	—	—	—
September ..	—	1,108 (14)	—	2,000 (18)	—
October ..	—	1,363 (5)	—	2,210 (8)	1,049 (1)
November ..	—	1,456 (8)	—	2,250 (6)	1,120 (2)
December ..	—	—	—	2,234 (5)	—
1918					
August ..	—	951 (3)	1,761 (4)	—	—
September ..	—	1,709 (42)	1,896 (22)	—	—
October ..	—	1,545 (47)	2,195 (28)	—	—
November ..	—	1,493 (51)	2,364 (17)	—	—
December ..	—	1,176 (9)	1,875 (5)	—	—

1919					
January ..	—	1,214 (34)	1,888 (4)	—	1,496 (43)
February ..	812 (8)	954 (42)	1,050 (1)	—	2,721 (48)
March ..	964 (14)	1,020 (32)	1,017 (7)	—	1,609 (18)
April	1,016 (4)	1,149 (18)	1,380 (23)	—	1,579 (10)
May	—	1,355 (22)	1,561 (13)	—	1,853 (3)
June	—	1,421 (16)	1,544 (16)	—	1,734 (1)
July	—	1,531 (7)	1,468 (11)	—	—
August ..	—	1,379 (13)	1,628 (12)	—	—
September ..	1,041 (8)	1,445 (18)	1,463 (14)	1,910 (4)	—
October ..	—	1,533 (15)	1,659 (16)	1,486 (1)	—
November ..	—	1,537 (9)	1,615 (11)	—	—
1920					
January ..	—	1,615 (5)	1,837 (13)	—	—
February ..	—	1,490 (11)	1,790 (13)	—	—
March ..	—	1,644 (17)	1,724 (14)	—	—
April	—	1,699 (13)	1,780 (10)	—	—
May	—	1,588 (16)	1,772 (10)	—	—
June	—	1,601 (26)	1,918 (10)	—	—
July	—	1,444 (38)	1,555 (8)	—	—
August ..	—	1,562 (59)	1,562 (19)	—	—
September ..	—	1,725 (11)	1,735 (12)	—	1,712 (13)
October ..	—	1,556 (19)	1,680 (3)	—	1,673 (10)
November ..	—	1,610 (12)	1,544 (5)	1,796 (18)	1,505 (10)
December ..	—	1,750 (14)	1,909 (2)	—	1,795 (10)
1921					
January ..	—	1,465 (3)	1,485 (7)	—	2,471 (1)
March ..	—	2,100 (16)	1,826 (4)	—	—
April	—	1,971 (16)	2,432 (15)	—	—
May	—	2,012 (8)	2,277 (19)	—	—
June	1,391 (5)	1,842 (5)	2,178 (14)	—	—
July	—	1,783 (16)	2,125 (17)	—	—
August ..	—	—	2,303 (21)	—	—
September ..	—	1,909 (14)	2,030 (24)	2,366 (4)	—
October ..	—	1,400 (63)	1,679 (38)	2,635 (17)	—
November ..	1,228 (5)	1,842 (5)	1,764 (11)	2,643 (9)	—
December ..	—	2,400 (8)	2,287 (11)	—	—
1922					
January ..	—	1,869 (19)	2,333 (11)	—	—
February ..	—	1,792 (16)	2,441 (10)	—	—
March ..	—	1,881 (3)	2,211 (2)	—	—

TABLE 109—*continued*

Month.	Dredged Cut.	Queen's Channel.	Crosby Channel.	Askew Spit.	Taylor's Spit.
1922—*cont.*					
April	2,000 (1)	1,869 (15)	2,616 (18)	—	—
May	—	1,736 (16)	2,545 (28)	—	—
June	3,000 (1)	1,811 (16)	2,298 (29)	—	—
July	—	1,764 (16)	2,476 (28)	—	1,909 (3)
August ..	—	1,934 (7)	2,578 (34)	—	3,316 (3)
September ..	—	2,132 (10)	2,681 (27)	—	3,036 (6)
October ..	—	2,400 (16)	2,749 (36)	—	3,231 (1)
November ..	—	2,229 (13)	2,679 (25)	—	2,739 (3)
December ..	1,428 (5)	2,196 (8)	2,724 (19)	—	3,231 (1)
1923					
January ..	1,615 (6)	1,956 (17)	2,477 (22)	—	—
February ..	1,588 (15)	1,680 (23)	2,405 (13)	—	—
March ..	1,813 (6)	2,074 (8)	2,457 (22)	—	—
April	2,211 (3)	2,123 (14)	2,638 (25)	—	—
May	—	1,979 (9)	2,433 (23)	—	—
June	2,211 (2)	2,291 (3)	2,136 (6)	—	—
July	2,471 (1)	2,262 (14)	2,369 (33)	—	—
August ..	1,235 (1)	2,158 (15)	2,174 (44)	2,415 (7)	—
September ..	2,000 (1)	2,122 (19)	1,926 (63)	—	—
October ..	1,438 (35)	2,150 (16)	2,173 (46)	3,000 (8)	2,788 (15)
November ..	1,459 (7)	1,853 (16)	2,049 (34)	2,800 (3)	3,073 (27)
December ..	—	2,283 (5)	2,744 (13)	—	—
1924					
January ..	1,775 (6)	2,456 (20)	2,618 (24)	—	—
February ..	1,750 (1)	2,352 (14)	2,861 (28)	—	—
March ..	1,695 (22)	2,224 (17)	2,537 (9)	—	—
April	1,804 (7)	2,211 (8)	2,882 (28)	—	—
May	1,701 (16)	1,680 (1)	3,211 (25)	—	—
June	2,800 (1)	—	2,756 (29)	—	—
July	1,714 (2)	2,061 (8)	3,179 (38)	—	—
August ..	1,718 (3)	2,163 (12)	2,630 (31)	—	—
September ..	1,714 (2)	2,561 (10)	2,404 (27)	—	—
October ..	—	2,315 (14)	2,520 (18)	—	1,987 (11)
November ..	—	2,447 (7)	2,979 (10)	2,296 (1)	1,870 (22)
December ..	—	2,027 (9)	2,945 (11)	—	1,771 (7)

Month.	Dredged Cut.	Queen's Channel.	Crosby Channel.	Askew Spit.	Taylor's Spit.
1925					
January ..	—	2,152 (34)	3,000 (4)	—	—
February ..	—	1,711 (17)	2,746 (17)	—	—
March ..	—	2,192 (17)	2,612 (13)	—	—
April	—	2,096 (14)	2,763 (15)	—	—
May	2,269 (26)	2,270 (6)	2,976 (9)	—	—
June	2,240 (4)	3,128 (7)	2,360 (5)	—	—
July	1,739 (27)	2,002 (9)	2,131 (17)	—	—
August ..	2,126 (46)	—	1,824 (3)	—	—
September ..	1,625 (27)	3,500 (1)	2,860 (8)	—	—
October ..	1,702 (38)	—	3,059 (11)	—	—
November ..	1,692 (19)	2,250 (9)	2,653 (6)	—	—
December ..	1,365 (8)	2,062 (11)	2,250 (6)	—	—
1926					
January ..	1,926 (32)	2,135 (3)	2,244 (4)	2,759 (1)	—
February ..	2,075 (39)	3,500 (1)	1,348 (6)	3,230 (1)	—
March ..	1,956 (35)	—	3,500 (1)	1,448 (1)	—
April	2,150 (39)	—	3,231 (1)	—	—
May	2,123 (2)	3,000 (1)	3,500 (1)	—	—
August ..	1,167 (1)	1,851 (12)	1,650 (11)	—	—
September ..	1,444 (8)	2,027 (20)	2,042 (14)	—	—
October ..	1,771 (21)	2,026 (8)	2,739 (3)	—	—
December ..	1,680 (4)	2,548 (2)	2,598 (6)	—	—
1927					
January ..	1,367 (8)	2,100 (2)	2,982 (10)	2,625 (1)	2,471 (1)
February ..	1,810 (28)	1,895 (2)	2,520 (6)	—	—
March ..	1,944 (11)	1,387 (5)	2,893 (7)	—	—
April	1,976 (13)	2,208 (5)	2,530 (10)	—	—
May	1,806 (31)	2,000 (1)	2,428 (17)	—	—
June	1,657 (22)	3,231 (5)	2,164 (3)	—	—
July	1,806 (42)	—	2,344 (4)	—	3,696 (1)
August ..	1,988 (36)	—	2,188 (13)	—	—
September ..	1,820 (19)	2,471 (2)	2,779 (12)	—	—
October ..	1,747 (24)	2,333 (1)	3,097 (9)	—	—
November ..	1,820 (5)	—	3,000 (5)	—	2,127 (7)

1928					
January ..	1,960 (1)	—	—	—	—
February ..	1,103 (12)	1,556 (2)	2,333 (1)	—	—
March ..	1,023 (9)	1,530 (36)	2,377 (3)	—	—
April	2,471 (1)	1,945 (21)	2,759 (19)	—	—
May	2,015 (10)	1,529 (16)	2,657 (21)	—	—
June	2,086 (16)	2,721 (14)	2,732 (8)	—	—
July	2,382 (28)	2,831 (3)	2,688 (8)	—	2,739 (3)
August ..	1,597 (35)	—	2,532 (17)	—	2,601 (27)
September ..	2,120 (42)	—	2,800 (2)	—	—
October ..	2,273 (33)	3,000 (1)	2,710 (2)	—	—
November ..	2,309 (17)	2,398 (6)	945 (1)	—	—
December ..	2,408 (19)	2,333 (2)	2,132 (6)	—	—
1929					
January ..	2,034 (18)	1,473 (2)	—	—	—
February ..	1,368 (22)	—	4,606 (1)	—	—
March ..	1,987 (39)	2,000 (4)	—	—	—
April	1,830 (9)	1,890 (3)	1,488 (24)	—	2,938 (10)
May	2,283 (17)	2,057 (17)	1,766 (31)	—	—
June	2,038 (14)	2,048 (12)	3,111 (16)	—	3,818 (1)
July	2,470 (4)	2,264 (20)	2,470 (10)	2,625 (2)	—
August ..	1,645 (17)	2,386 (20)	3,182 (5)	—	2,625 (1)
September ..	1,440 (9)	2,083 (25)	1,938 (3)	—	2,000 (1)
October ..	1,484 (4)	2,217 (13)	2,709 (10)	—	—
November ..	1,350 (7)	1,479 (5)	1,692 (8)	—	2,065 (6)
December ..	—	1,600 (4)	1,372 (5)	—	1,702 (3)
1930					
January ..	1,756 (9)	1,829 (20)	1,387 (14)	—	1,924 (22)
February ..	1,398 (18)	2,033 (18)	2,934 (3)	—	—
March ..	1,412 (9)	1,666 (6)	—	—	—
April	1,431 (14)	1,735 (23)	—	—	—
May	1,256 (5)	1,561 (67)	1,826 (2)	1,673 (21)	—
June	890 (1)	1,639 (46)	1,448 (1)	1,587 (42)	2,334 (1)
July	—	1,871 (28)	2,117 (6)	2,100 (7)	1,721 (8)
August ..	778 (1)	1,419 (41)	1,096 (5)	—	1,793 (24)
September ..	—	1,393 (65)	939 (4)	1,839 (16)	1,909 (16)
October ..	1,155 (4)	1,628 (23)	1,147 (4)	1,731 (4)	—
November ..	1,433 (4)	1,936 (12)	—	—	—
December ..	1,881 (12)	1,909 (12)	—	—	2,800 (3)

1931					
January ..	2,136 (8)	1,900 (14)	—	—	—
February ..	2,191 (5)	1,930 (19)	—	—	—
March ..	2,447 (11)	1,895 (36)	—	—	—
April	1,424 (11)	1,677 (12)	—	—	—
May	1,981 (4)	1,632 (34)	—	—	—
June	1,925 (3)	1,668 (44)	—	—	2,066 (3)
July	1,642 (4)	1,664 (43)	790 (10)	—	2,022 (13)
August ..	1,182 (2)	1,364 (22)	1,948 (27)	—	1,942 (16)
September ..	1,331 (8)	1,506 (28)	2,077 (7)	—	1,965 (10)
October ..	1,119 (8)	1,509 (15)	1,141 (5)	1,405 (2)	1,780 (9)
November ..	1,050 (11)	1,382 (26)	772 (7)	1,714 (2)	1,954 (4)
December ..	891 (6)	1,145 (23)	1,481 (5)	2,000 (2)	2,143 (10)
1932					
January ..	1,102 (5)	1,420 (28)	1,184 (7)	2,414 (2)	2,100 (10)
February ..	915 (12)	1,412 (54)	845 (8)	1,900 (11)	2,079 (14)
March ..	1,867 (2)	1,385 (59)	919 (4)	2,301 (8)	2,149 (11)
April	—	1,372 (42)	920 (6)	1,890 (9)	1,881 (6)
May	—	1,368 (57)	1,207 (22)	1,686 (12)	1,901 (12)
June	2,730 (1)	1,503 (47)	943 (1)	1,826 (18)	1,895 (12)
July	—	1,615 (13)	—	—	—
August ..	—	1,435 (69)	1,834 (9)	1,870 (13)	1,836 (16)
September ..	—	1,295 (41)	1,239 (9)	2,036 (8)	1,814 (13)
October ..	—	1,282 (41)	1,169 (16)	2,079 (10)	2,099 (10)
November ..	—	1,171 (65)	1,138 (8)	—	1,787 (4)
December ..	—	1,166 (47)	1,015 (6)	2,270 (4)	1,909 (2)
1933					
January ..	—	1,431 (29)	—	—	—
February ..	—	1,840 (22)	2,864 (3)	—	—
March ..	—	1,663 (31)	1,697 (4)	—	2,382 (2)
April	—	1,820 (34)	2,545 (2)	—	—
May	—	1,898 (41)	1,041 (5)	—	2,333 (4)
June	—	1,867 (45)	1,361 (4)	—	—
July	2,092 (10)	1,993 (28)	—	—	—
August ..	—	2,284 (31)	1,615 (1)	—	—
September ..	—	2,439 (11)	—	—	—
October ..	—	1,670 (20)	2,947 (4)	—	—
November ..	—	1,506 (33)	—	—	—
December ..	—	1,396 (29)	—	—	—

TABLE 109—*continued*

Month.	Dredged Cut.	Queen's Channel.	Crosby Channel.	Askew Spit.	Taylor's Spit.
1934					
January ..	—	1,718 (20)	—	—	—
February ..	—	1,736 (18)	2,250 (6)	2,211 (2)	2,440 (7)
March ..	1,929 (4)	1,807 (20)	2,333 (3)	1,697 (4)	—
April	1,832 (4)	1,889 (28)	1,680 (4)	2,171 (6)	—
May	—	2,031 (35)	—	1,888 (4)	—
June	—	1,899 (39)	2,380 (3)	—	—
July	—	1,736 (43)	2,085 (7)	2,150 (13)	—
August ..	—	1,850 (41)	2,154 (7)	2,255 (8)	—
September ..	—	1,529 (41)	1,920 (9)	2,182 (20)	—
October ..	—	2,173 (12)	—	2,000 (2)	—
November ..	1,810 (10)	1,676 (10)	2,100 (16)	1,954 (2)	—
December ..	1,976 (3)	1,881 (34)	2,625 (1)	—	—

Month.	Dredged Cut.	Queen's Channel.	Crosby Channel.	Askew Spit.	Taylor's Spit.
1935					
January ..	—	1,705 (29)	2,470 (4)	2,100 (3)	—
February ..	—	2,018 (13)	2,146 (7)	1,909 (1)	—
March ..	—	1,879 (39)	1,318 (2)	2,049 (2)	—
April	—	1,845 (25)	2,930 (3)	2,049 (2)	—
May	1,289 (24)	1,512 (18)	2,681 (3)	2,800 (1)	2,800 (1)
June	—	1,316 (26)	1,853 (3)	2,333 (14)	—
July	—	1,763 (22)	—	2,111 (13)	—
August ..	—	1,853 (46)	3,000 (34)	2,283 (5)	—
September ..	—	1,857 (13)	1,273 (34)	2,769 (6)	—
October ..	—	1,184 (2)	1,092 (34)	2,345 (22)	1,500 (1)
November ..	—	1,452 (24)	1,060 (19)	2,385 (18)	2,625 (1)
December ..	823 (1)	1,413 (20)	1,113 (4)	2,301 (12)	—

TABLE 110—*Average Yearly Rate of Dredging by the " Leviathan " and " Coronation "*

Tons per Hour

(Figures in brackets indicate number of loads per year)

Year.	Sand Pump Dredger " *Leviathan.*"					Sand Pump Dredger " *Coronation.*"				
	Queen's Channel.	Dredged Cut.	Crosby Channel.	Askew Spit.	Taylor's Spit.	Queen's Channel.	Dredged Cut.	Crosby Channel.	Askew Spit.	Taylor's Spit.
1909	4,963(413)	2,640(233)	3,463(226)	—	—	3,768(37)	—	—	—	3,887(130)
1910	4,825(198)	2,513(191)	3,699(173)	—	—	3,336(117)	—	—	—	3,805(182)
1911	4,652(441)	2,548(260)	4,386(373)	—	—	3,182(115)	—	—	—	3,554(269)
1912	6,155(347)	3,502(291)	4,649(383)	—	—	3,047(39)	—	—	4,285(5)	3,627(257)
1913	4,876(368)	3,006(221)	4,483(413)	—	—	—	—	—	—	2,899(130)
1914	3,801(329)	2,152(12)	3,194(204)	5,505(109)	4,399(246)	2,070(52)	—	—	3,043(5)	2,095(217)
1915	2,843(389)	1,854(127)	3,956(179)	3,901(19)	5,699(18)	1,466(133)	868(7)	1,392(6)	1,318(7)	1,741(96)
1916	3,401(484)	1,911(170)	4,461(286)	5,234(48)	3,357(19)	1,408(189)	937(7)	1,076(2)	1,622(148)	1,107(97)
1917	3,319(623)	2,634(72)	4,229(245)	6,154(2)	3,243(8)	1,358(189)	—	—	2,061(129)	1,343(65)
1918	3,748(53)	—	3,523(65)	4,282(6)	—	1,507(152)	—	2,030(76)	—	—
1919	3,467(329)	2,653(20)	3,621(301)	4,615(22)	—	1,222(226)	948(34)	1,488(128)	1,780(5)	1,999(123)
1920	—	—	—	—	—	1,574(231)	—	1,719(119)	1,796(18)	1,668(43)
1921	Out of Commission.					1,935(154)	1,304(10)	1,925(181)	2,598(30)	2,471(1)
1922	4,434(274)	4,399(368)	4,938(371)	5,769(54)	5,250(105)	1,931(155)	1,615(7)	2,551(267)	—	3,014(17)
1923	4,843(53)	3,982(603)	5,295(428)	5,370(41)	4,956(152)	2,019(159)	1,742(77)	2,229(334)	2,710(18)	2,965(42)
1924	4,517(48)	3,346(650)	4,834(467)	4,667(13)	4,137(47)	2,280(120)	1,736(60)	2,788(278)	2,296(1)	1,882(40)
1925	4,358(6)	2,405(555)	3,996(411)	4,119(5)	3,620(12)	2,116(125)	1,855(195)	2,620(114)	—	—
1926	3,698(20)	1,854(87)	3,698(137)	—	3,415(14)	2,054(47)	1,927(181)	1,953(47)	2,210(47)	—
1927	Out of Commission.					2,067(23)	1,811(239)	2,595(96)	2,625(1)	2,295(9)
1928	2,917(72)	2,715(351)	3,529(240)	—	—	2,230(103)	1,956(223)	2,614(93)	—	2,614(30)
1929	4,340(76)	2,887(350)	3,677(507)	—	4,800(1)	2,074(125)	1,768(160)	1,758(163)	2,625(2)	2,179(22)
1930	3,799(203)	2,028(85)	3,613(501)	4,434(59)	3,975(45)	1,717(361)	1,462(77)	1,378(29)	1,690(102)	1,866(74)
1931	3,706(235)	2,143(69)	3,464(428)	5,170(32)	—	1,545(366)	1,391(81)	1,376(61)	1,680(6)	1,993(65)
1932	Out of Commission.					1,496(563)	1,063(20)	1,143(96)	2,062(95)	1,954(110)
1933	.. ..					1,952(354)	2,029(10)	1,673(23)	—	2,333(6)
1934	.. ..					1,702(341)	1,856(21)	2,014(56)	2,067(61)	2,487(7)
1935	—	—	2,556(5)	—	4,623(208)	1,679(277)	1,274(25)	1,269(147)	2,310(99)	2,136(3)
Total No. of loads (1909–1935)	4,961	4,715	6,343	410	875	4,753	1,434	2,316	779	2,035

TABLE 111—*Average Yearly Rate of Dredging for all Positions in Liverpool Bay*

Tons per hour

Year.	"Leviathan."	"Coronation."	Year.	"Leviathan."	"Coronation."
1909	3,686	3,860	1923	4,535	2,114
1910	3,677	3,610	1924	3,881	2,393
1911	3,793	3,430	1925	2,969	2,079
1912	4,604	3,549	1926	2,863	1,956
1913	4,170	2,899	1927	—	2,010
1914	4,129	2,104	1928	2,984	1,975
1915	2,798	1,493	1929	3,385	1,874
1916	3,414	1,385	1930	3,487	1,676
1917	3,468	1,528	1931	3,415	1,544
1918	3,678	1,648	1932	—	1,522
1919	3,640	1,428	1933	—	1,938
1920	—	1,633	1934	—	1,788
1921	—	1,945	1935	4,543	1,614
1922	4,626	2,287			

TABLE 120—*Example of Computation of the Capacity of the Upper Estuary between Sections* 0 *and* 100 *by adding the Volumes between Successive Horizontal Planes*

Year 1906.	Below 0 ft. (L.B.D.).	0–10 ft. above L.B.D.	10–20 ft. above L.B.D.	20 ft. above L.B.D. to H.W.	Area (sq. in. on chart).
Sections 0–47					
Area (sq. in. on chart)	157·97	18·15	8·68	9·41	194·21
Mean Level (ft. from L.B.D.)	35·39	4·29	15·38	23·49	
Wedge Capacity (cu. yds.)	160·3	3·0	1·1	2·0	
Prism Capacity (cu. yds.)	0	45·3	50·5	58·3	
Total Volume (cu. yds.)	160·3	48·3	51·6	60·3	
Accumulated Volume (cu. yds.)	160·3	208·6	260·3	320·6	
Sections 47–67A					
Area (sq. in. on chart)	142·16	142·20	59·54	14·04	357·94
Mean Level (ft. from L.B.D.)	11·76	4·47	14·16	24·57	
Wedge Capacity (cu. yds.)	47·9	22·5	10·0	2·8	
Prism Capacity (cu. yds.)	0	40·8	81·5	114·4	
Total Volume (cu. yds.)	47·9	63·3	91·5	117·2	
Accumulated Volume (cu. yds.)	47·9	111·2	202·8	320·0	
Sections 67A–83					
Area (sq. in. on chart)	18·54	119·70	209·32	162·00	509·56
Mean Level (ft. from L.B.D.)	3·98	6·12	15·15	24·62	
Wedge Capacity (cu. yds.)	2·1	13·3	29·1	37·5	
Prism Capacity (cu. yds.)	0	5·3	39·6	126·6	
Total Volume (cu. yds.)	2·1	18·6	68·8	164·1	
Accumulated Volume (cu. yds.)	2·1	20·7	89·5	253·6	
Sections 83–100					
Area (sq. in. on chart)	0	6·52	50·96	27·06	84·54
Mean Level (ft. from L.B.D.)	0	8·40	15·91	25·92	
Wedge Capacity (cu. yds.)	0	0·02	6·0	5·7	
Prism Capacity (cu. yds.)	0	0	1·9	21·9	
Total Volume (cu. yds.)	0	0·3	7·8	27·7	
Accumulated Volume (cu. yds.)	0	0·3	8·1	35·8	
Total accumulated capacity	210·4	340·9	560·8	930·1	Total area for 1906 1,146·25
Capacity (cu. yds.) adjusted for difference between scales of 1906 and 1931 charts	211·0	342·0	562·5	932·9	
Total volume between levels (cu. yds.)	210·4	130·5	219·9	369·3	Total standard area for 1931 1,150·79
Adjusted total volume between levels (cu. yds.)	211·0	131·0	220·5	370·4	

TABLE 121—*Volume of the Upper Mersey Estuary from Rock Light to Runcorn, calculated from Data supplied by the Mersey Docks and Harbour Board*

Methods of computation used :—
- A. Method used by Mersey Docks and Harbour Board. Simpson's Formula for odd No. of Sections. Mersey Docks & Harbour Board standard distances between Sections.
- B. Simpson's Formula for even No. of Sections. Mersey Docks & Harbour Board standard distances between Sections.
- C. Formula for even No. of Sections. Remeasured distances between Sections.
- D. Capacity computed separately between each pair of Sections. Remeasured distances between Sections.
- E. Method of horizontal planes.

Year of Survey.	Volume between Sections 0 and 100 (millions of cubic yards).					Percentage of the volume found by method used by Mersey Docks and Harbour Board (column A) for same year.				
	A.	B.	C.	D.	E.	A.	B.	C.	D.	E.
1861	959·3	971·2	927·4	933·3	903·5	100	101·24	96·67	97·29	94·18
1871	931·0	940·7	897·8	903·0	896·4	100	101·04	96·43	96·99	96·27
1881	938·7	949·0	906·7	913·6	909·3	100	101·10	96·59	97·33	96·87
1886	979·4	989·7	945·8	947·4	943·1	100	101·05	96·57	96·73	96·29
1891	924·4	937·0	895·1	899·1	896·8	100	101·36	96·83	97·26	97·01
1896	952·8	965·5	921·7	927·7	916·0	100	101·33	96·74	97·37	96·14
1901	954·6	965·2	921·5	926·0	916·1	100	101·11	96·53	97·00	95·97
1906	965·9	978·6	934·4	939·6	932·9	100	101·31	96·74	97·28	96·58
1911	948·8	960·8	917·9	924·5	912·4	100	101·26	96·74	97·44	96·16
1916	931·5	943·0	899·7	903·4	897·9	100	101·23	96·59	96·98	96·50
1921	919·1	930·4	888·2	894·6	887·0	100	101·23	96·64	97·33	96·51
1926	914·3	927·0	885·0	889·6	882·6	100	101·39	96·80	97·30	96·50
1931	913·0	924·5	882·6	887·7	882·8	100	101·26	96·67	97·23	96·67
Average						100	101·22	96·66	97·19	96·28

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