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A MACRO REVIEW OF THE COASTLINE OF ENGLAND AND WALES

Volume 8. The North West. The Great Orme to the Solway Firth.

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ABSTRACT

This report reviews the coastline of the North West. In it is a description of natural and man made processes which affect the behaviour of this part of the United Kingdom. It includes a summary of the coastal defences, areas of significant change and a number of aspects of beach development. There is also a brief chapter on winds, waves and tidal action, with extensive references being given in the Bibliography.

This is the eighth report of a series being carried out for the Ministry of Agriculture, Fisheries and Food. For further information please contact Mr J M Motyka of the Coastal Processes Section, Maritime Engineering Department, Hydraulics Research Limited.

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1 INTRODUCTION

In 1985, the Ministry of Agriculture, Fisheries and Food commissioned Hydraulics Research, Wallingford to carry out a review of the coastline of England and Wales. The principal aim of this review is to provide information on various factors affecting the development of the coastline, including the physical processes, any coastal defences which may affect these processes, as well as natural factors such as the coastal geology, geomorphology, winds, waves and tidal action. Also included is a bibliography containing details of reports, studies and papers describing this particular coastline.

In this review the coastline of England and Wales has been sub-divided into regions, with each major region being covered by a separate report. The present report is Volume 8 of the series, and covers the North West coast from the Great Orme to the Solway Firth.

One of the fundamental objectives of this review is to identify those stretches of coast which can be treated, from a coast protection viewpoint, as individual units or cells. Such cells are judged to be self contained in those areas where it is found that beach or nearshore changes within a particular cell have no significant effect on processes taking place in adjoining cells. Identification of littoral cells is intended to help planners determine the length of coastline likely to be affected by coastal works in any particular area.

It is hoped that this type of 'overview' will assist in the understanding of the coastal system as a whole and may lead to a more unified approach to the planning of coastal defences.

Throughout these reviews the phrase 'Schedule 4 boundary' is often used. This is a term from the 'Coast Protection Act of 1949' which defines the boundary, chiefly on rivers and estuaries, upstream of which the Act ceases to apply. It is used here for convenience to establish a cut off point with regard to coast protection. Briefly the Coast Protection Act establishes relevant maritime authorities as the 'coast protection authority' giving them general powers to carry out coast protection work within their specified boundaries. The other relevant Act of Parliament is the 'Land Drainage Act of 1976'. This deals (among other things) with the prevention of flooding by the sea, ie 'sea defence', and is usually the responsibility of the Water Authorities. Both Acts now come under the jurisdiction of the Ministry of Agriculture, Fisheries and Food.

The major coastal units are set out in Chapter 2 and the more important coastal features highlighted. Chapter 3 describes the geology and recent coastal evolution. General information on winds, waves, tides and tidal currents is given in Chapter 4. The main body of the report is contained in Chapter 5, which describes the coastal defences and their effect on coastal processes.

2 SUMMARY

The coastline bounding the eastern part of the Irish Sea is predominantly low lying land, consisting mainly of alluvial deposits. The beaches are wide and sandy and have few natural boundaries, hence large stretches of shoreline can be included into natural littoral units or cells. From a planning view point the cells could be considered as follows:-

Great Ormes Head to the River Mersey

With the exception of Little Ormes Head and Rhos Point at the western end of this frontage there are few boundaries which arrest littoral drift effectively. The nett direction of littoral drift along this coast is from west to east. Where this drift is obstructed by groynes or other such structures there are serious downdrift erosion problems. Essentially all the beaches along this coastal should be considered as being strongly dependent. The beaches at the western end of this frontage have been deprived of a source of material supply ever since the River Conwy was deflected onto its present course to the west of the Great Orme. The problems of reduced material supply have gradually spread in an eastward direction. These problems are compounded by the proliferation of coastal defences along this frontage. The defences while necessary from the point of view of preventing flooding, have in many places exacerbated erosion by causing beach scour in front of them. At the present day most of the frontage from the Great Orme to the River Dee is suffering from coastline recession. Beaches between the Dee and the Mersey are also suffering from erosion despite the presence of very extensive sand banks at the mouth of the Dee and within Liverpool Bay. The Dee estuary acts as a vast sink for muds and silts but it is by no means a zero-transport boundary. Sand is transported across the mouth of the Dee in an eastward direction via the West Hoyle Bank and East Hoyle Spit. It is then driven eastwards accreting at the mouth of the Mersey on the Great Burbo Bank. With the training of the Mersey approaches the Crosby channel can now be considered as a fairly effective barrier to littoral drift. It is unlikely that any coastal engineering works west of the Crosby channel will have a significant impact on the coastline to the east, or vice versa.

River Mersey to the Lune estuary

Between the estuaries of the Mersey and the Lune lie continuous sand beaches. The dune belt of south west Lancashire is one of the largest areas of wind blown sand, extending from Bootle docks to Southport. Sand gives way to salt marshes within the Ribble estuary, however there is a nett drift at the estuary mouth via the sand banks of Horse Sand and Crusader Bank. There is also believed to be some onshore sand transport at the estuary mouth as a result of the landward residual drift near the sea bed. Further northward continuous sand beaches extend to the mouth of the Wyre at the southern end of the Lune estuary. There is accretion on both the south and north shores of the Ribble and thus the whole stretch from the Mersey to the Lune can be considered as one coastal unit.

The Lune Estuary and Morecambe Bay

Both the Lune Estuary and Morecambe Bay are shallow water areas in which large expanses of sand and mud banks are exposed at low tide. Both areas contain vast quantities of silt and sand probably deposited there by glaciers. The sediments within the Lune estuary also contain large quantities of mud and large areas of saltmarsh which have developed as a result of the more sheltered conditions in that area. These areas are normally well sheltered from wave attack but during large surges the coastal fringe is very susceptible to flooding. Both the Lune Estuary and Morecambe Bay are effectively sinks for the deposition of sand, silt and mud. Morecambe Bay has a deep water channel called the Lune Deep which allows wave action from the south and south-west to propagate to the south shore of the Bay. Only in the upper reaches are conditions sufficiently sheltered to allow the deposition of silt and mud and the development of saltmarsh. Both areas can be considered as independent units subject to the same type of problems with regard to coast protection, namely flood induced damage.

Morecambe Bay to St Bees Head

There is a continuous stretch of sand foreshore extending from the south end of Walney Island almost to St Bees Head. In places the sand is backed by storm shingle ridges. Littoral drift is weak and is generally in a nett southward direction. The coastline has a number of rivers and estuaries (principally Duddon and the Esk) which are infilled with sand and do little to interrupt the movement of material from one side of the estuary mouth to the other. The coastal stretch is largely undeveloped and can be considered as one coastal unit. Due to the weak littoral drift it is unlikely that coast protection works, for example on Walney Island, would have a significant impact on the coastline to the north.

St Bees Head to the Solway Firth

St Bees Head marks an important divide in the direction of littoral drift and thus forms a natural "coast protection boundary". To the north of St Bees Head the littoral drift though not strong is predominantly northerly. This drift is partly interrupted by the harbours of Whitehaven, Workington and Maryport. Much of the backshore in this area has been reclaimed from the sea by the tipping of mine waste. Now that the deposition of mine waste on the foreshore has largely ceased there is rapid coastline recession between Whitehaven and Maryport. Further northward from Allonby into the Solway Firth the coastline becomes more natural consisting of sands and muds on the lower foreshore and shingle ridges on the backshore. Within the estuary itself there are extensive areas of saltings. These saltings are generally in a healthy condition although there is some local erosion due to the meandering of tidal channels. The frontage can be considered as one large coastal unit. Within this unit there are a number of smaller cells formed by the harbours of Whitehaven, Workington and Maryport. Because drift bypasses these harbours the frontages between them should be treated as "partly dependent" cells. The Solway Firth itself forms a natural sink for fine sediments and thus forms a natural boundary to this frontage.

3 COASTAL PROCESSES

3.1 Geological background

Along the coastline of North-West England between the Great Orme headland and the Solway Firth the solid geology ranges from the Carboniferous limestones and coal measures to the marls and sandstones of the Triassic period (New Red Sandstone) (200-350m years ago). However these rocks have little direct influence on the coastal scenery except between Maryport and St Bees and the Orme headlands on the Welsh coast. For the most part the rocks are overlain by thick formations of superficial unconsolidated glacial and post glacial materials and the present coastline has been cut in these sediments.

Carboniferous limestones are exposed around the coast of Morecambe Bay and along parts of the coast of North Wales. With the exception of the headlands of the Great and Little Orme these limestone clifflines are not usually under current marine attack. Millstone grits and sandstones underlie the coast along the Heysham peninsula but are only exposed in the low cliffs at Heysham Head. The coal measures between St Bees and Maryport have led to the industrial development of this particular stretch of coast. Finally most of the remaining parts of the north-west coastline, that is parts of North Wales, the Wirral, Lancashire and Cumbria, are underlain by younger Triassic sandstones which are only exposed as the impressive cliffs at St Bees.

The coastal outline has developed to its present configuration since the end of the Ice Age that is over the past 10000 years. During the Pleistocene period the whole area including the floor of the Irish Sea was covered by massive ice sheets which deposited vast thicknesses of debris, generally known as boulder clay or glacial till. The eventual retreat and melting of the ice contributed to a global (eustatic) rise in sea levels. The Irish Sea area was gradually submerged and Ireland was eventually separated from mainland Britain. The glacial deposits were sorted by wave action and the boulder clay was rapidly eroded with the advance of the surf zone.

Rates of sea level rise in this area have been complicated by isostatic adjustments of the land mass due to the release of the weight of the ice. Thus post glacial sea levels have fluctuated relative to land levels and there is evidence of levels both higher and lower than at the present day. Gresswell (Ref 1) proposed that a single marine transgression created a fossil cliff of boulder clay some miles inland, called the 'Hillhouse coastline', and forms a marked present day feature in south-west Lancashire and the Wirral. Other terrace features in Morecambe

Bay and the Solway Firth have also been attributed to periods of higher sea levels.

During subsequent periods of lower sea levels silts, clays, and peat were laid down over boulder clay under estuarine and lacustrine conditions. The low lying 'Mossland' area to the seaward of the 'Hillhouse coastline' was formed in this way. The sea has since readvanced submerging these deposits which are now sometimes exposed in the intertidal zone for example in Penrhyn Bay and at Formby Point. The slow but progressive rise in sea level is continuing and implies that coastal recession along exposed coasts with an inadequate littoral supply of sediment is likely to continue in the long term. The glacial sediments and the erosion of boulder clay cliffs have produced a vast reservoir of sands and muds which have been redistributed by wave induced littoral drift and tidal currents to accumulate within the estuaries and bays and form offshore banks.

3.2 Coastal processes

The coast of the north-west of England forms the southern and eastern shores of the Irish Sea. The coastline is mostly formed in soft glacial and post glacial unconsolidated materials which have receded rapidly during the post glacial period. In general the stretches of open coastline are subject to continued long term recession and foreshore lowering while accretion is occurring in the estuaries and the bays. Much of the coastal region is low lying fringed by sand dunes, salt marsh and shingle ridges which provide limited natural protection from the sea. Elsewhere for example in North Wales, the Wirral and along the Fylde coast sea defences have 'fixed' the high water line.

The coastline faces to the north and to the west and therefore is exposed to the prevailing winds from the western sector and to storm conditions from the north-west. However fetches from the south and west are limited by Wales and Ireland respectively and from the north by the Scottish coast. The Isle of Man produces some sheltering effects by significantly reducing fetches for example from the north-west along the coast of North Wales. The relative wave exposure of any part of the coastline therefore relates to its orientation and the direction of maximum fetch. Offshore bathymetry further complicates the pattern of wave approach and in places sand banks provide some shelter, for example in Liverpool Bay. The whole area is subject to a large tidal range. The coastline is particularly vulnerable to increased water levels and surge conditions which can lead to widespread flooding. The devastating effects of floods in November 1977 has prompted the upgrading and reinforcement of many defences and embankments in the region.

The overall trend of littoral drift is from west to east along the coast of North Wales and then northwards to the Solway Firth. However the magnitude of the drift varies with wave exposure and the pattern is segmented into sub-units by the estuaries and bays where tidal currents dominate the movement of sediment. The wide estuaries of the Dee, Ribble, Solway and Morecambe Bay are sinks for marine sediments and have a long history of siltation and salt marsh development. In general Liverpool Bay has been accreting material as wave and tidal current forces within the Irish Sea produce a net eastward drift of sand. But long term erosion along the North Wales coast has been associated with inadequate inputs to the littoral drift and localised erosion on the Wirral and at Formby Point is probably associated with changes in bed and channel configurations within the bay either natural or induced by man.

North Wales - Great Orme to the Point of Air

Along the coast of North Wales east and downdrift of Great Orme the beaches are suffering the effects of long term erosion and lowering of foreshore levels promoted by the gradual diminishing supply of available beach sediments and exacerbated by man's activities.

At Great Orme's Head steep cliffs of Carboniferous Limestone are subject to occasional landslips. Llandudno is situated on Ormes Bay which is enclosed between the limestone promontories of the Great Orme to the west and the Little Orme to the east. There is an extensive flat sandy beach with shingle on the upper foreshore. The bay faces north and to some extent is sheltered from the west and north-west by the Great Orme which also acts as a barrier to the movement of sediment into the bay from the west. Similarly the Little Orme effectively contains material within the bay and very little is lost to the east. The extension of the Great Orme beyond the general coastal line of North Wales induces a clockwise eddy circulation in the general west to east tidal stream which promotes a small localised flow in the eastern part of the bay. For the most part the beach appears to be stable although sand levels are lower in the west. At the eastern end of the bay sand is replaced by shingle at the high water mark which is some distance from the sea wall. Littoral drift is generally low but some littoral movement of sediment occurs from west to east within the bay during winter storms.

Penrhyn Bay faces north-east between Little Orme and Rhos Point. Prior to the 6th century the River Conwy flowed into the sea along the Afon Ganol to the east of Great Orme into Penrhyn Bay supplying vast quantities of sediments to the littoral zone. At that time the coastline is thought to have been 2 to 3 miles to the seaward of its present position. Land subsidence resulted in the penetration by the sea and the course of the River Conwy was diverted to enter the sea to the west of Great Orme. The cutting off of this supply of sand and shingle to the coastal zone east of Great Orme is thought to mark the onset of the long term recession not only in Penrhyn Bay but along the North Wales coast in general since present day supplies of material are limited to local erosion of the headlands of Great and Little Orme.

The intertidal foreshore at Penrhyn is now much depleted of sand and shingle and consists mainly of rocks and boulders washed out from the localised erosion of boulder clay cliffs on the east side of the Little Orme. Peat and forest beds are revealed at low tide. The bay is only significantly exposed to waves east of north but the refraction of waves around Little Orme and the configuration of the bay gives rise to edge-wave effects inducing a pronounced easterly drift of sediment. A drift reversal due to tidal eddies in the flood stream within the bay similar to that in Ormes Bay is only likely to be significant during calm conditions. Very little beach material actually reaches Penrhyn Bay from the west around the Little Orme but the bay is less effectively enclosed at the eastern end and prior to the construction of the breakwater at Rhos-on-Sea beach material was readily transfered eastwards into Colwyn Bay. The low lying land behind Penrhyn Bay is protected by a promenade sea wall but problems of wave overtopping and flooding have persisted where the sea wall is under direct wave attack. During north-westerly gales coincident with high tides large storm waves travel along the sea wall increasing in height as they progress from west to east. This situation has also served to exacerbate the erosion as beach levels have continued to fall in front of the wall. It has been proposed to construct two shore-connected breakwaters and renourish the intervening beach between with a mixture of sand, shingle and cobbles in an effort to protect the sea wall in the west part of the bay from direct wave attack. The effect on the coast downdrift to the east is likely to be minimal providing the beach is well nourished (Ref 2).

Now built (1989) plus rock revetment to Rhos Point (1992)

At Rhos-on-Sea the construction of a rock offshore breakwater has led to the accumulation and redistribution of sediment along the adjacent coastline. The breakwater has been effective in trapping the small drift of material eastwards from Penrhyn Bay as well as attracting a reverse westerly drift of material from Colwyn Bay to the east and finer mud from offshore. However this has exacerbated the already falling sand levels along Colwyn Bay. Some recent sand accumulation at the toe of the wall is likely to be derived from offshore but is on a very small scale. Beach levels at Colwyn are likely to continue to deteriorate as material is transported both to the east towards Pensarn under littoral drift and to the west under tidal currents.

- Rock revetment and long groynes have resulted in increased levels
- Shingle beach to east

Further eastwards towards Llandulas there are increasing proportions of shingle in the beach material which is built up into a wide shingle ridge in places. The River Dulas is deflected eastwards by such a bank of shingle. Shingle fringes much of the shoreline eastwards to Rhyl. The flat sandy foreshore often with exposures of peat and clay show the effects of a progressive reduction in levels and 'rolling

- New material from Penmaen Head
- Rock revetment Llanddulas
- Rock groynes Llanddulas
- Timber groynes - tip -
- Towyn Wall

back' of high water mark. The low lying land behind and urban development there have necessitated the construction of sea walls and revetments to reduce the risk of flooding. Groyne construction has followed as foreshore levels have continued to fall in front of these walls but as a result the amount of beach material reaching the downdrift frontage further east at Prestatyn has been reduced. Extraction of beachmaterial west of Rhyl during the last century for the construction of the Liverpool Docks has contributed to this situation. Map studies show that parts of the Rhyl to Prestatyn foreshore have been reduced in width by 50% to 500m over the past 100 years as the high water line now 'fixed' by the positions of the sea walls has been unable to recede landwards (Ref 4). Timber Groyne systems have been ineffective in promoting any accumulation of sand. Foreshore erosion, due to tidal scour along gullies close inshore and wave reflection from the walls, now exposes theunderlying clay substratum and with a lack of sufficient sand supply this process is likely to continue.

Bars probably [illegible] slowly evolving in cyclic erosion/accretion

Recharge + groynes — Prestatyn — losses to east

East of Prestatyn to the Point of Air natural sand dunes form the only coast protection against the sea. The wind blown sand from the offshore banks exposed at low tide accumulates under onshore wind conditions and the easterly littoral drift moves the sand towards the mouth of the Dee estuary. Although the area is fairly remote it has nevertheless suffered erosion and damage close to access points. Parts of the dunes are now fenced off to prevent such damage by the public. The Point of Air forms a prominent 'ness' of sand and shingle with a coastal belt of high dunes capped by marram grass.

due to trampling

Dee Estuary

The estuary of the River Dee forms a wide funnel shape 8 km wide at its mouth and 30 km in length up to Chester. Large expanses of drying sand and salt marsh cover about two-thirds of the area at low spring tides. The estuary has straight sides marked by a low cliff or break of slope cut into boulder clay for the most part. The line of the estuary may have originated as an overdeepened (possibly glacial) fault trough. The rock floor is now over 50 m below OD and is covered to that depth by post glacial alluvial sediments. The history of the Dee has been one of gradual siltation, salt marsh growth and deterioration of channel depths as post glacial sea level rise has ceased to balance the rate of deposition which has been accelerated by man's activities (Ref 5).

Silting has been a problem for navigation to the port of Chester since the Middle Ages and other ports have since been located downstream. Large areas of marshland have been reclaimed and navigable channels regulated. These together with the natural processes of siltation have led to a progressively smaller tidal volume and in turn to an acceleration of natural accretion. The shape of the estuary widening seawards means that tidal scour is ineffective in removing sediment on the ebb which has itself been reduced by the control of land water discharges, while strong flood currents encourage material to move up the estuary from Liverpool Bay. All these factors have led to an area which is and will continue to be a major sink for sand, silt and mud. During the 18th century the course of the river below Chester was diverted from the lower north side of the estuary to the Welsh bank by excavating a new channel through well consolidated saltings and restraining its movement by the construction of training walls. By

1916 26% of the total area of the estuary at high water had been lost by reclamation between the new channel and the east shore. By 1983 deterioration due to loss of tidal storage had been so severe that efforts to maintain navigation depths in the upper estuary were abandoned. Marker estimates that silt and sand have collected on the marsh at a rate of 25mm/year and notes that a sandy beach existed at Parkgate in the late 1930's but within 10 years it was covered by salt marsh which has continued to expand along the east shore to Heswall. The introduction of Spartina grass at Connah's Quay in the 1920's has also accelerated the rate of growth of salt marsh.

Some bank erosion along the estuary takes place as a result of meandering channels and wave action. The land adjacent to the estuary is low lying and is protected from flooding by embankments behind the marsh around much of the periphery. Many engineering studies of the Dee estuary have been carried out relating to the problems of navigation and to various proposals for road crossings and to the feasibility of a barrage scheme (Ref 6).

The Wirral Peninsula

The Wirral Peninsula lies between the estuaries of the Rivers Dee and Mersey. The coastline is formed in low lying boulder clay overlain by post glacial deposits and which for the most part has been retreating rapidly. Rock outcrops are limited to the north-east and south-west, at Perch rock, New Brighton and off Hilbre Point. The main defences are substantial sea walls built to alleviate problems of flooding and wave overtopping. The low lying land between Birkenhead and the Wallasey embankment is known as the Wallasey Pool and is thought to be a past sea channel of the River Mersey with the north-eastern corner of the

Wirral at New Brighton forming an island. Before the construction of the Wallasey embankment there was a danger that the sea would break through and a permanent channel to the Mersey re-established.

The Wirral is exposed to the maximum fetch occurring across the Irish Sea and this coincides with the direction of the strongest prevailing winds from the west to the north-west. The East Hoyle sand bank provides some protection at the western end of the peninsula where some accretion has occurred. However, training walls in Liverpool Bay have had the effect of reflecting incident wave energy onto the north-east Wirral coast so increasing the exposure of the shoreline to wave attack. Sediment derived from the North Wales coast and offshore in the Irish Sea tends to be transported in a net easterly direction along the North Wirral coast and into the Mersey estuary. Studies of the East Hoyle Bank have shown that sand movement is strongly influenced by wave induced currents and the effect of tidal currents appears to be minimal. Tracing experiments show the movement to be in a west-east direction although at a relatively slow rate (Ref 7). However, littoral drift at the eastern end in the mouth of the River Mersey is more complex due to the interaction of waves and strong tidal currents.

The Wirral coast has a history of long term erosion and shoreline recession. The changing pattern of the offshore sand banks, particularly the East Hoyle Bank, have important consequences on the rate of erosion along the shoreline for example at Dove Point. Gradual shoreward migration of the bank initially increases erosion as a tidal channel is pushed closer inshore until it is eventually infilled by siltation. Erosion of the seaward face of the Leasowe dunes has progressed steadily since measurements were taken in

1882 reaching a maximum rate of about 1.5 m/year (Ref 8). The dunes remained unprotected from wave attack until recently with the construction of a clay embankment covered by rip-rap. Rock breakwaters were also constructed at either end of the frontage to reduce any 'end' effects created by the walls to each side.

Elsewhere along the coastline of the Wirral general erosion and foreshore lowering has been taking place exposing the clay substratum on the foreshore. These changes in beach level are probably related to the changes that have taken place on the offshore sea bed in Liverpool Bay and have been accelerated by the adverse effects of the sea walls themselves. Foreshore lowering at New Brighton at an annual rate of 0.3m between 1933 and 1945 prompted the construction of groynes in the 1940's with only limited success in attracting beach sediments (Ref 9). In the past 25 years beach levels have continued to fall at a similar rate and this has led to the recent construction of several submerged shore connected and offshore breakwaters designed to intercept waves and reduce tidal scour.

The Mersey Estuary

The outer estuary of the River Mersey in Liverpool Bay consists of extensive sand banks exposed at low water. Shipping crosses the bay by way of the main navigation channel, the Crosby Channel, between training walls of tipped stone over a distance of 15 km before reaching the Narrows. Beyond the Narrows lies the large tidal basin of the upper estuary. Siltation in the upper estuary of the Mersey has long been a problem in providing navigable access to the docks upstream. The source of the material appears to be from Liverpool Bay and a net landward drift of water near the bed of the estuary carrying the sand upstream. The state of the tide appears to have little effect on the rate of landward drift. It has been shown by physical models of the estuary that the construction of the training walls in Liverpool Bay have altered the sediment circulation pattern thereby increasing the supply of material to the mouth of the estuary. Another factor contributing to siltation in the upper estuary has been the partial stablisation of the movements of the low water channel which usually provide a natural flushing of accumulated sediments. Both of these factors have led to the reduction of the tidal capacity of the estuary and thus promoted further secondary sedimentation (Ref 9). Recent studies based on the examination of chart evidence and computer simulation techniques have catalogued the bed changes in the River Mersey (Ref 10 and 11). Such information about the changes in the estuary and the processes of sediment circulation have important implications for the nature and location of the dumping of various wastes (sludge, dredged spoil and colliery tailings) at sea in Liverpool Bay (Ref 12).

South-West Lancashire - the Mersey to the Ribble

The west facing coastline of south-west Lancashire is moderately well protected from wave action by the sand banks in Liverpool Bay and in no direction is the fetch greater than 200km. The coastline is characterised by a wide flat sandy foreshore backed by sand dunes. About 1km offshore and running parallel to the beach is the deep water entrance channel to the River Mersey. The low lying area inland called 'Mossland' stretches from the north of Liverpool to become part of Martin Mere east of Southport. Much of the area lies below the level of mean high tide and is therefore vulnerable to marine inundation, the only protection being the naturally occurring coastal sand dunes. At present there are areas where the dunes are relatively narrow and may not provide the necessary protection if subjected to a combination of high tide and storm surge attack.

The sand dunes of South-West Lancashire form one of the largest areas of wind blown sand in Britain stretching northwards from the docks at Bootle to Southport where they merge with the salt marshes of the Ribble Estuary. The dunes, which have a maximum inland extent of 4km and rise to a height of 20m at Formby, are backed by flatter sand links.

Accretion along much of the coast during the 19th century has been followed by the progressive recession of the shoreline at Formby Point since about 1906 at an average rate of some 5 to 6m/annum. Coastal erosion at Formby is caused by sand being transported away from the Point by wave action. Off Formby there is a point of net drift divergence with sediment being transported northwards towards the River Ribble and southwards towards the River Mersey. Sand is now not being replaced in sufficient quantities from offshore to prevent erosion of the sand dune belt and reduction of the level of the foreshore exposing the underlying Holocene deposits in many areas.

The zone of erosion has gradually affected an increasingly wide frontage, spreading northwards at a rate of 100m/year and southwards at 33m/year (Ref 13). However at Southport to the north and at Raven Meols south of Formby Point the coast is still accreting. The onset of dune erosion was probably caused by changes in the morphology of the offshore zone coinciding with major construction, dredging and dumping relating to the training of the Outer Mersey estuary as it crosses Liverpool Bay. The resulting changes in the configuration of the banks and channels have subsequently modified the inshore pattern of wave attack and tidal current activity and interrupted the transport of sand from the offshore sea bed. Evidence also suggests an increase in the incidence of westerly type weather and associated storm systems since the turn of the century which could have encouraged erosion. Trampling of embryo dune vegetation and erosion of deep gullies in the foredune ridge by pedestrians were important additional factors leading to accelerated erosion at Formby before 1978. Dune restoration work undertaken since that time has significantly reduced the severity of the problem.

The intertidal zone increases northwards from about 500m width at Formby to 3km at Southport. The foreshore is characterised by ridge and runnel features up to four in number (termed fulls and lows by Greswell), in the inter tidal zone. The bars appear to be "permanent" features approximately 1-1.5m high and 150m from crest to crest. They lie at an angle of about 8 degrees to the coastline but parallel to the crest of the westerly waves as they are refracted inshore. It appears therefore that the banks are adjusted to the predominant direction of wave approach. At Formby Point the bars are closely spaced but further northwards in the area of accretion their spacing increases and they are formed further offshore. The bars are destroyed by storms but are capable of re-establishing themselves rapidly under calmer wave conditions. The littoral material is transported northwards along the outer bars on to the offshore banks such as Horse Bank, south of the Ribble estuary. This bank provides the coast north of Southport with considerable shelter from wave attack and saltmarsh has developed along the south bank of the estuary. However, strong tidal currents in the inshore channels are still capable of transporting fine sand and silt. Under storm conditions coinciding with high water levels, the banks are submerged and waves break inshore causing widespread flood damage.

The sandy bed of the Ribble estuary completely dries at low water except for the main navigation channel. Before training works and dredging (started in the mid 1800's) were carried out to improve the navigation of the River Ribble to the Port of Preston 25km upstream the estuary was crossed by a large number of low water channels which constantly changed their alignment. Now the flow is restricted to the north channel with siltation in the earlier channels and accretion on the adjacent sand banks. In the upper estuary saltings advanced from the original bank almost up to the training walls reducing the tidal storage. This process gradually progressed downstream and has been accompanied by reclamation since the middle of the 19th century to the present day especially on the south side of the estuary. The rate of salt marsh growth has been accelerated by the spread of Spartina grass.

The net drift of sediment northwards continues across the mouth of the Ribble estuary but the actual pattern of sand movement is complex. There is a net influx of sand from offshore and large quantities of sand remain in the vicinity of the estuary mouth (Ref 14). Changes in the tidal behaviour in the estuary have also led to accretion on the banks at the mouth of the estuary. At Lytham St Annes on the north shore of the Ribble the littoral drift is variable depending on the prevailing wind conditions ie southwards towards the Ribble during north-westerly winds and northwards during the more prevalent south- west winds. As a result the net drift is small and the foreshore is accreting. Sand is currently extracted from the foreshore at Lytham St Annes (Salters Bank) and from the Horse Bank. Clearly the rate of extraction may cause changes in the wave climate and sediment balance inshore and is closely monitored such that no adverse effects are experienced along the adjacent shoreline (Refs 14 to 16).

Fylde Coast - the Ribble to the Wyre

The natural recession of the boulder clay cliffs of the Fylde coast is now halted and the position of high water fixed by massive sea walls which are continuous for 20km from Squire's Gate, Blackpool to Fleetwood. Prior to this the rate of erosion at Blackpool used to be approximately 2m/annum. However erosion has continued along this frontage resulting in falling beach levels and undermining of the sea walls which have been extended by sloping aprons. The gently sloping sandy foreshore is about 500m wide at low tide but is completely covered at high tide. The coastline is aligned north to south so clearly the direction of drift will depend on the direction of the onshore winds. Since the fetch for winds from the south sector are greater and can therefore generate greater wave heights there is a net south to north drift along the Blackpool frontage. However offshore banks in the Ribble estuary provide relatively sheltered conditions inshore at the southern end of the frontage and it is more difficult to determine the net direction of drift. Between Squire's Gate and Crusaders Bank there appears to be a zone of zero net drift while further south the shape of the estuary leads to a predominance of wave activity from the north and accumulation at the mouth of the Ribble estuary.

A limited analysis of beach profiles at Blackpool (Ref 15) show beach levels to be relatively stable. These long term trends should be taken with caution since only a relatively small number of surveys (10) were used over the 25 year period of study. However the results highlighted the extreme fluctuations in beach levels (up to 3m) in the short term especially close to the toe of the sea walls as a result of wave reflection and scour. The study concludes that the beaches at the northern end of the frontage are marginally healthier than those at the south and the analyses so far have not identified whether the frontage as a whole is eroding or accreting. Finally the report concludes that the dredging at Lytham St Annes has not adversely affected the beaches at Blackpool.

Further north at Fleetwood the intertidal zone narrows and the proportion of shingle on the upper foreshore increases as wave exposure and therefore littoral drift from the south increases. At Rossall Point the coastline turns eastwards and forms a recurved spit into the mouth of the River Wyre. The coastline to the east of the Wyre to the River Lune is low lying and fringed with the saltings of the Cockerham and Pilling Marshes. Historically storm damage and associated flooding have been persistent problems along this coast. Most of the original clay embankments have therefore been reinforced and upgraded.

Morecambe Bay

Morecambe Bay forms a large shallow indentation of the Irish Sea extending from the Lune Estuary to Barrow-in-Furness on the south Cumbria coast. At the head of the bay are the wide estuaries of the Rivers Kent and Leven separated by the Cartmel peninsula. The bay was formed by post glacial submergence of a number of deep river valleys which have since become infilled with sediments. The coastline is mostly formed in unconsolidated Pleistocene and Holocene deposits. The estuaries of the Lune, Leven and Kent and the eastern part of the bay at Silverdale, Carnforth and Hest Bank are characterised by large expanses of saltings which in total comprise about 5% of the area of saltmarsh around the British coast. The saltings provide a valuable natural defence from wave attack except under conditions of high spring tides and storm surges although some areas are currently suffering severe erosion. Rock outcrops in the form of cliffs and shore platforms occur along very limited sections of the coast, for example at Heysham Head (Millstone Grit) and Humphrey Head at the south-east tip of the Cartmel peninsula (Carboniferous Limestone). Between Silverdale and Arnside there are extensive cliffs of limestone which form promontories at Blackstone Point and Jenny Brown's Point and which back areas of rapidly eroding salt marsh.

The remaining coastline is backed by low ground underlain by glacial and post-glacial deposits. Eroded drumlin features (small hills of glacial debris) form cliffs rising up to 30m. The larger pebbles and cobbles which cannot be moved away by wave action remain at the foot of the cliff and often extend seawards for some distance forming what are locally known as a 'scar' or 'skear' and represent the former extent of the drumlin.

The bay acts as a large sink of sediments, mainly fine sand of glacial origin with finer silt and muds found in the more sheltered low energy environments at the heads of the estuaries. The sediments reach thicknesses of 80m over the rock floor in places. The large tidal range results in over half the area of the bed of the bay being exposed at low spring tides. The wave pattern within Morecambe Bay is very complex as the waves are refracted over the numerous banks. Significant wave heights are generally low because fetches are limited in all directions except in a narrow window to the south-west and water depths are insufficient to allow the propagation of large waves. However the height of both high and low water may be raised considerably when strong winds blow from between south and west for any duration. A storm surge on the 11- 12 November 1977 produced a surge height of 1.85m and caused extensive coastal flooding and damage. This was followed two days later by an even greater surge although it arrived at low water and had little adverse effect. Another serious storm surge affected Morecambe Bay on 31 January-1 February 1983.

Sediments are moved into the bay both by littoral drift and by the tidal streams. Within the sheltered conditions of the bay alongshore drift is negligible but the channels and sand banks are highly mobile and rapid movements occur especially during conditions of high tides and south-westerly storms. Tidal currents associated with the flood tide are capable of moving large quantities of the fine sand and mud into suspension and therefore sediment is continually moving around in the bay. Changes in the configuration of the sea bed in the south-eastern part of the bay have been traced since 1845 from Admiralty charts and more recent surveys suggest a long term north-west to south-east migration of the banks and channels off Heysham in a cyclical fashion (Ref 17). On a tidal time scale radioactive tracing experiments have shown sediment motion orientated to the tidal direction with Heysham Lake acting as a flood channel and Grange Channel acting as an ebb channel such that sediment circulates in an anticlockwise direction (Ref 18).

Sediment movement is strongly influenced by tidal streams and has been demonstrated by sea bed drifter investigations to show the net drift of water close to the sea bed (Refs 19 and 20). Two distictly different patterns of drift were revealed: an anti-clockwise movement in the outer part of the Bay directed towards the southern end of Walney Island and the south Furness coast and a north-easterly movement on the inner part directed towards the head of the bay. Both these movements are governed by tidal currents which may be reinforced by wind-wave induced drifts.

Changes in the positions of the channels and banks have very significant effects on the adjacent coast within the bay. The growth of the salt marshes has fluctuated in relation to the position of the low water channels of the principal rivers flowing into the Bay and at earlier times to efforts to reclaim land and train the rivers. A characteristic feature of the saltmarshes of Morecambe Bay is the presence of cliffs, which may be up to 1 m high, often separating large flat terraces. Similar terraces are common in the Solway and Ribble estuaries. The cliffs represent the eroding edge of the marsh as the low water channel moves inshore. At a later stage when the channel moves away, saltmarsh gradually redevelops at a lower level.

The movement of the Kent channel eastwards close inshore (probably in the late 1970's) has initiated a phase of serious erosion along the the saltmarshes of Carnforth and Silverdale. Prior to the 1850's Silverdale was a popular bathing resort but then began to decline as the foreshore became muddy and marsh developed. By 1893 marsh covered an area of 127ha (314 acres) but was destroyed in the early part of this century as the Kent channel swung back to the east. In 1955 the channel returned to the Grange side and the saltmarsh re-established itself at Silverdale. So far in the current phase of erosion the width of the marsh at Silverdale has been reduced to about one fifth (200m) of its former extent and the marsh has been deeply incised along the creeks for example at Jenny Brown's Point. In places the limestone cliffs behind the marsh are actively developing under present marine attack. In contrast the periods of erosion at Silverdale have coincided with accretion on the west side of the Kent estuary and the rapid spread of Spartina along the shore at Grange-over-Sands and Kent's Bank.

Proposals to build one or more tidal barriers across Morecambe Bay were made over twenty years ago with the aim of developing a number of large inland freshwater reservoirs and possibly providing the added benefit of carrying a main road to improve access to the Cumbrian coast (Ref 21). The effect of these water conservation works on the tides, currents and the sediment regime in the areas seaward of the proposed works have been investigated by means of physical model techniques (Refs 22 and 23). Results showed that the construction of either one barrage across the bay or separate barrages across the estuaries of the Kent and Leven would have the effect of reducing the tidal volume and ebb velocities. This would lead to an increase in the rate of accumulation of sand and channel siltation such that Heysham could no longer function as a deep water port without dredging. Also many of the saltmarsh areas behind the barriers would become freshwater 'polders' and new areas of saltmarsh would eventually develop to the seaward of the barrier on the eastern side of the bay.

While much of the coastline of Morecambe Bay is relatively sheltered, the town frontage of Morecambe receives lees protection from the Furness Peninsula and is more exposed to waves approaching from a larger sector to the west. Much of the land area around Morecambe is low lying and in part below the level of extreme tides. Sea walls extend along a 7km frontage. The walls are subject to wave attack at high tides and wave overtopping and flooding are frequent problems in heavy seas. There has been a gradual loss of sand and lowering of beach levels promoted by scour and wave reflection such that much of the foreshore now consists of stones embedded in silt with only a fine veneer of sand. Additional coastal protection measures have recently been constructed such as a wave return wall at the back of the promenade. Present works include the construction of several rock groyne structures to encourage sand deposition, rock armouring of the toe of the sea wall and renourishment of the beach.

The mainland coast of the Furness peninsula between the estuaries of the Leven and the Duddon is sheltered by Walney Island which lies south-east to north-west just offshore. The island is about 20km long from North End Haws to South End Haws and 1.5km wide opposite Barrow-in-Furness but narrows irregularly to the north and south. A narrow channel separates the island from the mainland and was probably formed about 8000 years BP during the post glacial sea level rise. The island consists entirely of superficial deposits of glacial boulder clay, sand and gravel, alluvium, wind blown sand and shingle. These materials offer little resistance to wave attack on the western shoreline where the low till cliffs provide the beaches at their foot with a continuous supply of beach material. The wide sandy foreshore is backed by a steep shingle upper beach with boulder scars offshore. Sand bars (ridge and runnel features) on the lower foreshore are found especially at the north end of the island and open northwards at a small angle from the coast towards the Duddon estuary. The eastern shore adjacent to the Walney Channel is well sheltered from waves and tidal streams within the channel seldom reach velocities sufficient to move sediment. Some narrow shingle beaches are found but elsewhere salt marshes have developed.

The effect of long term marine erosion on the western side of the island has been a gradual narrowing of the island as a whole. Phillips and Rollinson have catelogued detailed coastal changes from cartographic evidence (Ref 24) and one area that appears to be particularly vulnerable is between Hare Hill and Hillock Whins where the island is at its narrowest, now less than 500m wide.

Phillips and Rollinson also measured beach profiles at monthly intervals over a two year period from October 1963 to October 1965. The main changes in the profiles related to the formation and combing down of swash bars on the upper beach with the occurrence of offshore and onshore winds respectively while the lower beach showed the gradual landward migration of sand ridges in response to wave and tidal conditions. The greatest changes in the beach profiles were associated with periods of winds approaching from the south-west over the open Irish Sea, ie with maximum fetch and over the maximum water depths, which results in large waves being driven onshore with the minimum of refraction.

The northern and the southern ends of Walney Island curve eastwards suggesting that beach material from the west coast is being carried both to the north into the Duddon estuary and to the entrance of the Walney Channel in the south. Sand dunes have developed at both ends. Accretion along the sand and shingle spit at South Haws Point in the south-east was interrupted by the commercial gravel extraction in the latter part of the last century resulting in a reduction of the size of the spit. However since the extraction ceased in 1900 a recurved spit has been re-established and by 1970 had grown to a length of about 500m. Recurved shingle ridges represent the former extent of the spit and earlier stages in its growth. The spit appears to be extending by the addition of banks of shingle which are swept round the south-eastern tip. Refraction causes waves to break at a large angle to the beach which produces a considerable amount of longshore beach drifting from the west. This has been demonstrated by pebble tracing experiments (Ref 24). At the northern end of Walney island there has also been some accretion of sand and shingle and some material probably crosses Scarth Channel to contribute to accretion at Sandscale Haw on the eastern side of the estuary of the River Duddon.

The Duddon Estuary to the Solway Firth

Northwards from the River Duddon towards St Bees Head the coastline consists of low cliffs cut in glacial material, sand and shingle beaches and areas of wind blown sand for example at Haverigg Point, Eskmeals, Drigg and Seascale. The Ravenglass estuary is the result of submergence of the Irt, Mite and Esk River channels and the presence of extensive tidal flats and shoals suggests that it has been or is currently an area of deposition of sediments. However peat deposits exposed in the inter-tidal zone off the Ravenglass estuary demonstrate that the shoreline was at one time during the post glacial period to the seaward of its present position and at a lower level. The direction of littoral drift along this particular stretch of coastline is unclear. The sand spit at Eskmeals and the northward deflection of the River Annas suggest a northward drift to the south of the Ravenglass estuary. However the sand spit at Drigg Point on the northern side of the estuary is clearly the result of a net southerly movement of sediment alongshore. It would appear likely that, since the coast is orientated to the west of south-west, the direction and magnitude of littoral movement of sediment is variable and net rates are relatively small. The accumulations of material within and around the Ravenglass estuary suggest that on balance there is a net influx or convergence of sediment in this area.

The land rises northwards to St Bees Head where high steep sandstone cliffs rise up to 100m. These form the only prominent cliffs of solid rock along the coast of the North-West. The greater resistance of these rocks to wave action has formed a headland standing seaward of the general line of the coast and forming the most westerly part of the Cumbrian coast. Thus St Bees Head creates a divergence of sediment paths with a northward littoral drift to the north of St Bees and a southward drift to the south.

To the north of St Bees rocks belonging to the Coal Measures are exposed and this has led to industrial activities which have had an important effect on the coast between Whitehaven and Maryport. The original source of beach material along this coast was from the cliffs at St Bees Head but in more recent times the primary supply of beach material has been colliery and steel mill waste, such as slag and shale which have been dumped in large quantities on the foreshore and subsequently redistributed by the northerly littoral drift. The width of the beaches has increased substantially and the natural position of the high water line, ie prior to tipping, is in places unclear. Accretion has been greatest to the south of Workington and Maryport where material has accumulated against the harbour arms. Shoreline advance south of Maryport has been of the order of 200m (Ref 25). Now that dumping has been very much reduced in scale due to the closure of collieries and later the steel mill south of Workington, the coastline is generally eroding as a result of the discrepency between the rate of alongshore drift and the reduced rate of supply of new material. South of both Workington and Maryport this erosion seems to have been exacerbated in the recent past by beach mining for aggregate. It seems likely that the erosion will continue at least until the present reserves of waste material are removed.

To the north of Maryport the smooth coastline is cut in boulder clay but is fringed by low sand dunes and shingle ridges. North of Silloth the estuary of the Solway begins to narrow and the inter-tidal zone widens. The south-westerly aspect promotes a convergence of littoral drift and sediments become trapped and eventually deposited within the estuary. Wave activity is reduced as the shelter provided by both the north and south coasts increases upstream. The estuary channels meander across extensive flats exposed at low tide. The sand banks are often veneered with coal dust transported northwards from the Workington area and muds and finer sediments are deposited further upstream and at the sheltered margins. Wide tracts of salt marsh have developed on the south shore of the estuary and in Moricambe Bay but changes in the position of the channels and tidal-induced scour causes the localised erosion of the saltings.

4 WINDS, WAVES AND TIDAL CURRENTS

4.1 Wind and wave climate

The eastern part of the Irish Sea is a relatively shallow semi-enclosed basin having a sea bed of predominantly fine to medium sized sand. Much of the area is open to the prevailing south-westerly winds and despite the lack of very severe wave activity the bed is relatively clean, being regularly disturbed by the combined action of waves and tidal currents.

The coastline is fairly well protected against Atlantic swell and there is only a small gap, between the south-west corner of Ireland and Anglesey, where the fetch is virtually unlimited. The area is therefore one in which wind-wave predictions using radial fetch methods can be used successfully to simulate the wave climate.

There are in fact a number of ways in which wave data can be derived for offshore locations around the coastline. Weather observation stations have measurements of mean hourly wind speed and direction and the data for the more exposed sites can then be converted to "over the sea" wind information. This wind information can then be used to reproduce wave data by means of computer simulation techniques (Refs 26 and 27). Such information can be obtained from the Meteorological Office, Bracknell, in a number of variable formats. The format being dependent upon the type of analysis which is to be carried out. For example a statistical analysis may require the data to be "grouped" while for simulation of real time wave conditions hour by hour listing of data may be required.

One can also use measured wave data which may come from a number of sources. Offshore wave data is collected by weather ships, light vessels and visual ship observations. In the present report a listing is provided of instrumentally recorded data, see below. There is no doubt that visually observed wave information, usually from vessels or lightships, can be valuable in the open sea. Although individual observations may not be particularly accurate the large mass of data usually provides ample compensation. Around the coastline of the United Kingdom, however, there are considerable difficulties in using visually observed wave data for coastal engineering purposes. This is because ship observations are grouped into "sea areas". For the varied exposure around the UK coastline these areas are too large to be applied with any confidence at a particular location.

A report has been prepared for the Department of Energy which uses both existing wave observations and numerical techniques to predict maximum extreme wave heights for a 1 in 50 year storm (Ref 28). The predictions indicate that the maximum wave height in the 50 year storm is likely to be about 18 metres at the southern entrance to the Irish Sea, reducing to about 14m in the eastern part ie off the north-west coast. However, records from the Mersey Bar light vessel, taken over a period of 7 years indicate that maximum wave heights in excess of 6 metres are very rare. These "offshore" predictions thus bear little relation to the inshore wave climate and only give a general picture of the relative severity of wave action around different parts of the north-west coast. Listed below are the known records of the offshore wave climate obtained from an as yet unpublished HRL report (Ref 29).

Offshore wave data for the Irish Sea

Location	MIAS Ref	Lat (N)	Long (W)	Instrument	Mean Water Depth (m)	Period of Data recording From	To
Morecambe Bay	174	53°52'30"	3°30'	swr	22	13.11.56	20.1.59
Morecambe Bay	145			wrb		1974	1976
Douglas, IOM	148	54°08'31"	4°27'17"	wrb	20	13. 6.73	23.4.74
Douglas, IOM	149	54°08'31"	4°27'17"	wrb	20	22.11.74	2.4.75
Douglas Light	801	54°08'36"	4°27'36"	wrb	27	24. 6.80	10.6.81

swr - Shipborne wave recorder

wrb - Wave rider buoy

pg - pressure gauge or sensor

The above information, which has been recorded in relatively deep water (taken as the 20m depth contour or deeper) can be considered as typical for relatively large stretches of coast. However, in order to determine the wave conditions at any particular coastal location requires the use of wave refraction models (Ref 30) to transform the information from offshore to the inshore location. There is also a certain amount of inshore wave data. Such data is usually very site specific and should not be used to extrapolate to conditions at adjacent stretches of coast without the refraction models referred to above. For it to be used at an adjacent site the data would need to be refracted outwards into deep water and then transformed back to the new position on the coastline. This type of transformation is complex and expert advice should be sought as to the suitability of records at any particular site for use at adjacent sites.

Inshore wave data for the north west coast

Location	MIAS Ref	Lat (N)	Long (W)	Instrument	Mean Water Depth (m)	Period of Data recording From	To
Llandudno	-	-	-	wrb	-	Dec 83	Mar 84
Penrhyn Bay	-	-	-	wrb	-	Dec 83	Mar 84
Rhyl	1507	53°25.2'	3°30'	wrb	15	5. 2.85	7.5.86
Hilbre Island	144	53°23'	3°14'	pg	3.5	Jan 69	May 70
Mersey Bar	173	53°32'	3°20'54"	swr	17.5	12. 9.65	12.9.66
Mersey Bar Lv	173	53°32'	3°20'54"	swr		1962	1969
Fleetwood	143	53°57'50"	3°01'02"	wrb	3.5	1.10.74	18.3.76
Heysham	-	54°01'28"	2°56'56"	wrb	9	1. 7.78	30.6.79
Barrow	52	-	-	pg	-	1988	

4.2 Tides and tidal currents

Tidal range

By contrast to the variable and unpredictable nature of wave activity the rise and fall of the tide is both regular and predictable. The effect of the tidal range is considerable in that the breaking point of the waves will vary in position at different stages of the tidal cycle. Thus the effect of wave action can be exerted over a considerable width of the beach. From the viewpoint of the design of coastal defences the magnitude of the tidal range is important in determining the crest elevation of coast protection structures, the likelihood of embankments being overtopped etc.

The whole of the Irish Sea is subject to a large tidal range. In effect high water can be considered as a standing wave whose crest along the north-west coast is at much the same time.

The tidal range increases from west to east. During spring tides the range is about 7m off the Great Orme increasing to 8.4m at Liverpool. North of Liverpool the range is variable, being about 8.3m at Fleetwood, 7.3m at Whitehaven and 8.4m at Silloth. Details of the predicted tides can be found in the Admiralty Tide Tables (Ref 31) but the mean spring tidal and neap ranges at a number of locations around the Welsh coast are as follows:-

Mean Tidal Ranges - The north west coast

Location	Spring Range (m)	Neap Range (m)
Llandudno	6.9	3.5
Hilbre Island	7.7	4.2
Liverpool	8.4	4.5
St Anne's Pier	7.9	3.4
Fleetwood	8.3	4.5
Heysham	8.4	4.3
Barrow Docks	8.1	4.4
Tarn Point (near Ravenglass)	7.4	3.9
Whitehaven	7.3	3.7
Maryport	7.7	4.1
Silloth	8.4	4.6

Tidal currents

In the eastern Irish Sea maximum tidal currents exceed lm/s throughout the area. In river mouths and estuaries the currents alone may have sufficient velocity to carry sand sized material. Within the Mersey Narrows maximum tidal current velocities during mean spring tides are as high as 5½ knots. Such currents can transport sand sized material in suspension.

Apart from tidal currents there are also residual currents (non tidal drift of water) in the Irish Sea which tend to transport muds and fine silts in a landward direction. This is evident from the movement of spoil and sludge dumped in the outer parts of Liverpool Bay. Thus while the sea bed in the Irish Sea generally consists of clean sand there are pockets of mud, particularly in the approaches to the Mersey and off the south Lancashire coast. Such material does not settle out on the open coast because conditions are too disturbed for the deposition of fines.

The open coastline of the north-west is unlikely to be affected by tidal current activity to any significant degree, littoral movement being dominated by waves breaking at an angle to the beach contours. Within the estuary mouths, however, siltation takes place as a result of settling out of sands, silts and muds both from offshore as well as from upstream sources, see Chapter 3. There is also a great deal of sand accretion at the estuary mouths as the result of sand transport as littoral drift. The major estuaries such as the Dee and the Ribble while acting as sinks for material, are nevertheless bypassed as a result of material transported across the nearshore banks.

Surges

In addition to tide level variations there are changes due to fluctuations in the atmospheric pressure. These can either raise or lower the still water level by a considerable amount. On the north west coast much of the low lying alluvial plain is vulnerable to flooding. (During extreme conditions the storm surge elevation could be as high as 2m.)

Wind induced surges thus play an important part in raising water levels above that predicted by "astronomic" tide tables. Recent studies by the Institute of Oceanographic Sciences give predictions on maximum sea levels that can be expected for various return periods (Ref 32). In these predictions both astronomical tides and surges are included in the analysis. For the coastal engineer often it is the joint probability of occurrence of wave overtopping by both waves and tidal levels that is necessary for design purposes. A number of such analytical techniques have been developed at Hydraulics Research and have been used in the design of major flood defence schemes in Britain (Refs 33 and 34).

5 REVIEW OF COASTAL DEFENCES

5.1 Great Orme to the Point of Air

Due to the lack of any significant fresh input of beach material, the north facing coast of Wales, between Anglesey and the Dee is gradually losing its beach deposits. The littoral material is being transported eastwards towards the Dee Estuary and Liverpool Bay and is not being replaced by sand from the west. Coastal defences cover the majority of the coastline and in certain areas beach lowering has been exacerbated by the presence of highly reflective steeply sloping or vertical concrete sea walls.

Four maritime Councils have the responsibility for coast protection on the North Wales coast. They are, from west to east, the Borough Councils of Aberconwy, Colwyn, Rhuddlan and Delyn.

At the western end of this frontage Aberconwy's responsibility extends from some 37Kms west of Great Ormes Head east to the county boundary in Penhryn Bay.

The high steep cliffs from Great Ormes Head to near Llandudno Pier consist of carboniferous limestone with rocky outcrops with practically no foreshore and no beach deposits. This area is subject to landslips from time to time. Cliff stabilisation has been carried out north of the pier. This includes 'rock bolting' concrete buttresses onto the cliff face.

The town of Llandudno is situated on low lying, former marsh land in Ormes Bay between the limestone headlands of the Great Orme to the west and Little Orme to the east. The bay faces north and has a steep shingle beach overlying sand which is exposed at low tide. The shingle beach is groyned at the western end of the bay, to prevent littoral drift from depleting this area of beach material. The headland of the Little Orme acts as a major barrier so alongshore drift is constrained within the bay. The absence of any appreciable quantities of sand in Penhryn Bay also indicates that the Little Orme also arrests sand movement (or possibly deflects it seawards by tidal currents).

South of Llandudno Pier there is a masonry sea wall some 250m long which is maintained by the Council. The beach here is quite low and has a gentle slope. It is covered at high water and there is a proposal in hand to renourish the foreshore from the pier eastwards over a distance of about 1500m and to construct two massive rock groynes at either end of the frontage to modify wave effects as well as arrest movement of beach material.

The town frontage is protected for a distance of 1.7Kms with a concrete stepped revetment fronted by timber groynes. These groynes do not extend very far seawards beyond the toe of the shingle beach and hence do not affect the movement of sand over the flat lower foreshore. This revetment extends eastwards to a paddling pool in the centre of the frontage which is protected by about 100m of masonry sea wall. The foreshore is a steep shingle beach overlying sand. East of the pool there are no coastal defences for 450m, and the sand and shingle foreshore is backed by a grassed bank, which is eroding slowly. The foreshore here is wider and with a steeper gradient than that to the west. Its composition is mainly shingle and the high water mark just reaches the bank. At the eastern end of the bay there is a mixture of masonry sea walls protecting private property. These walls extend for about 450m, beyond which there are eroding clay cliffs and, further east, the rocky headland of the Little Orme.

The nett littoral movement of material in Orme Bay is low and in a nett west to east direction. Because the bay is largely self contained and strongly indented the beaches fronting the town are relatively stable and littoral movement occurs mainly during winter storms. There is however a slow depletion of beach deposits within the bay.

As mentioned above, the coastline of North Wales is experiencing a long term problem of recession due to a reduction in the supply of beach material. This material (sand and shingle) was once brought down the River Conwy when it flowed into the sea east of the Great Orme. Land subsidence (which is believed to have occurred in the 6th century) allowed the sea to penetrate landwards and the Conwy river became diverted from its former course to enter the sea west of the Great Orme. This dramatic change cut off the supply of sand and shingle to the beaches east of the Great Orme and now the only source of fresh material is local erosion from headlands such as the Great Orme and the Little Orme. While Orme Bay is well enclosed by two major headlands, Penhryn Bay is 'open' at its eastern end. Erosion has been felt most strongly in Penhryn Bay though the dearth of beach supply has also been affecting the adjoining Colwyn Bay also for several decades. Penhryn Bay stretches from the headland of Little Orme, east to Rhos Point. Very little, if any, littoral material enters the bay from the west. Rhos Point however at the eastern end of the bay is a much smaller obstruction and what littoral drift there is can pass easily to the Rhos on Sea breakwater. The transfer of material from Penhryn Bay into Colwyn Bay is however insignifint, since beach deposits within Penhryn Bay are now almost non existent. Some material is trapped at the north end of the breakwater off Rhos Point but this consists of small volumes of pebbles and cobbles, moved eastwards during storms. Some sand and mud accretion also takes place in the lee of the breakwater. At one time the river Conwy used to discharge to the sea across what is now the golf course and the foreshore in Penhryn Bay was originally sandy. Since the construction of the sea wall, beach levels have fallen rapidly. The beach now consists mainly of large and small boulders with small patches of sand.

At the western end of Penrhyn Bay, over a distance of about 1150m, the coastline has a mixture of privately owned coastal defences. These are generally in poor condition and properties are at risk. The clay cliffs to the west are eroding and here also some properties are at risk. A road and promenade extends along the centre of the bay over a distance of about 850m to the Borough boundary. It is protected by a concrete wave wall and stepped revetment, constructed in 1954. The beach has groynes over the eastern end but these are now derelict. To protect a particularly vulnerable stretch of this concrete sea wall, an experimental open timber revetment was constructed in 1980 on the upper foreshore. This was built some 100m seaward of the sea wall, is 100m long, and is closed by conventional vertical timber groynes. When constructed it was filled with rock and the beach behind it renourished. It has not fared too well, a good deal of the rock fill has been lost and the beach behind has dropped sufficiently to expose the sheet steel piles of the concrete sea wall. The maintenance and stability of the coastal defences in Penhryn Bay over the years have been the subject of several investigations and some of the engineering reports are referenced in the bibliography. A renourishment scheme has been proposed for this stretch of coast which is to extend from beyond the private sea walls in the west to the clubhouse of the local golf course in the east. It is proposed that the new beach (probably a mixture of sand, shingle and boulders) would be held in place by two large shore connected rock groynes of fish tail design (somewhat similar to those built on the Wirral).

The County and Borough boundary runs along what was once the bed of the river Conwy (now the Afon Ganol) and responsibility for coast protection to the east of the boundary rests with the Colwyn Borough Council. Their coast protection responsibilities extend east to the River Clwyd, a length of about 19Kms. A coastal strategy report has recently been published by the Colwyn Borough Council indicating the scope of work which is deemed necessary to prevent further serious deterioration of the beaches and of the coastal defences along the more urban stretches of the frontage. The need for major repair to fairly recently constructed 'low cost' structures which now show signs of serious deterioration (e.g.integrated cable and block revetment at Llandulas) is clearly set out.

From the boundary with Aberconwy to Rhos Point the low lying hinterland is protected over a distance of 1200m by masonry/concrete sea walls and aprons which were built in the mid forties and fifties and which have been subjected to increasing exposure to wave attack as levels at the toe have continued to drop. This frontage has virtually no beach deposits and it is to be expected that sea wall maintenance costs will escalate unless the beach is improved. This wall is followed by some 200m of eroding clay cliff which adds small quantities of fines to the beach. Finally there is a 100m stretch of concrete revetment protection to the toe of the bank. At Rhos Point the promenade is protected by 400m of old masonry sea wall with a concrete support wall. Built in about 1860, the masonry wall in particular has been breached and subsequently repaired during recent years, and has been overtopped on numerous occasions. There is a strip of low lying land to the landward of Rhos Point which was at risk from flooding and the Council had to find a means of either increasing the protection afforded by existing walls or reducing the inshore wave conditions so as to reduce the flood risk. Given that beach levels in the area have been falling it was considered that upgrading the existing sea defences would not suffice as a long term solution to the problem. A rock armoured offshore breakwater (built in 1983) was opted for and this now protects the promenade opposite the Cayley Arms. Rock left over from the breakwater construction was used to build a short groyne on the coast immediately to the west. The sheltered conditions between the breakwater and the shoreline has led to the accumulation there of a mixture of shingle, sand and mud. The breakwater has if anything been too effective in trapping beach material and is now preventing the small amount of littoral drift from the west from reaching the beaches in Colwyn Bay. Possibly more seriously it also attracts material from Colwyn Bay itself during periods of reverse drift (ie during easterly storms). Clearly some means of establishing sediment bypassing is necessary if the drop in beach levels in Colwyn Bay is not to accelerate.

From Rhos Point to Old Colwyn (a distance of about 3.5Kms) the sand beach is backed by a masonry wall the western parts of which date back to the 19th century. This wall has been subject to a great deal of repair and reconstruction. The situation has not been helped by the fact that groynes along parts of this frontage were allowed to fall into disrepair allowing beach levels at the toe of the wall to deteriorate. The Council constructed a 650m long rock berm to the toe along the most severely affected stretch of wall in 1987, and this has encouraged some sand accretion adjacently thus further assissting sea wall stability. Some groyne construction is presently being undrtaken at the western end of the bay. Further works are anticipated within the Borough's frontage and particularly in Colwyn Bay, these being outlined in the Council's Technical Services Report (see Bibliography). These include a sand bypass scheme to Rhos breakwater. A 400m length of seawall, east of the eastern end of the Caley promenade has recently been investigated. A report on this stretch of wall indicates that it consists of material which has a very low crushing strength and the width of the wall is about half the accepted minimum.

East of this wall there is a 600m length of concrete sea wall, built as part of a railway embankment and which is maintained by British Rail. There is a steep shingle storm ridge in front of this wall and the lowering of beach levels here is less serious than in the western part of Colwyn Bay. In the centre of this short stretch levels at the wall toe have improved marginally. This is despite the fact that groynes which front much of this coastline have been allowed to deteriorate, including the stretch in front of the British Rail embankment.

From Colwyn Bay east to Pensarn a broad belt of carboniferous limestone changes the character of the coastline, giving cliffs and headlands. At the eastern end of Colwyn Bay some 400m length of the A55 trunk road have been protected by rock armouring and beyond that is the rock limestone promontory of Penmaen Head which requires no protection. Limestone quarrying in the vicinity has led to the loading jetties being constructed on the coast at Llysfarn west of Llandulas.

The coastline east from Penmaen Head to the R.M.C. loading Jetty, a distance of some 1500m, is now protected by the embankment of the new A55 trunk road. This protection consists of rock armour and Dolosse units. The toe of this recently constructed embankment is very effective in dissipating wave energy and the bottom layer of the armouring is partly buried as a result of local sand and shingle build up. It is not clear whether this material has been attracted from the lower part of the beach or whether it has been brought in from offshore or possibly from spillage from the jetty. Whatever the mechanism which has resulted in the build up of the level of the upper part of the beach it is clear that this frontage is not likely to require additional protection for some years to come. The beaches to the east of the Jetty have a progressively larger shingle content. From the Jetty eastwards over a frontage of about 300m the accreting shingle beach is backed by a clay cliff. This is eroding partly due to marine action and partly due to weathering, but no properties are at risk.

Eastwards to the outfall of the River Dulas, a 900m long timber revetment built in 1986 is fronted by rock armouring. The shingle foreshore is groyned and accreting slowly. The mouth of the river Dulas has been trained by means of a rock 'breakwater' which was constructed in 1974/5. The training was necessary since the nett west to east littoral drift tended to deflect the river mouth strongly in an eastward direction. So much so that the river once discharged almost parallel to the beach putting the boulder clay cliffs at the Llandulas Caravan Camp at some risk. Downdrift, that is to the east of the river mouth the 700m of natural shingle beach has been eroding in recent years, despite being groyned. Nevertheless the beach is still very healthy and provides good protection to the backshore.

At Llandulas a flexible concrete mattress was constructed in 1983 to protect the seaward face of a rubbish tip. The mattress now shows signs of deterioration, this being exacerbated by falling beach levels which are allowing some leaching out of the backfill. If this situation is allowed to continue then the refuse will begin to be washed out. This will cause pollution at the amenity beach at Pensarn. Protection to the revetment in the form of a rock toe to counter undermining was put in hand in 1988. Although the shingle beach in front of the revetment is groyned the Council's surveys indicate a quite serious lowering of beach levels from 1980 to 1986. The construction of this dissipative rock toe should help to reduce the rate of beach erosion.

East of this revetment, over a distance of 2.8Kms to Pensarn Railway Station, the flat sand foreshore is backed by a wide shingle ridge. Although vegetation tries to gain a hold on the ridge, vehicular traffic is inhibiting growth and stopping natural stabilisation. Although the position of the crest of the beach remains unchanged there appears to be some steepening of the shingle ridge and lowering of the sand foreshore. The situation is giving rise to concern at the eastern half of the frontage where foreshore lowering has exposed peat layers and the clay substratum. The problem is most acute at the junction of the flat sand beach and the steep shingle bank. A replenishment scheme was carried out in 1987 and a number of rock groynes were constructed to keep the beach fill material in place. The scheme was a relatively 'low cost' one and is being monitored to determine whether further works will be needed in the future.

A concrete sea wall and groyne system protect the coast from Pensarn to Towyn over a distance of 3.1Kms. This wall is maintained by British Rail and protects the railway line which at this point is located very close to the shoreline. The land behind this sea wall is low lying and subject to flooding from the sea. Beach lowering has taken place along this frontage and at the western end, near Towyn, large areas of the clay substratum are exposed during periods of beach erosion. This frontage was once extensively groyned but the groynes have been allowed to fall into disrepair. The concrete apron at the toe of the wall has had to be extended downwards in response to falling beach levels. It is believed that British Rail have recently carried out an experimental scheme consisting of a limited amount of beach replenishment and the construction of two new groynes. It is not known how this scheme has fared since as far as we are aware the situation is not being monitored by beach surveys.

From Towyn to the River Clwyd, a distance of 2.2Kms, the coast is protected by a concrete wall (with a wave return) maintained by the Colwyn Borough Council. The wall which was built in the mid sixties is fronted by an accreting sand and shingle beach and is groyned. The wall is in good condition and no serious coastal defence problems are anticipated in this area. At the entrance to the Clwyd Estuary, on its western bank, there are low, eroding sand dunes. These dunes have become almost levelled as a result of holiday traffic and a timber breastwork is installed on the line of the sea wall to the westward. The beach is groyned and does not appear to be eroding seriously. The upstream schedule 4 boundary is accepted as being the Foryd Road Bridge.

The river marks the eastern end of Colwyn Borough Council's responsibility and the start of the Rhuddlan Borough Council's frontage. The coastline of Rhuddlan extends east from here to Gronant, a distance of about 11Kms.

The town of Rhyl is situated to the east of the Clwyd Estuary and the river flows eastwards along the Rhyl frontage for about a kilometre before being trained seawards across the wide sand foreshore. The river bank is protected by a retaining wall and the river flow is contained by a massive training wall constructed in the early 1930s. Historical maps show that there have been large fluctuations in the position of the low water line and of the river entrance over the period 1871 to 1983, but no significant improvement or deterioration.

The urban frontage of Rhyl over a distance of about 2.5Kms, is protected by a concrete sea wall topped by a wave return and with a stepped apron at the toe in places. This wall is backed by a wide promenade. The wall has been in position for many yearsand has 'fixed' the position of the high water mark at its toe. However beach lowering at Rhyl has evidently been taking place so that the low water line between the estuary mouth and Splash Point moved landwards by as much as 600m between 1871 and 1900. Recession has continued since 1900 but the situation has been improved by the construction (in the early 1970s) and the maintenance of long timber groynes along the Rhyll frontage. Beach levels are generally acceptable although serious foreshore lowering is manifesting itself at the toe of the sea wall which continues around Splash Point. This point is a prominent feature since the wall changes direction by about 90° at this location. Proposals are in hand to extend the toe of the sea wall here, in the long term. To the east of the urban area the golf course is now protected by some 1.75Kms of concrete sea wall, stepped revetment and promenade slab (built in 1951 and extended in 1972). This stretch of wall terminates at the Rhyl/Prestatyn boundary. Before the sea wall was built the coastline here was receding rapidly. For example between 1871 and 1959 the high water line moved landwards by about 170m, while the low water line had receded by up to 600m. Since the construction of the sea wall and groynes the high water line has not been able to continue to retreat landwards uninterruptedly and there has been little significant change in its position. The low water line has fluctuated and over the period 1959 to 1983 there has been a nett advance in a seaward direction. This stretch of coast is slightly embayed and is therefore more sheltered against wave activity by comparison with the adjacent urban frontages of Rhyll and Prestatyn. In the long term however with the dwindling of sand supply from the west the situation in this area will also deteriorate. The beach material consists largely of silty sand and the nett littoral drift is from west to east. The sea defences and promenade join onto the newly constructed work at Frith Beach, Prestatyn.

The beaches of Prestatyn are of medium fine sand and can be conveniently divided into three main areas. Between the Rhyl/Prestatyn boundary and Y-Frith, dunes back the coastal defences. Central Beach fronts the town and Barkby Beach is situated to the east where it is backed mostly by holiday camps. Between the

Rhyl/Prestatyn boundary and Y-Frith erosion has been prevelant. The width of the inter tidal zone is now less than 300m as compared with 600m in 1871, the greatest change being the landward retreat of the low water line. A number of large permeable groynes were constructed along this frontage in the 1950's. These did little in the way of trapping drift and were allowed to fall into disrepair. The masonry revetment apron suffered increasing wave attack as a result of falling beach levels. The apron was overtopped damaging the sand dunes on the backshore. By the mid 1980's the apron was in disrepair. In 1986 a comprehensive programme of sea wall renewal and foreshore management was begun and this has included the replacement of the concrete revetment by a 1Km length of new sea wall. This consists of a bituminous revetment at a slope of 1 in 4 with a concrete wave return wall at the rear. The lower half of the bituminous slope is of a permeable open stone asphalt mix while the upper half is of dense asphaltic concrete. Temporary rock groynes have been placed in front of the new revetment to deter the tendency for falling beach levels which were prevalent in this area.

The 2.25km long frontage of Prestatyn (Central Beach) is protected by a stepped concrete revetment, built in 1960 and 1971, with a sheet steel piled toe. The promenade slab topping the stepped revetment has a wave return well at its rear. Beach lowering has been very serious along this frontage and as foreshore levels have fallen so the bar and gully system has migrated shorewards. Because of wave reflections from the wall, erosion has been particularly serious at its toe and the sheet steel piling (put in as a downward extension of the wall) is at risk. A study by Hydraulics Research in 1986 concluded that with the lack of sufficient sand supply, the continuing reduction in foreshore width in this area and the presence of tidal gullies close inshore, there will always be a tendency for beaches to erode. The level of the beach at the toe of the sea wall is now so low in places that it would be quite impractical to return beaches levels to their original height since this would involve beach nourishment of a massive scale. It is envisaged that large energy absorbing groynes will be needed to reduce inshore tidal currents and that the inshore gullies may need to be infilled. The toe of the sea wall will require reconstruction as the existing sheet steel piles are now in a poor condition. Some form of energy absorbing design (eg rock armour) is needed to deter further toe erosion.

At the western end of the frontage the groynes are 40m long at 60m centres (some extended in 1985 on an experimental basis), but these are generally in a poor condition. The proposal is for extending the profile of the existing stepped revetment down to existing beach level by asphaltic construction with a sheet pile toe over the 2.25km length. Between Barkby Beach and the Rhyl/Prestatyn boundary beach, management works will comprise the replacement of existing timber groynes with 13 No. 150 metre long rock groynes, with some beach replenishment. The construction is phased and a contract for the construction of 4 groynes at the eastern end, and some 700m of wall extension was began in early 1989. Littoral drift is from west to east along this frontage.

East of the Prestatyn sea wall there is a stretch of some 200m where an extension to the stepped concrete apron was made and gabions placed as transition to the dunes in 1984. To the east of this a low rock revetment (built 1984-1986) protects the toe of the Gronant sand dunes for about 350m and from there on the dunes continue unprotected for a further 2kms to the Borough boundary. Erosion downdrift of the sea wall continues to take place and the gabion revetment is likely to have a relatively short life span. The toe of the dune system is still under attack and will require further protection in the long term. The beach management proposal, referred to above, will extend to this frontage and to the Ffrith Beach areas. At Gronant, at the eastern end of the Rhuddlan frontage, some sand accretion is taking place and the dune system is relatively stable.

Responsibility for coast protection from Gronant some 2.5Kms to the Point of Air and then along the west bank of the river Dee to a point north west of Connah's Quay, lies with the Delyn Borough Council. The responsibility for the maintenance of the coastal defences is shared with private landowners, Welsh Water and British Rail.

From the Rhuddlan border east to the Point of Air the area is privately owned and has a number of large holiday camps. The area is low lying and the sand dune system forms the only coastal protection against the sea. The dunes are partly fenced off to prevent damage by the public. The steep dunes are nevertheless eroding, due largely to overuse, and the littoral drift is taking the sand eastwards towards the estuary mouth.

The Point of Air is a prominent 'ness' of shingle and sand and the coastal belt of high dunes capped with marram grass continue round into the Dee estuary.

5.2 The Dee Estuary

A general trend within the Dee Estuary is one of long term siltation with mud, silt and fine sand deposits generally reducing water depths in the estuary as a whole. The process of siltation has been taking place for many centuries and much of the upper reach has now been reclaimed. One of the reasons for siltation is the funnel shape of the estuary which (unlike the Mersey narrows) is not conducive to tidal scour. The changing coastal regime of the bay is described in Chapter 3, the most important factor is that the estuary is and will continue to be a major sink for sand, silt and mud. Nevertheless bank erosion does take place as a result of meandering channels and wave action. The coastal strip is generally flat and low lying.

Responsibility for coast protection on the west bank of the Dee lies with the Delyn Borough Council to a point north of Connah's Quay. This responsibility is shared with British Rail, Welsh Water and various private landowners (mainly industrialists). The coastline here is almost completely built up and large areas are reclaimed land. The whole of this west bank of the Dee Estuary is designated S.S.S.I. The beach is of sand and mud and saltings fringe much of the coast, especially upstream of the Mostyn Docks.

Just south of the Point of Air a grassed embankment extends for some 1100m and protects the low lying hinterland from flooding. This bank is reinforced with stone chippings along its crest. The bank is variable both in width and in height and shows signs of being vulnerable to breaching in places. Responsibility here lies with Welsh Water. The beach in front of the bank is sand and mud and shows signs of accreting (being sheltered by the spit extending east from the Point of Air). While the general direction of nett littoral drift is from west to east along the coast, during high tides and severe storms, wave action is sufficiently strong to transport some sand southwards into the Dee Estuary, where it becomes intermixed with the mud and silts brought downstream by tidal currents. South of this embankment to the railway line is a 1Km long bank fronting an area of reclaimed land. This is the property of the National Coal Board and is the site of the Point of Air Colliery. From here to Mostyn Quay, a distance of some 3Kms, the main railway line to Holyhead runs alongside the south bank of the estuary. The railway embankment is protected by a masonry wall, owned and maintained by British Rail.

South east of the railway embankment, Mostyn Docks and an industrial complex juts out into the estuary. Because of the silting up of the Dee further upstream, Mostyn became the only harbour in the estuary for sea going ships. The docks comprise some 600m of harbour and quay installations. Upstream of the docks over a length of some 1.2km is an area of industrial waste ground which is subject to erosion. This erosion is normally combatted by infilling with locally pre-fabricated concrete blocks. This industrial area is followed by some 4Kms of stone rip-rap walling which is maintained by British Rail. Along this stretch a small river runs into the estuary at Llannerch y mor and an old cruise liner, once used as a shopping and amusement centre, is permanently beached here. There is a proposal to develop this area into a leisure complex.

The frontage to the small village of Greenfield is largely reclaimed land and has a 900m frontage of industrial tipped waste. Upstream of this to the Borough boundary near Connah's Quay, the river's edge is firstly grassed embankment and then saltings, some of which are reclaimed. This includes the stretch fronting the town of Flint where the dock and channel have long since silted up. Much of this is low lying land and the estuary banks in some areas are liable to erosion (despite the large scale silting up of the estuary). Erosion south east of Flint Castle has been particularly serious and there is clear evidence of the low bank continuing to retreat landwards. A short stretch fronting the rugby ground has been protected by a gabion revetment. The revetment is at a rather steep slope and although only constructed in recent years already shows signs of damage due to settlement. Some gabion baskets near the crest of the revetment are empty and appear to have been vandalised.

On the east side of the Dee Estuary the picture is again of general siltation within the estuary flats but with some bank erosion. Saltings fringe the estuary as far downstream as Heswall. The responsibility for coast protection lies with the Wirral Metropolitan Borough Council from the Schedule 4 boundary (at Gayton) to Hilbre Point and beyond. This is shared for a short length at Heswall with Welsh Water and some short lengths are also privately maintained. The whole of this east bank of the Dee is designated an S.S.S.I.

Just upstream of the Schedule 4 boundary is Parkgate. In the 18th century this was a thriving Port. Due to siltation the harbour walls now look out onto large areas of saltings. The frontage of Gayton downstream (north) of Parkgate is protected by 1.7km of stone sea wall. Due to the mild wave climate this far upstream, the sea wall, built in 1900, is still in a fair condition and there is some accretion on this frontage.

The frontage of Heswall is also fringed by saltings and the areas of urban development are protected by intermittent stone sea walls. Built in 1930 these walls are in a fair condition and are the responsibility of the individual frontagers which include Wirral Metropolitan Borough Council. At the northern end of this frontage, a concrete sea wall followed by a stone faced clay embankment, protects low lying land at Heswall cum Oldfield over a length of about 500m. This wall and embankment are maintained by Welsh Water.

From Heswall north to Caldy on the outskirts of West Kirby the unprotected east bank of the Dee is part of the Wirral Country Park. The low clay cliffs here are eroding. From Caldy north along the urban frontage of West Kirby, bank protection consists of various types of sea wall, revetments and rock armouring. This protection, which runs for a distance of 2.8km, is of varying age (1900-1980) and is generally in an adequate condition. The sandy foreshore here is wide and the mean high water mark is some distance seaward of the shoreline. Rock protection extends north to the Royal Liverpool Golf Links and beyond that sand dunes extend north to Hilbre Point. These unprotected dunes are fronted by a very wide expanse of inter tidal sand flats, forming the western end of the East Hoyle Bank. Grasses help to form embryo sand hills within the intertidal zone.

5.3 The Dee to the Ribble

The Wirral peninsula lies between the Dee and the Mersey estuaries and the coast protection authority from Gayton to Seacombe is the Wirral Metropolitan Borough Council.

Changes in this area and within Liverpool Bay have been recorded over a long period of time and a description of these can be found in a series of reports carried out by Hydraulics Research in the 1960's (see Bibliography). More recent coastline changes are being monitored by the Wirral Metropolitan Borough Council who are responsible for major reconstruction works carried out over the last 15 or so years. Littoral drift along the Wirral frontage is generally in a nett west to east direction. However, because of the very active movement of sediments in Liverpool Bay the situation is rather complex, especially with regard to beach changes near the mouth of the Mersey. At New Brighton for example, where vertical sea walls were built to reclaim land, beach lowering is not due just to the loss of the upper foreshore (that part which is most effective in reducing inshore wave energy) but is connected also with the migration of the nearshore channels.

As mentioned above, major reconstruction of the Borough's coastal defences has taken place since 1972 involving two major sea walls (the Wallasey embankment and the Leasowe revetment), plugging a gap in the defences in Leasowe Bay and the construction of a number of large groynes and offshore breakwaters. Expenditure on coast protection and sea defence in this area (within the period 1974-1988) has been of the order of £19 million. The research prior to construction and a description of the capital works themselves has been well documented (see Bibliography). The situation with regards to both structural performance and beach behaviour is also being monitored.

At the western end of the North Wirral frontage is the Hoylake and West Kirby sea wall which extends over a frontage of some 4Kms. To the seaward of this wall is the wide expanse of inter tidal sands known as the East Hoyle Bank. Fluorescent tracer experiments carried out by Hydraulics Research in 1969 found the littoral drift to be in the same nett direction as the nearshore drift ie from west to east. High beach levels at the Hoylake sea wall, together with the protection afforded by the Bank, results in a fairly sheltered coastal wave climate. This is helped also by an outcrop of red sandstone offshore forming a natural breakwater. The upper foreshore is sufficiently high to allow the growth of spartina grass. Some parts of the Hoylake wall are quite old, however, and local repairs are necessary from time to time. (The Marine lake also acts as a coast protection structure.)

From the east end of Hoylake to Leasowe Bay low lying land is protected against flooding by the Wallasey embankment. This embankment was first constructed in the early part of the 19th century out of locally derived material (mainly sand, silt, clay and peat), trimmed to a shallow slope and given an impermeable facing. The facing has since been reconstructed a number of times and the bank extended to its present length of about 3.6Kms. The most recent reconstruction of the embankment was completed in 1987, when 36500m² was replaced and given a cellular concrete facing, laid to a slope of 1 in 5. Precast concrete upstands ("Enervators") were laid over three lengths of the embankment face in order to reduce run-up and littoral drift. The eastern end of the embankment has, in recent years, been more susceptible to damage and beach erosion than the western end. It is now protected by an offshore rock armoured breakwater (known as the Wallasey breakwater) which is designed to reduce tidal scour between the breakwater and the backshore and to encourage an increase in beach levels by reducing the wave climate in its lee. The breakwater, completed in 1981, had a shore link constructed in 1987 and in conjunction with other breakwaters and rock groynes to the eastward (see below) has resulted in a general improvement in upper foreshore levels in the area east of it.

Leasowe Bay is an indentation in the coastline resulting from the long term erosion of the unprotected stretch of sand dunes between the Wallasey embankment and the coastal defences further to the east. This area had been eroding for over two centuries and dune recession in this 400m gap was of the order of 85m between 1829 and 1953. During the early 1970's much of the sand was replaced with suitable fill material which was then protected from erosion by the provision of a riprap revetment with the stone (placed in 1979) extending to 1.2m above the highest recorded tidal level. Above the riprap a clay faced embankment extends to an access road some 5m above the highest recorded tide and this is backed by well vegetated fill material. Foreshore protection consists of two rock breakwaters and a fish tail shaped rock groyne. The Wallasey breakwater extends sufficiently far eastwards to give some protection also to the Bay as well as to the eastern end of the Wallasey embankment itself. The shore connected fish tail groyne, constructed in 1981, is situated at the west end of the bay to protect the riprap revetment from scour and to stabilise falling beach levels at the head of the Bay. A second offshore breakwater was built in 1982 at the eastern end of the bay at the junction between the riprap and the Leasowe revetment. This is called the Leasowe breakwater and has a shore link formed of artificial concrete armour units (Diodes). It has been particularly effective in arresting foreshore deterioration and a large tombolo has formed in its lee. The nett drift along this coast is from west to east and the build up in the lee of the breakwater has presumably led to some reduction in sand supply to the downdrift coastline ie along the Leasowe revetment.

The Leasowe revetment extends for almost 2Kms from Leasowe Bay to the western end of Kings Parade. It was reconstructed by 1981 to a similar hydraulic design as the Wallasey embankment and consists essentially of a concrete facing at a slope of 1 in 3.75 and topped by a pre cast concrete wave return wall. Beach levels along this frontage are being monitored by the Borough as is the situation with regard to the efficiency of the offshore breakwaters.

East of the Leasowe revetment to the mouth of the River Mersey is the urban frontage from Wallasey to New Brighton. In the 1930's a 3Km long frontage of vertical concrete sea walls was built to reclaim a section of land on which to construct a promenade (King's Parade). These walls are intact although in the mid 1970's it was discovered that some sections were in a poor condition due to both wear and tear and to falling beach levels. Beach erosion has been developing here over at least two decades and in places the levels have fallen by up to 4.5m. This is partly due to wave reflections from the sea wall (built well out into the inter tidal zone) and partly due to the scouring action of the tidal currents. With the high tidal range in this area and the highly reflective sea walls backing the foreshore, traditional methods of groyne construction have done little to reduce the rate of beach lowering over the years. It was therefore considered that more substantial structures would be needed if they were to have any significant effect on the beach regime. In the early 1980's therefore a beach stabilisation scheme was begun, and this included a whole series of shore connected and offshore breakwaters. The system was completed in 1985. The breakwaters consist of a sand core covered by rock armour and with a crest consisting of concrete 'Reef' blocks. The system was developed as a result of extensive field measurements, numerical and hydraulic studies by the Borough and by Hydraulics Research. These have been constructed to be submerged to a depth of about 1m at mean high water and are intended to both increase existing beach levels and serve as coastal defence (by reducing wave attack). There is also local protection to the toe of the existing wall in the form of energy absorbing 'revetments'. These revetments are rock armoured and protected by concrete 'Diode' blocks. A report by Brampton and Smallman in 1985 entitled 'Shore protection by offshore breakwaters' covers most of the recent breakwater construction around the U.K. coastline (see Bibliography) and includes a description of these units. During 1986 a 75m length of concrete sea wall was constructed at New Brighton in front of the existing vertical sandstone wall. This length of sea wall encloses an area of foreshore within which a sewage pumping station has been constructed. The wall was formed by 20T pre cast concrete "Mermaid" units which absorb wave energy by means of a voided front face formed by individual vertical concrete columns and an inner reservoir. All the Mermaid units (46 No) and a sample of the Diodes and Reefs are being monitored in terms of concrete durability by the University of Liverpool. This monitoring forms part of a research project to assess non-destructive electrical methods of testing concrete.

The schedule 4 boundary which is situated close to the mouth of the river Mersey was amended in 1983 to include approximately 3.6kms of old sandstone wall between New Brighton and Seacombe.

Changes in the estuarial regime are well documented, see Bibliography. Responsibility for coast protection on the east bank of the River Mersey lies with the Sefton Metropolitan Borough Council. This frontage extends from the Schedule 4 boundary in the Mersey to Crossens Marsh north of Southport. Apart from the

Council, North West Water, the Mersey Dock and Harbour Company and various private landowners have responsibility for coast protection.

The Schedule 4 boundary in the Mersey Estuary runs from a point where the north side of the Seacombe Ferry landing stage meets the Mersey River Wall, across to the south corner of Royal Seaforth Dock at Bootle. Seawards of the Schedule 4 boundary, over a coastal stretch of about 2.5Kms, are the Seaforth Docks. The docks are protected by a concrete sea wall and rubble mound breakwater which are owned and maintained by the Mersey Docks and Harbour Company. North from the docks to Crosby, a distance of some 3.5Kms, the coastline is protected by a concrete sea wall. At Waterloo, south of Crosby, the deep water at the Docks gives way to an increasingly wide sandy foreshore known as Formby Bank. The sea wall, built between 1972 and 1976, is occasionally overtopped at its southern end and has suffered some damage at its northern end. There appear to be few serious coast protection problems here, although the foreshore is believed to be slowly falling at the northern end of Crosby.

From Crosby to the River Alt (near Hightown) the low cliffs fronting the golf course are protected by a "revetment" of tipped rubble and a short length of concrete sea wall which is privately maintained by the Blundell Sands Sailing Club. However, there is a potential flood risk to a large area around Hightown landward of the eroding sand dunes. The outfall of the River Alt runs south (following the nett littoral drift), hugging the coast for some 2.5Kms before it runs out to sea across the beach just north of Crosby. At Raven Meols some sand accretion is taking place on the beach. However the dune belt is narrow and might not provide a sufficient degree of protection if subjected to very high tide levels coupled with a storm wave attack. Worries about the possibility of a breach through the dunes and possible flooding of the catchment area of the River Alt led North West Water to construct a secondary defence bank in a gap in the dunes, an area where sand extraction had taken place in the past.

Offshore is the Crosby Training Bank which parallels the coast for about 3kms. The nett littoral drift is south towards the Mersey and the coastal strip is generally eroding.

Sand dunes dominate the coastal strip from Hightown to Southport. They form the most extensive dune system in the north west and form a belt over 1Km wide. However in some areas the width has been reduced as a result of sand removal for industrial use and more importantly, due to rapid recession at Formby. Apart from beach dune stabilisation at Formby, conifers have been planted on the hinterland to deter the sand from being swept inland by onshore winds. Further north the coast is unprotected as far as the southern outskirts of Southport.

Sediment movement between Hightown and Formby is complex and probably related to changes in the regime following the training of the Mersey. The training banks have attracted sand and one possible effect is additional shelter against wave activity leading to the dwindling of some of the minor drainage channels and, due to reduced input by tidal currents, sand moving away from Formby Point. Off Formby there is a point of nett drift divergence with material being transported north towards the River Ribble and south towards the Mersey. The northward drift rate is much higher than the southward drift.

The sand dune promontory of Formby was accreting until the early 1900's. Subsequently a phase of rapid erosion set in at the Point and this has continued, with the dune line being cut back over an increasingly wide frontage. There is much debate about the reasons for the onset for erosion at Formby and there is no general consensus. However it would appear to be too strong a coincidence that the beginning of erosion followed large scale training and dredging which has dramatically altered the regime of this part of Liverpool Bay. At Formby Point the average recession rate is some 5 to 6m per annum. The area is looked after by the Sefton Metropolitan Borough Council who control access to the beach so as to reduce the dune areas damaged by human traffic and there are some attempts to stabilise the dunes by sand fencing. The whole frontage from just north of Altcar around Formby Point to Ainsdale is nevertheless characterised by dunes which are being undercut by wave action. The foreshore north of Formby Point is very wide and flat and cut by tidal gullies, the deepest of which (near the Point) are eroded down to the clay sub stratum and they then become permanent features. The foreshore widens from Formby Point north to Southport and the number of gullies and sandbars increase. As the foreshore widens so some of this littoral material travels along the outer bars and finds its way onto the offshore areas such as Horse Bank at the mouth of the Ribble Estuary. There are no coast protection works along the duned frontage until the outskirts of Southport are reached and here Sefton Borough maintain a thin concrete apron fronting the promenade at the southern end. This apron has been gradually extended northwards and protects the embankment on which the coast road has been built. Here, at the northern end of the frontage, is a large area of reclaimed saltings. Though the wall is generally of fairly light construction the problems of coast protection are not normally serious because of the sheltered nature of the area. However, under very high water levels the offshore banks become submerged and if this coincides with storm wave activity extensive damage can occur to the coast road.

The drift is believed to be in a northerly direction across the mouth of the Ribble although a large proportion of the sand deposits remain in the vicinity of the estuary mouth. For example the lower foreshore at Lytham St Annes is accreting rapidly allowing sand to be extracted from this area. Similarly Horse Bank south of the river channel is also an area of accretion and has also been used for sand extraction. Mud and silt movements in the sheltered areas to the landward of these banks are dominated by tidal currents.

The margins of the lower part of the Ribble are of fine sand and mud which is steadily being colonised by vegetation. This has allowed large areas of the south bank to be reclaimed over the centuries. The southward spread of Spartina is now causing problems to the Southport beaches and steps are being taken to eradicate it.

Minor flooding may occasionally take place over the coast road north of Southport but otherwise the south bank of the Ribble appears to have no serious coast protection problems.

The boundary of the Sefton Metropolitan Borough Council treminates just north of Fiddler's Ferry. Beyond that to the Schedule 4 boundary in the Ribble opposite Naze Mount, the responsibility lies with the West Lancashire District Council although in fact the large areas of reclaimed land here are protected by North West Water by means of clay embankments.

Progressive reclamation is reducing the tidal prism and encouraging further siltation and saltings development.

5.4 The Ribble to Walney Island

On the north shore of the Ribble Estuary, apart from low lying areas protected by North West Water, the coast defences are the responsibility of Fylde Borough Council. The Council's jurisdiction in the Ribble extends over a distance of 16Kms from Naze Mount (the Schedule 4 boundary), downstream to Warton Bank. There are two short stretches of sea wall, one near Bush Farm and the other to the east of Warton Bank. Apart from this the shoreline is unprotected and the area is one of general stability. From Warton Bank to Lytham, a distance of 3Kms, low lying land is protected by a clay embankment, which is the responsibility of North West Water. This embankment is within an embayment within which are saltings. From the east end of the Lytham Promenade to Fairhaven the foreshore becomes increasingly more exposed to wave action and there are increasing quantities of sand on the foreshore. The nett littoral drift is west to east, as a result of waves from the Irish Sea propagating along the north shore of the estuary. This area is one of general accretion. The urban frontage is protected by about 4.1Kms of masonry and concrete sea walls, which are 60 to 90 years old. They are still in a reasonable condition although extensively repaired.

From Fairhaven north to the boundary of Fylde Borough Council's responsibility at Squires Gate, the backshore consists of sand dunes. With urban development taking place however, short stretches of sea wall have been built along this frontage. The foreshore here is very wide and has a number of inter tidal sand banks which give partial shelter to the coastline. Between Salters Bank to the south and Crusader Bank to the north there is an area of sand extraction. The rate at which the material has traditionally been removed from this area is less than the rate of influx of sand. However in recent years the extraction rate has increased considerably and this has coincided with a significant reduction in the rate of beach build up. At the southern end at Fairhaven there is dune erosion over a frontage of about 1500m and there is some flood risk to the urban area. This is not thought to be connected with the sand extraction taking place on the outer part of the inter tidal zone.

The urban frontage north to St Anne's Pier, a distance of 800m, is protected by sea walls some 60 to 90 years old. They are in a fairly good condition although some terminal scour is taking place at the southern end. From St Anne's Pier to the Borough boundary, a distance of 3.3Kms, the dunes are largely unprotected, except for a short length of private sea wall at the North Hollow Convalescent Home. Sand accretion is takng place along this frontage. The foreshore here is still partly protected by the offshore sand banks at the mouth of the Ribble.

The heavily developed urban frontage of Blackpool stretches from Squires Gate to south of Cleveleys, a distance of 11Kms. The whole stretch is protected by massive masonry and concrete sea walls which are the responsibility of the Blackpool Borough Council. Maintenance of this frontage is a heavy and ongoing committment the sea walls being of varying age and dating as far back as the 1900's. Many of these walls have required protection against undermining and this has been carried out by adding sloping concrete aprons which themselves in places now require reconstruction.

The beach is groyned but because of the width of the foreshore (almost 500m) and the high reflectivity of the near vertical sea walls it is difficult to maintain a stable beach close to their toe. Before coastal defences were built, the natural rate of shoreline retreat was about 2m per year. Since the coastline has become "fixed" in position, erosion now manifests itself in a lowering of beach levels in front of the sea walls. A study by Hydraulics Research carried out for the Borough Council showed, rather surprisingly, that no serious beach lowering could be detected from analysis of the frontage over a period of 25 years. The number of surveys on the various profile lines studied was, however small, surveys only being carried out on average on about 10 occasions within this period. Some erosion was evident at the south end of the frontage at Squires Gate and some accretion appeared to be taking place at the northern end. What is more significant is that upper beach levels were seen to fluctuate by up to 3m. The large vertical changes have been attributed to beach lowering during storm wave activity and increased beach levels during periods of strong onshore winds and dry weather. The beaches are of sand and the littoral drift is from south to north.

From just south of Cleveleys to the Schedule 4 boundary (in the entrance to the River Wyre), the authority responsible for coast protection is the Wyre Borough Council. The Cleveleys to Fleetwood coastline (a distance of about 8Kms) is generally low lying and protected by sea walls over the entire frontage. These have been upgraded at various times; most recently after the severe storm/surge of the 11th and 12th of November 1977 which produced considerable overtopping at Fleetwood West Shore. Model tests have been carried out by Hydraulics Research to determine the optimum sea wall design for various stretches of this frontage, (see Bibliography). The walls have now been upgraded to give a high degree of protection against flooding. The foreshore narrows and the shingle content gradually increases from Clevelys north to Rossall Point. From Rossall Point to the mouth of the Wyre the urban frontage is developed along a recurved spit. The direction of the nett littoral drift is northwards to Rossall Point and then eastwards into the Lune Estuary. The whole frontage is extensively groyned with the groynes being relatively short and designed to retain the upper beach.

The coastline to the east of the Wyre is largely fringed with saltings of the Pilling and Cockerham Marshes. The sands fronting Knott End are gradually replaced (to the east) by mudflats and the low lying hinterland is protected by clay embankments. These are the responsibility of North West Water.

The urban frontage at Knott End, which has a concrete sea wall and wave return wall as protection, is partly the responsibility of North West Water. This responsibility is shared with Lancashire County Council where the road runs close to the shoreline. To the east of the town the clay embankments have been faced with rock armouring. Certain stretches of this embankment were badly damaged by storms. The embankment at Pilling for instance has been reinforced and rebuilt on a number of occasions. The saltings fronting the embankment appear to be damaged in some areas. The littoral drift is non existent in this area.

North of Pilling the responsibility for coastal defences lies with the Lancaster City Council and their frontage extends north some 43Kms to Silverdale. From Pilling to the Schedule 4 boundary at Fishnet

Point in the Lune Estuary and then downstream along the north bank of the Estuary to Sunderland Point, the low lying land is protected by floodbanks. Responsibility for these defences lies with North West Water round to a point just south of the hamlet of Sunderland. The embankments are mostly clay and, in places, are reinforced by concrete panelling. Along this section, apart from the shoreline between Pilling and Cockerham where North West Water have had to reconstruct the banks, there is a fair degree of shelter against wave activity. The walls north of Cockerham are fronted by extensive saltings and sand flats and there have been no serious sea defence problems along this frontage. Between the Schedule 4 boundary and Sunderland Point on the north bank of the Lune the coastline is particularly well sheltered and the banks are intermittent.

The coastline around Sunderland Point is the responsibility of the Lancaster City Council. Erosion is taking place along the boulder clay cliffs at the mouth of the Lune and the road connecting Sunderland with Overton is flooded during high tides. The coastal defences here consist of a short section of sea wall and gabion work. Just to the south west the Point itself continues to erode. Middleton Sands, a large expanse of sand at the mouth of Morecambe Bay extends north to Heysham Harbour. It provides the coastline with a good degree of shelter and because of this the backshore does not need to be protected. Small areas of saltings have developed near the high water mark which in this area is well seaward of the shoreline. A massive sea wall has been constructed to protect the Power Station at Heysham Harbour from flooding. This wall extends over a frontage of some 1100m from Red Knab to the south jetty of the harbour. Feasibility studies have been carried out by Hydraulics Research into the coastal regime of

Middleton Sands and hydraulic model tests were carried out to determine the optimum profile for this wall (see Bibliography). The land on which the Power Station stands was infilled with sand won from the inter tidal zone. There is a pronounced north to south littoral drift along this frontage and the depressions left after sand extraction were rapidly infilled from updrift ie from Middleton Sands.

The harbour, built in 1904 is owned by British Rail and the wharves together with the concrete sea wall to the north of the entrance are in a reasonable condition. North of the harbour there is a short stretch of unprotected rocky foreshore. Beyond that the whole of the urban frontage from Old Heysham north to Hest Bank is protected by concrete and masonry sea walls. In some areas the land is liable to flooding. Following the severe flooding which took place on the 11th of November 1977, the defences along parts of the Morecambe Bay frontage were upgraded by the addition of wave return walls set some distance back from the main sea walls. These return walls were constructed principally to the west of the stone jetty and along the golf course frontage at Happy Mount Park. On the 31st of January 1983 flooding again took place and plans were put in hand for further improvements to the sea defences.

There are no known problems with regard to beach stability along this frontage and sediment movement is generally regulated by tidal action. For example beach movements along the Morecambe frontage are believed to have a nett east to west residual. This must be connected with tidal movements since the largest wave heights are generated in the Irish Sea and would tend to move material in the opposite direction.

Upstream of Hest Bank as far as Silverdale (the Lancaster City boundary) the land is low lying and largely unprotected. There are extensive saltings in this part of the estuary. There are intermittent stretches of floodbank at Bolton le Sands and again at Carnforth. The railway embankment provides protection against flooding along parts of this frontage. There was a scheme during the last century to reclaim large tracts of saltings between Bolton le Sands and Park Point. After spending some £84,000 the scheme was abandoned, the only remaining evidence being an old wall out on the mud flats. At Silverdale there is an extensive area of saltings in front of the original cliff.

The frontage from the east bank of the River Kent, from Silverdale to the Kent Viaduct, is the responsibility of the South Lakeland District Council whose jurisdiction continues for some 50Kms along the north shore of Morecambe Bay almost as far as Rampside.

Between Silverdale and the Kent Viaduct (the Schedule 4 boundary) the shoreline is unprotected apart from a 100m stretch of stone wall at New Barns and a further 800m at Arnside. At New Barns the short length of wall protects low lying land and is the responsibility of North West Water. At Arnside the stone walls (the responsibility of the District Council) protect the urban frontage, the walls being necessary because the Kent Channel runs close inshore at this point. Although the saltings here are generally healthy, there is an area north of Arnside where the meandering low water channel is cutting into the edge of the salt marsh.

On the west shore of the River Kent, from the Viaduct to Grange over Sands, there is a stretch of about

3.8Kms of railway embankments running close to the shoreline and fronted by saltings. These serve to protect low lying land and are the joint responsibility of British Rail and North West Water. Between Grange over Sands and Kents Bank Station about 40% of the frontage is protected by concrete sea walls and the rest is protected by a railway embankment where it runs close to the shoreline. This is an urban area and the responsibility for coast protection is shared between British Rail and the South Lakeland District Council. South of Kents Bank there are two further stretches of railway embankment which serve as coast protection and the responsibility for these is shared between British Rail and North West Water. These consist of 400m of embankment from Kents Bank Station to 300m west of Kirkhead End. The low lying land between Humphrey Head and Cowpren Point was reclaimed in the early 1800's and protected by a 5Km long clay embankment. A few years later the Leven cut through this embankment and much of the land to the west was lost. A new wall was built across Low Moor to protect the rest of the reclaimed land and the area lost to the Leven is now a natural salting. Responsibility for the upkeep of these embankments rests largely with North West Water but there are also some private frontages. North West Water and British Rail again share responsibility for the railway embankment stretching from north of Gulley Nab across Carmel Sands to Plumpton Hall.

Plumpton Hall is the Schedule 4 boundary in the River Leven. South from here towards Foulney Island the coastline has intermittent coast protection, the responsibility for which rests either with the South Lakeland District Council, Cumbria County Council or North West Water.

South of Plumpton Hall, the District Council have jurisdiction over 1Km of unprotected stretch of coastline (extending south from the Leven Viaduct). Southwards to the old Ulverston Canal (which was built in 1795 and sealed off in the 1940's), North West Water maintain a 400m long rock revetment, while south of the Canal the District Council maintain a short length of stone sea wall. At Sandhall, south of Ulverston, North West Water maintain some 900m of earth embankment set back some distance landward of the present shoreline. This embankment is part of an old railway line and is used to protect low lying land from flooding. The foreshore along this stretch is mainly of sand and the low water channel runs close inshore. It is believed that the foreshore here is groyned, presumably to prevent the channel migrating landwards and causing bank erosion.

The District Council have responsibility for a long stretch of coastline from south of Sandhall almost to Newbiggin. This responsibility is shared with the Cumbria County Council. Protection along this frontage consists of some 1800m of rock revetment at Conishead Bank, and a length of stone sea wall protecting the Country Park at Bardsea. South of here the coastline is unprotected, except for about 100m of gabion work at Moat Farm, where the County Council use this to protect the coast road. At Aldingham there is a long history of erosion, and several houses have been lost to the sea over the years. The upper beach is of shingle while the lower foreshore is sand.

South of Newbiggin to the Council's boundary at Peasholmes, the responsibility for coast protection lies chiefly with North West Water although this is shared with both the District and County Councils. Coast protection consists of a 300m stretch of sea wall and gabion work protecting the road just south of

Newbiggin, this being the responsibility of the County Council. From Roosebeck House, south of Newbiggin, to the District boundary the coastline is protected mainly by concrete faced earth embankments (with a wave return wall in places) and a short length of concrete sea wall at the southern end of this frontage. This frontage is the responsibility of North West Water and the Cumbria County Council, except for the sea wall to the south which is maintained by the District Council.

South of the South Lakeland District Council's boundary at Peasholmes, the responsibility for coast protection rests with the Barrow in Furness Borough Council. They have a coastline of some 62.5Kms and this includes the periphery of the islands of both Walney and Piel. The responsibility for coast protection work is shared with British Rail, North West Water, the British Transport Docks Board (B.T.D.B.) and some private landowners.

From Peasholmes to Rampside, a distance of 1500m, stone and concrete sea walls protect the coast road. The more exposed east face of the artificial causeway to Roa Island is protected by a sloping "gabion" revetment. This consists of a thin mattress of wire netting filled with rock. Protection to the mattress has been added by pouring bitumen over the surface. However the netting is not PVC coated and is therefore liable to rust quickly in areas where the bituminous protection has spalled off. The Island, which is privately owned, is protected by rock revetments and concrete and masonry walls, some of which are rather dilapidated. The coastline to Westfield is unprotected, while from Westfield to Barrow Docks, North West Water protect the coast with a 1300m length of earth bank.

The south facing frontage of Barrow Docks stretches for some 2.5Kms and here the B.T.D.B. maintain a masonry sea wall which backs Roosecote Sands. A short breakwater extends southwards from the western end of this wall to deter the Sands from entering the Walney Channel. The main frontage of Barrow Docks has masonry sea walls which extend over a distance of 3.8Kms. The Walney Channel runs close to these walls, various stretches of which are in different ownership including private owners, the B.T.D.B. (the southern end) and British Shipbuilders Ltd (from Devonshire Dock northwards). North of Devonshire Dock the Walney Channel becomes narrow and meanders between sand banks. The mainland coast north to the Borough boundary is largely unprotected except for a 500m long clay bank at Sandscale Haws within the Walney Channel (North West Water) and a 1600m clay bank and railway embankment north of Askham in Furness (North West Water and British Rail), both of which protect low lying land.

Piel Island is sheltered by Walney Island to the west. It is the responsibility of the Department of the Environment and is protected by some 500m of concrete revetment and gabion work, mainly on the east side of the Island.

Walney Island is a thin strip of land formed of glacial deposits of clays, gravels and sand. It is less than 500m wide in places and has been inundated on a number of occasions. The coastline consists mainly of marram covered sand hills. On the landward face of Walney Island, protection is intermittent and consists mainly of earth banks. At North Scale, towards the north end of the Island, there is a 500m long, privately owned rock revetment which is in rather a poor condition. Further south a 2km long rock revetment protects the urban frontage at

Vickerstown. There is then a short frontage between Vickerstown and Tummer Hill which appears to have no coast protection. South from Tummer Hill to Biggar, a 2km long clay bank with stone pitching protects a road and low lying land which is liable to flooding. From Biggar Hill to Copt Hill there is a further unprotected stretch of coastline. Protection of the low lying land south of Copt Hill consists of a 2km long cobble revetment protecting the road edge and a 400m long stretch of privately owned earth bank at Wylock Marsh which also appears to be protection to a minor road. From Wylock Marsh to South End Haws the shoreline is very sheltered and there are no formal defences except for a stretch of embankment near Old Park Lane where the land is particularly vulnerable to flooding. South End Haws is an old shingle spit now partly covered with sand dunes. The eastern end of the spit has been used for aggregate extraction. Here a shingle bank has been made up and this forms the seaward edge of a road which separates the gravel pits from the sea. The bank is narrow and could possibly be breached given a suitably severe combination of wave activity and high tidal levels. The area in the vicinity of Haws Point is duned while the foreshore has extensive shingle banks. Thus the extremity of the island is reasonably safe from flooding. Again there are extensive sand dunes on the south face of the spit known as South End Haws and this area too seems relatively safe from flooding or breaching.

On the seaward side of Walney Island, a straight beach more than 16Kms long is dotted with rock outcrops among the sand. Coast protection is intermittent. Changes in this area have been studied by Phillips and Rollinson (see Bibliography). Their report indicates that erosion is taking place in the centre of the Island while accretion is dominant at both the northern and southern ends. The reclaimed land on the seaward face of Wylock Marsh is protected by about 1Km of revetment (White Horse Scar). Further north a rock revetment protects a low cliff at Bent Haw. At Earnse Scar an old, extensively repaired, concrete revetment protects the Furness Golf Course. The nett littoral drift along the seaward face of the Island is both northwards and southwards with the divergence point being just south of the Furness Golf Course.

5.5 The Duddon Estuary to the Solway Firth

The Duddon Estuary is an extensive area of sand flats fringed by saltings and with occasional limestone outcrops. There are three maritime authorities in the estuary although in practice a large stretch is maintained by North West Water. On the eastern bank of the estuary, Barrow in Furness Borough Council are responsible for the section as far as Pear Tree Beck and South Lakeland District Council then re-assume responsibility for a further 7.5Kms north to the Schedule 4 boundary at the Foxfield Viaduct.

From the dunes at Sandscale Hawe upstream to Marsh Farm (north of Askam in Furness) the coastline is unprotected except for a 500m long section of clay bank (landward of Sanscale Hawe) protecting low lying land. North of Marsh Farm to the Borough boundary British Rail and North West Water are responsible for the railway embankment and flood bank which protect the low lying hinterland.

From Pear Tree Beck upstream to the Foxfield Railway Viaduct (the Schedule 4 boundary), the railway embankment is protection to the low lying hinterland. This is the responsibility of British Rail and North West Water.

Copeland Borough Council are the coast protection authority for the west bank of the estuary and then north along the open coast as far as Lowca. This is a stretch of some 69Kms and the responsibility is shared with North West Water, Cumbria County Council, British Coal, British Rail, the Whitehaven Harbour Commissioners and private landowners.

From the Schedule 4 boundary at Foxfield to Millom, a continuos 5.5Km stretch of clay embankment is maintained by North West Water. The embankment is situated some distance seaward of the railway line and protects reclaimed marshland. The foreshore has extensive saltings.

The town of Millom at the mouth of the estuary expanded during the late 19th century when its iron mines were the largest and busiest in Britain. The last of these closed in 1968 and the harbour area is now derelict. The town still has the remains of the old pier and the harbour wharves and a large frontage east of the town is reclaimed land, formerly a slag heap. The town frontage faces into the estuary and is well sheltered from wave action. South of the derelict pier (near Crab Marsh) to Hodbarrow Point the coastline consists of clay cliffs, a rocky upper foreshore, and a wide expanse of inter tidal sand flats. From Hodbarrow Point to Haverigg, a privately owned, 2.1Km long masonry sea wall (the Outer Barrier) protects the site of the former ironworks against flooding. The western end of this sea wall would appear to be damaged and the face is covered by rock armouring. The Haverrig frontage east of Haverigg Pool, is protected by some 500m of old stone sea wall. The concrete cladding on the seaward face is rather badly damaged and parts of it have been repaired with stone setts. West of Haverigg Pool the road edge is very close to a steep sided stream and is protected by a parapet wall consisting of gabion boxes capped by a concrete slab. The gabion boxes are PVC coated and filled with angular rock. This part of the wall is well outside the reach of normal tides and appears to be in satisfactory condition. The wall continues westwards between the road and the damaged sand dunes at the east end of Haverigg Bank but without the concrete capping there is damage to the gabion boxes. Here too the wall is above the tidal limit and most of the damage is probably caused by pedestrians. Further westwards the dunes appear to be stable and there is some evidence of sand accretion near Haverigg Point. The dunes extend to north of Kirkstanton Haws where they give way to clay cliffs. The erosion of the cliffs releases substantial quantities of shingle which are transported a northward direction by littoral drift. The sand and shingle beach extends northwards to the mouth of the River Esk. Along this stretch there are few coastal defences.

The clay cliffs disappear at Annaside and there is low lying land at the mouth of the River Annas. The mouth is deflected strongly northwards by the littoral drift and the spit on its seaward side is reinforced by a shingle bank. North of Annaside there are again short stretches of low clay cliffs extending to Marshside, and erosion is taking place along this stretch. At Marshside the road runs close to the shore. Here the crest of the shingle ridge has been reinforced by a gabion revetment which extends over a frontage of about 200m. The gabions are believed to be about 10 years old and are showing signs of wear and tear. To the north of Marshside the shingle ridge extends along the toe of the Eskmeals sand dune system. The M.O.D. buildings to the north of Marshside are protected by having the shingle scraped from the lower part of the beach and pushed onto the crest of the shingle ridge.

There are no formal coastal defences along the M.O.D. frontage which extends to the mouth of the Esk.

The village of Ravenglass is situated at the head of the Esk Estuary. It is fronted by a wide sand foreshore and protected by extensive sand spits and sand dune systems on either side of the mouth of the Esk. Part of the village has in fact no formal defences with the houses backing directly onto the foreshore and themselves acting as "coastal defences". Because of the tortuous nature of the Esk Channel there is very little direct wave activity along this frontage. There are short stretches of wall to fill in the gaps in the informal defences. These walls are old but are believed to be in adequate condition. At the north end of the town a low earth bank is protected from river current erosion. This protection consists of a low gabion wall, which is about 10 years old. Vegetation in front of parts of this wall suggests that the erosion problem is not serious. There are a few short groynes near the railway bridge north of the village. These are subject to more severe tidal scour and are damaged. North West Water share the responsibility for protecting the village with Copeland Borough Council.

The wide belt of sand dunes to the north of the Esk Estuary appear to be stable and some accretion is believed to be taking place at Drigg Point just north of the river mouth. The foreshore here is about 1Km wide at low tide and accretion is probably the result of sand being blown inland from the beach. The sand dunes are unprotected and extend northwards to Seascale.

The town of Seascale sits on a flat boulder clay shelf. At the south end of the town the coast road runs close to the shoreline and coastal defences here consist of a 600m long concrete sea wall constructed in 1950. The wall protects low clay cliffs. The beach here is narrow and consists of sand and shingle over lying a rocky foreshore platform. Short gabion groynes were constructed in 1980 in an attempt to improve beach levels. The groynes are subject to a considerable degree of abrasion by beach pebbles and have deteriorated badly. The amenity area to the north of the concrete wall consists of a low clay bank which is subject to erosion. A gabion sea wall has been partially successful in retarding erosion but has been subject to considerable damage at its southern end. The beach in front of this wall consists of sand and shingle and is partly grassed over suggesting that wave induced erosion at the toe of the wall takes place intermittently. Responsibility for the concrete sea wall at the southern end of Seascale is shared between the Cumbria County Council and the Copeland Borough Council. The gabion wall is presumed to be the responsibility of the Borough Council. North of the defences at Seascale a shingle ridge, the responsibility of British Rail, protects the coast for a further 1500m.

From Seascale north to St Bees Head there are intermittent stretches of sea wall which are mostly the responsibility of British Rail since the railway line runs along the backshore as far north as St Bees Bay. Some of these walls and revetments are very old and in a poor condition. Maintenance is often carried out by concrete patching of the damaged areas. Littoral drift along this frontage is low.

Immediately to the north of Seascale there are clay cliffs partly covered by sand dunes. British Rail maintain a shingle embankment over some 1.5Kms along this frontage.

At Netherton the railway line runs in a cutting and some 600m of frontage is the responsibility of the Copeland Borough Council. Here the foot of the cliffs protected by a gabion sea wall. This wall is built at the crest of the shingle ridge and is liable to damage during periods of severe storms when beach draw down takes place. In places the shingle beach is quite substantial (to the south of Netherton for example) and there are no formal defences. Some of the chalets built on the backshore have their own rudimentary protection in the form of concrete walls or timber breastworks. All the defences along this frontage are of a fairly low cost nature. At the small promontory midway along the Copeland frontage the beach is steep and susceptible to draw down during storms making the construction of effective defences rather difficult. British Rail protect the railway line north of Netherton and their responsibility extends as far as Marsh House, St Bees Bay. Just to the north of Netherton a massive concrete groyne has resulted in a significant build up of shingle to the south, indicating that the drift is from south to north. The railway lines protected by an old concrete and masonry faced embankment. The embankment is constructed on the rocky foreshore and though it is somewhat dilapidated it appears to be functioning adequately.

Marsh House is protected by a short length of stepped concrete sea wall, the responsibility of British Rail. South of the wall the clay cliffs are protected in places by a sloping masonry embankment. The mouth of the stream at Marsh House is protected by a low gabion wall extending over a frontage of some 300m. The wall is situated at the crest of the shingle beach and at the toe of the clay cliffs. It is now in rather poor repair. North of the wall the clay cliffs along the golf course frontage are eroding rapidly. At the north end of the golf course there is a 400m length of sheet steel piled wall backed in parts by a concrete promenade. The shingle beach here is narrow and groyned. The coastal defences are the responsibility of the Copeland Borough Council. To the north of these defences the eroding clay cliffs reappear and are fronted by a shingle beach with a sandy lower foreshore. This stretch of rural coastline is undefended almost to Whitehaven.

Some 1.5Kms south of Whitehaven the toe of the friable sandstone cliffs is protected by a 100m length of sea wall protecting British Coal frontage. Immediately to the south of Whitehaven harbour there is a 200m long gabion retaining wall protecting amenity land at South Beach. Constructed about 10 years ago the wall looks to be sited sufficiently far up the beach to be unaffected by wave action except during the highest tides. The beach is of rounded quarry spoil and the foreshore between the colliery and the pier is of sand and shingle scattered with rocky outcrops. The nett drift is in a south to north direction.

Within Whitehaven Harbour the piers, walls and quays are the responsibility of the Whitehaven Harbour Commissioners. The coastline to Redness Point, a distance of almost 1Km, is unprotected and the shingle beach, held within the embayment formed by the North Pier and Redness Point, is believed to be relatively stable. This frontage is the responsibility of Copeland Borough Council.

From Redness Point to Parton the railway once again runs close to the shore. Here, British Rail are responsible for some 1.4km of sea wall which both supports and protects the main railway line. Near the station at Parton a strip of reclaimed land is protected by a 400m length of gabion revetment. This revetment, which is the responsibility of the Borough

Council, is believed to be a little over 10 years old and is in a poor condition. The foreshore rock platform here is covered with a substantial layer of pebbles and, judging by the overturning of some of the gabion boxes during storms, the beach is subject to large changes in level.

From just north of Parton to the Borough boundary near Lowca, the railway line runs along the edge of the sandstone cliffs. Along this 3.3Km frontage intermittent sea walls protect the main railway line. These are maintained by British Rail. The beaches along this stretch are of shingle with sand on the rocky lower foreshore platform. The nett drift is from south to north.

From north of Lowca to Easton Marsh in the estuary of the Solway Firth the coast protection authority is the Allerdale District Council. Their coastal responsibility extends over a frontage of some 69Kms and is shared in part by North West Water, Cumbria County Council, British Rail and several harbour and dock authorities. For about 700m north of the District boundary the coastline is undefended and parts of this stretch has been reclaimed from the sea. The next 500m, extending to the south breakwater of Harrington Harbour, is also reclaimed land. It is protected by a concrete sea wall and the beach is groyned.

Originally the source of beach material for the stretch of coastline between St Bees Head and Workington were the cliffs at St Bees Head. In more recent years the primary supply of beach material and the areas of land reclamation behind the present beach has been colliery and steel mill waste ie slag and shale. A great deal of this material has been dumped on the foreshore over the years and as a result the beach width has increased substantially. However, within the last twenty years the supply of waste has declined with the closure of steel mills and collieries in the area. The slag and shale is gradually reducing in volume as a result of abrasion and decomposition and hence areas which were once zones of accretion now require protection. This appears to be the situation south of Harrington Harbour.

At Harrington Harbour, on the southern outskirts of Workington, the various piers, walls and quays are maintained by the Harrington Harbour Commissioners.

Between Harrington and Salterbeck the stretch of coastline (about 1Km) is unprotected and privately owned. It does not receive a large supply of material since Harrington Harbour interrupts a proportion of the littoral drift. Erosion is likely to continue in this area. North from Salterbeck as far as the breakwater south of Workington Harbour (about 3.5Kms) the coastal fringe is the responsibility of British Steel. This is largely unprotected and will also erode but at a lower rate than the 1Km stretch to the south. The coastline is dominated by large quantities of steel mill waste and between Salterbeck and Workington tipping has resulted in the high water line being moved seawards by as much as 125m. The reduction of this supply has resulted in the onset of erosion. Material eroded from these cliffs travels northwards in the direction of the nett littoral drift to accrete against the south breakwater of Workington Harbour. For a number of years this material was extracted from the beach near the harbour and used for aggregate. This operation has now ceased and the beach, in due course, is likely to recover. Ultimately the coastline will try to revert to its natural position prior to dumping since the waste is generally less resistant to breakdown than natural beach material.

The piers, jetties and walls of Workington Harbour are maintained by the Cumbria County Council.

North of the harbour the coastal strip consists of reclaimed land. Here the supply of colliery waste has for many years outstripped the rate of northward drift and accretion has been taking place until quite recently. Because this area is downdrift of the harbour it is suffering from a deficit of beach material. Although there is still a large quantity of waste material the construction of coastal defences has reduced the supply of material available to be transported northwards. Here too, much of the land lying seaward of the "natural" high water line is likely to be at risk in the long term. Two stretches of stepped concrete sea wall, separated by a small headland, have been constructed by Allerdale District Council to protect an area of reclaimed land south of Siddick. Beach erosion is taking place along this frontage and concrete/gabion groynes have been used to hold the beach and reduce the rate of northward drift. These are in poor repair. A concrete bag groyne has fared somewhat better although it would be liable to failure if beach levels fall sufficiently to undermine the structure. A gabion revetment which once protected the frontage to the Siddick industrial area failed and has been partly replaced by a riprap protection. North of the riprap protection there is a short stretch of stepped concrete wall which is an unfinished state. To the north the beach is narrow and the crest of the shingle ridge (on which the railway runs) is liable to overtopping. In the severe storms of 1977 a breach occurred here, washing away parts of the railway embankment. The repaired embankment is still at the same level and the area continues to be at risk of flooding. An embankment has been constructed by the Council landwards and parallel to the railway embankment so as to protect the Process Industry Park from flooding.

From Siddick northwards the coastal area is privately owned and unprotected for a distance of about 4.5Kms. The beach here consists of shingle overlying a sandy lower foreshore. Like the frontage at Siddick this area too is undergoing beach erosion and the coastal area is liable to flooding. This frontage did not receive the large quantities of waste material which was dumped on the foreshore further southward. The beaches therefore have less of a buffer of artificial material and are now subject also to diminishing drift from the south.

From Risehow Farm to Maryport Docks the unprotected coastline (1.25Kms) is the responsibility of the County Council. This area once had an accreting beach due to the nett south to north drift being arrested by the piers of Maryport Harbour. Erosion is now taking place here and the colliery waste tip at Risehow is being undermined. The south pier is now exposed to wave action where until recent years, there was a substantial beach. It seems likely that erosion in this area is connected with the former extraction of material from immediately south of the harbour entrance. The problem of erosion in the future may be compounded by the fact that the Maryport dock area was developed on reclaimed land.

Maryport Harbour has a total frontage of about 600m, and the piers, walls and quays of the harbour are maintained by the Harbour Commissioners. The harbour, built in the 18th century, has now silted up and is now only of use to yachts and small fishing boats. Siltation in the docks is believed to be largely the result of settlement of river borne silt. However siltation within the approach channel and at the entrance to the docks consists of material from the beaches adjacent to the South Pier. Bypassing of the harbour takes place (the seaward ends of the piers dry out at low tide).

To the north of the harbour entrance, the District Council maintain some 2.2km of sea walls which extend to Bank End at the northern end of the town frontage. The protection is made up of sheet steel piling and concrete encased masonry walls. Built some 60 years ago the walls protect sandstone cliffs which are prone to erosion. The condition of the walls is rather poor despite being repaired in recent times. The beach of shingle over sand lies downdrift of the harbour and, despite some bypassing across the harbour entrance from the south, is also subject to a deficit in beach volume.

The sandstone cliffs give way to low lying land to the north which are bordered by low sand dunes and grassland and with sand and shingle on the foreshore. This typifies the conditions on the west coast of Cumbria with sand dunes extending over much of the frontage to Silloth.

From Bank End on the northern outskirts of Maryport to Dubmill Point the eroding coast is unprotected except for some sand dune stabilisation. The land is low lying and relies on the dunes and the shingle ridge at their toe for prevention against flooding. This stretch of coast is in private ownership. At Dubmill Point the County Council maintain some 800m of concrete sea wall fronted by gabion groynes. These defences protect the coast road which runs close to the shore at this point. The wall has been in place for a number of years and still gives some protection.

However the gabion groynes have now become badly damaged as a result of corrosion by salt water and attrition by beach pebbles, making them largely ineffective in arresting the littoral drift.

From Dubmill Point north to Silloth the coast is protected by a long shingle ridge over a muddy sand foreshore. The foreshore, which increases in width in a northward direction, is quite flat and the inter tidal area extends seawards over 1.5Kms at low water. The coast is backed by low sand dunes which extend to Silloth. Silloth Docks are owned by the British Transport Docks Board who maintain the piers, quays and wharves of the small harbour.

5.6 The Solway Firth

Wide tracts of saltings and marshland have developed on the south side of the estuary and extend from Silloth upstream to the schedule 4 boundary and beyond. The land is low lying and, with the exception of a stretch of sea wall and rock revetment north of Silloth, is either protected by clay embankments or is undefended.

The coastline turns north east into the Solway Firth. Between Silloth Harbour and Skinburness, concrete sea walls and groynes protect a frontage of some 3.2Kms. The upper foreshore here is groyned and there is evidence of erosion taking place to the north of the harbour. Protection has been extended northwards to Skinburness and consists of some 500m of rock revetment. Responsibility for both the sea wall and revetment lies with the Allerdale District Council.

To the east of Skinburness there are large expanses of saltings and marshland and wide inter tidal mudflats. The low lying hinterland is protected from flooding by intermittent stretches of clay embankments which are the responsibility of North West Water. The first stretch of clay embankment extends from Skinburness to Calvo Marsh. Further east the bay is well sheltered from wave action and here the landward edge of the marsh is undefended. Further upstream the banks are intermittent and fragmentary. The land behind the marshes of Skinburness and Newton is protected by some 7.5Kms of clay embankments.

Around the fringe of Bowness Common and eastwards to Herdhill Scar and Bowness the coast is largely unprotected and in private ownership. The inter tidal zone in some areas is slowly accreting while other areas are relatively stable. The small "headland" of Herdhill Scar is all that remains of the embankment that once carried the railway line across the Firth to the Scottish coast.

The coastline to the east of Herdhill Scar is eroding slowly, probably due to the landward movement of the low water channels. Immediately east of Herdhill Scar the County Council maintain a short length of concrete revetment which protects the road. The low lying coastal strip continues up the estuary to the Allerdale District boundary and beyond. At Bowness on Solway, about 1.5Kms east of Herdhill Scar, the County Council protect a further stretch of highway over a distance of 700m, with concrete and stone revetments. From Bowness the privately owned shoreline is unprotected as far east as Drumburgh (with the exception of a short length of sea wall at Port Carlisle). East of Drumburgh to the District boundary there is some 1.5km of embankment being the line of an old railway. This protects the land behind Easton Marsh.

The next coast protection authority is Carlisle City Council. They have some 2.5kms of coastline, 2.3Kms of which are protected by North West Water. This protection is provided by the old railway embankment running across the accreting Burgh Marsh and extending up to the schedule 4 boundary on the River Eden at Dykesfield. This embankment protects low lying land which nevertheless suffers occasional flooding.

The wide, silt laden estuary of the Solway Firth is subject to continuous change with accretion and erosion of the marshlands and coastal fringe often taking place in much the same area. This is largely due to the unpredictable meandering of the low water channels and strong tidal currents.

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7 REFERENCES

1. Gresswell R K. Sandy shores in South Lancashire. The geomorphology of South-West Lancashire. Liverpool University Press, 1953.

2. Hydraulics Research Ltd. The North Wales Coast. A review of the sea defences. Report No EX 648. May 1974.

3. Hydraulics Research Ltd. Report No EX 1630. Proposed coast protection works, Penrhyn Bay. September 1987.

4. Hydraulics Research Ltd. Prestatyn coast defence, executive summary. Report No 1480, August 1986.

5. Marker M E. The Dee estuary; its progreesive silting and saltmarsh development. Trans Inst Brit Geog, Vol 41, 65-71, 1967.

6. Hydraulics Research Ltd. Dee estuary scheme. General description of Hydraulics Research Station studies, with summary of results and conclusions. Report No EX 527, December 1970.

7. Hydraulics Research Ltd. Report No EX 488. The transport of sand on East Hoyle Bank. April 1970.

8. Hydraulics Research Ltd. The Wirral Coastline. A report of the sea defences. Report No EX 455, June 1969.

9. Price W A and M P Kendrick. Field and model investigation into the reasons for siltation in the Mersey estuary. Proc Instn Civ Engrs, Vol 24, 473518, 1963.

10. Hydraulics Research Ltd. Changes in the tidal capacity of the River Mersey, Report on studies made in 1982-83. Report No IT 244, March 1983.

11. Hydraulics Research Ltd. Changes in the tidal capacity of the River Mersey, Report on the studies made in 1984-85. Report No SR 43, March 1985.

12. Department of the Environment. Out of sight out of mind. Report of a working party on the disposal of sludge in Liverpool Bay. 4 Volumes. HMSO. 1972.

13. Hydraulics Research Ltd. The South West Lancashire coastline, a report of the sea defences. Report No EX 450, 1969.

14. Hydraulics Research Ltd. Report No EX 708. Sandwinning at Southport. July 1975.

15. Hydraulics Research Ltd. Report No EX 1379. Analysis of beach profiles at Blackpool. Effects of sandwinning at St Annes. January 1986.

16. Lytham St Annes foreshore, sand winning. Report No EX 760, January, 1977.

17. Kestner F J T. Cyclic changes in Morecambe Bay. Geographical Journal, 136, 85-97, 1970.

18. Hydraulics Research Ltd. Sand movement in Morecambe Bay, a radioactive tracer study. Report No EX 471. 1969.

19. Phillips A W. A sea-bed drifter investigation in Morecambe Bay. The Dock and Harbour Authority, 49, 571, 9-13, May 1968.

20. Phillips A W. Sea-bed water movements in Morecambe bay. The Dock and Harbour Authority, 49, 580, 379-382, February 1969.

21. Water Resources Board. Morecambe Bay: Estuary Storage. HMSO. 1972.

22. Hydraulics Research Ltd. Feasibility study of water conservation in Morecambe Bay: prototype studies and tidal results from the fixed bed model. Report No EX 502, 4 volumes, 1970.

23. Kestner F J T. The effects of the water conservation works on the regime of Morecambe Bay. Geographical Journal, 138, 178-208, 1972.

24. Phillips A W and W Rollinson. Coastal changes on Walney Island, North Lancashire. Department of Geography, University of Liverpool, 1971.

25. Hydraulics Research Ltd. Workington to Maryport, Cumbria, report on a visit to assess coastal erosion problems. Report No 1206, April 1984.

26. Hydraulics Research, Wallingford. HINDWAVE - A Wave Hindcasting Model, Report EX 1486, September 1986.

27. Golding B. A wave prediction system for real time sea state forecasting.

28. Department of Energy. Environmental parameters on the United Kingdom Continental Shelf. Report No OTH 84 201, prepared by Noble Denton and Associates Ltd. HMSO, 1984.

29. Hydraulics Research. Wave data around the coast of England and Wales. A review of instrumentally

recorded information. Report SR 113 (unpublished), February 1987.

30. Hydraulics Research Lt. OUTRAY - A wave refraction model. Report EX 1561, September 1987.

31. Admiralty Tide Tables. Volume 1. European Waters. Published by the Hydrographer of the Navy.

32. Graff J. An investigation of the frequency distributions of annual sea level maxima at ports around Great Britain. Estuarine Coastal and Shelf Science, 12, 1981.

33. Hydraulics Research Ltd. Statistical treatment of seawall overtopping. Summary Sheet 87, 1982.

34. Hydraulics Research Ltd. North Wales Coast Road. A55 Llanddulas to Aber, sea defences at Llanddulas. A study of return periods for overtopping discharges and armour stability, Report EX 808, March 1978.

BIBLIOGRAPHY

Coastline Geology, Topography etc

AA Illustrated Guide to Britain's Coast. 1st Edition, 1984.

Athurton R S and Wadge A J. Geology of the country around Penrith. Memoir for 1: 50,000 geological sheet 24. Geological Survey of Great Britain, Institute of Geological Sciences, HMSO, 1981.

Ashton W. The evolution of a coastline, Barrow to Aberystwyth and the Isle of Man, with notes on lost towns, submarine discoveries, etc. Edward Stanford, 1920.

Barron J. A history of Ribble navigation from Preston to the sea. Corporation of Preston, 1938.

Bird E C F and May V J. Shoreline Changes in the British Isles during the past century. Division of Geography, Bournemouth College of Technology, 1976.

Collins H C. Lancashire plain and seaboard. Dent, 1953.

Dixon E E L and others. The geology of the Carlisle, Longtown and Silloth district. HMSO, 1926.

Eastwood T. The geology of the Maryport district. HMSO. 1930.

Edgell J A. Report on the present state of the River Mersey. Report to the Minister of Transport.

Edwards W and Trotter F M. British regional geology - the Pennines and adjacent areas. Geological Survey and Museum, HMSO, 3rd edition, 1954.

Evans W B and Others. Geology of the country around Macclesfield, Congleton, Crewe and Middlewich. HMSO, 2nd Edition, 1968.

Fletcher T. Offshore island builds up eroding coastline. New Civil Engineer, p15 - 16, 16 September, 1982.

Gray A J. The ecology of Morecambe Bay. V: The saltmarshes of Morecambe Bay. J Applied Ecology, 9: 207-220, 1972.

Gresswell R K. Sandy shores of south Lancashire. The geomorphology of south-west Lancashire. Liverpool University Press, 1953.

Hemingway J E. Geology of the Whitby area. A survey of Whitby and the surrounding area. Shakespeare Head Press, 1-47, 1958.

HR EX 449. Computation of littoral drift. October 1969.

HR EX 1206. A H Brampton. Workington to Maryport, Cumbria. Report on a visit to assess coastal erosion problems. April 1984.

HR EX 1397. Analysis of beach profiles at Blackpool. Effects of sand winning at St Anne's. January 1986.

Hunter A R. A study of south Walney. Barrow in Furness Borough Council, March 1980.

King C A M. Beaches and coasts, 2nd Edition. Edward Arnold, 1972.

King C A M. Northern England. Methuen and Co Ltd, 1976.

National Conservancy Council. Coastal survey 1985 (survey of SSSI's and GCR's).

Parkinson J. Preston's losing battle against geography. New Civil Engineer, p21-22, 6 August, 1981.

Poole E G and others. Geology of the country around Nantwich and Whitchurch. HMSO, 1966.

Price D and others. Geology of the country around Preston. HMSO, 1963.

Robinson A and Millward R. The Shell book of the British coast. David and Charles, 1983.

Rose W C C and Dunham K C. Geology and hematite deposits of south Cumbria. Economic memoir for 1:50,000 geological sheet 58, and southern part of sheet 48. Geological survey of Great Britain, HMSO, 1977.

Steers J A. The coastline of England and Wales in pictures. 2nd Edition. Cambridge University Press, 1969.

Steers J A. The coast of England and Wales in pictures. Cambridge University Press, 1960.

Taylor B J and others. Geology of the country around Stockport and Knutsford. HMSO, 1963.

Wedd C B and others. The geology of Liverpool, with Wirral and part of the Flintshire coalfield.

Wray D A and others. Geology of Southport and Formby. HMSO, 1948.

Winds and Waves

Darbyshire J. Wave measurements with a radar altimeter over the Irish Sea. Deep-sea Research, Volume 17, p893-901, 1970.

Draper L and Blakely A. Waves at the Mersey bar light vessel. National Institute of Oceanography, Wormley. Internal report A37, March 1969.

HR EX 691. Lune foreshore investigation. Preliminary studies of the effects of reclaimed islands on flow patterns, bed regime and wave climate. June 1975.

HR EX 730. Lune foreshore, Morecambe Bay. Further studies of flow patterns and wave climate for various cooling-water and reclamation schemes. May 1976.

HR EX 754. Lune foreshore, Morecambe Bay. Wave statistics. December 1976.

HR EX 785. Sand winning at Southport. Calculation of wave heights. July 1977.

Marine Information and Advisory Service. The MIAS catalogue of wave data, Second edition. Institute of Oceanographic Sciences, 1982.

Meteorological Office. Frequency of observations of visually estimated wind speeds and non coarse-code wave heights in the Main Marine Data Bank. Marine Climatology, 1985.

Meteorological Office. Marine climatology, observation count (world distribution of wind and visual wave observations). Meteorological Office, Bracknell, August 1985.

Meteorological Office. Observation count (world distribution of wind and visual wave observations). Meteorological Office, Bracknell, August 1985.

Meteorological Office. Tables of surface wind speed and direction over the United Kingdom, MO 792. HMSO, 1968.

Parkinson J. Direct approach beats the north-west storms. New Civil Engineer, 10 December 1981, p20-21.

Reynolds G. A wind analysis for the northern Irish Sea. Quarterly Journal of the Royal Meteorological Society, Volume 82, No 354, p469-480, October 1956.

Shellard H C and Draper L. Wind and wave relationships in United Kingdom coastal waters. Estuary and Coastal Marine Sciences, 1975.

White P A. The offshore wind-energy recource around the United Kingdom. BWEA International Symposium on Offshore Wind Energy Systems, Royal Aeronautical Society, London, 21 October 1983.

Tides and Tidal Currents

Admiralty Hydrographic Office. Irish Sea. Tidal Stream Atlas. NP 256, 1943 revised 1962.

Agar M and McDowell D M. The sea approaches to the Port of Liverpool. Proc ICE, Volume 49, p145-156, June 1971.

Bowden K. Circulation and mixing in the Mersey Estuary. International Association of Scientific Hydrology, Helsinki, 1960, p352-360.

Bowden K F and Gilligan R M. Characteristic features of estuarine circulation as represented in the Mersey estuary. Limnology and Oceanography, volume 16, No 3, p490-502, May 1971.

Bridges P H and Leeder M R. Sedimentary model for intertidal mud flat channnels, with examples from the Solway Firth, Scotland. Sedimentology, volume 23, No 4, p533-552, August 1976.

CEGB. Heysham Hydrographic survey. Northern Project Group, survey carried out by George Wimpey and Co Ltd, 1968.

Department of Energy. Environmental parameters on the United Kingdom continental shelf. HMSO, 1984.

Engel M. Numerical storm surge forecasting. Proceedings 16th Coastal Engineering Conference, Hamburg, 1978, volume 1.

Harvey J G. Atmosphere and ocean, our fluid environments, first edition. The Artemis Press, 1976.

Heaps N S. Estimation of density currents in the Liverpool bay area of the Irish Sea. Geophysical Journal of the Royal Astronomical Society. Volume 30, p415-432, 1972.

HR EX 210. Proposed Rathmell reservoir. Interim report on the effect of the reduced fresh water flow on bed levels in the Ribble estuary. May 1963.

HR EX 280. An investigation of sand movements in the Ribble estuary using radio-active tracers. July 1965.

HR EX 281. Investigation of siltation in the estuary of the River Ribble. July 1965.

HR EX 465. Comparison of turbulent diffusion in prototype and model - Heysham. November 1969.

HR EX 471. Sand movements in Morecambe Bay - a radioactive tracer study. December 1969.

HR EX 488. The transport of sand on East Hoyle Bank. April 1970.

HR EX 691. Lune foreshore investigation. Preliminary studies of the effects of reclaimed islands on flow patterns, bed regime and wave climate. June 1975.

HR EX 730. Lune foreshore, Morecambe Bay. Further studies of flow patterns and wave climate for various cooling water and reclamation schemes. May 1976.

HR EX 742. Lune foreshore investigation. Numerical studies of cooling-water; heat dispersal. July 1976.

HR EX 1054. The Mersey Estuary. Observations of tidal current, salinities and suspended solids concentrations - WRC pilot study, March 1982. April 1982.

Hydrographic Department. Admiralty Chart 1346, Solway Firth and approaches, natural scale 1:100000. Hydrographer of the Navy, May 1979.

Hydrographic Department. Admiralty Chart 1552. Ports in Morecambe Bay; (A) River Lune and approaches to Heysham, (B) Approaches to Fleetwood, natural scale 1:25000; (C) Fleetwood, (D) Heysham, natural scale 1:10000; (E) Glasson, natural scale 1:12500. Hydrographer of the Navy, February 1987.

Hydrographic Department. Admiralty Chart 1826, Irish Sea - eastern part, natural scale 1:200000. Hydrographer of the Navy, May 1979.

Hydrographic Department. Admiralty Chart 1951, Approaches to Liverpool, natural scale 1:25000. Hydrographer of the Navy, September 1983.

Hydrographic Department. Admiralty Chart 1961, Rossal Point to St Bees Head, natural scale 1:75000. Hydrographer of the Navy, May 1979.

Hydrographic Department. Admiralty Chart 1978, Great Ormes Head to Liverpool, natural scale 1:75000. Hydrographer of the Navy, June 1987.

Hydrographic Department. Admiralty Chart 1981, Approaches to Preston, natural scale 1:75000; Preston docks, natural scale 1:10000. Hydrographer of the Navy, May 1979.

Hydrographic Department. Admiralty Chart 2010, Morecambe Bay, natural scale 1:37500. Hydrographer of the Navy, May 1979.

Hydrographic Department. Admiralty Chart 2013, St Bees Head to Silloth, natural scale 1:50000; Workington Harbour, natural scale 1:7500; Whitehaven Habour, Harrington Harbour, Maryport Harbour, Silloth docks and approaches, natural scale 1:10000. Hydrographer of the Navy, February 1987.

Hydrographic Department. Admiralty Chart 3164, Barrow Harbour and approaches, natural scale 1:12500; Deep water berth, natural scale 1:2500. Hydrographer of the Navy, December 1985.

Hydrographic Department. Admiralty Chart 3478, Manchester ship canal and upper Mersey, natural scale 1:25000; Manchester docks, Runcorn and Western Point docks, Ellesmere port and Stanlow oil docks, Partington basin, natural scale 1:10000. Hydrographer of the Navy, December 1976.

Hydrographic Department. Admiralty Chart 3490, Port of Liverpool, natural scale 1:15000. Hydrographer of the Navy, October 1986.

HR EX 1069. The Mersey estuary. Observations of tidal currents, salinities and suspended solids concentrations during a neap tidal cycle. July 1982.

HR EX 1088. The Mersey estuary. Observations of tidal currents, salinities and suspended solids concentrations during a spring tidal cycle. November 1982.

HR EX 1171. The Mersey estuary. Observations of tidal currents, salinities and suspended solids concentrations during a spring tidal cycle. November 1983.

HR EX 1250. The Mersey estuary. Observations of tidal currents, salinities and suspended solids concentrations during a mean tidal cycle October 1984.

HR IT 244. Changes in the tidal capacity of the river Mersey Report on studies made in 1982-83. March 1983.

HR SR 43. Changes in the tidal capacity of the river Mersey Report on studies made in 1984-85. March 1985.

HR Z 72 . Note on the approach to Heysham harbour based on an examination of the Ordnance Maps and Admiralty Charts of Morecambe Bay, Lancashire. April 1952.

Hunter J R. The determination of current velocities from diffusion/advection processes in the Irish Sea. Estuarine and Coastal Marine Science, Volume 3, p43-55, 1975.

Lee A J and Ramster J W. Atlas of the seas around the British Isles, Fisheries Research Technical Report No 20. Ministry of Agriculture, Fisheries and Food, 1979.

Phillips A. A sea-bed drifter investigation in Morecambe Bay. Dock and Harbour Authority, Volume 49, No 571, p9-13, May 1968.

Phillips A. Sea-bed water movements in Morecambe Bay. Dock and Harbour Authority, Volume 49, No 580, p379-382, February 1969.

Price W A and Kendick M P. Field and model investigation into the reasons for siltation in the Mersey estuary. Proc ICE, Volume 24, p473-518, April 1963.

Pugh D T. Estimating extreme currents by combining tidal and surge probabilities. Ocean Engineering, Volume 9, No 4, 1982.

Ramster J W. The residual circulation of the Northern Irish Sea with particular reference to Liverpool bay. Ministry of Agriculture, Fisheries and Food, Fisheries laboratory, Lowestoft. Technical report No 5, January 1973.

Coastal Engineering Studies

Allen J. Scale models in hydraulic engineering. Longmans Green and Co, 1947.

Al-Muttair F F. A hydrological and economic appraisal of present and future dredging methods on the Mersey Estuary (UK). MSc Thesis, University of Manchester, December 1974.

Aston S and Rae J E. The deposition of Windscale radiocaesium in the Wyre estuary and the measurement of sedimentation rates. Marine Environmental Research, Volume 7, No 2, p83-90, September 1982.

Aston S R and Stanners D A. Local variability in the distribution of Windscale fission products in estuarine sediments. Estuarine, Coastal and Shelf Science, Volume 14, No 2, p167-174, February 1982.

Barber P C and Davies C D. Offshore breakwaters - Leasowe Bay. Proc ICE, Part 1: Design and Construction, volume 77, p85-109, February 1985.

Brodie J S. Blackpool and some of its municipal works. Proc IMCyE, volume 34, 1907-8.

Campbell J A, Chan E Y L and Riley J P. The distribution of mercury in the Mersey estuary. Marine Pollution Bulletin, volume 17, No 1, p36-40, January 1986.

Carr A P and Blackley M W L. Implications of sedimentological and hydrological processes on the distribution of radionuclides. The example of a salt marsh near Ravenglass, Cumbria. Estuarine, Coastal and Shelf Science, volume 22, No 5, p529-543. May 1986.

Carr A P and Blackley M W L. Implications of sedimentological and hydrological processes on the distribution of radionuclides in a salt marsh near Sellafield, Cumbria. IOS, Wormley , report No 197, 1985.

CEGB. Heysham nuclear power station. Tidal model investigation of the intake and discharge of cooling water. Northern Project Group, survey carried out by Wimpey and Co Ltd, 1969.

CEGB. Proposed 240MW nuclear power station in north-west England. A civil engineering appreciation of alternative sites. Volume 2: detailed ground and marine investigation reports. No 1: Heysham. Consulting Engineers: C S Allott and Son, 1966.

Central Water planning Unit. The Morecambe Bay, Dee Estuary and Wash feasibility studies of estuaral water storage in the United Kingdom. H B Jackson, 1977.

Consulting Engineer. Mersey barrage 'a crazy idea'. Volume 45, No 12, p2, December 1981.

Contract Journal. Wirral builds on latest sea defence technology. 16 September 1982.

Davies C D. Offshore breakwaters at Wirral. Municipal Engineer, Volume 2, p198-207, August 1985.

Dixon A. The Mersey Estuary pollution alleviation scheme. Journal of the Institution of Water Engineers and Scientists, volume 39, No 5, p401-413, October 1985.

Dock and Harbour Authority. Sea Wall construction gets underway at damaged Wallasey. March 1976.

Drake J. Municipal works at Blackpool. Proc IMCyE, volume 66, 1939-40.

Dunkerley P. Reconstruction of hard coast protection works at Blackpool. Municipal Engineer, volume 2, p177-207, August 1985.

Foster P. Inhibitions to pollutant dissipation in the north-east Irish Sea. Marine Pollutant Bulletin, volume 15, No 6, p222-225, June 1984.

Hamilton A S. Municipal works of Blackpool 1957. Proc IMCyE, Volume 84, 1957.

Hayward D. Mersey poised for tidal barrage. New Civil Engineer, No 685, p22-24, 10 April 1986.

HR DE 16,20,27,33,36,41,49,54,58,64; SR 9,71,97. Sludge disposal in Liverpool bay. Bed monitoring surveys 1-13, March 1973 - December 1985. October 1973 - July 1986.

HR EX 145. Mersey investigation. Report and recommendations (Part 2). January 1961.

HR EX 503. Morecambe Bay barrage. Model investigation of alternative methods of closure. August 1970.

HR EX 708. Sand winning at Southport. July 1975.

HR EX 760. Lytham St Anne's foreshore. Sand winning. January 1977.

HR EX 849. Mersey estuary. Preliminary assessment of new sewage outfall. December 1978.

HR EX 871. Fleetwood and Cleveleys sea defences. A study of return periods for overtopping discharge exceeded. March 1979.

HR EX 890. A proposed sewage outfall to the River Mersey. September 1979.

HR EX 900. Walney Channel, Barrow-in-Furness. The effects of dredging for landfill. January 1980.

HR EX 906. Siltation at Heysham Harbour. November 1979.

HR EX 915. Disposal of colliery tailings into Liverpool Bay. A desk study. June 1980.

HR EX 948. River Ribble - cessation of dredging. September 1980.

HR EX 1007. Windscale - proposed heavy load jetty. July 1981.

HR EX 1042. Morecambe bay gas field. Model investigation of the scour potential of offshore structures. January 1982.

HR EX 1066. Merseyside development. Disposal of silt from south docks. July 1982.

HR EX 1102. Sand dumping in the Mersey estuary. Report to the Acting Conservator of the Mersey on field and desk studies. January 1983.

HR EX 1119. Maryport Harbour. March 1983.

HR EX 1280. Ince and Stanlow banks reclamation scheme. Desk study of low water channel position. April 1985.

HR EX 1399. Ince and Stanlow banks reclamation scheme. First report on hydraulic model tests. January 1986.

HR EX 1402. M P Kendrick. Ince and Stanlow banks reclamation scheme. Fourth report on hydraulic model tests. March 1986.

HR SR 92. Jones R J and Turner K A. Sludge disposal to sea. Liverpool Bay bed ripple survey, 1984. April 1986.

HR Z 33. Mersey investigation: report and recommendations. June 1960.

Institution of Civil Engineers. Dredging in the sea-channels of the Mersey. Transactions of the Engineering Conference, ICE, p101-137, 1907.

Kestner F J T. The effects of water conservation works on the regime of Morecambe bay. Geographical Journal, Volume 138, part 2, p178-208. June 1972.

Ladmore P W. Recent municipal works in Morecambe and Heysham. Proc IMCyE, volume 57, 1930-31.

Lockwood G O. Sea defence works at Silloth, Cumberland. Proc ICE, February 1953.

McDowell D M. Liverpool bay, a better site than Maplin? Surveyor, 16 November 1973, p13-15.

Melville W M. Fleetwood's sea defence works and promenades, with a reference to the flood of October 1927. Proc IMCyE, volume 58, 1931-32.

Melville W M. Post-war coast protection works at Fleetwood, Lancashire. 1946-50. Proc ICE, June 1953.

Natural Environment Research Council. Liverpool Bay. An assessment of present knowledge compiled by members of the Liverpool Bay study group. Publications series C, No 14, April 1975.

NCE. Wirral gets sea defences down to a T. 28 September 1978.

Norton M G, Rowlatt S M and Nunny R S. Sewage sludge dumping and contamination of Liverpool Bay sediments. Estuarine, Coastal and Shelf Science, volume 19, No 1, p69-87, July 1984.

Paynting T. Mersey barrage fuels the imagination. Surveyor, Volume 158, No 4662, p20-21, 22 October 1981.

Perkins E J. The Solway project. Spectrum, No 97, p12-13, 1972.

Rae J E and Aston S R. Mercury in coastal and estuarine sediments of the north-eastern Irish Sea. Marine Pollution Bulletin, volume 12, No 11, p367-371. November 1981.

Roberts D G M, Summerton J D, Palmann O and Thompson V G. North Wirral Authorities and Hoylake UDC long sea outfall. Proc ICE, 1972 supplement (v), paper 7495 S.

Smith W, ed. A scientific study of Merseyside. Published for the British Association by the University Press of Liverpool, 1953.

Surveyor. All for one, and one for all (sea defences at Pilling). p8-10, 9 October 1980.

Surveyor. Forum puts up £400M Mersey barrage scheme. 15 October 1981.

United Steel Companies Ltd. The silting of Workington dock. Research and Development Department, Stockbridge, Sheffield, 10 February 1949, Ref No G2905/1.

Water Resources Board. Morecambe bay: estuary storage. Report of the economic study group. HMSO, 1972.

Wilkinson L St G. Ten years municipal development in Wallasey. Proc IMCyE, volume 60, 1933-34.

Wood A K. Morecambe's wave reflection wall. Municipal Engineer, volume 2, p183-197. August 1985.

Working party on the disposal of sludge in Liverpool Bay. Out of sight, and out of mind. Reports of a working party on the disposal of sludge in Liverpool Bay. Volumes 1 (main report), 2 (appendices), 3 (report for 1972-73) and 4 (1973-75). DoE, HMSO, 1972-76.

World Water. 675 million dollar barrage to cross the Mersey and generate 500 MW of power. Volume 9, No 6, p11, July 1986.

FIGURES

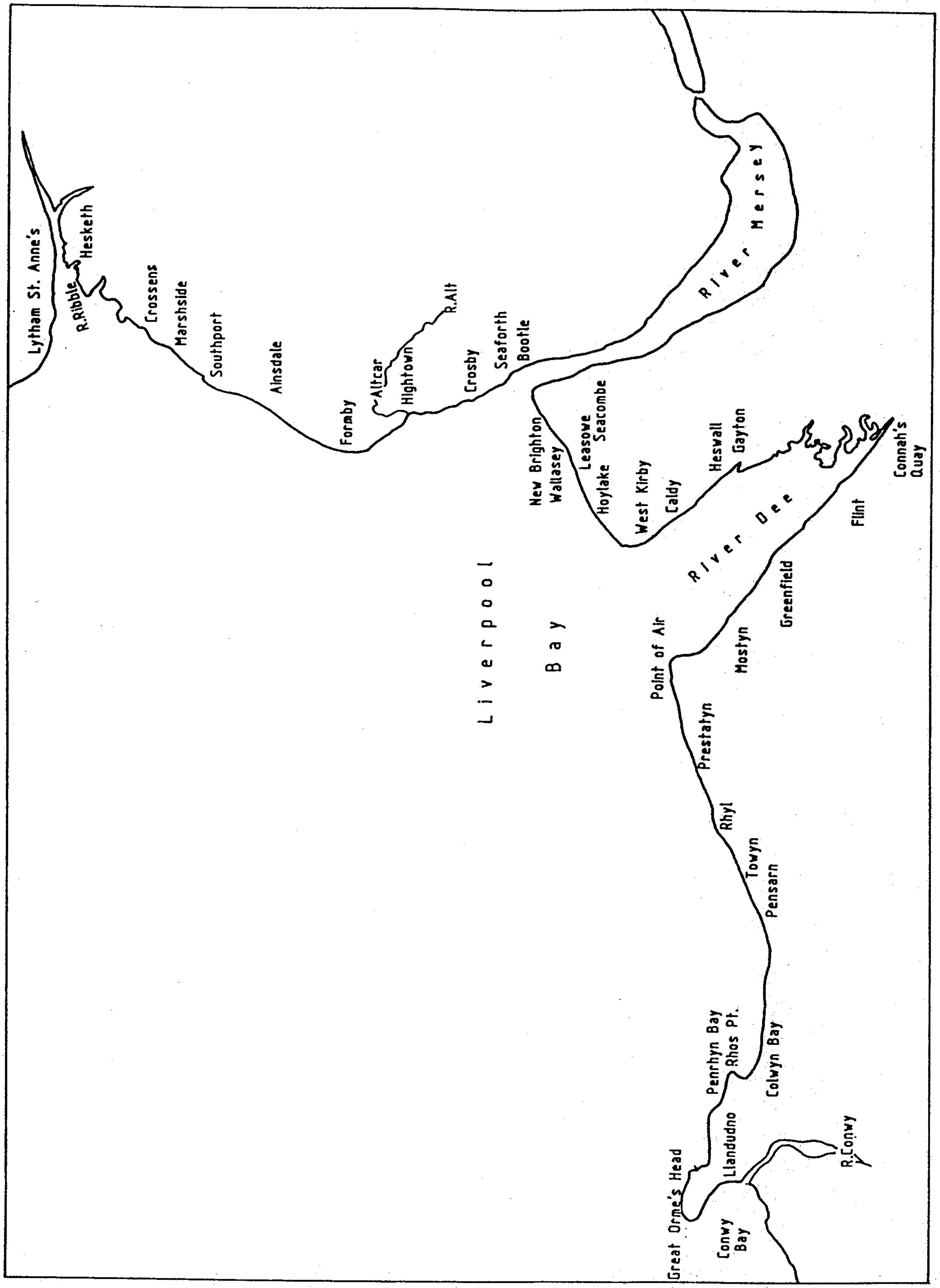

Fig 1 River Conwy to River Ribble

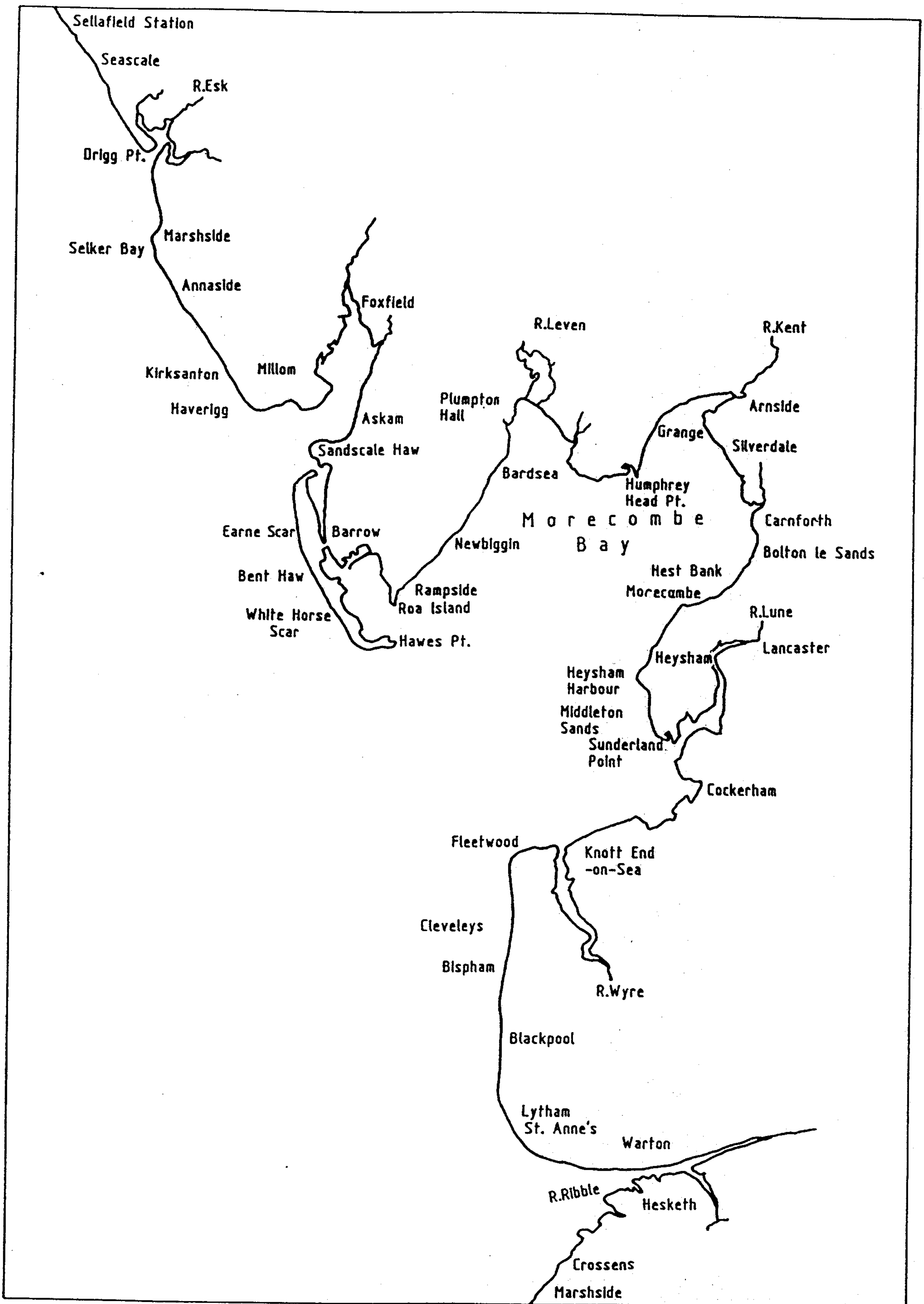

Fig 2 River Ribble to River Esk

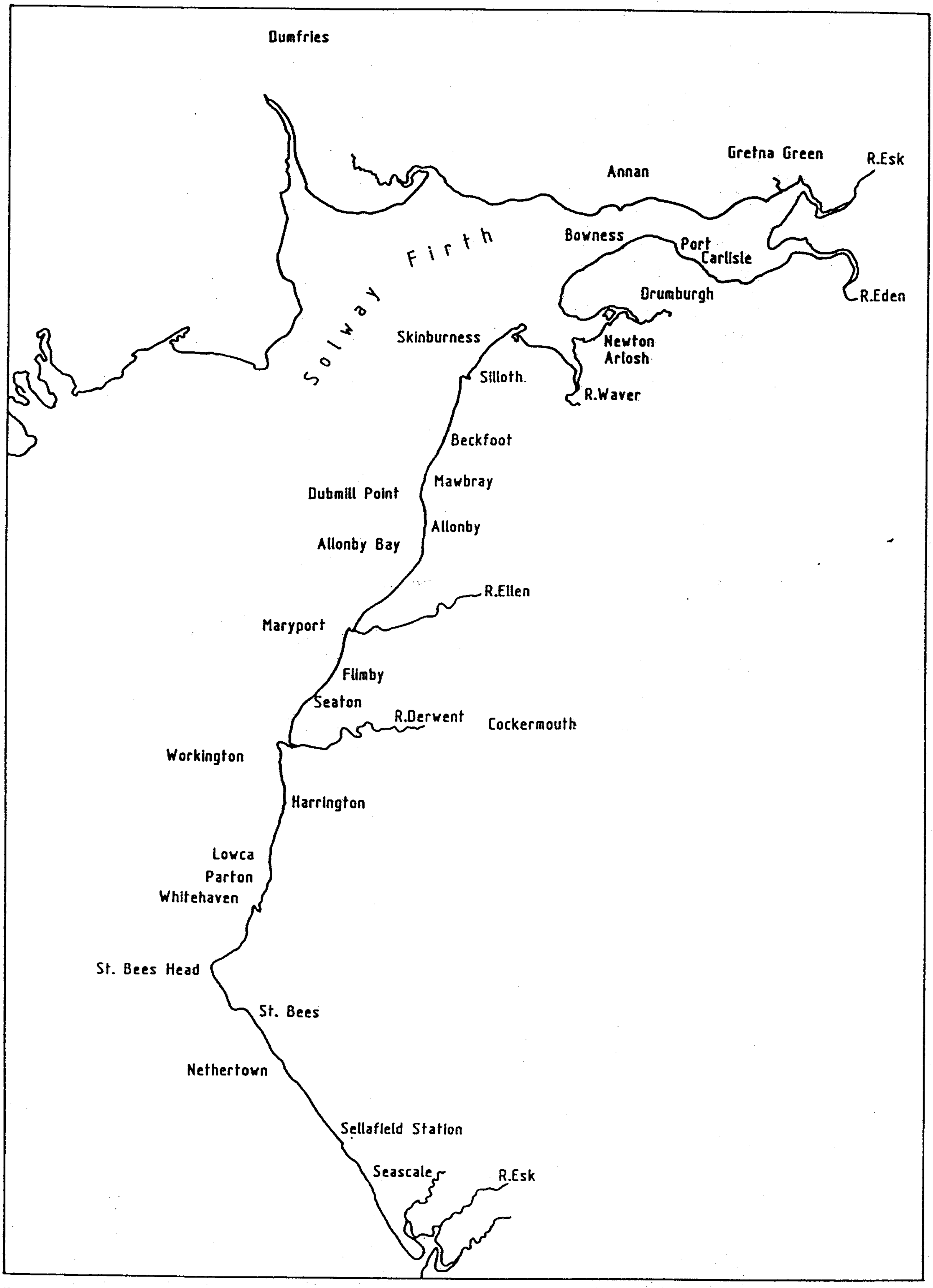

Fig 3   River Esk to Solway Firth