UTILIZATION OF ENVIRONMENTAL IMPACT ASSESSMENT (EIA) TECHNIQUE IN ASSESSMENT OF IMPACT OF HUMAN INTERFERENCE ON NATURAL ECOLOGY OF ESTUARIES - A CASE STUDY OF MERSEY ESTUARY

A thesis submited for the degree of Doctor of Philosophy (PhD)

BY

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The work reported in this thesis is a result of three years of research in the utilization of Environmental Impact Assessment (EIA) in the assessment of impacts of human activities on the natural ecology of estuaries - using the Mersey Estuary as a case study.

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The Scholarship for this study was granted by the Kebbi State Government of Nigeria, which I very sincerely acknowledge.

DECLARATION

I declare that the study presented in this thesis is the result of my own investigation.

B. L. Aliero

I declare that this work has under no circumstance been submitted in candidature for any other degree.

B. L. Aliero

Salford, April/1994

ABSTRACT

A Conceptual study of the impacts of human activities on the natural ecology of estuaries was carried out. The Mersey Estuary was used as a case study. Environmental Impact Assessment Techniques (EIA) was used to identify and evaluate impacts generated by various activities of Man on estuaries.

The study was conducted with materials and data gathered from scientific papers, documents, reports and other related literature sources.

The findings of the research reveal that estuaries exist in several forms and shape. They are characterised by graded salinity ranging from marine condition (3.5%) to fresh water (0.05%) and periodic and spontaneous tidal movements. Estuaries are highly productive ecosystems and support large wildlife and fish.

For many years Man has exploited estuarine resources. However, in the last two hundred years, the advent of the industrial revolution led to dramatic growth of navigation and establishment of industries close to estuarine waters. Consequently estuaries attracted large human populations which discharged sewage along with industrial effluent direct into their waters causing rapid deterioration in water quality and severe distress of the biota.

The Mersey Estuary is typical of such industrialized estuaries. The level of engineering modification and the extent of pollution witnessed in the Estuary is possibly unparalleled by any other estuary in the U.K. These activities have significantly affected the ecosystem of the Mersey and the socio-economic life of people living within its catchment boundary and beyond.

EIA has become an important tool in environmental planning and management. I have used its principles and techniques in the identification and analysis of impacts caused by activities of Man on the Mersey Estuary.

Analysis of results indicate that the construction of training wall along the sea channels and the building of the Manchester Ship Canal were most important, reducing estuarine capacity and the stabilization of the inner estuary navigation channel. The heavy organic load from sewage and industry discharged directly into the estuary caused severe deficiency of dissolved oxygen and consequent loss of fish and wildlife. The drive to clean up the Estuary started in the 1970s and so far positive changes are being recorded showing improved wildlife which reflect general improvement in the whole Estuary.

PREFACE

Estuaries are intermediaries between marine and fresh water environments and consist of ecosystem ranging from purely aquatic with species of planktons and fish, through intertidal macrobenthos to salt marsh vegetation that is only intermittently covered by tides. The salt marsh grades into reeds and then to terrestrial ecosystem. Estuaries are extremely important in nature conservation supporting a wide variety of birds including some rare species facing the danger of extinction. They are however, centres of world trade and around them are located ten of the most densely populated cities in the world including London, New York and Tokyo.

The importance of estuaries is achieved by virtue of the natural advantages present in them. The volume of water in them is deep enough to accommodate large ships and they are located inland where ships can dock to load and unload goods and merchandise. The geochemical fluxes ensure that contaminants such as heavy metals and nutrients such as nitrogen and phosphorous are both removed and renewed into the system. This self cleaning ability enable them to accept limited levels of pollutants. Their ability to trap and re-release nutrients makes them areas of high primary productivity. The high primary productivity result in high yields of animals such as oysters and mussels, and attract great numbers of juvenile fish and birds.

The self cleaning ability of estuaries has over the years been misused and abused by the discharge of more material than the estuary can absorb with the result that many estuaries became polluted and lost their productive capacity.

The Mersey Estuary has a unique configuration which enabled it to catch trade from its silting neighbour, the Dee Estuary, in the 18th century. Since then, the Mersey has grown in importance. Its position on the north west coast of England acted as a booster with the opening of trade with America, Africa and South East Asia. The opening of trade with the outside world made the Port of Liverpool, the principal town on the Mersey and second to only London in terms of trade handled the shipment of bulk quantities of raw materials from the outside world encouraged the establishment of industry and as a result dramatic population expansion. Trade effluent from industry and sewage from the population were freely discharged into the Estuary to the extent that it became one of the four most grossly polluted estuaries in Britain. This state of affairs turned a once flourishing fisheries centre to virtually dead fish-less water. Further the site was deserted by the visiting wintering birds due to a virtual absence of the prey organisms for which estuaries are known.

The implementation of the EIA directive in 1969, in the U.S.A and the subsequent environmental awareness that spread throughout the world among other factors sharpened the concern for the state of the Mersey. Several studies have been carried out on the biological, chemical and most recently comprehensive study covering all aspect of the estuary features including its physical state and hydrology. The studies on the biology and chemistry were mainly concerned with the pollution of the Estuary. This study aim to utilise information generated from these and earlier studies on the Estuary and to apply EIA methodology to assess the impacts of the various human activities that have led to the deterioration of the Estuary and its biota. It is hoped that this thesis will contribute to the identification of the activities which have had greatest impact on the ecology of the Estuary. It is also hoped that this information will contribute to the future management of the Estuary and serve as a guide for environmental management in general.

OUTLINE OF THE THESIS

This thesis is presented in eight chapters as follows:-

Chapter one

In this chapter definitions and descriptions of the physical characteristics of estuaries are given. Eight types of estuaries are identified and discussed. The distribution and importance of the various estuary types in Britain is described.

Chapter two

The location and catchment of the river Mersey Estuary and the geological origin and configuration of the Estuary are outlined. Prevailing wind and visibility over the Estuary catchment is described. Water movement and sedimentation in the Estuary are given and the ecosystem components including the pelagic, intertidal, fish and salt marsh vegetation are discussed. Finally the conservation value of the Estuary in terms of overwintering and wading birds is discussed.

Chapter three

Here a brief history of the growth of human populations around the Mersey Estuary. Changes in industrial development from port and dock based prior to the 1930s and the shift to chemical, food and paper industry afterwards is mentioned.

Chapter 4

The concept, process, technique and development of Environmental Impact Assessment (EIA) is discussed. Emphasis is given on development of EIA in Europe in general and United Kingdom (U.K.) in particular. Efficiency and criticisms of EIA technology are discussed.

Chapter five

Chapter five gives a general discussion of human activities and their impacts on estuaries. Emphasis is placed on the effects of land claim and pollution on estuaries.

Chapter six

Impacts of human activities on the Estuary of the River Mersey are classified and discussed. Physical changes brought about by the construction of training walls and the Manchester Ship Canal are discussed. The impact of sewage and industrial effluent on the biota and conservation importance of the Estuary is described. The 1989 oil spillage in the Estuary and its impact is treated as a special event and discussed separately.

Proposals for major development activities such as the expansion of the Stanlow Oil Refinery, the Mersey Barrage, the expansion of the Liverpool Airport and the Mersey Crossing are outlined and risk assessment of such projects made.

Chapter seven

In chapter seven an attempt is made to apply EIA methodology to assess impacts of human activities on the Mersey Estuary and the result analyzed and discussed.

Chapter eight

Chapter eight gives a summary discussion of the Thesis and recommendations.

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CHAPTER ONE INTRODUCTION

1 INTRODUCTION

1.1 GENERAL CONSIDERATION

Estuaries are highly productive ecosystems and unique in their ability to support wildlife and fish. For example the heat storage capacity of the sea reaches a maximum in late summer, so that whilst the productivity of terrestrial ecosystems declines during the autumn, that of the mud-flats in estuaries actually reaches its peak at that time. Thus the maximum biomass of prey species is available near the time when the maximum numbers of predators are present (Wilson, 1988). The immense resources available in estuarine mudflats were probably responsible for flourishing shellfish industries in medieval Britain and the exploitation of wildfowl and wader populations by professional wildfowlers.

At high water, the flats are important feeding grounds for fish such as flounders and the channels and creeks which drain them support substantial local stake and netting fisheries.

Due to the influence of human activity especially in the wake of the industrial revolution, many estuaries formerly regarded as rich in natural resources are now reduced to mere sport hunting grounds and areas where shellfish was once part of the local economy have become spots for weekend pastime activity. There is therefore the need to understand estuaries in all thier aspects including their formation, factors that are responsible for their high productivity, what led to their degradation and the effort to salvage what remains in attempt to restore them back to their traditional values in terms of conservation and fishing, while at the same time maintaining their benefit, use for navigation and industrial activity.

1.2 OBJECTIVE OF THE STUDY

The fundamental objective of this study was to develop skill in utilizing Environmental Assessment Techniques to assess human impact on natural environment with a view to provide efficient environmental planning and management. The unique position of estuaries as complex ecosystems combining terrestrial and aquatic features provides a good background environment for study. Detailed objectives of the case study included the assessment of engineering activities on hydrology and sedimentation of the Mersey Estuary, the impact of pollution on the biota and consequent effect on the fisheries and conservation value of the Estuary.

1.3 DEFINITION OF ESTUARY

Several definitions have been given to try to describe the word " Estuary " is derived from latin - estuarium, a place reached by aestus, " the tide " . The Encyclopedia Britannica defines " estuary " as the mouth of a river where sea and fresh water meet and where tidal effects are conspicuous. Barnes and Green (1972); Barnes (1977), gives a simplified definition of an estuary as a region through which a river discharges into the sea. Ketchum (1951), defines it as a basin in which river water mixes and dilutes sea water. Pritchard's (1967(ii), definition is a semi enclosed coastal body of water which has free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage.

Other definitions are morphological: for instance, Steers (1964) describe it as a trumpet shaped and usually the single mouth of tidal river. Walker (1988) define an estuary as an inlet of the sea at the mouth of a river. In his definition Fairbridge (1980) describe it as an inlet of the sea reaching into a river valley as far as the upper limit of tidal rise, usually being divisible into three sectors:-

a) a marine or lower estuary, in free connection with the open sea;
b) a middle estuary, subject to strong salt and fresh water mixing and
c) an upper fluvial estuary, characterized by fresh water but subject to daily tidal action.

In 1991, Davidson et al, describe estuaries as being a partially enclosed area at least partly composed of soft tidal shores open to saline water from the sea and receiving fresh water from rivers, land run-off or seepage.

Although the process based definitions describe the dynamic nature of an estuary, they are short term unlike morphological definitions which are long term and allow for climatic changes. For the purpose of this thesis, Fairbridge's definition has been adopted.

1.4 FEATURES OF ESTUARIES

a) Tides

b) Changing salinity

a) Tides

Estuaries are characterised by periodic and spontaneous tidal movements (McLusky,1989; Dyer,1973; Davidson et al, 1991; Odum, 1971 and Wiley, 1976). Periodic tides are determined by rotation of the Moon in relation to the Sun. Spontaneous tides are usually dependent on climatic factors, mainly wind and are less predictable.

Tides rise (flood tide) to a high water peak and then fall (ebb tide) to a low water trough twice in a day. In Britain the typical flood / ebb cycle takes approximately 12.5 hours (Davidson et al, 1991).

Maximum monthly tidal rise (spring) occurs when the gravitational pull of the Moon and the Sun coincide, causing water to rise to very high levels and to fall to a greater extent than neap tides which are formed when the gravitational forces of the Sun and the Moon are in opposition. They reach lesser heights at high water and also drop less at low water. The highest astronomical tides in British estuaries occur in a regular cycle, one in autumn and another in spring (Davidson et al 1991).

During periods of low atmospheric pressure, storm surge tides can force water into estuaries even to an extant when they overflow banks. This type of unusual water rise may sometimes overshadow the periodic tidal cycles (Kennedy, 1980).

b) Changing salinity

Salinity is a measure of the salt content of water, expressed as total concentration of salts in grams contained in one kilogram of sea water. In the open sea, the salinity is approximately 35 $^{0}/_{00}$ NaCl, tending to be lower (33 $^{0}/_{00}$) in temperate seas and as high as 37 $^{0}/_{00}$ in tropical waters. In fresh water the salinity is always less than 0.5 $^{0}/_{00}$. Estuaries being links between sea and fresh water, salinity ranges from 0.5 to 35 $^{0}/_{00}$ (Pritchard, 1967(i); Dyer,1973; Olausson and Cato,1980 and Perkins, 1974).

The pattern of salinity distribution within estuaries is influenced by the volume of fresh water entering an estuary from rivers and land drainage; the volume of water coming from the sea and the rate of evaporation from the surface. Depending on the pattern of mixing estuaries are classified as positive, negative or neutral. In positive estuaries the surface evaporation is less then the volume of fresh water entering the estuary with the result that the heavier saline water coming from the sea displaces the less heavy fresh water coming from rivers and channels creating a salt wedge below the fresh water due to frictional forces. Salt water passes and mixes with surface water in the seaward direction. Movement of fresh water downward is limited by advection currents (Figure 1.1 a). In temperate waters, positive estuaries are typical .

In negative estuaries, the reverse situation happens. Evaporation from the surface exceeds the volume of fresh water entering the estuary. Excess evaporation causes increases in the surface water salinity, when surface water become denser than the water underneath, it sinks downward. Consequently in a negative estuary, water coming from both the sea and river channels enters the estuary on the surface. After the process of evaporation and sinking they leave the estuary as an outgoing bottom current. Negative estuaries are common in the tropics. Examples include the Laguna Madre and Texas. Negative estuaries may be found in temperate climates in areas where fresh water input is limited as in the Isefjord in Denmark. Figure 1.1 b, illustrates the water circulation pattern in a negative estuary.

In rare circumstances the fresh water inflow to an estuary equals the evaporation and in such situations a static salinity regime occurs. Such an estuary is termed a neutral estuary (Figure 1.1 c).

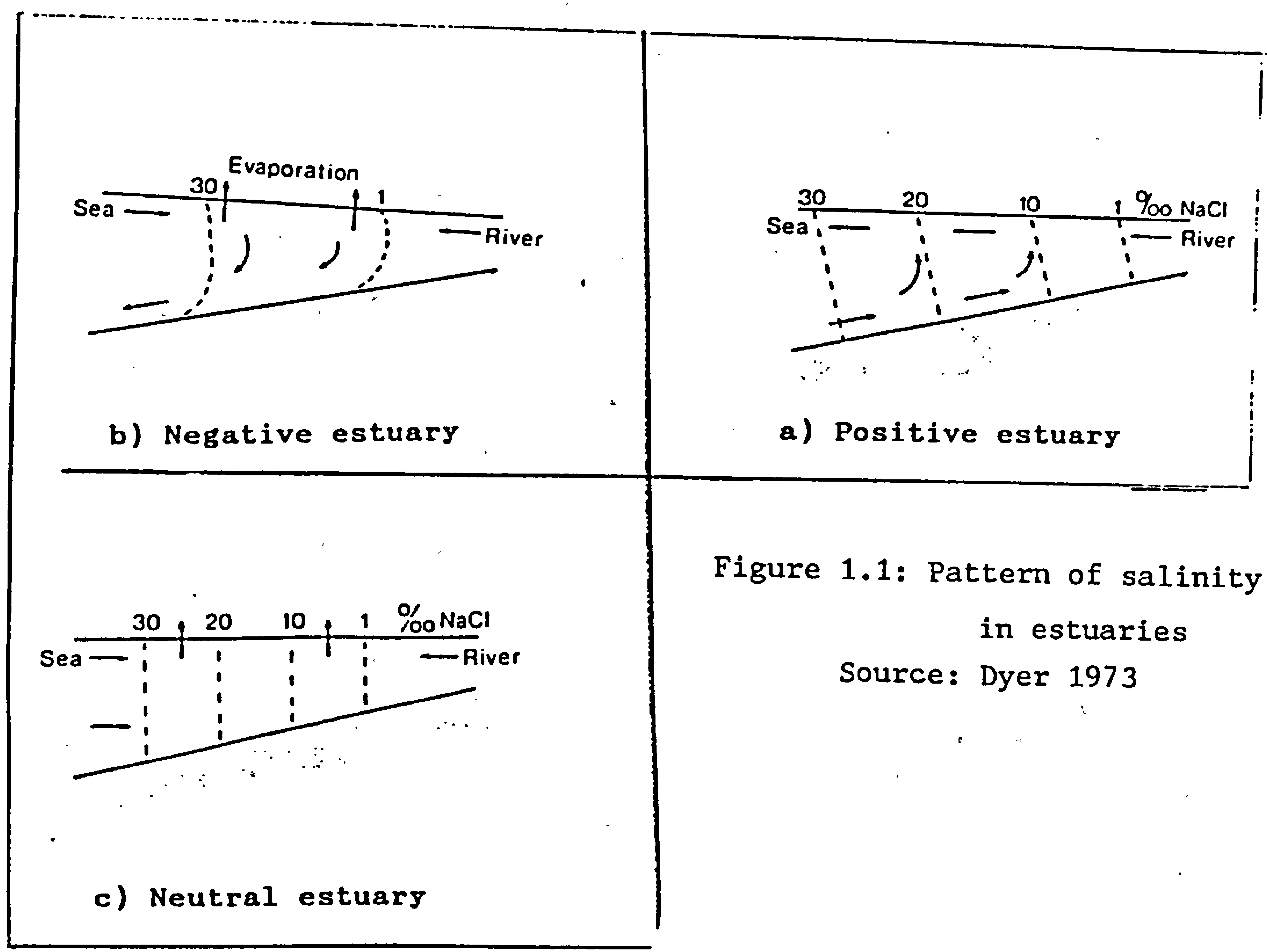

Figure 1.1: Pattern of salinity distribution in estuaries

Source: Dyer 1973

1.5 TYPES OF ESTUARIES

Estuaries have been grouped into the following morphological types (Dyer, 1973; McLusky, 1971, 1989; Fairbridge, 1980 and Davidson et al, 1991) :-

i. Fjord
ii. Fjard
iii. Ria
iv. Coastal plain
v. Bar - built
vi. Complex
vii. Barrier beach
viii. Embayment

i. Fjord

Fjords (Figure 1.2), are essentially high relief drowned glacial troughs. They are often associated with major lines of geological weakness and have a v - shaped valley profile. They are found in areas once covered by Pleistocene ice sheets where glacial erosion has been intense or selective in its operation. Fjords have a close width - depth ratio, steep sides and most, almost a Longitudinal cross section. The sharp bend giving the V - shape form reflects the underlying geological structures. Their floors are usually very rocky or with a thin veneer of sediments. Sediment deposition is usually restricted to the head of the fjord in association with major rivers. River discharge into fjord estuaries is small compared to the total volume but large in relation to the tidal prism due to restricted tidal ranges.

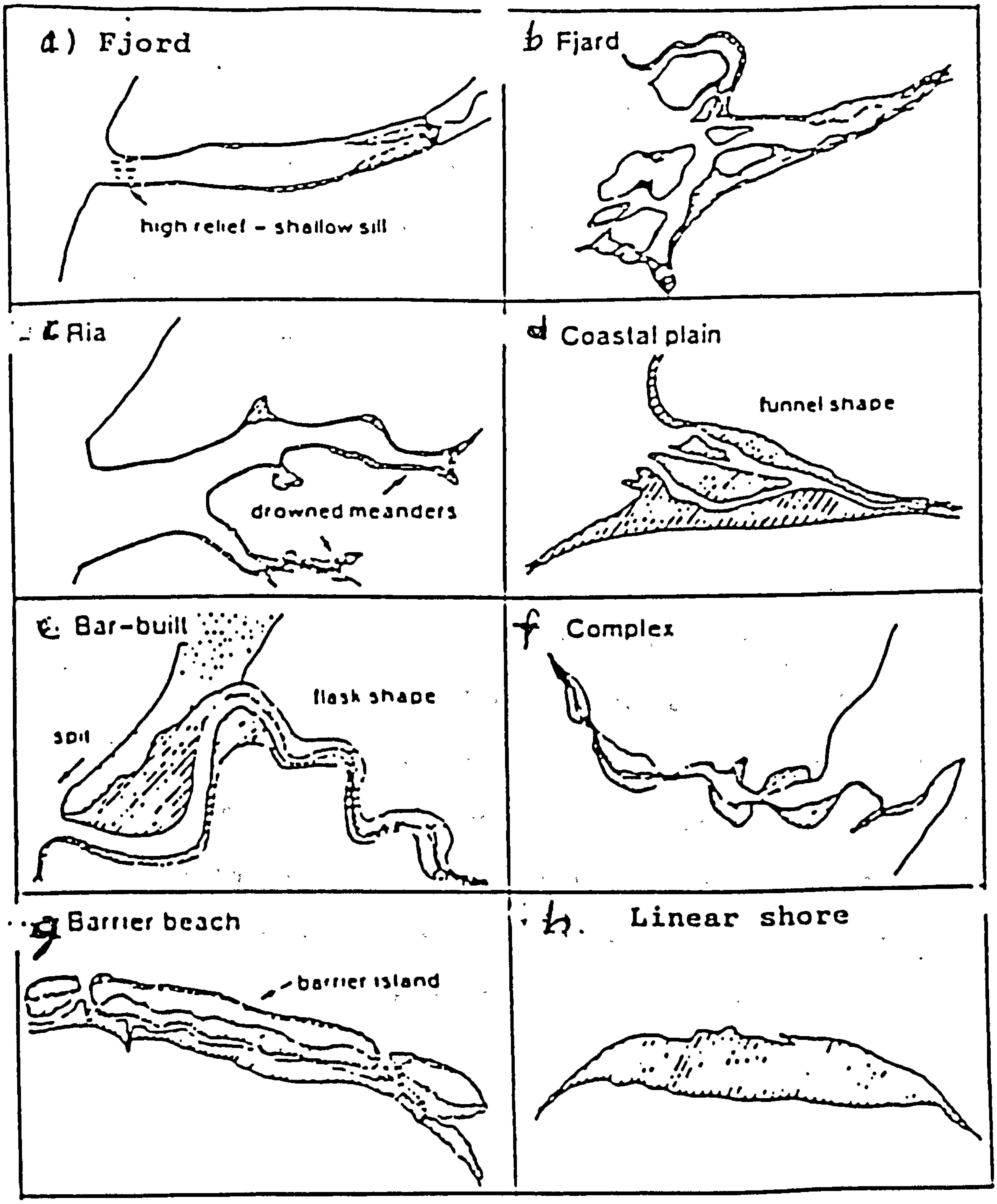

Figure 1.1: Types of Estuaries

Source: Davidson et al 1991

ii. Fjards

Fjards are more structurally complex than Fjords (1.2 b) . They are characteristic of more open and irregular coastlines are often with no main channel and are relatively shallow . Their form also frequently reflects the underlying geological structure and they are more exposed to current than fjords but are sheltered in their upper reaches.

iii. Rias

Rias are drowned river valleys formed by Tectonic subsidence of the land, a rise in sea level or a combination of both. They are relatively deep and narrow with a well defined channel (Figure 1.2 c). There is no entrance sill or ice scoured rock bars and rock basins and they are almost completely under marine influence . The predominant substrate is the bedrock which may be masked due to secondary sedimentation. Rias predominantly occur in areas of Carboniferous and Devonian rocks .

iv. Coastal Plain

Estuaries of this category are formed through the flooding of pre - existing valleys in both glaciated and unglaciated areas. Their cross sectional area is similar to that of normal valleys and they deepen and widen towards their mouths, which may be modified by spits (Figure 1.2 d). They have large width -

depth ratio depending on the rock through which the valley was cut . Here also the river flow is relatively small. Examples of Coastal plain estuaries include the Mersey Estuary and the Thames on the North West and South East coasts of England respectively.

v . Bar-built

Bar - built estuaries are similar to coastal plain estuaries with bars across their mouths (Figure 1.2 e). Bars are formed where waves break on the beach . They are associated with depositional coasts and are a few metres deep, often with extensive lagoons .

vi. Complex estuary

Estuaries of this type belong to the River Group estuaries but due to complex origins do not fit into the types in the above classification (Figure 1.2 f). They are formed from a mixture of geological constraints such as hard rock outcrops, glaciation, river erosion and sea level change .

vii. Barrier beaches

These are open coast systems, which characteristically develop on soft shores in shallow water, where dissipation of wave and current energy offshore leads to the development of bars and barriers (Figure 1.2 g).

viii . Linear shore

Embayment or blind estuaries are formed where the line of the coast follows a concave sweep between rocky headlands (Figure 1.2 h).

1.6 THE BRITISH ESTUARIES

Here the distribution of the various estuarine types described above in the British Isles is considered . The type of estuary occurring in an area is an indicator of the estuarine resources available since the morphology of an estuary influences the formation of tidal flats and the subsequent establishment of salt marshes . Flushing time influences water quality which indirectly influences the type and population of fish that can thrive and their availability for fishing and predation . Estuaries are also important places for wild birds and in economic terms for Navigation and industrial development.

Britain has the largest number of estuaries of any other country in Europe. Davidson et al (1991) reviewed 155 Estuaries around the coast of the British Isles . The number includes all the estuarine types identified above and also Linear / little indented coastlines.

The Bar-built are the most widely distributed types of estuaries and constitute 30.3% of the total estuaries (Table 1.1). The main areas of distribution are West Wales, the South Coast of England , East Anglia and Eastern Scotland (Fig.1.3).

Table 1.1: Distribution of estuary type in Britain

ESTUARY	ENGLAND	SCOTLAND	WALES
Fjord	0	6	0
Fjard	0	19	1
Ria	13	0	2
Coastal plain	29	1	5
Bar-built	24	10	13
Complex	4	0	0
Barrier beach	2	0	0
Linear shore	4	2	1
Embayment	6	4	3

Source: Davidson et al 1991.

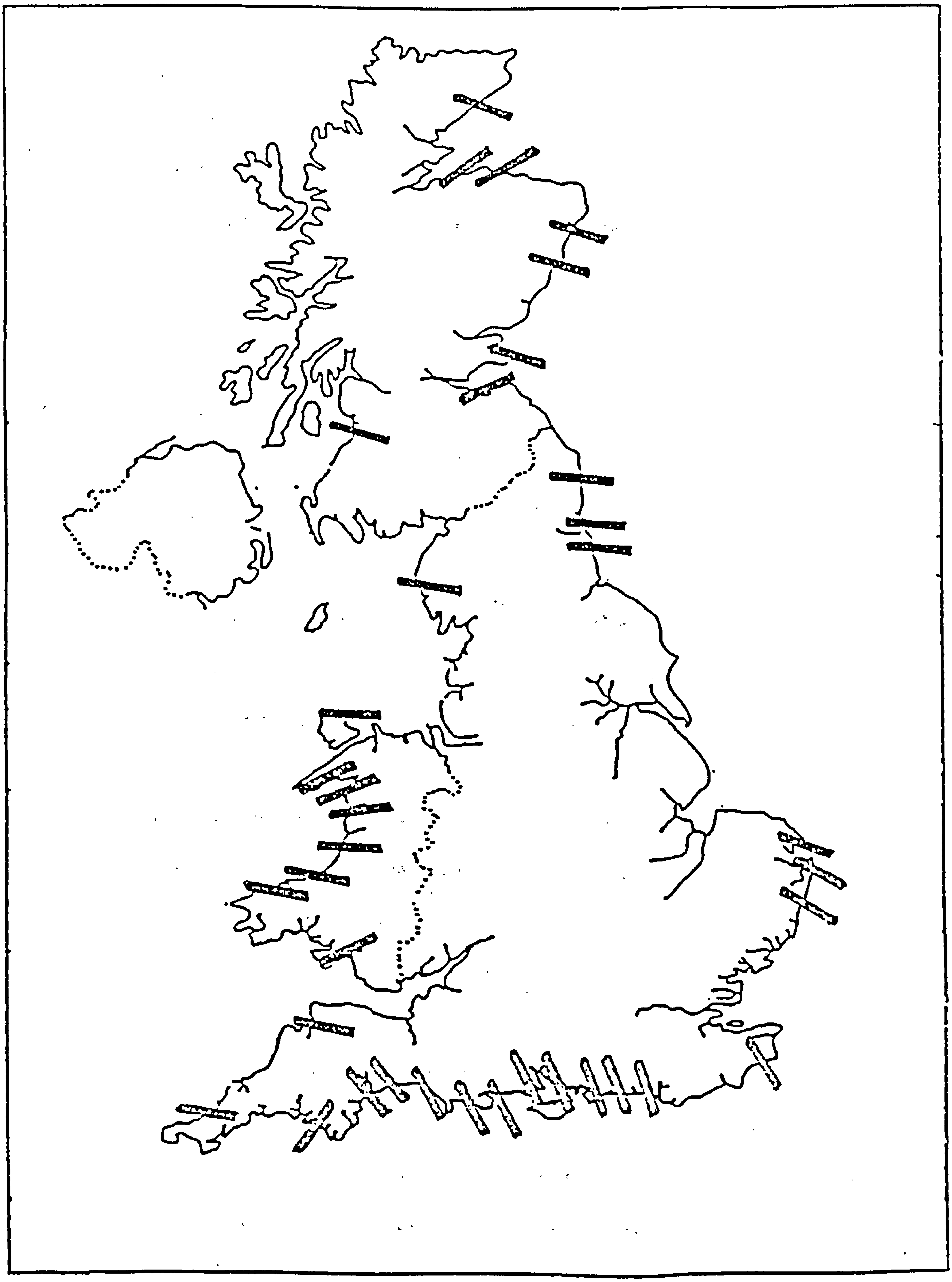

Figure 1.3: Distribution of Bar-built estuaries in Britain

Source: Davidson et al 1991

There are 35 (22.6 %), coastal plain type estuaries in Britain (Table 1.1). They are mainly distributed in England and Wales, particularly in Suffolk, West Sussex, Hampshire, South Wales, and the North Wales and the Lancashire stretch of the West Coast of England (Figure 1.4). The Mersey Estuary belongs to this category.

Some of the Britain's largest estuaries for instance the Severn Estuary, the Welsh Dee, the Humber and the Thames estuary complex, are of the coastal plain type.

The fjards rank third in Britain's estuarine types . They are mainly concentrated in Scotland but some are found the western and northern coast between Anglesey and Orkney

The Rias are the next most important group, distributed in Devon and Cornwall and South Wales . Milford Haven and the Neath Estuary are examples (Figure 1.4).

Fourteen embayments were selected along the coast of Britain and are widely distributed. They include the Carmarthen Bay, Morecambe Bay and The Wash. Locally each of these three Estuaries demonstrate characteristics of the coastal plain type.

The Complex Estuaries are the next important group of estuaries in Britain . They are distributed along the coasts of Scotland and England (1.5). Examples are the major Estuaries along the coast of Scotland such as the Firths of the Solway, the

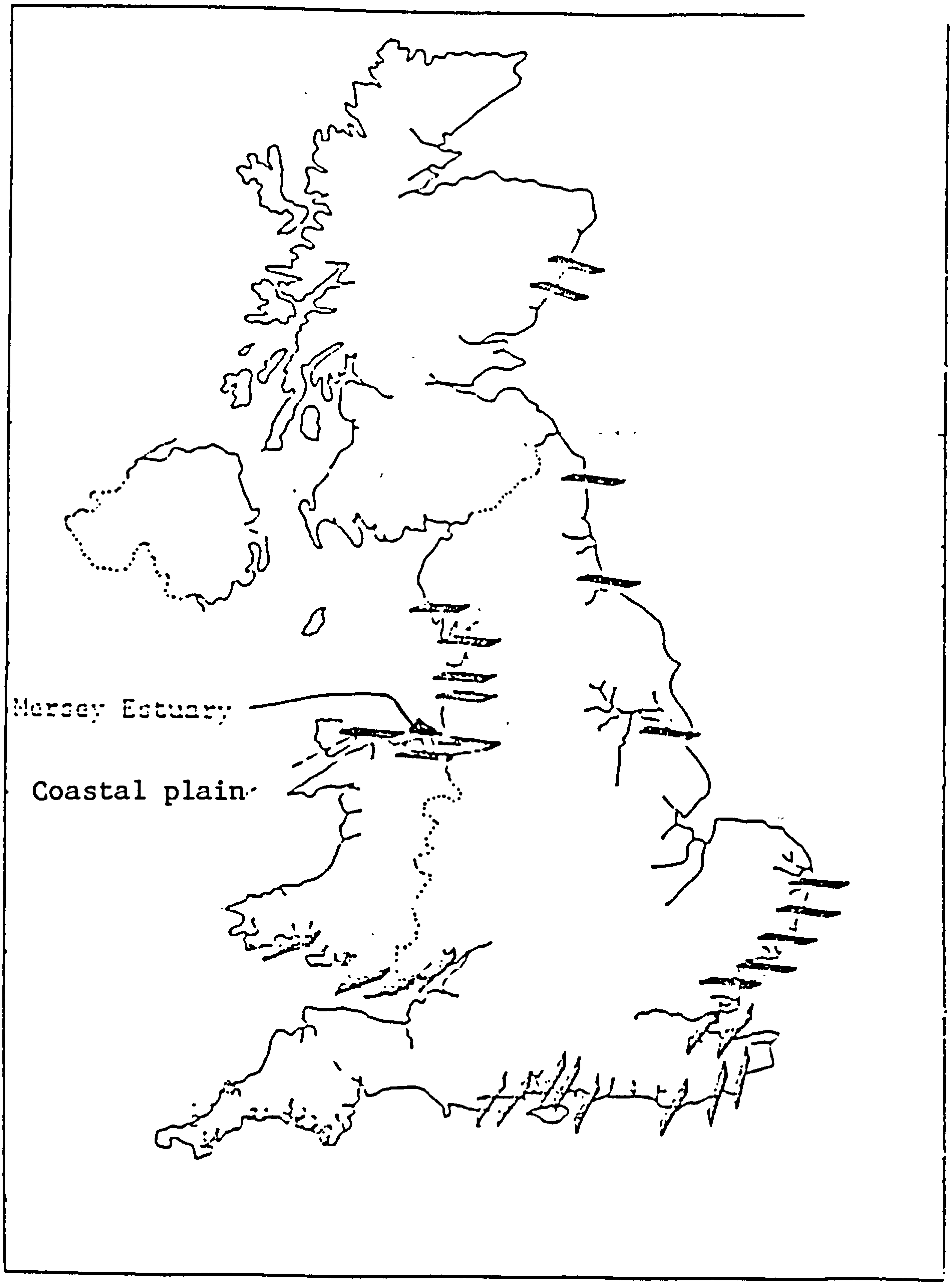

Figure 1.4: Distribution of Coastal plain estuaries and Rias in Britain

Source: Davidson et al 1991

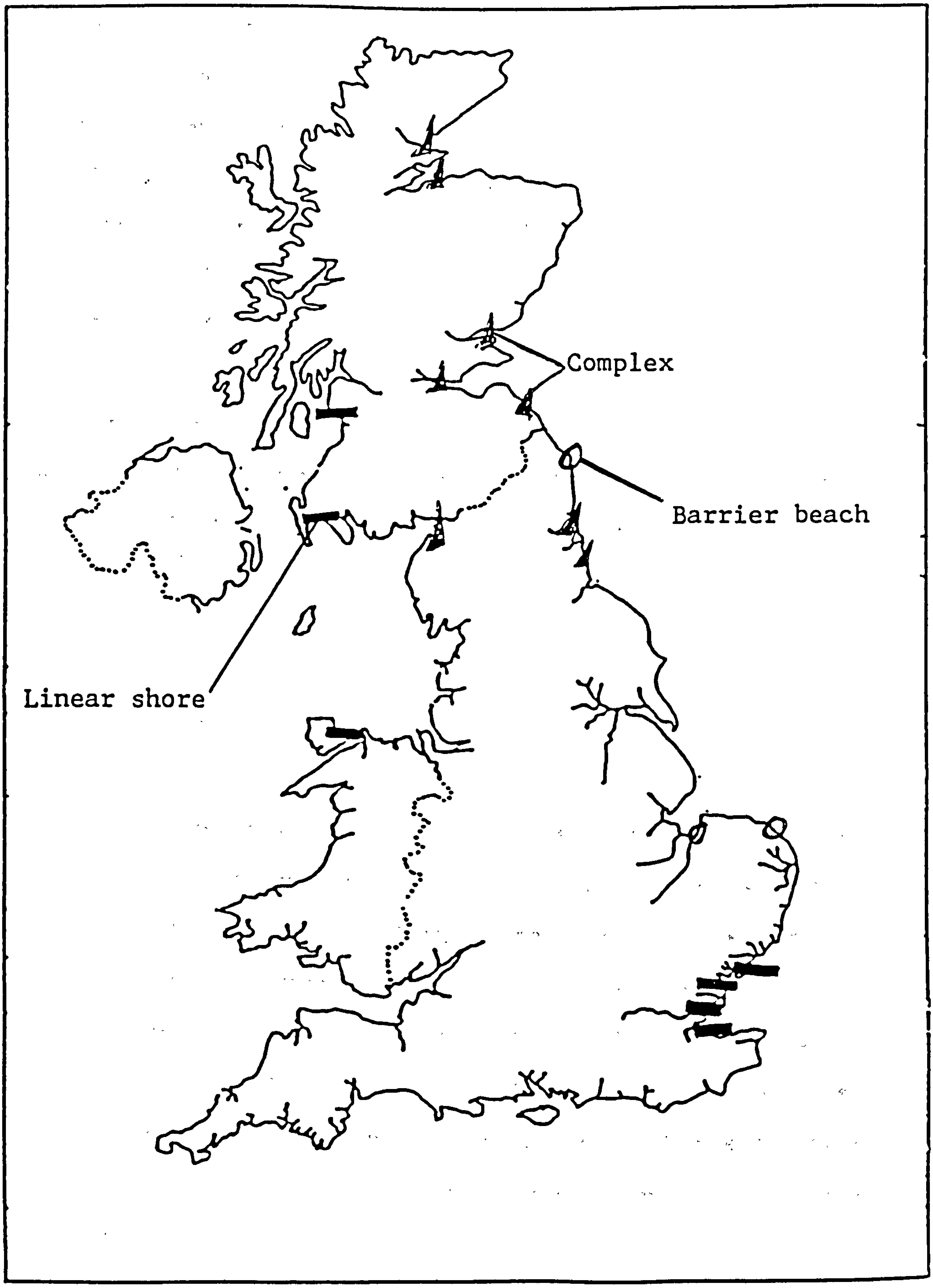

Figure 1.5: Distribution of Complex, Barrier beach and Linear shores in Britain

Source: Davidson et al 1991

Moray, Cromatry, Dornoch, Tay and Firth of Forth. The six Fjords along the coast of Britain are all distributed along the coast of Western Scotland. The two barrier beaches are on the coast of England . The North Norfolk Coast is however, the only classic barrier beach system. Lindisfarne on the Northumberland Coast, has also developed mostly in the shelter of an extensive dune and shingle system (Figure 1.5).

Seven sites of linear shore or slightly indented coasts have been included in the estuarine classification . They are mostly distributed in South East England at Dengie, Maplin, Southend and North Kent Marshes (Figure 1.5).

1.7 SUMMARY

Estuaries are interphase bodies of water between land and sea characterised by periodic and spontaneous tidal movements dependent on rotation of the Moon in relation to the Sun and climatic factors. Salinity in estuaries ranges from 0.05% to 3.5%. Eight types of estuaries have been identified namely, Fjord, Fjard, Ria, Coastal plain, Bar-built, and Complex estuaries. Others are Barrier beach and Embayment. There are over 150 estuaries in Britain. Out of these number about 30% are Bar-built and 23% Coastal plain types.

CHAPTER TWO

CHAPTER TWO THE MERSEY ESTUARY

2.1 GENERAL CONSIDERATION

The name Mersey is a derivative of old English (Post-Roman)."Mersc" - a Marsh. In the modern Dutch. "Mersche" means Marsh (Ashton, 1920). The Mersey Estuary is situated on the North West coast of England between the estuaries of the Ribble and the Dee (Steers 1964). Figure 2.1 show the location of the Estuary.

The tidal limits of the Estuary extend some 50 km from the sea to Howley Weir. Warrington and it carries a total volume of 400 m^3 at mean water level (Taylor et al. 1990). Three major rivers:- the Mersey, Tame and Goyt forming a confluence at Stockport, are the main sources of fresh water coming into the Estuary. Water from this confluence flows through the southern outskirts of the Greater Manchester conurbation and enters the Manchester Ship Canal near Irlam. After leaving the Ship Canal at Bollin Point it flows through Warrington and over the normally accepted tidal limit of Howley wier.

The Estuary of the River Mersey has long been a subject of interest due to its importance in navigation and industrial development. Studies on different aspects of the Estuary's characteristics have been conducted ranging from geology meteorology and hydrology to its biology and nature conservation. Studies on sedimentation and pollution of the Estuary have also been carried out.

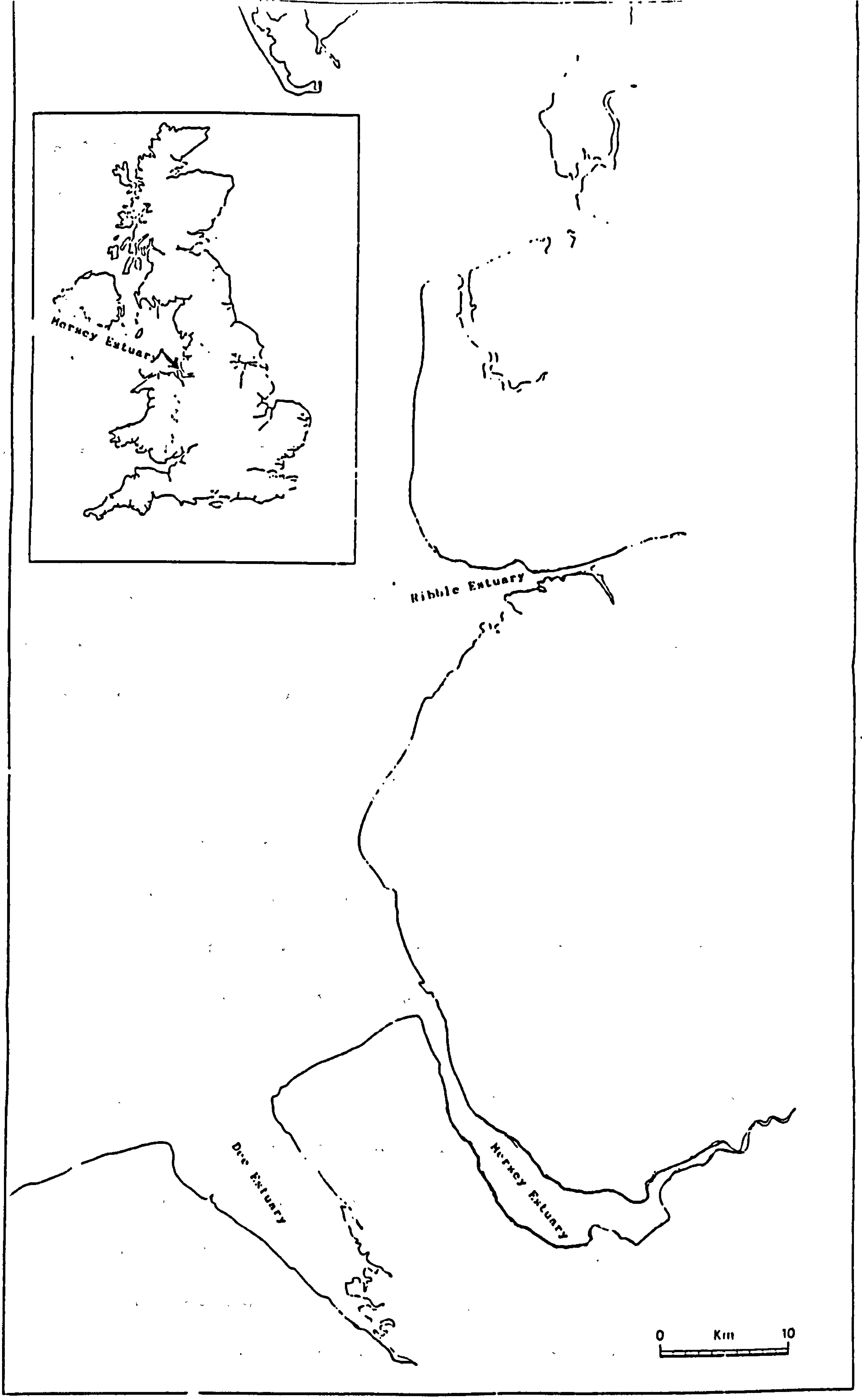

Figure 2.1: Location of the Mersey Estuary

Source: Ordinance Survey Map. Sheet 108

Gresswell (1953, 1964), Howell (1973), Shackleton (1953) and Bathurst and Branchley (1975) carried out studies on the Estuary geology and the surrounding coast. The Estuary was found to be glacial in origin with irregular rock-bound hollows and other features on its floor.

In a scientific survey, Gregory (1953) described weather and climate in the region of the Mersey. In 1953, Bowden gave an account of tidal currents and temperature and salinity variation in the Estuary water. Silt distribution and siltation processes were studied by Halliwell and O'Connor (1966) . Other studies on sedimentation include those of O'Dell (1969) and O'Connor (1971).

Fraser (1931, 1932, 1935 & 1938) conducted studies on the flora and fauna of the Mersey with reference to pollution and sedimentary deposits. Bassindale (1938) classified the fauna and reported on its abundance and variety in the Outer Estuary as against abundance of only a few species in the Inner Estuary. The densely inhabited banks of the Upper Estuary were mainly composed of mud. Corlett (1947) studied the sediment and marine fauna of the Estuary. In 1948, he investigated the pile fauna of the Mersey. Holland (1971a) conducted a preliminary survey of the macrofauna of the Mersey Estuary. Rees (1975) and Williamson (1975) reported on the Benthic and littoral fauna of Liverpool Bay. Between 1976-1980, Salford University biology research team carried out a comprehensive study of the Biology of the Estuary (Pugh.Thomas (ed) 1980). Ghose (1979, 1980) studied the distribution and abundance of macrobenthic invertebrate fauna in the Estuary, Curtis and Eryes (1980) studied the microbenthic fauna of the Estuary as well it temperature, salinity and pH. Gargari (1978, 1980) worked on the diatoms and Srivastava (1982) investigated the fish and Hodgson (1976, 1980) studied the birds. Karthegisan and Pugh Thomas (1980) reported on the effects of tidal heights on the distribution and abundance of Coliform bacteria in sediments.

Burrows, 1957 b, and Buxton and Fairhurst (1978) gave accounts of the salt vegetation of the Estuary. Earlier in 1937, Massey reported on the distribution of Spartina townsendii . Reports on Mersey Marshes and adjacent areas and Physical resources in the Mersey Marshes were produced by the Cheshire County Council and Yasin (1988) studied the effect of herbicides on salt marsh vegetation.

Hardy (1941) reported the wildlife importance of the Liverpool area. Bostock (1950), Allen, (1958) and Hodgson (1976) reported work on the Estuary birds. In 1977, Ratcliff., classified a substantial part of the Mersey Estuary as a site of special scientific interest (SSSI). Armitage (1989) studied the conservation importance of the Estuary.

The pollution state of the Mersey had become a source of concern by 1930 and as a result the Mersey Docks and Harbour Board set up a committee to investigate the effect of discharge of crude sewage into the Estuary and its report concluded that sewage discharge was responsible for the silting of the Estuary

The Department of Scientific and Industrial

Research reported on the effect of the discharge of crude sewage into the Estuary and submitted its report in 1960. Other works on pollution include O'Sullivan (1972,) and O'Connor and Croft (1967). Porter (1973) produced a classic report on pollution of four industrial estuaries in the U.K. and identified the Mersey as one of the most grossly polluted. The level of copper and zinc was found to increase in-shore of the Mersey Estuary as a result of effluent discharge (Abdullah and Royle, 1973 ; Abdullah et al 1972; Craig and Morton 1976 and Airey and Jones 1982). Concentration of PCBs and dieldrin was found but only at levels in marina animals from Liverpool Bay (Riley and Wahby, 1977).

2.2 GEOLOGICAL ORIGIN

The Estuary of the River Mersey is considered to be an iceway cut as an escape route for a glacier which occupied the Irish sea during the Pleistocene Period (Readle 1873, Lomas 1904, Wills 1912 and Gresswell 1964). During the height of the glaciation the period the Irish sea was fed from a vast accumulation of ice from the north that accumulated from South-western and Southern Scotland and in North-eastern Ireland. As these sheets moved southward they encountered ice radiating from the mountains of the North Wales near the present northern Welsh coast and were forced to divide into two streams. One flowed to the west of the Welsh ice over Angelesey and the Lleyn while the other turned east to move southwards to the Cheshire/Shropshire plain.

These eastern flows of ice curved out deep broad channels in the triassic and carboniferous rock, between the Welsh Hills and the Wirral. These were in the vicinity of the present day Dee, Mersey, Alt and Ditton rivers (Figure 2.1). Borings made at Shotton and Sandycroft pointed to the irregularity of the underlying rock surface. Howell (1973) attributed the irregularities of the buried rock to the rivers of meltwater flowing beneath the ice sheet eroding particularly deep rocks to form hollows and the direct gouging described by Gresswell (1964). These rivers formed a buried valley network tending approximately north-west to south-east. The morphometry of the buried channel network is characteristic of a fluvial system although the cross valley profiles are incised and long profiles ungraded (Figure 2.2).

Radiocarbon dating proved that the earliest drift material was deposited approximately 57, 000 year B.C. and can be as thick as 90 metres in places in the form of glacial drift boulder clay (NCC 1978). The drift deposits seems to be divided into three layers, an upper and lower of boulder clay being separated by a horizon of sand gravels and stratified clays. Over these boulder clay strata are fluvio-glacial sediments of sand and gravel.

As the fluvio-glaciated activity came to a close the glaciers abated but sedimentation still continued in the Estuary. These sediments consisting of sand, silt and muds were deposited by the sea and river. Although peat and in places trunks and roots of trees are found as signs of forests that once thrive in the region (Ashton 1920).

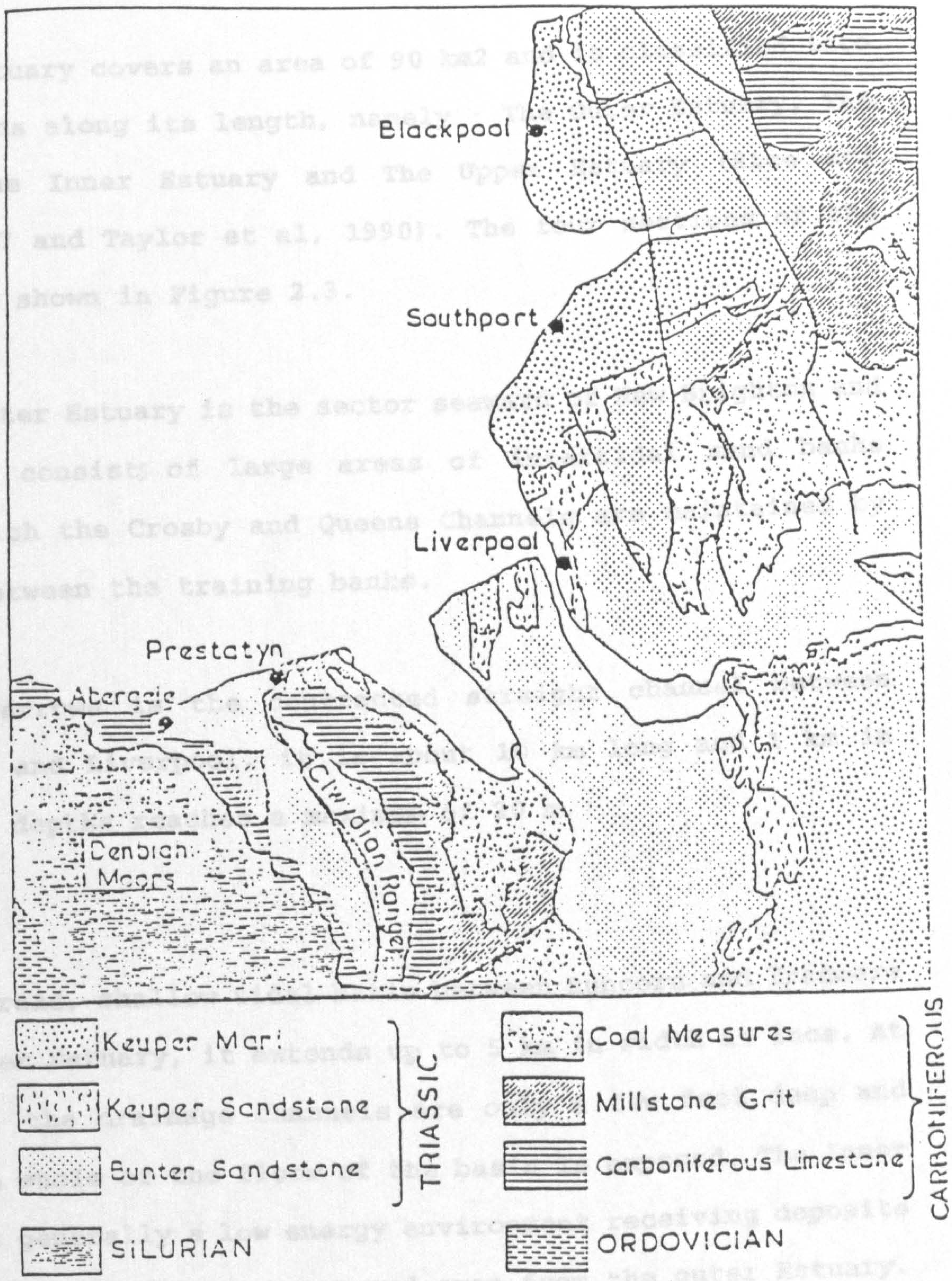

Figure 2.2: Geological origin of the Mersey Estuary

Source: Gresswell, 1964

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2.3 PHYSICAL CHARACTERISTICS

a) Size and Configuration

The Estuary covers an area of 90 km2 and is classified into four sections along its length, namely - The Outer Estuary, The Narrows, The Inner Estuary and The Upper Estuary (Rice and Putwain 1987 and Taylor et al, 1990). The four sections of the estuary are shown in Figure 2.3.

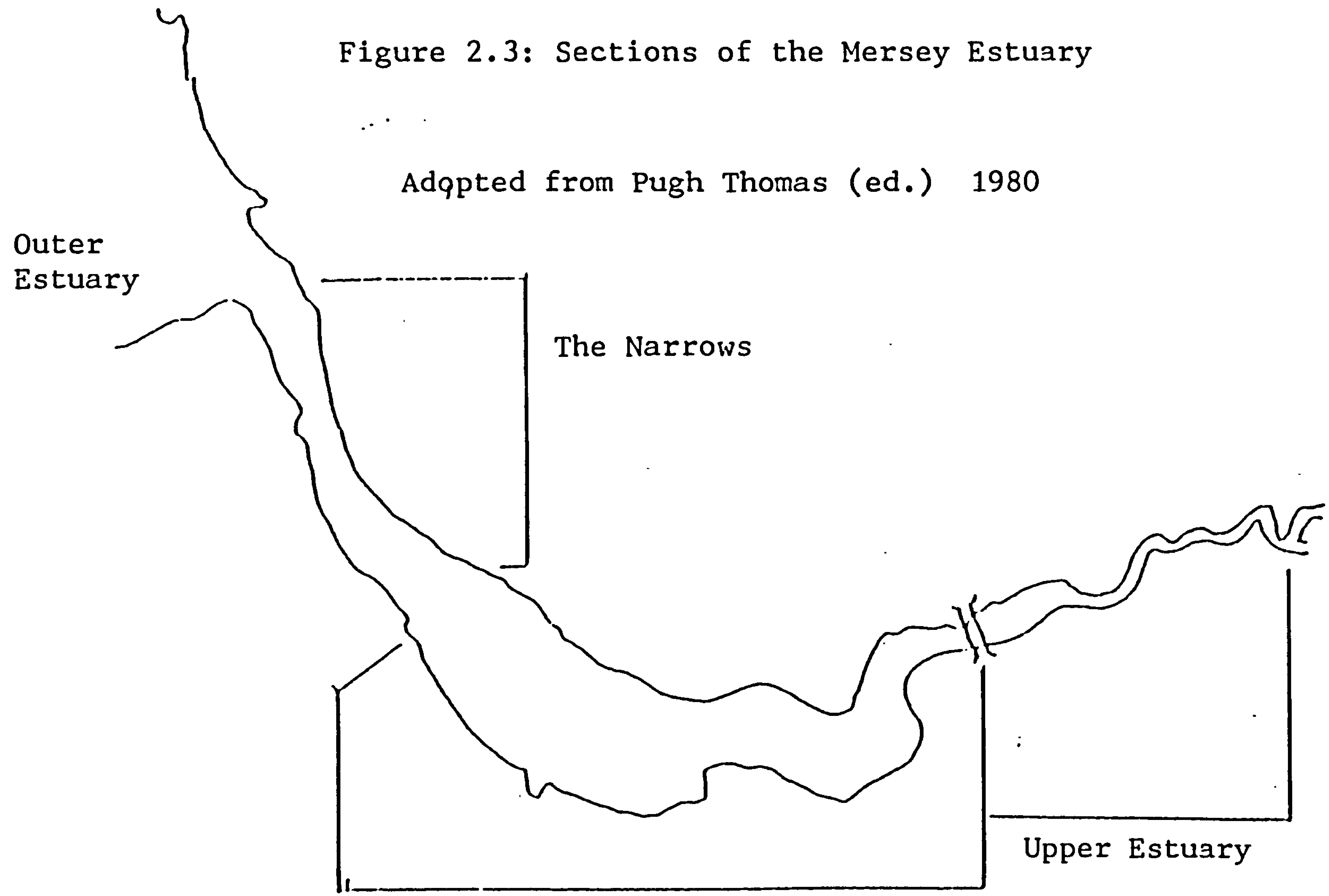
The Outer Estuary is the sector seaward of New Brighton and Crosby. It consists of large areas of intertidal sand banks through which the Crosby and Queens Channels are maintained by dredging between the training banks.

The Narrows is the contracted straight channel between Birkenhead and Liverpool, it is about 10 km long and 1 km in width. Its depths reaches a maximum of 20 m.

The broad, shallow tidal basin between Runcorn and Tranmere is the Inner Estuary, it extends up to 5 km in width at Ince. At low water, the drainage channels are only a few feet deep and almost the whole of the floor of the basin is exposed. The Inner Estuary is generally a low energy environment receiving deposits of sediments from the upstream and even from the outer Estuary. The Upper Estuary extends from Runcorn to the tidal limit at Warrington. It is narrow with a meandering channel but opens into a small, shallow basin at approximately 8 km from Howley Weir.

Figure 2.3: Sections of the Mersey Estuary

Adqpted from Pugh Thomas (ed.) 1980



The Upper Estuary joins the inner Estuary through a constricted gap in the bed rock between Widness and Runcorn.

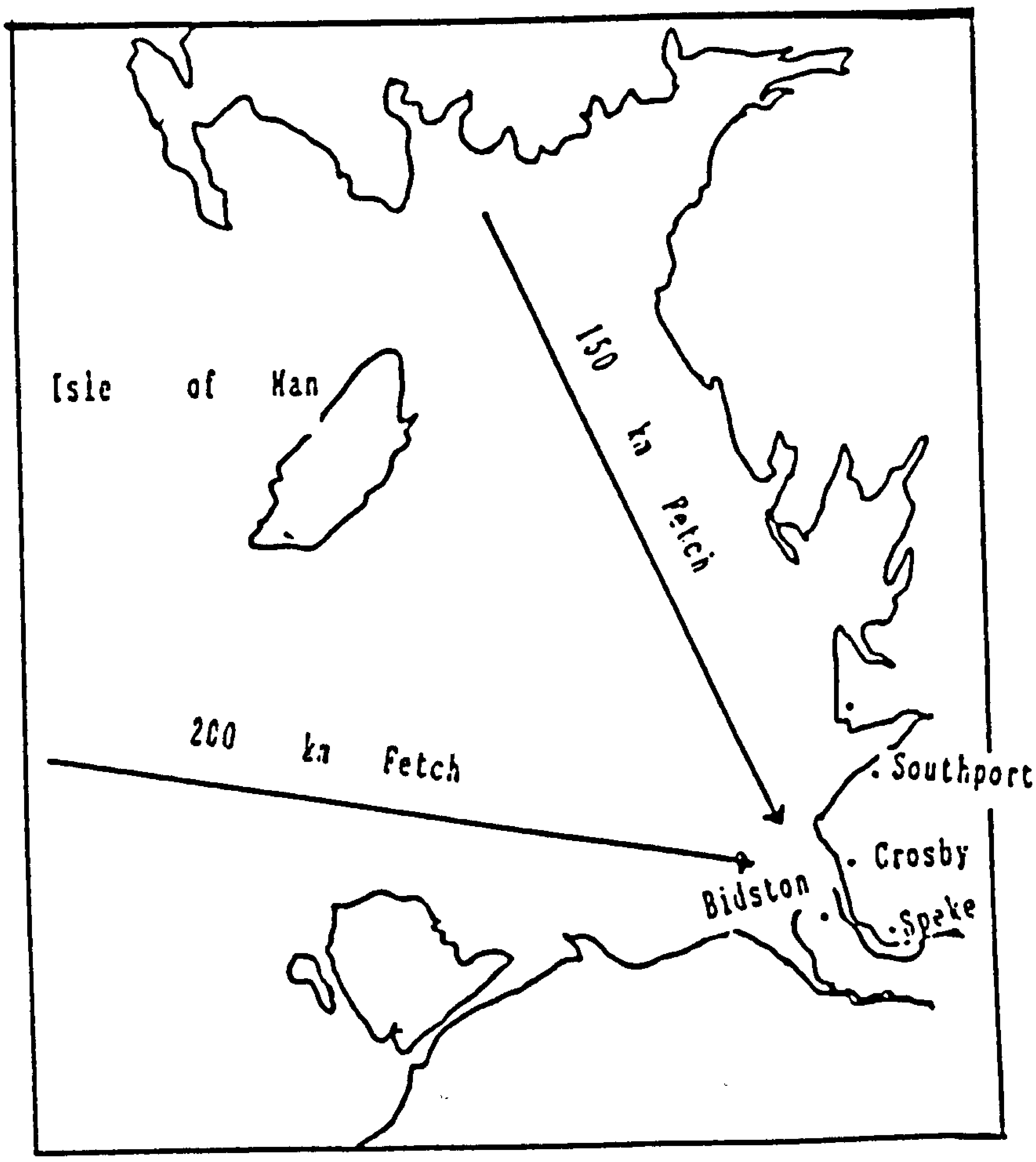
b) Meteorology

The main meteorological features of the Estuary are wind and visibility. Wind influences movement of water and therefore distribution of sediments as well as other suspended and dissolved materials. It also influences the amenity use of both water and foreshore areas by direct means and through distribution of sediments and suspended materials. Visibility is significant in commercial navigation and recreation.

i. wind

Wind direction and fetch are important to the use of estuaries. The Mersey Estuary is sheltered from southerly winds by the high lands of Wales thus, the westerly wind coming across the Irish Sea is the more significant (Rice and Putwain, 1987). This and South westerly winds are dominant over the Mersey . Generally high speed winds and gales are more frequent in winter and autumn but occur in any month except in the period April to August. Gusts of over 148 km/h have occurred at Bidston (Figure, 2.4), a maximum of 163 km / h occurred in October, 1938 (Rice and Putwain, 1987).

Figure 2.4: Wind direction and fetch to the Mersey Estuary



Source: Rice and Putwain, 1988.

ii. visibility

Data on the visibility record of the Mersey are shown in Table 2.1. The data were originally recorded at Speke Airport and Crosby Points. This record shows the Estuary to be a very foggy area and particularly for the months of September to March (An Area where visibility is less than 1 000 m is considered foggy).

Table 2.1: Monthly visibility record on the Mersey Estuary

VISIBILITY (m)	DAYS IN A MONTH												TOTAL (DAYS)
	J	F	M	A	M	J	J	A	S	O	N	D	
0 - 200	122	80	51	19	0	0	11	11	68	88	78	162	690
200-1000	173	165	82	37	19	10	34	35	99	148	119	171	1092
TOTAL	295	245	133	56	19	10	45	46	167	236	197	333	1782

Data from Bidston Observatory, 1977-92.

c. water movement

Water movement in estuaries is in form of tides, residual currants and storm surges (Dyer, 1973 ; Davidson et al, 1991 , McLusky, 1989 and Pritchard , 1967 (i). The rise and fall of tides produces tidal currants, residual (non-tidal) currants are driven by winds . A storm surge is an increase or decrease in sea Level in relation to predicted tidal level. Water movement controls the distribution of saline and fresh water as well as dissolved and suspended matter. The distribution of pollutants influences the type and distribution of biota.

In the Mersey, tidally induced water movements are dominant over residual currants in near shore areas. This is because of the large tidal range of the area (Table 2.2). In the deeper offshore areas, currants are affected, by winds, salinity and the Coriolis force produced by the Earth's rotation .

Table 2.2: Tidal elevation along the Mersey Estuary

Site	MHWS	MHWN	MKWN	MLWS	Mean spring range	Mean neap range
Run. chan.	8.9	7.2	2.7	0.9	8.0	4.5
Liverpool	9.3	7.4	2.9	0.9	8.4	4.5
Eastham	9.7	7.7	2.8	0.8	8.9	4.9
Widness	5.1	3.0	0.4	0.6	4.5	2.6
Fidl. Fer.	3.4	1.1	0.5	0.5	2.9	0.6

In the Mersey Estuary, a semidiurnal tidal regime with a range of up to 10.5 metres, has been reported (Rice and Putwain, 1987, MBC, 1992).

Maximum tidal current speeds occur in the Narrows section at about 2 hours before and 2 hours after high tides when currants can exceed 2.5 metres per second on spring tides . Vertically surface currants may be 40% greater than bottom currants and, for a short time around high water, surface and bottom currants may flow in different directions as tides changes (Rice and Putwain, 1987).

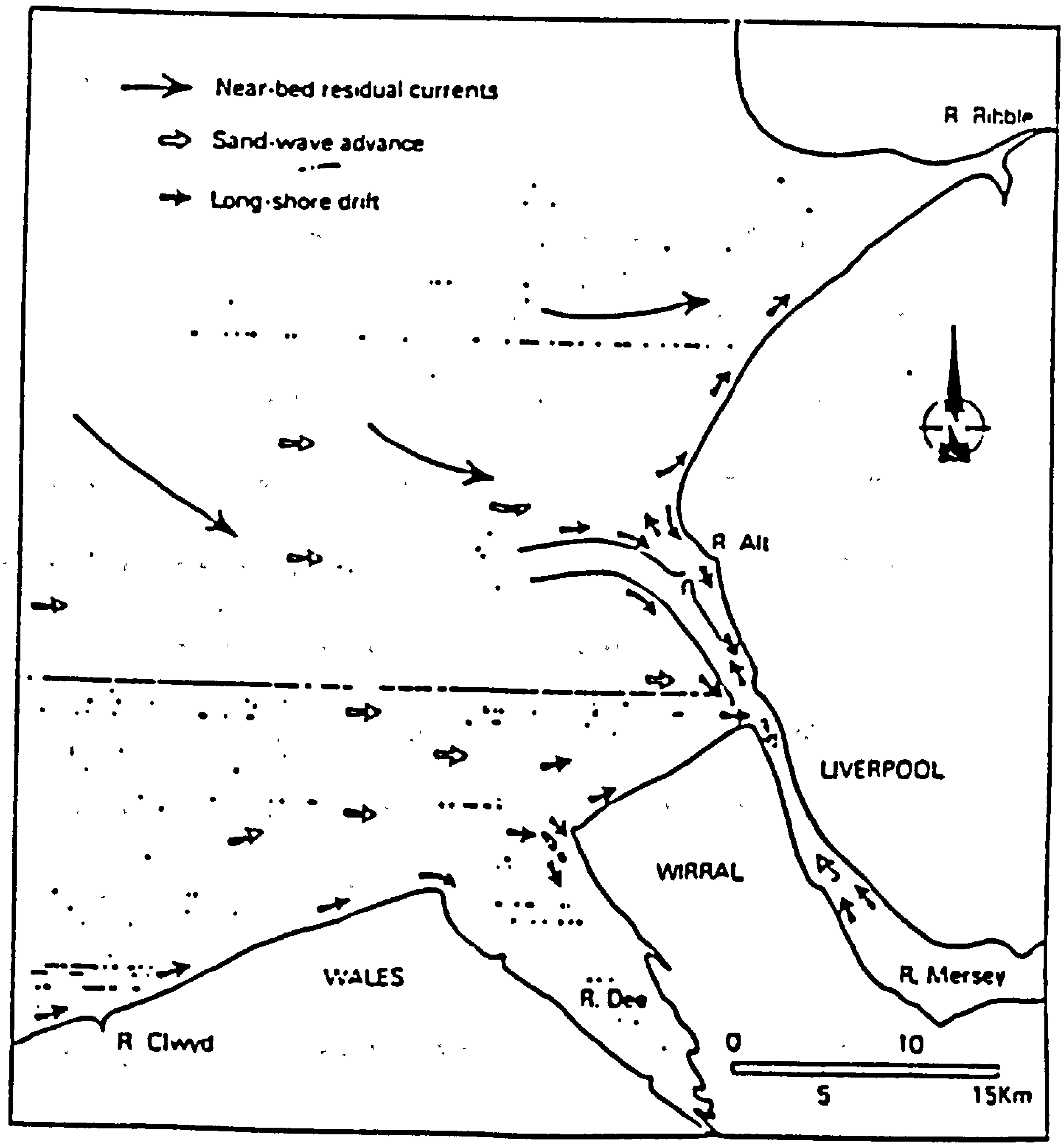
Residual currants, though non dominant are significant in sediment and pollution transport. In the Mersey, residual currants of 12 cm / sec., seaward in the upper layer and 10 cm / sec., landward in the lower layer have been recorded.

Storm surge is usually caused by the action of wind stress on the water surface which may be coupled with a change in level caused by variation in barometric pressure. The shallow north eastern part of the Irish Sea , Liverpool Bay, is particularly susceptible to storm surge and externally generated surge disturbance passing into the Irish Sea through St. George's Channel and North Channel. The highest astronomical tide (HAT) for Liverpool is 5.37 m above the Ordinance Datum Newlyn (ODN). In November 1977 when a severe storm coincide with spring tide, a theoretical maximum value of 6.1 ODN was exceeded (Rice and Putwain, 1987).

iv. Sediments

Sediment moving into the Mersey mainly comes from the Eastern Irish Sea (Allison,1949). This shallow, gently shelving area has an erodible bed material which supplies sediments to the coastal region (Figure 2.5) . In the Mersey Estuary, sand is deposited throughout the area with gravelly deposits in the deeper channels and muddy deposits found near the Mersey Bar and in the areas where the Formby Channel once existed. The Narrows is largely bare rock with some gravel due to strong currants; mud deposits occur in the intertidal zone especially around dock entrances. In the Inner Estuary the mid-region is formed predominantly of fine sand with medium sand becoming more abundant towards the Narrows. In the area upstream of Hale and in small patches of the Basin very fine sand may form more than 40 % of the substratum. In areas off Stanlow, Ince and near Frodsham Score, clay and silt may form 60-90 % of the sediments.

Figure 2.5: Sedimentation in the Mersey Estuary



Source: Rice and Putwain, 1988.

Sand banks and sandy beaches, exposed to constant reworking by wave action are characteristics of the Outer Estuary and open coastlines, with finer sediments in more sheltered pockets (Halliwell and O'Connor, 1966, O'Dell, 1969; Rice and Putwain, 1987 and Taylor et al , 1990).

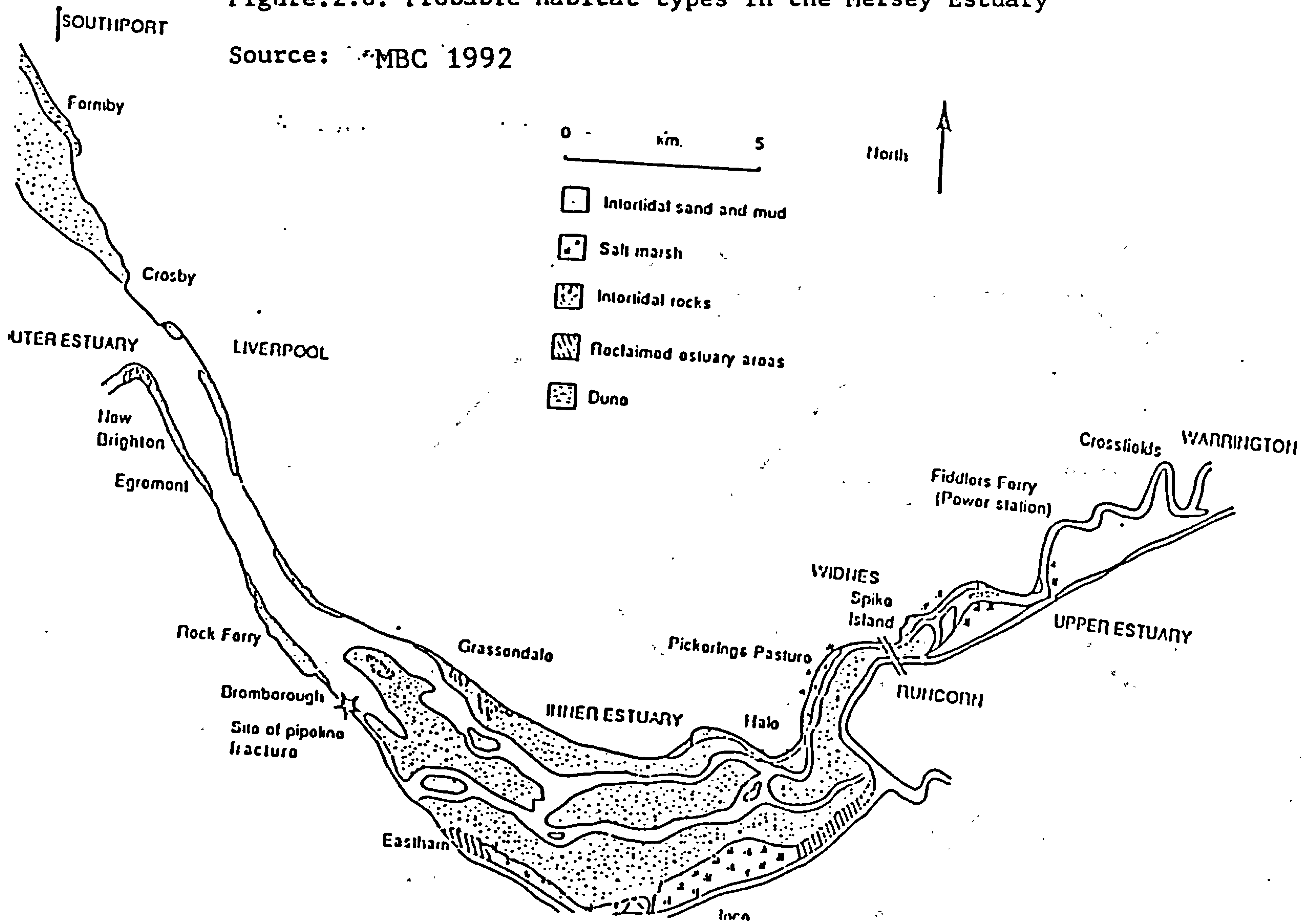
2.4 THE MERSEY ECOSYSTEM

The Ecosystem of the Mersey Estuary consists of a complex web of relationships between the biota, physical and chemical conditions between different trophic levels among the biota. The ecosystem was however affected by large scale alteration of the physical nature of the Estuary due to construction activity, reclamation of estuarine habitat and the heavy pollution load coming from industry and a heavily populated catchment area. Figure 2.6 shows predominant habitat types available and the probable foodweb shown in figure 2.7.

The foodweb consist of phytoplankton, benthic algae and salt-marsh as primary producers, photosynthesizing food by means of energy from sunlight, and water and mineral resources from the soil or water surface. The BOD/Detritus is a non Living component accumulating in the Estuary from the discharge of mainly organic effluent and waste and is acted upon by bacteria which then provide energy for primary consumer invertebrates such as Nematoda, oligochaetes, polychaetes, and Molluscs as well as mysids, shrimps, ragworms, gobies and flatfish. Whiting feed on invertebrates and mysids for food.

Figure:2.6: Probable habitat types in the Mersey Estuary

Source: MBC 1992



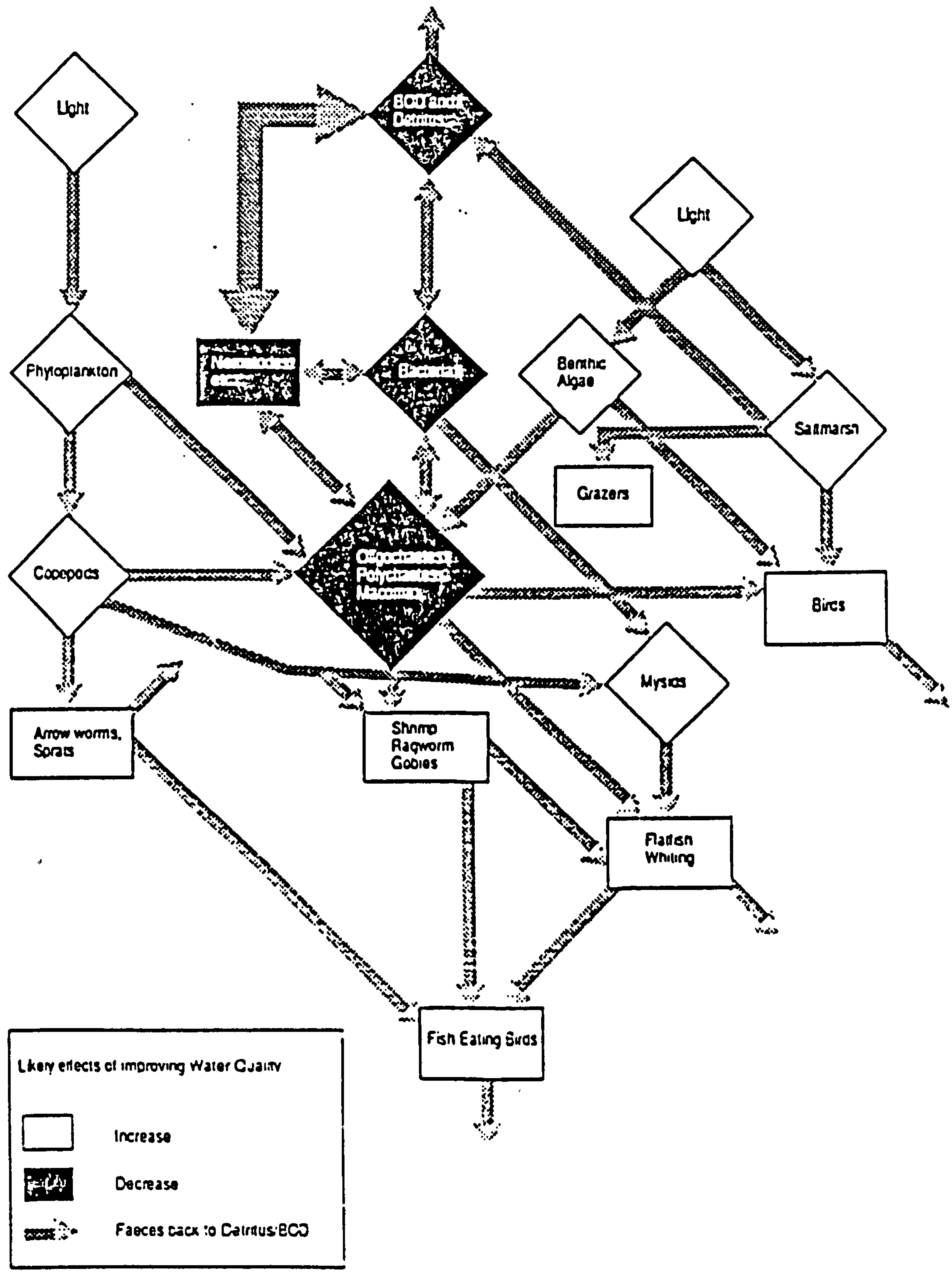


Figure 2.7: Probable foodweb pattern in the Mersey Estuary

Source: MBC 1992

2.4.1 Phytoplankton and Zooplankton

The pelagic ecosystem is very poorly characterised in the Estuary. Data on phytoplankton reveals a system of increasing importance. Gargari (1980) reported 225,000 individual phytoplankton cells per litre. In 1992, Mersey Barrage Company (MBC) reported 70 million individual cells per litre. This plant density compares very well with the total density of the Albert Dock which contain a much clearer water than that in the actual Estuary. In terms of species composition, the Estuary and the docks are superficially similar, and are dominated by small centric diatoms and dinoflagelates Prorocentrum minimum. Toxic dinoflagelates such as Gymnodinium spp. and the high number of euglenoids recorded in the Dock system in significant numbers have not yet been recorded in the Mersey esturial waters. The phytoplankton community increases sharply in numbers from early April to the end of June 1991 (Ghazzawi, 1933; MBC, 1992). Much of the increase is attributable to short-term blooms of the diatoms Thallassiosir and Skeletonema costatum and the colonial flagellate Phaecycstis pouchetti. Dinoflagellate numbers increased during the spring, but the proportional contribution of this group tended to decrease due to the diatom blooms.

The main littoral benthic diatoms were: Skeletonena costatum, Cocconeis scutelum var Minctissma, Melosiroa nummuloides, M. distans var. Navicula cryptocephala, N.rostellata and Raphoneis surirella.

The zooplankton community in the estuary is typical of other estuaries (Williams, 1984). Copepods are the dominant species of the community, although other organisms were of occasional numerical importance during blooms (MCB 1992). The anthomedusan Rathkea octopunta abundance peaked during March 1991 at the lower salinity sites. Barnacle larvae reached large numbers at the higher salinity sites during the Spring. Large numbers of polychaete larvae were characteristic of all sites from the end of May 1991 onwards. Mysids formed a large proportion of the community at the lowest salinity sites particularly during the summer 1991.

2.4.2 Benthic And Intertidal Organisms

Studies on the macro-invertebrate species of the Estuary reveal an abundant benthic faunal community. Macrobenthic invertebrates in estuaries are found in deposited tidal sediments, their composition and density varies with the constituent proportion of deposited sediment materials (Kennedy, 1980; Pugh Thomas (ed.), 1980 and Davidson et al 1991), for example sandy mudflats , are often dominated by bivalve molluscs such as the cockle, Cerastoderma edule and Baltic tellin, Macoma balthica and on stable muddy sandflats, by the polychaete, Arenicola marina.

Ghose (1979) recorded up to 135 species in the Estuary (Table 2.3). Out of these, 120 species were found in the outer Estuary, 38 species in the Narrows and 26 species in the Inner

Estuary. The distribution and abundance of invertebrate species such as Corophium volutator and Hydrobia ulvae are much increased in the Inner Estuary (MBC, 1992). Similarly the polychaete Arenicola marina has now been shown to be widely distributed in the Inner Estuary. This development after the work of Ghose is attributed to the general improvement in the baseline environmental conditions of the Estuary. The centrally placed intertidal sandbanks tend to support an impoverished macro-invertebrate fauna of low species diversity and abundance. The differential in distribution of the macrofauna is probably related to the characteristics of the sediment, such as particle size distribution, organic matter content and the availability of microfaunaal invertebrates. In general the muddier areas of the Mersey supports an abundant macro-invertebrate fauna (Moore, 1975; MBC, 1992).

Table 2.3: Species list of benthic invertebrates in the Mersey Estuary - 1976 and 1977 .

Phylum Coelenterata
Aurelia aurita L.
Obelia geniculata L.
Syncorne examina L.
Tubularia indivisa L.
Sertularia cupressina L.
Metridium senile L.
Acanthocardia echinata L.

Phylum Ctenophora
Pleurobrachia pileus (Muller)

Phylum Nemertina
Lineus ruber (Muller)
Lineus longissimus (Gunnerus)

Phylum Nematoda
Nemata sp.
Tricurus sp.

Phylum Annelida
Order Oligocheata
Chaetogaster diaphanus (Gruilhaisen)
Paranais litoralis (Muller)
Dero sp.

Nais elinguis (Muller)
Peloscolex benedeni (Udkem)
Monophylephorous irroratus (Verrill)
Monophylephorous rubroniveus (Levinson)
Tubifex costatus (Claparede)
Tubifex (Muller)
Tubifex pseudogaster (Dahl)
Limnodrilus claparedieanus (Ratzel)
L. hoffmeisteri (Claparede)
L. udekemianus (Claparede)
L.helveticus (piguet)
Clitellio arenarius (Muller)
Enchytraeius albida (Henle)
Enchytraeius sp.
Lumbriculus sp.

Order Polycheata
Amphrodite acueata (Linnaeus)
Phyllodoce maculata (Linnaeus)
Phyllodoce lamelligera (Gamelin)
Phyllodoce sp.
Eteone longa (Fabricius)
Nereis pelagica (Linnaeus)
Nereis diversicolor (Muller)
Nereis fucuta (Savigny)
Perinereis cultrifera (Grube)
Nereis virens (Sars)
Nephtys hombergi (Audouin and Milne-Edwards)
Nephtys caeca (Muller)
Nephtys cirrosa (Ehlers)
Nephtys longosetosa (Orsted)
Nephtys ciliata (Muller)
Nephtys sp.
Glycera convoluta (Keferstein)
Nerine cirratulus (Delle chiaja)
Pygospio elegans (Claparede)
Polydora ciliata (Johnston)
Ophelia bicornis (Muller)
Capitella capitata (Fabricius)
Arenicola marina (Linnaeus)
Arenicolides ecaudata (Johnston)
Owenia usiformis (Dellechiaje)
Amphitrite gracilis (Grube)
Pectinaria (Lagis) Koreni (Malmgren)
Lanice conchilega (Pallas)
Polymnia nebulosa (Montagu)

Family Sabellidae
Sabella (Paronina) (Savigny)
Manayunkia aestuarina (Bourne)
Scloplos armiger (Muller)

Phylum Mollusca
Mytilus edulis (Linnaeus)
Modiolus (Linnaeus)
Musculus discors (Linnaeus)
Montacuta ferruginosa (Montagu)
Mysella bidentata (Montagu)
Acanthocardia echinata (Linnaeus)
Cerastoderma edule (Linnaeus)
Mactra corallina (Linnaeus)
Spisula elliptica (Brown)
Spisula solida (Linnaeus)
Donax vittatus (Da Costa)
Tellina tenuis (Da Costa)
Tellina (Fabulina) fabula (Gamelin)

Lima lains (Gamelin)
Macoma balthica (Linnaeus)
Scrobicularia plana (Da Costa)
Abra alba (Wood)
Mya truncata (Linnaeus)
Mya arenaria (Linnaeus)
Ensis (Linneaus)
Pharus legumen (Linnaeus)
Ensis siliqua (Linnaeus)
Polas dactylus (Linnaeus)
Littorina littoralis (Linnaeus)
Littorina littorea (Linnaeus)
Littorina saxatilis (Olivi)
Hydrobia ulvae (Pennant)
Natica alderi (Forbes)
Planorbis (Linnaeus)
Retusa canaliculata (Linnaeus)
Euccinum undatum (Linnaeus)
Otina ovata (Brown)
Turritella communis (Risso)
Modiolus barbatus (Linnaeus)
Bittium reticulatum (Da Costa)

Phylum Arthropoda
Bathporeia pelagica (Bate)
Bathyporeia sarsi (Watkin)
Bathyporeia pilosa (Lindstrom)
Gammarus locusta (Linnaeus)
Gammarus duebeni (Linnaeus)
Eurydice pulchra (Leach)
Haustorius arenarius (Slabber)
Cancer pagurus (Linnaeus)
Carcinus meanas (Linnaeus)
C . portunus (Linnaeus)
Balanus balanoides (Linnaeus)
Balanus sp. (Linnaeus)
Chthamalus stellatus (Poli)
Balanus improvisus (Darwin)
Balanus perforatus (Bruguiere)
Elminius modestus (Darwin)
Eupagurus bernhardus (Linnaeus)
Neomysis integer (Leach)
Crangon vulgaris (Linnaeus)
Corophium volutator (Pallas)
Corophium arenarius (Crowford)
Lepus anatifera (Linnaeus)
Calanus sp.
Talitrus saltator (Montagu)

Phylum Echinodermata
Asterias rubens (Linnaeus)
Henricia oculata (Pennant)
Stichastrella rosea (Muller)
Ophiura texturata (Lamark)
Asteropecten irregularis (Pennant)
Echinocardium cordatum (Pennant)

Phylum Chordata
Gobius minutus (Pallas)
Pleuronectes platessa (Linnaeus)
Platichthys flesus (Linnaeus)
Solea vulgaris (Quensel)
Amodytes lanceolatus (Le Sauvage)

Source: Ghose, 1979.

Generally, the diversity of species is greater in the Outer Estuary than in the Inner Estuary . In The Narrows, the density is substancially reduced. High salinity may account for the diversity in The Outer Estuary and the reduced number in the Narrows is probably due to habitat destruction arising from the construction of docks and retaining walls. Reduced diversity in The Inner Estuary may, in addition be due to reduced salinity and also be caused by the restricting effect of the pollution load.

2.4.3 Fish

Before the Industrial revolution, Salmon run up the Mersey, and such other fishes as Sprat, Smelt, Sturgeon, Mullet,various flatfish, sand eels, and shell fish Lobsters, Oysters, Shrimps, Prawns and Cockles are all known to have been taken in the River, some as far upstream as Warrington (Holland, 1989). The present Sparling Street in Warrington was once a thriving commercial smelt fishery (Holland, 1989). The Estuary also served as a nursery for Sole, Plaice, Dab, Codling and White fish . In 1908, 3,854 tons of fish were landed at Birkenhead and 1, 692 tons at Holylake (Johnstone, 1910, 1928).

By the start of this century, increasing pollution had taken its toll and killed the Salmon run. Over the first two decades the shrimp and flounder fishery retreated to the middle of the estuary and had ceased completely by 1940 (Holland, 1989). In the mid 1970's the existence of fish in the Manchester ship canal was noted by the North West Water Authority which led to the setting up of a fish monitoring programme in 1977 . At this time there was still no commercial fishing activities in the tidal basin (Srivastava, 1980 and Holland, 1989). Corlett and O'Sullivan (1972) recorded that the banks of the Outer Estuary were mainly fished by small trawlers from Conway and Fleetwood and shrimpers from the Dee, Mersey and Ribble who fished within 8 km of the shore. The following species have been recorded at least once on water intake screens between 1977 - 1988 (Table 2.4).

Table 2.4: Common marine and brackish fish in Manchester Ship Canal (MSC) < 2 % occurrence, 1977 - 1978 .

Species
Dicentrarchus labrax L. (Bass)
Agonus cataphractus L. (Pogge)
Trisopterus luscus L. (Bib)
T.manatus L. (Poor - cod)
Raja brachyura Lafont. (Blonde ray)
Aspitrigla cuculus L. (Red gurnard)
Micromesistius poutassou Risso. (Blue whiting)
Liparis L. (Sea snail)
Ciliata mustela L. (Five bearded rockling)
Salmo trutta L. (Sea - trout)
Trachinus vipera Cuvier. (Lesser weaver)
Osmerus eperlanus L. (Smelt)
Cyclopterus lumpus L. (Lumpsucker)
Sardina pilchardus (Pilchard)
Polyprion americanus Bloch & Schneider. (Wreckfish)
Syngnanthus typhle L. (Pipefish)

Source : Holland 1989.

The Runcorn Screens receive occasional freshwater fish which have probably arrived in the Estuary via the River Weaver, Perch being the most common at 6 % (Table 2.5).

Whitebait (Sprat and a few Herring), gobies, whiting, sticklebacks and shrimps were recorded on over 20 % of the visits by the NWWA monitoring group (Holland, 1989).

Table 2.5: Common marine and brackish fish in MSC.
% occurrence 1983 - 1988 (n = 20).

Habitat	Runcorn	Stanlow
Marine Fish		
Whitebait	77.1	42.6
Pomatoschistus (Goby)	66.7	36.8
Merlangius merlangus L. (Whiting)	41.7	22.1
Solea L. (Sole)	18.3	8.1
Limanda L. (Dab)	5.0	1.6
Anguilla L. (Sand eel)	5.0	0.0
Pleuronectus platessa (Plaice)	2.5	0.0
Brackish Fish		
Gasterosteus aculeatus L. (Stickleback)	36.7	73.0
Anguilla L. (Eel)	18.3	16.4
Platichthys flesus L. (Flounder)	7.5	4.9
Petromyzon marinus L. (Lamprey)	3.3	0.8
Freshwater Fish - MSC, 1977 - 1978		
Abramis brama L. (Bream)		
Salmo trutta L. (Brown trout)		
Cyprinus carpio L. (Carp)		
Gobio L. (Gudgeon)		
Pungitus L. (Nine spined stickleback)		
Perca fluviatilis L. (Perch)		
Esox lucius L. (Pike)		
Rutilus L. (Roach)		
Scardinius erythrophthalmus L. (Rudd)		
Noemacheilus barbatulus L. (Stone loach)		

Adapted from Holland, 1989

Over the years a few salmon have struggled up the River and have been found dead on the banks at different points . In 1988 a blue whiting was found at Hale Head, having only once previously been recorded, in the Ship Canal in 1984 . Mullet are also known to have travelled as far upstream as Eastham (Holland, 1989).

In the Mersey Narrows anglers have over the years successfully caught many fish species (Table 2.6).

Table 2.6: Fish caught by anglers in the Mersey Narrows

Exclusively Narrows
Gadus morhua L. (Cod)
G. morhua L. (Codling)
Conger L. (Conger)
Scyliorhinus canaliculus L. (Dogfish)
Callionymus lyra L. (Dragonet)
Gaidropsarus vulgaris Cloquet. (Three bearded rockling)

Recorded in Narrows and Inner Estuary
D.labrax L. (Bass)
Limanda (Dab)
Anguilla L. (Eel)
Ciliata mustela L. (Five bearded rockling)
P. flesus L. (Flounder)
Trachinus vipra Cuvier (Lesser weaver)
Solea (Sole)
Merlingius merlangus L. (Whiting)

Source: Holland (1989)

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P. flesus L. (Flounder)
Trachinus vipera Cuvier (Lesser weaver)
Solea (Sole)
Merlingius merlangus L. (Whiting)

Source: Holland (1989)

Some of the above species , ie; cod, three bearded rockling, dragonet, dogfish and conger have never been recorded inland being restricted by reduced salinity . Most of the other species only feature occassionally inland , and then in small numbers.

Srivastava, (1982), recorded a total of thirty one species of fish found in the Mersey Estuary . Table 1.7, lists the total number of species encountered during her survey, the site where they were trapped and the method involved in catching the fish samples.

During the 1980's, the highest number of fish species counted in any one year was eighteen and that was in 1981 (Holland , 1989). Sand goby, herring, sprat and whiting, were recorded regularly every year and are the only species which can be said to be common in the Inner Estuary. Sticklebacks, which are of freshwater origin, are frequently recorded at cooling water intakes and appear to be permanently resident in the Manchester Ship Canal.

Since the work of Srivastava (1982), more fish species have been found in the Mersey . Holland (1989) reported forty one species of marine, estuarine and migratory fish. A further eleven freshwater species have been drawn into the Manchester Ship Canal from inland sources, bringing the grand total for the Estuary to

Table 2.7: Total species of Fish found in the Mersey Estuary during the 1976 - 1979 Survey .

	From intake screen	From intake screen Shell I.C.I Runcorn	Push-Netting all sites	Beam trawling inner Estuary	Shrimp trawling Outer Estuary
Lampetra fluviatilis. L.	+	-	-	-	-
Clupea harengus. L.	+	+	+	-	+
Sprattus sprattus. L.	+	+	+	+	+
Pomatoshistus minutus. Pallas	+	+	+	+	+
Pomatoschistus microps. Kroyer	+	+	+	-	+
Ammodytes tobianus. L.	+	-	+	-	+
Syngnathus rostellatus. Nilsson	+	-	+	-	-
Gasterosteus aculeatus. L.	-	+	+	-	-
Perca fluviatilis. L.	-	+	-	-	-
Anguilla anguilla. L.	-	+	+	+	_
Solea solea. L.	-	+	+	_	+
Pleuronectes platessa. L.	-	-	+	-	+
Limanda limanda. L.	-	-	+	-	+
Platichthys flesus. L.	-	-	+	+	+
Spinachia spinachia. L.	-	-	+	-	+

Pomatoschistus pictus. Malm	-	-	+	-	-
Pomatoshistus norvegicus. Collet	-	-	-	-	+
Aphia minuta Risso	-	-	+	-	-
Trachyinus vipera. Cuvier	-	-	+	-	+
Atherina presbyter. Valenciennes	-	-	+	-	-
Cranimugil labrosus. Risso	-	-	+	-	-
Liparis liparis. L.	-	-	+	-	+
Merlangius merlangus. L.	-	-	+	-	+
Pollachius pollachius. L.	-	-	+	-	+
Gadus morhua. L.	-	-	-	-	+
Trisopterus minutus. L.	-	-	-	-	+
Eutrigla gurnadus. L.	-	-	+	-	-
Myxocephalus scorpius. L.	-	-	+	-	-
Ciliata mustela. L.	-	-	-	-	+
Callionymous lyra. L.	-	-	+	-	+
Taurulus bubalis. Euphasen	-	-	-	-	+

Key
+ present, - Absent, total number of species 31

Source: Srivastava (1982).

fifty one .

2.4.4 Salt-marsh vegetaion

Salt-marsh vegetation has developed where deposition of fine sand and silt has occurred in sheltered conditions and where tidal scour and wave action are weak, allowing the material to become sufficiently cohesive for salt-tolerant plants to colonise. As the vegetation becomes established turbulence is further reduced, accelerating the rate of deposition and gradually raising the level of the marsh so that it is less frequently inundated by the tide. This process continues as wind-blown material, plant litter and sediment further accumulate, and eventually species which are less salt-tolerant can colonise. Mature salt marsh consists of a complex pattern of plant communities over a generally flat area crossed by a network of creeks through which the ebb tide drains (Buxton, 1978; Yasin, 1988).

In the Mersey Estuary, the salt marsh is not uniformly distributed. The Ince and Stanlow banks are the most important areas. On these banks Puccinellia is wide spread and dominant and an association of Puccinellia, Salicornia and Aster is common. Sports of Spartina are concentrated as patches in the vegetation. Salicornia, Suaeda and Atriplex have colonised the new marsh area of the Stanlow banks but populations of Salicornia on the North Mount Manisty was decreasing (Buxton, 1978). At Frodsham Puccinellia was dominant among other common species such as Atriplex, Suaeda and Cochlearia.

Other areas of marsh vegetation include Formby Bank which is characterised by Puccinellia maritima, Aster tripolium, Cochlearia sp. and some Salicornia sp. . In the area south of River Alt the vegetation is dominated by Puccinellia, and Cochlearia with some Plantago, Aster, Salicornia and Suaeda, while the portion near the tide mark has Halimione and Festuca. Spartina is sparsely spread throughout this area but become dominant in the narrower southern part. Oglet bank was colonised by narrow patches of Festuca, Puccinellia and Aster with occasional Salicornia, Atriplex, Plantago, Triglochin, and Cochlearia as well as some patches of Puccinellia and some Aster (Fairhurst and Buxton 1982). On Dungeon Bank Salicornia was dominant and Suaeda occurred occassionally toward high tide mark with rare patches of Puccinellia, Atriplex, Cochlearia, Triglochin and Plantago. Salicornia is similarly dominant in the Hale head shore, Puccinellia, Aster, Sueda, Atriplex, and Cochlearia are common. The Hale Decoy Marsh was dominated by Puccinellia and patches of mainly Aster, Cochlearia and annuals occurred along the contributory creeks. Norton, Gwerdley and Astmoor Marshes are occassionally submerged at times of heavy rain coinciding with spring tide. Small patches of Aster, Puccinnellia, Astriplex and Cochlearia colonise the creeks in the area.

It should be noted that the salt marsh community is not stable. Changes in water regime, sedimentation, weather conditions and contamination from large spillages influence the establishment and distribution of marsh vegetation. In the Mersey the marsh community has constantly changed over the years with some species appearing and disappearing (Buxton, 1978; CCC, 1980 and Fairhurst and Buxton 1982).

Spartina townsendii was introduced to the Mersey experimentally in 1930s but then disappeared subsequently. It began to reappear on the North shore at Oglet and Speke in 1967 and on the South Shore in 1971 (Fairhurst and Buxton, 1982). The Ince Banks have a number of clumps. On the North Side however, there is a continuous sward around Oglet Bay, which thins out towards Speke Gantry and Hale Head. The _Spartina_ provides cover and shelter for birds and invertebrates but its seeds are not very palatable to wildfowl or waders, and its aggressive colonisation often replaces the less stable but more accommodating Sea Aster, _Salicornia_ and _Atriplex_ marsh. In the long term it is likely to replace open or lightly colonised mudflats and may remove an important source of invertebrate food supplies for the birds. The protecting influence of the Manchester Ship Canal controls _Spartina_ spreading to important areas of Ince and Stanlow marshes.

2.4.4 The Bird life in the Estuary

The Mersey Estuary is one of the leading estuaries in Britain for its overwintering of wildfowl and wading birds. This position is by virtue of its rich macrobenthic fauna and location at the convergence of two great bird migration routes and forms part of the Liverpool Bay/Morecambe Bay complex of inter-tidal habitats which hold the largest population of migrating wading birds in north-west Europe. These areas are an integral and indispensable part of the East Atlantic Flyway. Britain has an important position on great bird migration routes, from Canada, Greenland and Iceland, and from Siberia and Scandinavia, where the birds breed. They have to move to warmer climates during the frozen northern winters, and the estuaries of the North Sea and Britain provide suitable wintering sites, though some birds merely rest here and then continue south to Africa.

The birds require reasonable temperatures, which are normally available through the action of the Gulf Stream, shelter which is provided by the indented shoreline of estuaries, and abundant food supplies. Estuarine mud is one of the most productive media. The long uninterrupted flights undertaken by these birds require large food supplies, and if these are not available on the migration pathways, bird may starve or be unable to withstand hard weather, or else show poor breeding performance which could threaten future survival.

Results of regular bird counting over many years has shown that the Mersey Estuary has nationally significant numbers of several species of wildfowl and waders (at least 1% of British populations) such as great crested grebe, grey plover, and curlew. Figures for golden plover and turnstone are close to the national level. There are internationally significant numbers (at least 1% of North West European populations) of pintail, teal, shelduck, wigeon, redshank and dunlin. Large numbers of gulls and terns also use the Mersey Estuary and its surroundings for feeding and roosting.

Some species will remain in the same area, but others will move between estuaries, and there is considerable interchange between the Mersey, Dee and Ribble. In addition, in a hard winter the West Coast is less likely to freeze than the East coast and in 1981, which was especially cold, the north western three estuaries held almost 90% of the pintail population and the Mersey had twice the normal number of teal and 1.5 times the normal number of shelduck. The Mersey is thus a significant area with regards to wildfowl and waders in normal winters, but vital in bad weather when extreme conditions threaten the number of birds in other estuaries through lack of food. The other significant factor in the high value of the Mersey for bird is its relative lack of disturbance. The Estuary has been disregarded in the past to such an extent that factories and docks have been built along a large part of the Waterfront, preventing access to the shore. In addition, the Manchester Ship Canal has cut off the Ince and Stanlow Banks which are the most important feeding and nesting areas. The high tidal range and polluted water of the Mersey has also restricted water sports. This is of particular importance, especially in cold weather, when the birds can feed and rest undisturbed, in contrast with the nearby Dee Estuary, where recreation is thought to have led to a sharp decline in roosting birds between 1975 and 1985.

2.5 SUMMARY

The Mersey Estuary has unique configuration that is some what like a cistern. The combination of high tide and flushing action through the narrow mouth supports the movement of sediment and maintains deep channels. Sediment deposition enhances accretion which raise mud levels and subsequent colonization by marsh plants in part of the Inner Estuary. The rich ecosystem includes fish, wildfowl and waders.

Deep channels facilitate shipping which attracted industry and population growth whose discharge of effluent and sewage put a severe stress on the natural ecosystem of the Estuary. Presently the condition of the Estuary has improved and it support birds in numbers of national and international importance.

CHAPTER THREE

HISTORICAL BACKGROUND OF THE STUDY AREA

3.1 HUMAN SETTLEMENTS AND INDUSTRIALIZATION

Human settlement on the Merseyside date back to the Bronze Age when there was considerable trade between England and Ireland. From about 700 BC to Roman times the area is believed to have been largely deserted due to wetter conditions, but by the thirteenth century, activity was increasing again due to fishing and renewed trade with Ireland.

Liverpool, the main town on the Merseyside, became a borough in 1207 and the Port was used by ships sailing to and from Ireland. After four centuries, Liverpool captured the trade of Chester, on the Dee Estuary, as the latter silted up. In addition trade with America and Africa was established and expanded leading to increased port facilities and associated industries. Until well into the nineteenth century, the economic history of Merseyside was almost entirely dominated by the activities of Liverpool. With the exception of Warrington the other, now very prominent urban areas, then barely existed (Porter 1973).

The population of Liverpool town was 5,000 in 1698. By 1750 it had grown to 20,000 and at the first census in 1801 its population was 78,000. This phenomenal growth throughout the eighteenth century is attributed to flourishing trade with America, Baltic and North Sea ports, to its own industrial growth, for instance in refining sugar from the West Indies, and to the industrial growth taking place inland and finding its outlet through Liverpool. The Cheshire salt fields, the Pennines textile industry and the metalworking of the Midlands all contributed to the merchandise handled at Liverpool.

In the period from 1801 to 1841 the population of Liverpool township almost trebled to 223,000, and the influx of Irish immigrants, particularly in 1846 and 1847 when famine in Ireland was acute, added significantly and suddenly to the population. But by mid-century central Liverpool had reached saturation point. Thereafter growth took place in the surrounding areas and congestion in the centre gradually reduced, every ward of central Liverpool decreasing in population by 1871. Within the enlarged Liverpool area population continued to grow, although at a decreasing rate, reaching 711,00 in 1901 and 857,000 in 1931, Since the 1930s it has, however, declined.

Industrial and residential growth on the Wirral peninsula awaited the arrival of the first steamships in the period 1815 to 1820. Ferry services soon ran from Liverpool to Runcorn, Eastham, Tranmere, Birkenhead and New Brighton, and Birkenhead developed initially as a centre for short pleasure trips, with tea-gardens and a hotel. In 1801 its population was 110;in 1841 over 8,000. This expansion was due to the founding in 1824 of a boilermaking and shipbuilding yard near Wallasey Pool. The first Birkenhead dock opened in 1847, the Laird shipyard expanded and by 1851 the population of Birkenhead was 24,000. Engineering works, and a fertiliser plant were all established near Wallasey Pool by 1890.

In 1888 there was another important development on the Wirral, the founding of Port Sunlight, W.H.Lever's soap factory. This was the beginning of the now very large Unilever complex at Bebington. Price's chemical works, founded in 1854, was later associated with the Unilever group of companies, and the Bromborough Dock was constructed in 1930 to serve the group, now growing in both number of employees and diversity of products.

The industrial history of the Ellesmere Port-Stanlow area began in the early nineteenth centuary, when cargoes from the Mersey boats were here transferred to boats on the Shropshire Union Canal. Later a galvanising works treating iron products from Wolverhampton was set up, along with three flour mills. During the first world war the Gowy marshes were drained, and in 1922 an oil dock was built. This marked the beginning of Shell's activities at Stanlow, at first in the distribution rather than the refining of oil. In the mid-1920s the first bitumen plant came into operation, and by 1930 the Shell organisation was well established on the Stanlow site and since then it has expanded.

Warrington was the only substantial town after Liverpool, in 1801. At that time it had population of 10,000, it had a tradition of manufacturing and an importance as a route centre dating from the Middle Ages. Throughout the nineteenth century Warrington grew steadily in population, and iron-founding, wire - working and brewing developed in the latter half of the century. The tanning of leather was of importance too and the tannery effluents were a major pollutant entering the River. Compared with Widnes and Runcorn, Warrington was not a major centre for heavy chemical manufacturing, but had a soap factory.

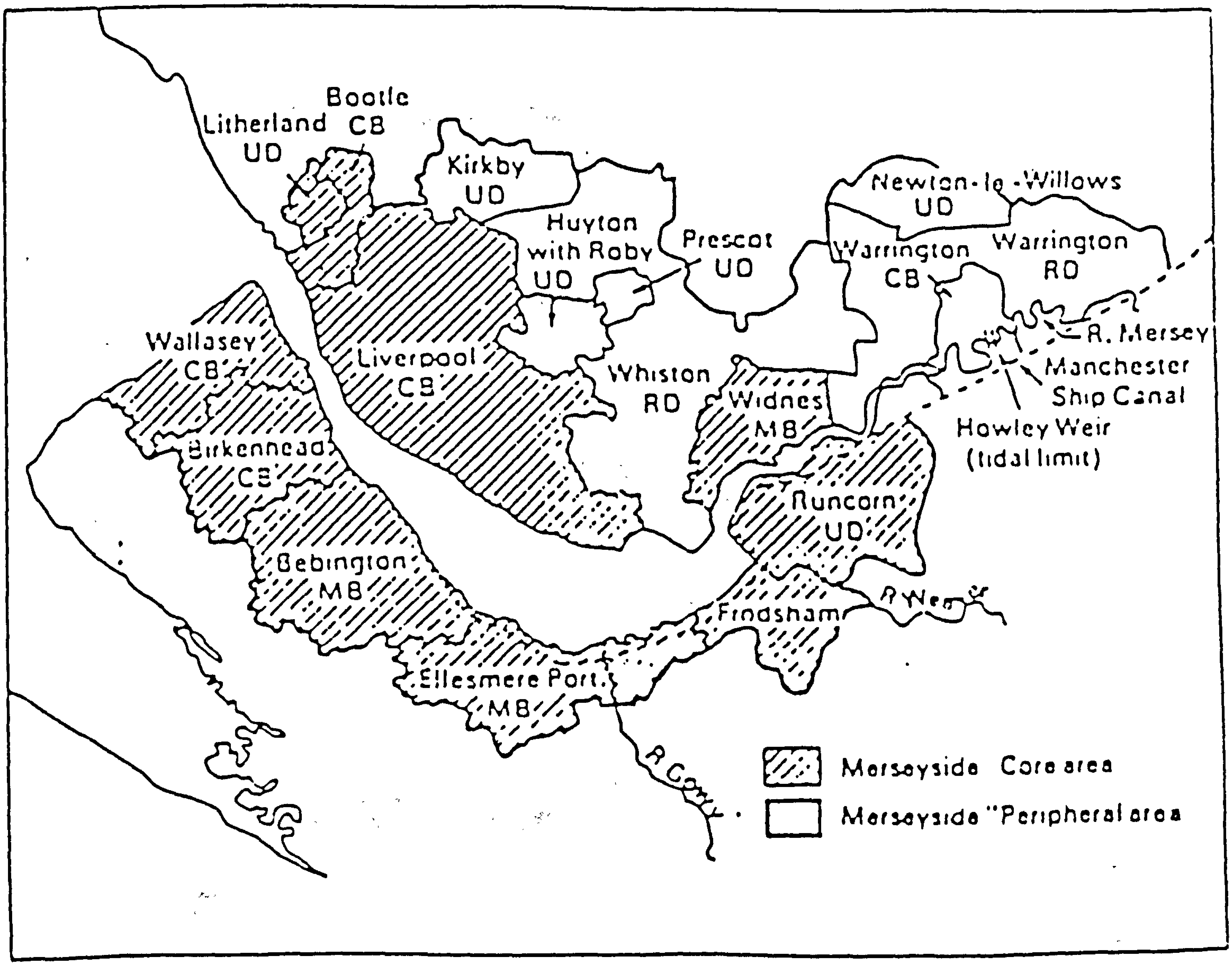
The earliest chemical works at Widness was opened in 1847, and several others followed soon afterwards, at a nodal point between the Lancashire coalfield to the north and the Cheshire salt field to the south. At first the Leblanc process was used to produce soda, soda ash and salt-cake, but this was later replaced by the Solvay ammonia soda process. In 1801 Widnes had been little more than a village, its inhabitants numbering 1,063. It experienced extremely rapid growth, especially in the period 1851 to 1881, and by 1901 its population was 32,000. At the height of the chemicals boom, around 1875, half the industrial labour forces was engaged in the chemical works. The spectacular rise of the chemical industry for a time completely eclipsed the older metal crafts of Widnes, but the copper industry soon returned, based on the extraction of copper from the pyrites used at the Leblanc works (Smith, 1953)

Runcorn developed rather later than Widnes. Modern large-scale industry began here with the establishment in 1897 of the Castner-Kellner Alkali Company, producing caustic soda and chlorine by the electrolysis of brine. In 1926 the nationwide merger which produced ICI, marked another phase of growth in the chemical industries of upper Merseyside.

Figure 3.1, shows the extent of Merseyside's built-up area in the late 1920s, together with the main areas of industry.

The population of the Merseyside area was around 1,528,000. Figure 3.2, shows population changes from 1901 to 1971. Within

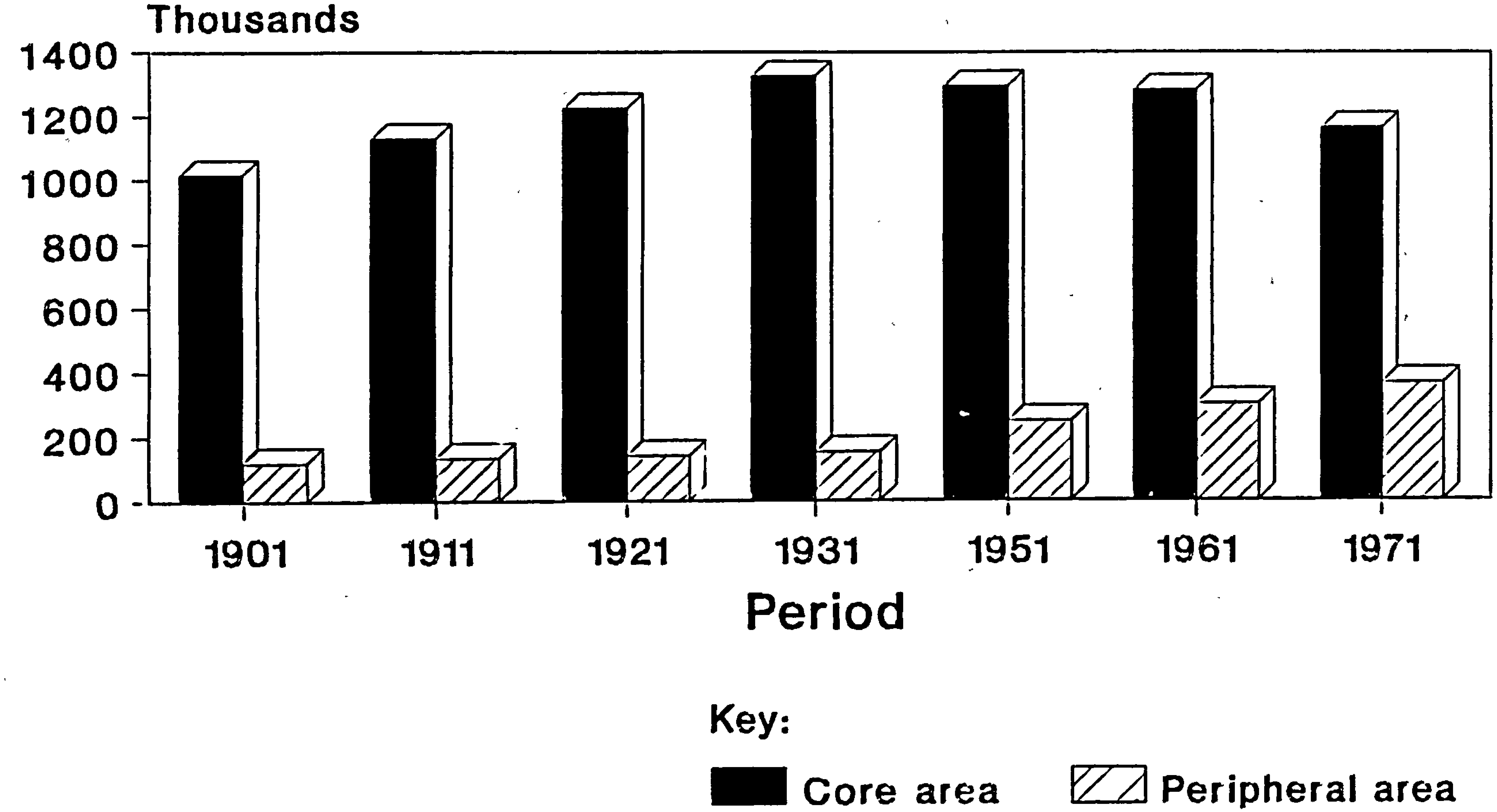
Figure 3.1: Built-up area in the Merseyside in the 1920s



Adopted and modified from Ordnance Survey

and other sources

Figure 3.2 Population changes in the Merseyside 1901 - 1971



Source: Porter, 1973

the area as a whole, population growth was fairly steady throughout the period 1901 to 1961, with a decrease in the last decade, but probably the most interesting feature is the marked contrast between those areas which have been losing population since 1931 and those which have been gaining rapidly.

Liverpool and Birkenhead, the most central part of the lower Merseyside, have both lost population, as has Warrington County Borough in upper Merseyside. These losses have been substantial, the population of the three towns being reduced by 25% of that of 1931. Much of the loses is attributable to the redevelopment of older areas, the lowering of housing densities in the centre, and the movement of people into the suburbs. Yet this decline has been more than compensated for, at least until 1950, by growth in the outlying areas, particularly in Bebington and Ellesmere port on the left bank and in the areas, surrounding Liverpool County Borough. The most spectacular growth was in Kirby, an Urban District in 1958 but formerly merely a parish of Whiston Rural District. In twenty years its population increased twentyfold, from 3,210 in 1951 to 59,918 in 1971. Huyton with Roby, Whiston Rural District and Warrington Rural District also saw very considerable increases at this time.

3.2 INDUSTRIAL CHANGES SINCE 1930'S

The industrial structure of Merseyside in the early 1930s rested principally on port-based industries and services, with about half the total jobs in the area being in shipping, shipbuilding, transport and distribution. Food-processing and the chemical and soap industries provided most of the remainder of employment in manufacturing. The depression of the 1930's exposed the basic weakness of this narrow range of employment opportunities, when the docks and port-based industries were seriously affected by the contraction of world trade. In 1932 the local rate of unemployment was nearly 30 percent, and in 1939, when the national rate had fallen to under 10 percent, Merseyside's unemployment was still nearly 20 percent (Porter, 1973).

Some indication of the changes which have taken place on Merseyside since the early 1950s. [illegible] The principal growth industries in terms of employment have been metals and engineering, vehicles, food-processing, and paper and board making, while there has been a notable decrease in shipping and the dock labour force, shipbuilding and chemicals. In the last case, the employment figures do not represent a decline of the chemical industry, but rather its increasingly capital intensive nature, but the figures for the other industries indicate in a general way their recent fortunes on Merseyside.

The industrial estates on the periphery of Liverpool have attracted several important firms in metal goods and engineering, including English Electric, Plessey and British Insulated Callender's Cables (BICC). The more recent Bromborough Port Industrial Estate on the Cheshire bank houses the plastics factory of the Metal Box Company Other developments on the

Wirral are in Wallasey, in marine engineering. As well as bringing much-needed employment, these industries are comparatively less harmful and do not add significantly to the estuary's pollution problem (Smith, 1969).

Similarly beneficial developments have occurred in the motor vehicle industry. Quite spectacular growth of employment resulted from the establishment on Merseyside of factories for Ford at Halewood, Vauxhall at Hooton Park, near Ellesmere Port, and Standard-Triumph, later British Leyland (now closed) at Speke. The Ford factory is the largest, occupying a 350-acre site at Halewood.

Another type of industry which has shown a major growth in employment is paper and board making, Warrington and Ellesmere Port being its two main centres. In Warrington the Thames Bowater corporation has a roundwood pulp mill and large factories producing newsprint and paper sacks. Liverpool, too, has its paper and board manufacturers, and in Merseyside as a whole the industry now employs 11,000 people.

The food processing industry on Merseyside has also expanded in the last 40 years. Liverpool is the leading centre, where the labour force of around 40,000 represents one-fifth of all industrial employment. on the Wirral, Wallasey, Birkenhead and Bebington together provide another 9,000 jobs in food processing. Merseyside has the largest flour-milling industry in Europe, a major sugar refinery and large seed-crushing plants for the making of vegetable oils and fats. All these follow the area's tradition of processing imported bulk commodities. In addition there are biscuit and chocolate factories, notably the new Cadbury's plant in Wallasey, and factories processing animal products for fats and gelatin (Smith, 1953; Smith, 1969 and Iliff, 1970).

The chemical industry has a long association with Merseyside, but major changes in the industry in the last 25 years or so have increased and diversified Merseyside's involvement with chemicals. Formerly the chemical industry concentrated on the manufacture of heavy chemicals, principally at Runcorn and Widness. Now a greater range of inorganic chemicals is produced here, and downstream at Stanlow Oil refining and petrochemical manufacturing have been established on a very large scale. During the 1940s and 1950s the expansion of the industry as a whole showed itself in increasing employment, but from 1960 onwards, employment has been reduced somewhat and the investment in plant greatly increased.

Shell's activity at Stanlow began after the construction of an oil dock by the Manchester Ship Canal Company in 1922, and until the end of the Second World War Shell produced lubricating oils, bitumens, rubber solvents, white spirit and liquid detergent with a total throughput of about 330,000 tons a year. The present throughput is around 18 million tons a year. The Shell complex occupies a site of about 2,000 acres and the plant represents an investment of over £200 million. In fact the Shell complex at Stanlow is one of the largest and most comprehensive in Europe (Gilfoyle,1990 and CCC, 1980).

Numerous chemical firms have plants in Runcorn, Widnes or Warrington, and most of the discharges of industrial effluent from this region originate from the 14 or so firms having their own separate outfalls. The Mond Division of ICI has its headquarters at Runcorn, having been formed in 1964 by the amalgamation of ICI's alkali, lime and general chemicals divisions. One of ICI's major research and development centres is here too, along with a plant for plastic production.

The characters of the upstream and downstream sections of the chemical industry are different in several respects, but both benefit from the ease of importing bulky raw material. The river and canal systems of Lancashire and Cheshire helped the early development of the alkali industry, and today the Mersey Estuary and the Manchester Ship Canal fulfil the same function of providing cheap and convenient access to the bulk processors. As the size of the carrying vessels has increased, so there has been a tendency for their terminals to be constructed progressively downstream. The oil terminals used by Shell demonstrate this clearly. The original oil dock at Stanlow was superseded by Queen Elizabeth II Dock at Eastham, opened in 1953. In 1960 the Tranmere oil terminal, further downstream still came into use, and the largest tankers now dock here. A pipeline carries the crude oil the 18 km to Stanlow, and there is also a pipeline connection to another of Shell's major installations at Carrington, west of Manchester. The end of this downstream migration is in sight for there are now detailed plans for the construction of a large, offshore mooring for tankers two miles off the coast of Anglesey. A sealine will bring the crude oil ashore and it will then be distributed by pipeline to the refineries (Millet, 1991).

3.3 SUMMARY

The growth of population in the Merseyside has been closely associated with the development of ports and port based industry around the Estuary. Up to 1930 the population was dominated by Liverpool. After this period, the population expanded on the peripheral areas. This shift was connected with the shift in production base which shifted from shipbuilding and docks to chemicals, metal engineering, food-processing and paper making.

In summary the industrial changes which have occurred on Merseyside since the 1930s are of two main types. One is the industrial growth which has taken place on the periphery of Liverpool, on the industrial estates and at the large motor vehicle plants. The kinds of firms attracted to the industrial estates have been many and varied, and there is a greater diversity of employment in the Greater Liverpool area than anywhere else in the Merseyside region. The other type of growth has been at the Stanlow and Bebington complexes, at fairly long established industrial sites where new aspects of traditional Merseyside industries have been developed soaps, chemicals and foodstuffs in many new guises.

CHAPTER FOUR

ENVIRONMENTAL IMPACT ASSESSMENT (EIA) AND METHODOLOGY OF WORK

4.1 GENERAL CONSIDERATION

Munn (1979) defined EIA as a process for identifying the likely impacts on the geophysical environment and Man's health and welfare of implementing particular economic development activities and conveying this information to those responsible for sanctioning the proposals. EIA has been described as an instrument having the ultimate objective of providing decision makers with an indication of the likely consequences of their own actions (Wathern 1990). Goode and Johnstone (1988) described EIA as an instrument which provides the opportunity to identify, mitigate, or enhance the potential environmental, health and social consequences of a proposed development activity and to generate alternative or additional options to that activity and to present information in such a way that it permits logical and rational decisions to be made and so provides the platform for the planning of the sustainable use of resources.

It should be noted that the definitions given above are general and not strict. They simply describe the basic idea of EIA as a process to ensure that the likely effects of projects on the environment are completely understood and taken into consideration before development is allowed to go ahead. EIA has also been described as a method for the identification and prediction of impacts and for influencing decisions related to the approval and implementation of development activities (Santos, 1992).

Basically, EIA comprises of the following distinct phases - impact identification, impact prediction, impact evaluation and impact monitoring and mitigation (Biswas and Geping, 1987; Clark, 1984). Impact identification is that stage of EIA capable of indicating those aspects of a project (or any on-going activity) deserving an in-depth study and consideration for further investigation and more conclusive assessment. It centres on Initial Environmental Examination (IEE) but is often expressed in different connotations such as Ecological Reconnaissance, Environmental Impact Investigation, Partial Environmental Impact Assessment and Preliminary Environmental Impact Assessment.

Impact prediction and measurement involves an estimation of the likely nature or characteristics of impacts in quantitative or qualitative terms. The magnitude of the change of a particular environmental feature due to the influence of the development is often estimated quantitatively. Measurement of changes in the state of environmental features is an important first stage activity in estimating nature of impacts.

Impact evaluation deals with determining the importance of an impact and relating it to that of other impacts of a different nature. This a continuous process through all the stages of EIA but is usually more intensified towards the end of EIA work, i.e. during preparation of the environmental impact statement (EIS). Once impacts have been evaluated, quantitative and qualitative information on impacts gathered during the whole process should be presented in a way that helps decision-makers and the public to arrive at definite conclusions on the merits and demerits of proposed development activities.

The next stage of impact monitoring and mitigation identifies impacts to be monitored during post-development periods. The is important in providing early warning of potential environmental damage so that measures can be taken to prevent or minimise the seriousness of unwanted impacts. Monitoring also helps to check predictions made prior to project activities. This activity can improve the accuracy of predictive techniques applied in future assessment (Shopley and Fuggle,1984).

4.2 DEVELOPMENT OF EIA

Historically, the legal use of EIA started in 1969 in the United States of America (USA) through the approval of the National Environmental Policy Act (NEPA/1969) and was adopted to ensure balanced decision-making on project approval. On 1st January 1970, legislation requiring EIA on major projects was also passed in the USA (Ahmad and Sammy,1985; Wathern 1990). The need for a broader look at the environment arose as a result of the failure of economic assessment in project planning, which often lead to unforseen adverse consequences to Man's social, economic wellbeing and health.

Since 1970, the legal requirement for the implementation of EIA has spread to many countries throughout the world. For example in Canada an Environmental Assessment and Review Process (EARP) was established by Cabinet decision on 20 December 1973 and adjusted by a second Cabinet decision on 15 February 1977 (Anderson,1986; Park, 1986). The purpose of EARP is to ensure that the environmental consequences of all federal projects, programmes and activities are assessed before final decisions are made and to incorporate the results of the assessments into planning, decision-making and implementation . Canadian Federal EIA procedures are not enshrined in legislation and decisions are not subject to public review. Instead an independent panel consisting of 5 to 7 members is established to review proposals considered environmentally significant by the initiating agencies. The panel conducts a public review based upon the EISs (by the initiator or project proponent) and advises the Environment Minister on the acceptability or otherwise of proposals and any conditions to which it should subject. The provinces each have their own approaches and requirements e.g. The Ontario Environmental Assessment Act was proclaimed in October 1976 requiring all projects proposed by the provincial government to be subject to environmental assessments which then refers them to the Environmental Assessment Board.

a) EIA in Europe

In Europe the general framework of the European Community's policy on the environment was laid down in a declaration of the EEC ' Action programme on the Environment' 22nd November, 1973. (Official Journal of EC, 1973, P.C. 112/3) The declaration states that - Effects on the environment should be taken into account at the earliest possible stage in all technical planning and decision-making processes. It is therefore necessary to evaluate the effects on the quality of life and the natural environment of any measure that is adopted or contemplated at national or community level. The basic objectives and principles of reducing pollution, avoiding damage to the environment and maintaining ecological stability of the environment were stated.

On 27 June 1985, the Council passed Directive 85/337/EEC on the Assessment of the Effects of Certain Public and Private Projects on the environment before approval was given for such a project. Projects are grouped into two general categories, Annex I, which are presumed always to have significant effects and for which EIA is mandatory, and a second list, Annex II, for which EIA is discretionary. Projects that do not fall in either of the categories are not exempted if they have a significant effect on the environment. In the UK they are covered by the discretion, resting with the Secretary of State, to issue a direction that a proposed development is a Schedule 2 application by reason of its effect. On 3rd July 1985, the EIA directive was notified to Member States. They were required to implement the directive by July 1988 (Bradley, 1989). The key aspects of the directive and of EIA procedures for consideration are :

- integration with decision-making;
- application of Annexes I and II;
- screening and scoping;
- public participation;
- review.

Table 4.1, summarises the state of implementation in the Member States (other than the UK).

Table 4.1: The Current Status of Implementation of the Directive

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Belgium: Requires regional implementation. Some EIA-like procedure already exist for classified establishments.

Walloon The EIA situation has been clarified by a 1987 Arrete which contains some relevant provisions. No direct implementation of directive has yet been applied.

Flanders During 1992, draft framework legislation on environmental assessment was proposed which included a number of suggested major improvements to the existing procedure. It also explicitly addressed EIA at the level of policies, plans and programmes, including area-wide assessments for land-use plans.

Denmark: On 13 th May 1987 Act No. 335 on EIA procedure was passed to amend the various environment and planning Acts in the country. By 1992 the implementation of EIA procedure has been about 10 EIAs per year and the procedure is reported to work satisfactorily. Among the projects assessed during th 1992 have been one for disposal of toxic waste, oil storage and treatment plants, a power production plant, tile works and motorways.

France: EIA legislation was enacted in 1976 and implemented by decree in 1977 establishing a two-tier EIA system. Further legislation covers classified establishments and public inquiry procedures.

Germany: A decree was passed on 20 May 1987 on the implementation of an Environmental Protection Act. The EIA Act was passed on 12 February 1990 and was applied to infrastructure projects, covered by the act by mid-1991. Before coming into force for industrial projects, a statutory ordinance had to be passed, which finally occurred in March 1992 (9. Verordnung zur Durchfuhrung des Bundesimmissionsschutzgesetzes, BGB11, S. 536ff). So by mid-1992, the German EIA act applied to all the projects with the exception of nuclear installations. The EIA act provides for a general administrative provision (Allgemeine

Verwaltungsvorschriften), that will serve as a guideline for the agencies.

Greece: Regulations to amend the present EIA system which applies only to classified establishments are currently in preparation.

Ireland: The Department of the Environment issued a circular letter to local authorities on 1st July 1988 enclosing a copy of the directive and advising how it should be operated from 3 rd July 1988. Between 1988-1990, a total of 12 statutory Regulations were pass to bring the EIA Directive into full operation. The regulation provide for the application of EIA to all Annex I projects and virtually all Annex II projects. So far the rate of submission of EISs has been quite high and rising. In the second half of 1988, thirteen EISs were submitted, 50 in 1989, 60 in 1990 and 83 in 1991.

Italy: A Decree of August 1988 implements the principles of the EIA Directive. Four years later a Law Decree of 14 August 1992 requires an EIA procedure for Annex 11 projects of EEC Directive 85/337 according to Art.6 of Law no. 349 of 8 July 1986 and Decrees no. 377 of 10 August 1988 and 27 December 1988.

Luxembourg: A draft law should be approved shortly.

Netherlands: Regulations to implement a 1986 enabling law were issued in 1987. On 5 August 1992, a comprehensive revision of the Decree was published. The extension of the field of application is focused on industrial activities, infra-structural projects and oil and gas production. Land development projects have also been listed as requiring EIA.

Portugal: A draft for discussion is being circulated around the relevant government departments.

Spain: The principles of the EIA directive were established in a 1986 decree which was implemented by a decree of 30 September 1988. Since then on 78 Declarations on Environmental Impact (written decisions of the environmental authority on the project, based on the EIA). Forty-nine of the Declarations were passed in 1992, 31 of which were on roads, 11 extractive industry, 4 dams, 2 ports and 1 industry.

Source : Compiled from EIA Newsletter series, Manchester EIA Centre,1985-1993.

b) EIA in the United Kingdom

Environmental policy making in the UK dates back to the early 19 century (Holdgate, 1983). In 1821 a Parliamentary Bill to cut down smoke emission from steam engines was passed and the Alkali Act was passed in 1863. More recently the Town and County Planning Act, 1971 contains many provisions found in EIA procedures.

Water Authorities were established in 1973 with responsibility for integrating the management of the entire hydrologic cycle in major river systems as part of which activity work was extended by some of them to protect estuaries and coastal waters. The Control of Pollution Act extended control to all waters and also underground aquifers in 1974 and in 1981 the Wildlife and Countryside Act consolidated previous law and established new measures for the conservation of species and habitats.

The thrust of pollution control policy in the UK prior to Directive 85/337/EEC, had been to remedy nuisances and to prevent Man made damage to the environment using the concept of "Best Practicable Means" requiring the cost of pollution control to be balanced against the damage costs prevented.

The discovery of North Sea oil and gas and the inquiry into the Third London Airport demonstrated the inadequacies of the traditional cost-benefit analysis in providing a balanced assessment of economic, social and environmental impacts. In response to this fact the Project Appraisal for Development Control (PADC) research group was jointly established by the Scottish Development Office, the Department of Environment and Welsh Office in 1973. PADC was based in the Department of Geography, University of Aberdeen.

Between 1991 and 1992 a number of new laws and regulations relating to environmental assessment (EA) have been implemented in the United Kingdom. The Harbour Works (Assessment of Environmental Effects) Regulations 1992 (S.I. No. 1421) were amended so that certain harbour works in Scotland were made subject to EA requirements. In addition The Town and Country Planning (Assessment of Environmental Effects) Regulations 1992 (S.I. No. 1494) were amended so that certain projects proposed by planning authorities in England and Wales were made subject to EA procedures. The Transport and Works Act (1992), which provides for the changes in EA procedures for developments approved by Private Acts of Parliament, received Royal assent and came into operation from 1 January 1993. The Scottish Office issued a Circular (SOEnD circular 26/1991) at the end of 1991 which provides guidance on the application of EA to Scottish private legislation and on the role of the Secretary of State in these arrangements.

The numbers of environmental statements (ESs) submitted in the UK by the end of 1991, was 792. The main categories of Annex I developments for which ESs are prepared are roads, waste disposal installations and power stations while Annex II infrastructure projects are the main sectors, with a relatively small number of ESs being prepared for industrial projects.

c) EIA in other countries

Since NEPA 1969, legislation in many countries around the world has established a system of environmental assessment and incorporated it into existing laws and guidelines governing development proposals. Brown et al (1991) compiled a list of countries in the Pacific Basin and Southeast Asia showing the level of EIA development in the various countries.

In addition to the rapid geographical spread of EIA in the last two decades, the technology has also developed beyond definitions, concepts and precepts to rationales and methods. A considerable number of these rationales and methods for the assessment of environmental impacts have been documented by Ditton and Goodale (1972) and Canter (1986). Methods of conducting an EIA are discussed in a separate section in this chapter. The rationale for EIA has grown so wide in scope that it can now be used to consider impact resource proposal upon economic efficiency, income redistribution, preservation of species and aesthetics, and political equity as well as environmental control (White, 1972).

4.3 THE EIA PROCESS

As soon as a project is identified by a developer or the Government, it is essential to carry out the following preliminary steps before the EIA process proper can start: identification of adequate decision-maker(s), selection of a coordinator, decisions have to be made on work allocation, a written description of the proposed development has to be made, and a wide review of existing legislation relating to the project has to be undertaken (Ahmad and Sammy, 1985). This list is by no means complete but only enumerates some of the fundamental steps that are necessary to make the actual EIA satisfactory.

The next phase is scoping and baseline studies. This phase is undertaken at an early stage of an environmental assessment and is very crucial for achieving the full effectiveness of EIA process (Santos, 1992). Scoping is the process of identifying, from a wide range of potential problems, a number of priority issues to be addressed by the EIA. It is a sifting process of serious from trivial or severe from mild impacts. According to Ahmad and Sammy (1985), scoping is a two part process involving firstly compiling a list of all potential problems, severe as well as trivial or a number of principal issues to be addressed by the EIA. The second part is then to carefully examine and to identify a manageable number of important impacts which are selected for study and the rest are then discarded.
The short listed impacts of the scoping process form the basis of planning the baseline survey / or impact identification which is then followed by impact prediction and evaluation. Figure 4.1

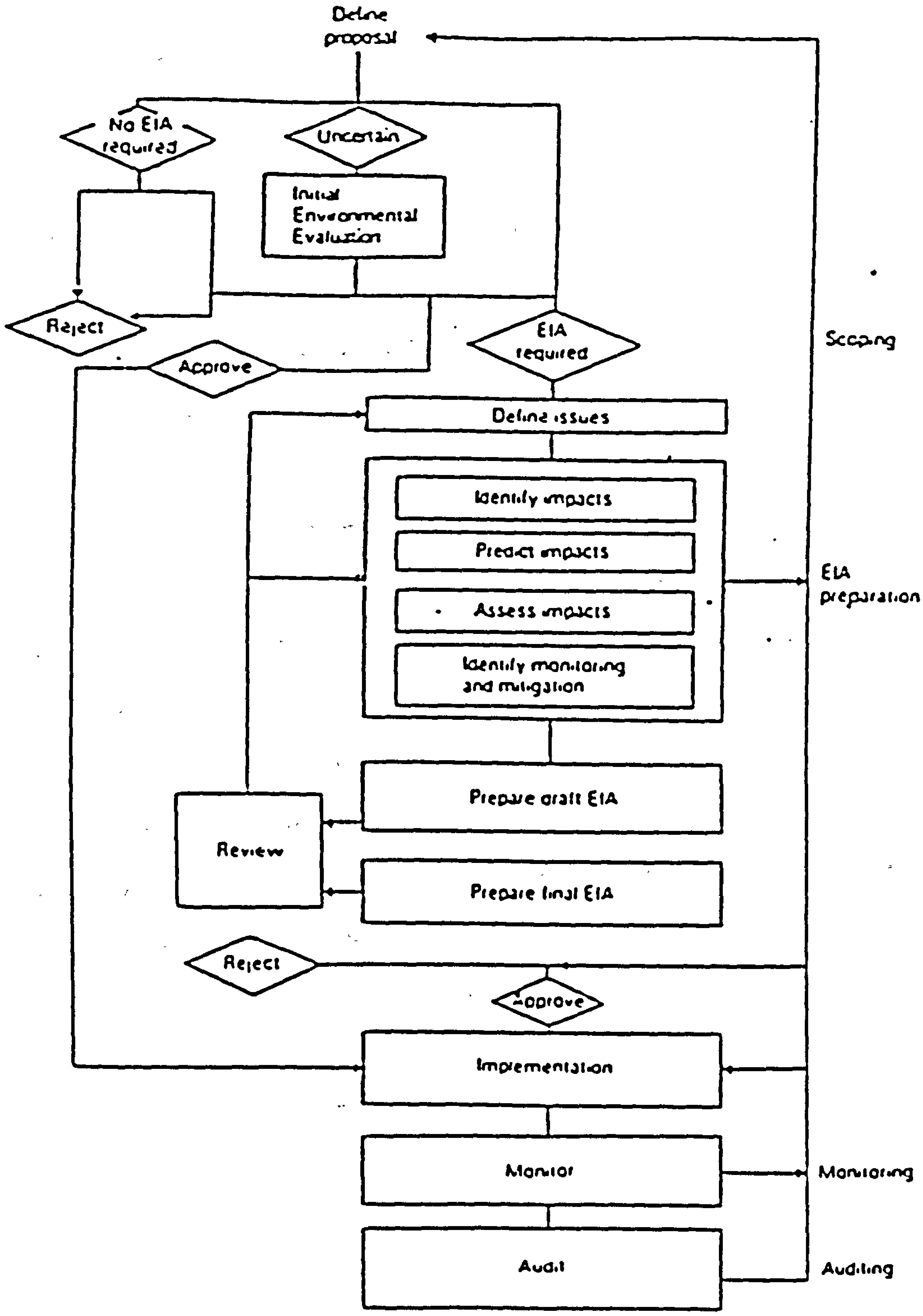

Figure 4.1: Components in EIA system

Source: Wathern, 1990

shows the main components of an EIA system.

The steps discussed above form the basis for starting an adequate EIA . The proper identification and understanding of the various steps in this process is the basis for the correct choice of an appropriate method of environmental assessment which is the next subject to be discussed in this chapter.

4.4 ENVIRONMENTAL ASSESSMENT TECHNIQUES

Since the recognition of the importance of EIA in project development, many attempts have been made to develope suitable techniques for assessing and estimating environmental impacts of proposed activities (McHarg 1968,1969, Leopold et al 1971, Ditton and Goodale 1972, and Fisher and Davies 1973, Schelesinger and Daetz 1973, Welch and Lewis 1976, Bonnicksen and Lee 1982, Lee 1983, Shopley and Fuggle 1984, Ahmed and Sammy 1985, Bisset 1980, Mitchell 1989 and Wathern 1990). The techniques identified can be listed as follows.

a. Adhoc
b. Overlays
c. Checklists
d. Matrices
e. Networks
f. Modelling

I shall briefly discuss these below:-

a). Adhoc

The adhoc approach to impact assessment indicates broad areas of likely impact . It is perhaps the oldest approach to Environmental Impact Analysis and was widely used by U.S.A. Federal agencies immediately after the introduction of NEPA (Shopley and Fuggle,1984). The method is very important in the initial identification of impacts but falls short of addressing indirect or secondary impacts and provides little guidance on how to assess impacts. It gives no guidance on the interpretation of impacts or the communication of results.

b). Overlays

Overlays are a series of transparent maps used to illustrate the nature, intensity and geographical distribution of impacts of a project on a series of environmental variables (McHarg 1968,1969; Haynes, 1982) . This method involves various stages of basic studies to collect information associated with the development of a proposal and the possible environmental implications connected to the impacts. Categories of information are then examined for their positive, negative or neutral effects on a prospective development or for the effect of development upon them. Afterwards values are attributed to the categories and mapped on transparent overlays. Categories assigned high value are given a dark shading, intermediate values are coloured in grey and low values are lightly shaded or left clear. Long-term irreversible impacts are considered to be more important than short-term reversible impacts and the weighting developed reflects their relative importance. The various overlays are superimposed and the cumulative effect of shading highlights those areas where impacts would be the least and greatest. Overlays have the advantage of providing an interesting visual display and are simple. The limitation of this technique is its failure to address characteristics such as probability, time and reversibility and it is not adequate for analysis of specific information (Wathern 1990). If too many transparencies are superimposed and the shading effect becomes difficult to distinguish. Thanks to technology, transparencies can now be produce on computer taking care of shading problem and the technique has become more efficient (Wathern, 1990). Overlays are particularly useful in assessing linear impacts such as road and railway construction but could be adopted for other projects as well.

c). Checklist Method

Checklists define areas of possible impacts and attempt to evaluate impacts qualitatively or quantitatively. Each impact is associated with a list of environmental parameters, and parameter data are measured to reflect the degree of impact. They provide the base for many of the cause effect matrices and the majority of them are used to ensure that important environmental considerations are not overlooked. Dee et al (1973) stated that checklists can thus be Simple, Descriptive, Scaling and Weight-scaling. The various types are described below.

i. Simple Checklists present a specific list of environmental parameters to be investigated for possible impacts. They do not establish cause-effect links to project activities. They may or may not include guidelines about how parameter data are to be measured and interpreted. They provide a structure for the comparison of alternatives and enable systematic decisions in selecting the best alternative. An example of a simple checklist is shown in Table 4.2.

ii. Descriptive Checklists provide detailed information relative to environmental features as well as impact prediction and assessment. They are useful for inventory, forecast and analysis as well as for the comparison of alternative plans. Descriptive checklists have the drawback of not highlighting the relative importance of the various environmental features, this often critical activity is left to the user (Haynes 1982).

iii. Scaling Checklists rank items on the checklists according to their order of importance. They are useful for the comparison of alternative plans and aid the selection process for selecting the best development proposal. Their main disadvantage is that certain impacts are not easily quantifiable and it is not always practicable to relate physical parameters to all types of impacts. Secondly, attention is mainly focused on numeric indicators of impact scale or rank to the exclusion of any consideration of actual impacts (Haynes 1982; Wathern, 1990).

According to Ahmad and Sammy (1985), checklists of

Table 4.7 Example of a simple checklist
(From Interim Guide for Environmental Assessment 1975)

PHYSICAL

1-Geology
1.1 Unique Feature
1.2 Mineral Resources
1.3 Slope Stability/Rockfall
1.4 Subsidence
1.5 Weathering/Chemical Release
1.6 Tectonic Activity/Vulcanism

2-Soils
2.1 Slope Stability
2.2 Foundation Support
2.3 Frost Susceptibility
2.4 Liquefaction
2.5 Erodibility
2.6 Permeability

3-Social Land Features
3.1 Sanitary Landfill
3.2 Wetlands
3.3 Coastal Zones/Shorelines
3.4 Mine Dumps/Social Areas
3.5 Prime Agricultural Land

4-Water
4.1 Hydrologic Balance
4.2 Ground Water
4.3 Ground Water Flow Direction
4.4 Depth to Water Table
4.5 Drainage/Channel Form
4.6 Sedimentation
4.7 Impoundment:Leakage and Slope Failure
4.8 Flooding
4.9 Water Quality
Organization

5. Biota
5.1 Plant and Animal Species
5.2 Vegetative Community
5.3 Diversity
5.4 Productivity
5.5 Nutrient Cycling

6. Climate and Air
6.1 Macro-Climate Hazards
6.2 Forest and Range Fires
6.3 Heat Balance
6.4 Wind Alteration
6.5 Humidity and Precipitation
6.6 Generation and Dispersion of

SOCIAL

8.Services
8.1 Education Facilities
8.2 Employment
8.3 Commercial Facilities
8.4 Health Care/Social Services
8.5 Liquid Waste Disposal
8.6 Solid Waste Disposal
8.7 Water Supply
8.8 Storm Water Drainage
8.9 Police
8.10 Recreation
8.11 Fire
8.12 Transportation
8.13 Cultural Facilities

9. Safety
9.1 Structures
9.2 Material
9.3 Site Hazards
9.4 Circulation Conflicts
9.5 Road Safety and Design
9.6 Ionizing Radiation

10. Physiological Well-Being
10.1 Noise
10.2 Vibration
10.3 Odor
10.4 Light
10.5 Temperature
10.6 Disease

11. Sense of Community
11.1 Community and
11.2 Homogeneity and Diversity
11.3 Community Stability and Physical Characteristics

12.Physiological Well-Being
12.1 Physical Threat
12.2 Crowding
12.3 Nuisance

13. Visual Quality
13.1 Visual Content
13.2 Area and Structure Coherence
13.3 Apparent Access

14.Historical and Cultural Resources

7. Energy
7.1 Energy Requirements
7.2 Conservation Measures
7.3 Environmental Significance

Source: Bisset, 1989

environmental parameters are most efficiently developed by the synthesis of EIAs on similar projects. They are useful for structuring the initial steps of the assessment. The disadvantages associated with checklists are cited in different sources (Ahmed and Sammy 1985; Santos 1992; Canter 1977). One such disadvantage is that they tend to be very rigid and concentrate only on direct impacts. They do not focus attention upon specific considerations, do not consider the interaction, magnitude or importance of the impacts and can generate voluminous amounts of information which is cumbersome to integrate into an overall plan of analysis. By providing a predetermined list, an important preliminary step of ecosystem description may be omitted.

Also they do not provide a means for identifying impacts considered important by the public. Another limitation of checklists is that they do not include uncertainty and risk. They only provide an incomplete basis for those carrying out the assessment to recommend appropriate monitoring procedures and sites.

d). Matrices

Matrices are tabular presentation of all actions which are part of a proposed development activity against every identified environmental parameter to ascertain whether an impact is likely to occur. They present first-order interactions and represent a step ahead of the checklists . The likely impact is broken into magnitude and significance (Leopold et al 1971, Fisher and Davis 1973; Welch and Lewis 1976).

The matrix method was first developed by Leopold et al (1971). They developed a complex matrix ideally suited for impact identification and which can be used to present the result of an environmental appraisal . In EIA matrices are arranged in a tabular form displayed with environmental process characteristics on the left-hand columns and the likely aspects of the project listed as column headings at the top (table 4.3). They aid systematic investigation of possible impacts so as to alert planning authorities to possible hazards. Data is filled into the matrix by putting a slash in each cell for which an action has a possible impact upon any kind of environmental characteristics, condition or dimension. In the upper left-hand corner of each slashed cell, a number from 1 to 10 is inserted to indicate the magnitude of the impact. In the lower right-hand corner, a number from 1 to 10 indicates the importance of the impact. The numbers assigned help to identify concerns arising from the interaction of projects activities with the environment.

Magnitude is considered to be a measure of the "degree, extensiveness or scale" of an impact and is assessed on the basis of the facts submitted. Importance is considered as the significance of an impact and is a subjective judgement on the part of individual investigator.

Table 4 A SECTION OF THE LEOPOLD MATRIX (COURTESY US GEOLOGICAL SURVEY)

Instructions

1. Identify all actions (located across the top of the matrix) that are part of the proposed project
2. Under each of the proposed actions, place a slash at the intersection with each item on the side of the matrix if an impact is possible
3. Having completed the matrix, in the upper left hand corner of each box with a slash, place a number from 1 to 10 which indicates the MAGNITUDE of the possible impact; 10 represents the greatest magnitude of impact and 1, the least, (no zeros). Before each number place + (if the impact would be beneficial). In the lower right-hand corner of the box place a number from 1 to 10 which indicates the IMPORTANCE of the possible impact (e.g. regional vs. local); 10 represents the greatest importance and 1, the least (no zeros)
4. The text which accompanies the matrix should be a discussion of the significant impacts, those columns and rows with large numbers of boxes marked and individual boxes with the larger numbers

Sample matrix

	a	b	c	d	e
a		/			/
b		/	/	/	/

Proposed actions — A. Modification of regime

			Exotic flora or fauna introduction	Biological controls	Modification of habitat	Alteration of ground cover	Alteration of ground water hydrology	Alteration of drainage	River control and flow modification	Canalization	Irrigation	Weather modification	Burning	Surface or paving	Noise and vibration
CHEMICAL CHARACTERISTICS	1 Earth	a. Mineral resources													
		b. Construction material													
		c. Soils													
		d. Land form													
		e. Force fields and background radiation													
		f. Unique physical features													
	2 Water	a. Surface													
		b. Ocean													
		c. Underground													
		d. Quality													
		e. Temperature													
		f. Recharge													
		g. Snow, ice and permafrost													

Proposed actions — B. Land transformation and construction

			Urbanization	Industrial sites and buildings	Airports	Highways and bridges	Roads and trails	Railroads	Cables and lifts	Transmission lines, pipelines and corridors	Barriers including fencing	Channel dredging and straightening	Channel revetments	Canals	Dams and impoundments	Piers, seawalls, marinas and sea terminals	Offshore structures	Recreational structures	Blasting and drilling	Cut and fill	Tunnels and underground structures
CHEMICAL CHARACTERISTICS	1 Earth	a. Mineral resources																			
		b. Construction material																			
		c. Soils																			
		d. Land form																			
		e. Force fields and background radiation																			
		f. Unique physical features																			
	2 Water	a. Surface																			
		b. Ocean																			
		c. Underground																			
		d. Quality																			
		e. Temperature																			
		f. Recharge																			
		g. Snow, ice and permafrost																			

Proposed actions — C. Resource extraction

			Blasting and drilling	Surface excavation	Subsurface excavation and retorting	Well drilling and fluid removal	Dredging	Clear cutting and other lumbering	Commercial fishing and hunting
CHEMICAL CHARACTERISTICS	1 Earth	a. Mineral resources							
		b. Construction material							
		c. Soils							
		d. Land form							
		e. Force fields and background radiation							
		f. Unique physical features							
	2 Water	a. Surface							
		b. Ocean							
		c. Underground							
		d. Quality							
		e. Temperature							
		f. Recharge							
		g. Snow, ice and permafrost							

Like all the assessment techniques mentioned above, matrices have their drawbacks. The technique is unable to identify indirect environmental impacts. It shows a direct cause and effect relationship which sometimes may not occur. A matrix does not differentiate between immediate and long-term impacts; this problem is, however, overcame by preparing a separate matrix for the different time periods. A high level of subjectivity is often associated with matrices, the scoring of magnitude and importance of any impact is left to the judgement of an assessor and different ones could come up with different conclusions. Matrices can be cumbersome involving the collection of much information and they can be laborious to construct. Matrices are relatively inflexible and hence can only cope with obvious effects. Another problem of matrices, is that certain intangible attributes of the environment such as noise, visual intrusion, loss of sense of satisfaction in for instance knowing that an animal species has been left undisturbed are beyond numerical specification.

PAGE
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e). Impact networks

Impact networks identify the chain of the interactions which may be triggered by a proposed development and the various causes and effects are codified .They revealed second-order and high-order impacts. The main aim of a network is to follow through the repercussive effect of an impact associated with an action on a particular environmental parameter (Sorensen, 1971; Haynes, 1982).

Impact networks are an extension of matrices incorporating long-term impacts of the project activities where the environmental components are generally interconnected in the form of webs or networks.The sequence of interactions is taken into consideration in a network recognizing that the development process and most of the environmental responses are dynamic rather than static (Haynes 1982).

Networks are easy to follow and can be of great assistance in informing non-experts such as members of the public on the consequences of the proposed activity on the environment. They are useful in studying indirect impacts, but do not provide any criteria for deciding whether a particular impact is more important than any other. Often the understanding of a cause-and-effect relationships is not enough to predict a chain of events and that renders the network method weak. This problem can however be overcome by attaching a summary document to indicate the important outcomes. Mitchell (1989) considered the network approach as conceptually superior to those based upon

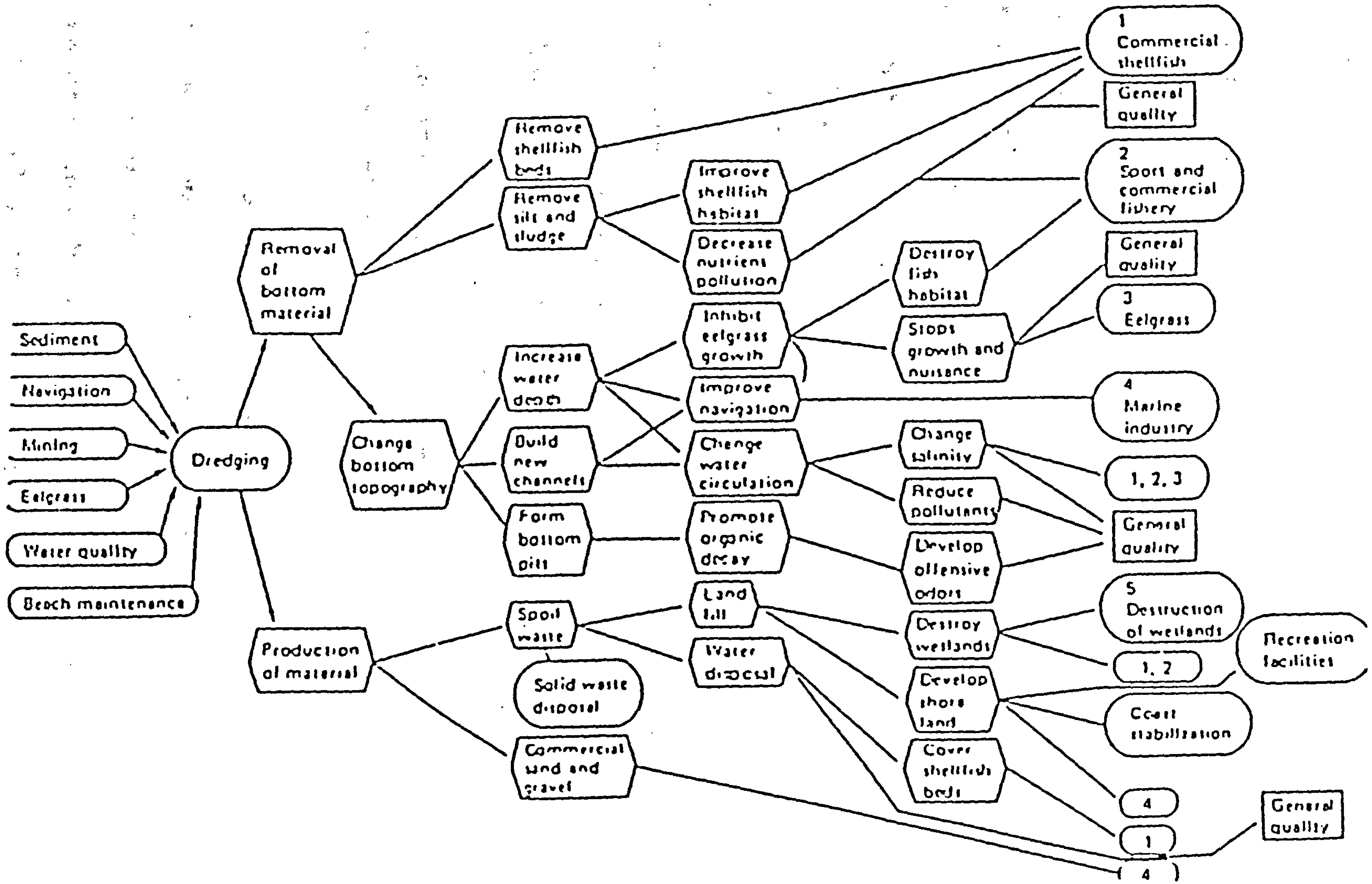


Figure 4.2: A Network Analysis of Dredging

Source: Sorensen, 1971

checklists, overlays and matrices. Networks are suitable for assessing single proposals where the impacts are relatively simple for example, a dredging activity (Canter, 1986). An example of network analysis is shown in figure 4.2.

f). Modelling Methods

Models are simplified representations of the real and complex systems which may be affected by a project (Munn, 1975). Models range from simple linear extrapolations to complicated energy system diagrams. Modelling can be used for environmental analysis with the primary aim of forecasting anticipated changes in environmental factors resulting from a series of different plans. Functional processes rather than structural components are responsible for defining relationships within a system. Therefore, the explicit identification and evaluation of impacts and particularly secondary impacts, require a study of the dynamic mechanisms that control the internal state of a system (Bisset 1980). Hence, dynamic models based on mathematical representation are best suited for extending the scope of an environmental impact study (Richle 1975).

Modelling is a resource intensive procedure and the resource requirements also vary considerably for various approaches. Ecosystem models which help in the assessment of secondary impacts were developed by Richle (1975). Predictive models for estimating the higher order impacts of major industrial and urbanisation projects, have been developed by Guildberg et al (1977).

Information gathered from models is, however, often misunderstood, and perhaps misinterpreted, particularly by individuals not familiar with the technical details of models. The reason for this is the highly technical nature of models and many cases lack sufficiently expert individuals to interpret them.

g). Other techniques of Impact Assessment

In an attempt to reconcile the necessity and high cost of EIA, certain methods which would be suitable for planning and administrative processes have been developed. One such method, descriptive rather than evaluative was recommended for use in the U.K. (Catlow and Thirtwall 1976). The authors emphasised that EIA and project design should be interactive so that the high cost associated with EIA could be avoided. Clark et al. (1980) devised an adaptive and comprehensive approach to impact assessment (Project Appraisal for Development Control, PADC Method) based on impact matrices and checklists of activities compatible with the U.K. planning structure.

Jain et al (1977) considered a computer-aided approach for impact assessment. When the information is loaded in the system it is partially in the form of interaction matrices which summarise the range of possible primary impacts. Further information is retrievable on secondary impacts, mitigating measures and pertinent legal provision. The method consolidates existing data and expertise to provide a comprehensive economically efficient and easily used approach to EIA.

These methods, although they broaden the capabilities of EIA are subjective and cannot substitute for the objective activity of assessing impacts. To minimise this element of subjectivity, an EIA technique must ensure a satisfactory undertaking of the different tasks involved. In this regard, a criteria for evaluating a technique discussed.

4.5 EVALUATION OF EIA TECHNIQUES

The various techniques described above have varying degrees of sensitivity and weakness and is difficult to categories between good and bad methods.

Different techniques have been developed to tackle this problem of evaluation of EIA methods and the following serve to illustrate the point.

Atkins (1984), presented list of criteria to compare certain EIA methods. These criteria seemed, however, to be too detail and suggest equal weights for all the items which could be misleading and may not be very helpful in practice. Nichols and Hyman (1980) took into consideration the utility of different methods in practice and proposed a seven point paired criterion of evaluating EIA methods on whether a method is deterministic or probabilistic, direct or indirect, static or dynamic, single or multiple objective, facts or value distinction, expert or participatory and lastly efficient or inefficient. This system is still not concise enough and tend to treat the different criteria independently.

However, on the basis of optimal use of available information, resources and mechanisms of providing adequate information to the decision-maker on environmental implications, EIA methods are assessed to determine their suitability. In this regard a four point criteria method of assessing EIA methodologies is considered most suitable. This assess methods assess technique on the basis of their replicability, consistency, adaptability and resource requirement.

a). Replicability Requirements

This criterion measures the repetitiveness of the same impact assessment result of a method when carried out by different assessors for a given project. It aims at reducing to the barest minimum, the element of subjectivity.

Simple checklist and network methods should score very high using the above criterion due to the fact that no values are attached to weigh impacts and it is most probable that skilled EIA practitioners would identify almost all the main impacts expected from a given project. The adhoc system may face a drawback on this criterion due to its very broad nature. Impact modelling should normally be reproducible. Because overlays involve the commutative result of segmented impacts it is likely that the final overlay sheet of different assessors will correspond. Individual value judgements may however, result in differential shading of similar impacts. Matrices are quantitative, where the range is narrow say 0-5, it is very likely that different assessors may come up with similar results but in case of a wider range of factors, variation may be found.

b). Consistency

Establishes the basis for a favourable comparison of the estimated environmental impacts of different projects with alternatives.

Impact matrices with quantitative values are easily comparable and give a good indication of alternative with less likely adverse effects. Scaled checklists are also very beneficial in the comparison of alternative proposals more especially so because of their unique feature of ranking items according to their order of importance. Modelling is also a good basis for comparing impacts. Adhoc measures can be cumbersome and make comparisons difficult. Overlay transference when pooled together may easily highlight different environmental components and make comparison of alternatives difficult. Impact networks assign no value to different impacts and make comparison difficult.

c. Adaptability

This measures the flexibility of a method in its application to different project assessments and the degree to which impact indicators are adjustable without altering the performance of the method.

Overlays measure intensity and distribution of impacts which make them easily amenable for any kind of project. Modelling is also subjective to manipulation and yet retaining its performance in the system. Input could vary and be adjusted to suite particular circumstances. Adhoc investigation is preliminary and broad based and can accommodate adjustment without much adverse effect. Checklists and matrices are restrictive concentrating on direct effects. Adjustment of the components of these systems can alter their performance since they link cause and effects. Networks are particularly suitable for assessing single proposals, where the impacts are relatively simple they can withstand much adjustment which will disrupt identified chains of effects of a project proposal.

d. Resource requirement

This implies the quality and quantity of data, costs, time and manpower.

The Adhoc method can be carried out fairly rapidly with less expertise, cost and manpower than other methods but the data generated can be voluminous and of low quality due to unsystematic nature of the technique. Overlays are relatively simple but conceal valuable quantitative information due to their inherent bias on intensity and spread of impacts, e.g. the impact of an oil spill on salt marsh vegetation falls short of giving the types of species involved, their number or biomass and stage of development, living fauna within the ecosystem is also not highlighted. Too many transparencies could obscure the value of the impact. Mobile organisms e.g. fish and birds that are not found dead or disabled within the affected area are not be accounted for using overlays. This system of assessment could be carried out fairly rapidly and can provide indication of areas on which to concentrate in subsequent investigation.

Checklists and matrices involve ranking of impacts which requires some level of expertise and therefore more costs. Public involvement to assess significance needs additional time and certainly increased costs. The data produce is "fairly" qualitative and helpful in decision making. Impact networks require a good understanding of the project and project area to identify high order impacts. This requirement for expertise increases the cost. The data is normally in form of a summary and is easily understood by lay-men but its failure to assign values undermines its quality. Modelling networks are highly technical and resource intensive. They are valuable in their ability to simulate the natural environment and provide opportunity for adjustment and modification before a final decision is made on the project.

Table 4.4: Evaluation of EIA Methods

	Repl.	Const.	Adpt.	Res.	Remarks
Adhoc	-	-	+	+	Broad base, non expert, unsystematic.
Overlays	-	-	+	+	Simplistic, static, subjective, adjustable to resource availability
Checklists	+	+	-	+	Deterministic, consistent, repeat quantification makes confuse, efficient but time consuming
Matrices	+	+	-	+	Cause/effect, consistent, concentrate on single objectives, straightforward and quick.
Modelling	+	+	+	-	Broad base, flexible, adapted to handle all important indirect effects, time consuming and very expensive.
Networks	+	-	-	-	path ways for direct and indirect effects, considers only adverse effects, does not deal with decision-making, intermediate expense for full assessment.

Key Repl. = Replicability + = Satisfactory
Const.= Consistency - = Not Satisfactory
Adpt. = Adaptability Res. = Resource requirement

Adapted from Atkin, 1984.

4.6 THE LIMITATIONS OF EIA PROCEDURES

In the last two decades, Environmental Impact Assessment has become a major factor in project planning and development. The technology is in essence a two component process used as a planning tool and as a procedure for decision-making (Kennedy,1988, Canter, 1977, 1986).

As a planning tool it has developed as a science with many techniques for identifying, predicting and evaluating environmental impacts associated with particular development actions. As a procedure for decision making, EIA has developed as an art dealing with mechanisms for ensuring an environmental analysis of proposed activities and for providing an informed guide in the decision-making process (Kennedy, 1988).

According to Kennedy, although hundreds of techniques have been developed to carry out environmental assessments, no national EIA system requires the utilization of a particular method or technique, and there is not a universally accepted list of approved methodologies. There is also no generally recognition on the part of practitioners as to which, if any predictive techniques are better than others. For instance in a study of eleven case studies of EIAs on high-ways and dam projects in six countries in Europe, the fundamental basis for predicting environmental impacts in all cases was best professional judgment and/or experience with previous similar projects (Kennedy 1988).

The very varied forms of EIA in different countries throughout the world may be classified into two forms - the formal-explicit and informal-implicit approaches.

The formal-explicit approach is one in which an EIA incorporates a requirement for assessing the environmental impact of major development action significantly affecting the quality of the human environment. The U.S NEPA process, and, to a large extent, the Canadian Federal Environmental Review Process are examples of the formal-explicit approach.

The informal-implicit approach involves adopting already existing legislation and planning procedures to give greater attention to the assessment of environmental impacts. This is the practice in countries with well established land use planning procedures. Examples of such countries are the United Kingdom, the Federal Republic of Germany, and most of the Scandinavian countries .

In the former case, Environmental Impact Assessment requirements are specifically codified in legislation or in legally binding regulations, for example as part of permitting and licensing procedures; Environmental impact statements or reports are prepared in which the environmental effects of development projects are assessed; and

-Authorities are accountable for the taking of EIA into consideration in decision-making, for example through administrative or judicial review.

The informal-implicit approach is one in which an EIA is modified or adopted to the needs of individual situations and proposals. It does not require an Environmental Impact Statement (EIS) and planning authorities are not accountable ta taking EIA into consideration in decision-making.

The practice of EIA has attracted many criticisms, one of which is that the exercise is time consuming and so delays project planning and so brings about increased costs. EIA has been used indiscriminately on all kind of projects, somewhere its use was not essential. Experience so far shows that the prime concern of EIA practitioners has been with the document itself rather than the purposes,to which it might be put. In addition the concern for the document has been more often based on its compliance with the rules, regulations and other procedural requirements than its scientific or methodological integrity.

In response to the indiscriminate application of EIA, some countries such as France, Japan, and the Netherlands have reduced this problem establishing a positive and negative list of specific project types that must always be submitted for EIA. Other countries, such as Australia, Canada, and the United States, have established screening criteria or guidelines which are applied to projects on a case-by-case basis to determine which should undergo an EIA.

Holling (1978) and Dickman (1991) described failures of EIA to predict certain impacts including major impacts as in the effect of mine tailings on a hyper saline lake in northern Canada.

Despite the problems mentioned above, EIAs have resulted in observable benefits. For example, over 70 percent of the EISs on waste water treatment facilities resulted in more protection of surface water quality than would have been afforded by originally proposed projects (Kennedy, 1988). Kennedy also reported the following successes of EIA:

- the plans for a flood control dam in West Virginia were modified to result in the construction of a "dry" dam (no permanent pool of water behind it), which reduced adverse impacts on water quality, air quality, archaeologic/historic sites, and wetlands;
-An interstate highway in New Hampshire, was tapered to a two-lane individual parkway in the most sensitive environmental areas of a national park and designed in such a way as to minimize effects on mountain sheep, fish, and other wildlife.

Kennedy further observed that the efficiency of EIA is determine by its integration into the project planning process and the necessary legal instrument to back its implementation and hence EIA is generally more efficient in those countries adopting formal-explicit procedures of impact assessment as compared to those following informal-implicit procedures. For example in

Ireland, a country adopting implicit procedure, Bradley (1989), pointed out confusion in implanting the EC Directive 85/337/EEC on the Assessment of the Effects of Certain Public and Private Projects on the environment, as there are no clear directives suspending the Environmental Studies Local Government Act of 1976. In practice therefore, it is left to the discretion of the relevant authority to decide.

4.7 SUMMARY

The need for the efficient utilization of environmental resources to minimise undesirable and often costly consequences following a development activity is now well recognised. EIA is specially designed to look at both nature (characteristics) and distribution (spatial spread, timing and effects on particular group of society) of impacts that might result from a proposed action or programme or policy initiative. The process of EIA involves:- impact identification, impact prediction and measurement, impact interpretation or evaluation, impact communication and impact monitoring and mitigation. Various techniques are used in EIA to systematically identify effects, following through relationships, ordering significance and evaluating outcomes. The aim of EIA is to serve as a guide in decision making on different alternatives for development and not a prescription for formulating planning policy (Haynes 1982). The efficiency of EIA is enhanced by the presence of legal instruments for its enforcement (Kennedy,1988).

Having established the importance of Environmental Impact Assessment in project development, the principles will now be used to assess the impact of human activities on the Estuary of the Mersey. The assessment includes all major developments around the Estuary since the time of the Romans. It is hoped that this thesis will bring together in one piece of work the different impacts on the physical, chemical, biological and to some extent socio-economic features around the Estuary of the River Mersey.

4.7 METHODOLOGY OF WORK

The thesis is essentially conceptual in approach. Relevant materials for its development were gathered from scientific papers, documents and reports. Seminars and conference attendance helped to broaden the grasp of the subject, site visits were carried out when desirable and individuals, organisations and local councils were contacted for information and material. The personal experience of the author, the expert advice of the supervisor and other staff members of the Environmental Resources Unit were also used.

A deliberate attempt is made to integrate EIA technology in discussing the implication of human activities on estuaries in general and on the Mersey Estuary in Particular. Similarly EIA methodology is applied to the quantification and analysis of the research findings.

CHAPTER FIVE

5 ECOLOGICAL IMPLICATIONS OF HUMAN INTERFERENCE ON ESTUARIES

5.1 GENERAL CONSIDERATION

The estuarine environment has been utilized by Man for many centuries. Initially, as a source of fish, for grazing animals and as harbours. At a latter stage the development of towns and cities on the shores of many estuaries, and the continuing expansion of industry and shipping, have led to extensive damage and destruction of habitat.

Effluent produced by urban industrial societies were freely discharged into estuarine water which made them heavily polluted. In addition the estuarine habitat has been freely used for waste disposal, tipping and land-claim and for a variety of other purposes. Most recently, leisure and recreation and the tapping of tidal energy to generate electricity, have placed increasing infrastructure and disturbance pressure on the wildlife using the remaining parts of estuaries. In Table 5.1, I have presented a summary view of various forms of human activities carried by Man on estuaries and their impacts.

This table summarises the main activities of Man on estuaries. The extraction of minerals from estuarine sediment is an old practice which provides job to a number of people but has the effect of blocking channels, increasing turbidity and may stir up toxic substance which may then get into the energy flow of an ecosystem and cause damage or sometimes death of some plants and animals and can affect Man through consumption of

Table 5.1: Generalized human estuarine activities and their impacts

Activity	Purpose	Impacts
Land claim	-tipping of waste and effluents	habitat destruction, seepage of pollutants.
	-flood protection	cut off tidal influences on inner habitat, siltation on the outer side of the wall.
	-farming	loss of natural habitat, nutrient enrichment.
	-building	habitat loss, landscape visual quality.
Extraction	-mineral mining	destroy habitat, increase turbidity, bring out toxins, block water channels.
	-sand winning	-do
	-bait collection	destroy habitat, micro habitat variation
Pollution	-sewage and effluent disposal	oxygen depletion, accumulation of toxins, loss of sensitive biota, low conservation and recreation value.
Barrages	-generate electric power -prevent flooding	inundate intertidal and salt marsh habitats, lower conservation value, promote recreation

contaminated fish or some plant produce (Kimura, 1988 and Alabaster, 1972). Land-claim on estuaries has also been practised for many years by construction activities and by biological use of plants such as <u>Spartina anglica</u>. Construction activities of various kinds are carried on estuaries which may alter current flow and sediment movement and deposition in estuaries. Direct fresh water discharge may be disturbed thus affecting dilution and scouring effect on estuaries, important habitats of salt marsh and intertidal mudflats are often cut off and permanently altered. Ports and navigation channels attract industrial siting along estuaries opening up employment opportunities leading to immigration and consequent urbanization. Intertidal mudflats along many estuaries,particularly on east coast of England have been reclaimed for agriculture by the use of the grass <u>Spartina</u> which facilitates accretion of sediments from tidal movement and deposition by air to levels beyond which tides can not reach (Davidson et al 1991, Gray, 1979, Knights and Phillips, 1979).

Effluent and Waste from industries and homes are directly discharged into estuaries resulting in pollution and disappearance of important sensitive species of plant and animals including fish, feeding niches for migratory birds become impoverish lowering conservation value of estuaries (O'Sullivan, 1971 and Wilson, 1988) . Huge costs are involved in attempts to restore what remains of estuaries to normalcy and in maintain socio-cultural breed as result of population interaction promoted by labour market.

The different impacts of the range of activities outlined above have been assessed by many authors among whom the following have been quoted in this thesis: Roberts and Holmes, 1984; Skulberg et al 1984; Swain, 1988; Pereira et al 1988; Michael and Claude, 1985; Anderson, 1988; Marcus and Thompson, 1986; Lauenstein et al 1990; Duncan and Neil, 1987; Overstreet, 1988; Dethlefsen, 1988, Nelson-Smith, 1977; and Hummon et al 1990, reported on various aspects of estuarine pollution. Others are Bryan and Langston, 1992, Nicholson and Rees, 1989; Baumann and Whittle, 1988; Bryan, 1971; Dawson et al 1988 and Hamilton, 1990. Some authors have contributed on the different aspects of land-claim from estuaries: Marjories, 1986; Bellessort et al, 1984 and Davidson et al 1991; Several others have also written on tidal modification and its consequences: Smies and Huiskes, 1981; Deeble and Stone, 1985; Carter and Newbould, 1984; Buxton, 1978; Ibara-Obando and Escofet, 1987; Elkington, 1977; Ferns, 1989; and Broyd et al 1984.

In this chapter, the implications of the various forms of pressure exerted by man on estuaries have been itemized and described.

5.2 LAND-CLAIM AND HABITAT LOSS

Land-claim or reclamation involves the construction of a sea-wall or bund across the intertidal areas, followed by the infilling of the bunded area with dredged estuarine mud, or hard-fill material derived from quarries, mine waste, ash waste from coal-fired power stations, or domestic refuse. In other schemes, the impounded area may be filled with fresh water to form reservoirs or drained and converted into agricultural land or polders as the case in Netherlands, the east coast of Britain, Denmark, India and Bangladesh (Wilson 1988, Beeftink 1975). Reclaimed areas of estuaries are also used as sites for industries, urban development, road, rail and air port development (Gray, 1979, Knights and Phillips, 1979, Goss-Custard, 1979 a&b, Elkington, 1977).

Davidson et al (1991), chronicled the pattern of land-claim in British estuaries. This activity has been widespread , cumulative and piecemeal. It has affected at least 85% of British estuaries, has removed over 25% of intertidal land from many estuaries, and over 80% in estuaries such as the Blyth (Suffolk), the Tees and the Tyne.

The largest area (47, 000 ha) has been progressively claimed from The Wash since Roman times (Fig. 5.1). In the last 200 years estuarine land has been claimed at 0.2 - 0.75 ha per year. Table 5.2 gives example of areas of historic land-claim from around estuaries in Britain. The purpose of land-claim was in most cases for rubbish and spoil disposal, transport (chiefly road) schemes, housing and car-parks and marinas. Estuarine land reclamation often followed by serious consequences on wintering birds and fishes.

In Louisiana, U.S.A, coastal wetlands are being lost at a rate of approximately 50 square miles (80 sq. km) a year and thousands of acres have been lost from other coastal states (EPA, 1987). The reclaimed land is used for residential, industrial and commercial development on the bays, estuaries and wetlands and

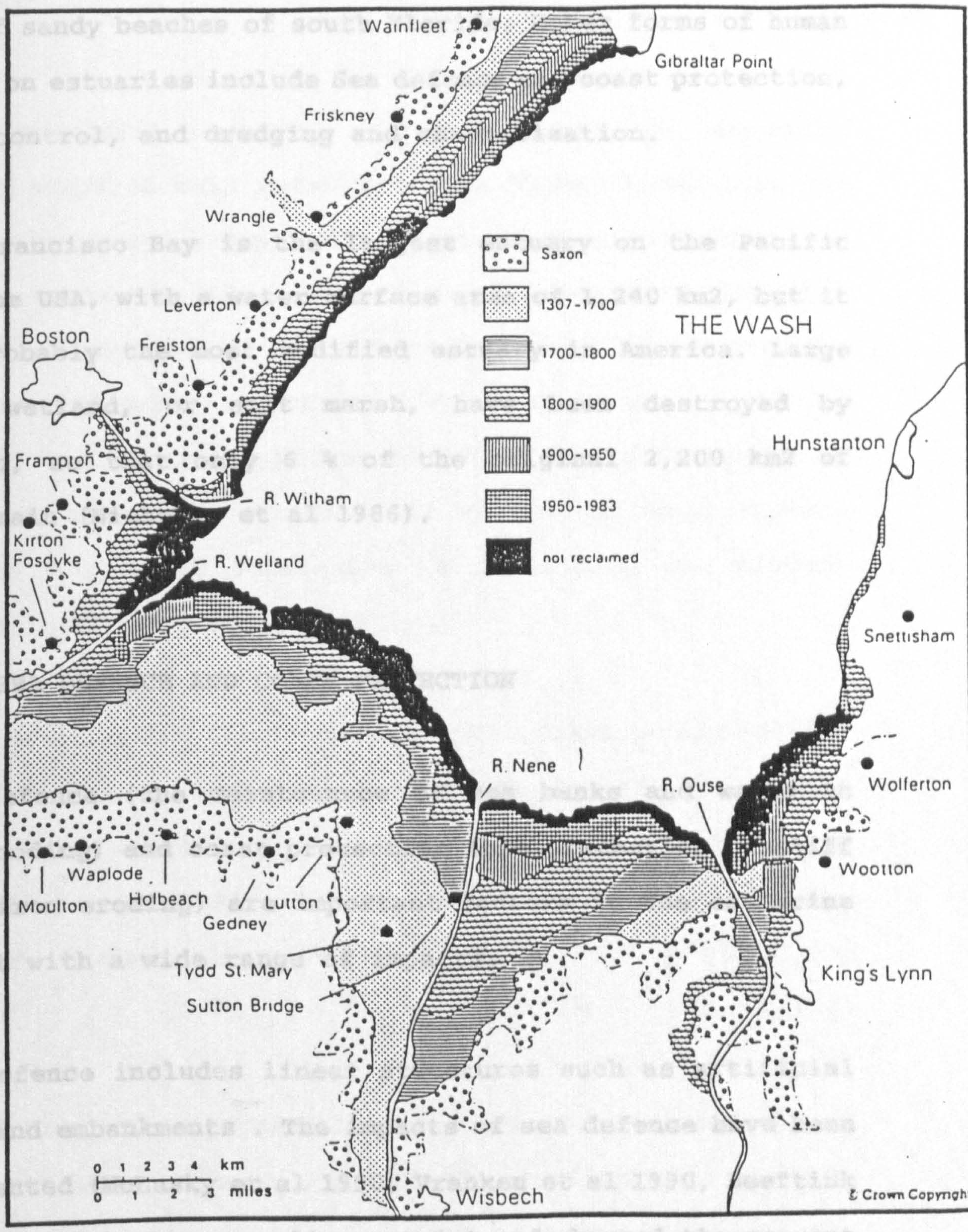


Figure 5.1: Area of historical land-claim from the Wash Estuary

Source: Davidson et al 1991

hundreds of sandy beaches of south Florida. Other forms of human activities on estuaries include Sea defence and coast protection, pollution control, and dredging and channelization.

San Francisco Bay is the largest estuary on the Pacific coast of the USA, with a water surface area of 1,240 km2, but it is also probably the most modified estuary in America. Large areas of wetland, or salt marsh, have been destroyed by reclamation, so that only 6 % of the original 2,200 km2 of wetland remain (Nicholas et al 1986).

5.2.1 SEA DEFENCE AND COAST PROTECTION

Sea defence (the maintenance of sea banks and walls to prevent flooding) and coast protection (the protection of cliff coastline from eroding) are important factors in the estuarine environment with a wide range of impacts.

Sea defence includes linear structures such as artificial sea-walls and embankments . The impacts of sea defence have been well documented (McLusky et al 1990, Vranken et al 1990, Beeftink 1975, Ashton 1920). Linear walls restrict and channel the current flows of streams and rivers discharging into the estuary. The area inside the wall is severed from tidal influence and consequently the biological community is changed for example salt-marsh vegetation is invaded and replaced by terrestrial flora or as often is the case the reclaimed area is used for agriculture or permanently converted for industrial and or urban development.

Beeftink (1975) observed that embankments on estuaries prevent discharge of rain water from the higher areas into the water - land boundary, except through sluices, they tend to narrow the estuarine waterways which results in an increase of the tidal current and of the range of the alternating brackish water-body. They also prevent expansion of the tidal marshes as a result of deepening of the waterways either naturally, in consequence of the narrowing process, or artificially for navigation processes. Consequently the marsh vegetation is diminished and pioneer species settlement prevented.

In Britain most of the estuaries are at least partly bounded by artificial defence, and often extensively. One of the earliest embankment constructed in Britain was that constructed between 1808 and 1811 on the Glaslyn Estuary in Wales extending for over one kilometre (Ashton, 1920).

In addition to the impacts on the estuarine ecosystem identified above, the enclosures have considerable implications for the future, particularly where sea level is rising relative to the land, since their maintenance is likely to become increasingly costly and difficult. Improvement to and repair of these sea defence also creates problems for conservation. In The Wash, for example, the traditional method of rehabilitating or raising the earth bank is to use excavated material from the seaward salt-marsh. This has the effect of removing the upper, often biologically the richest sections from the natural zonation of the shore. Coast protection which includes the erection of concrete sea-walls at the base of cliffs and the erection of groynes to slow down cliff erosion, exact an indirect impact by interfering with the natural processes of coastal erosion, long-shore drift and deposition but these may also upset the balance of shoreline change . The decrease in sediment availability may increase pressure elsewhere along the estuary and affect the fauna and floral component (Vranken, 1990; Beeftink, 1975 and Davidson et al 1991).

Another form of coastal protection is introduction of Spartina which spreads rapidly and invades intertidal flats which are rich in invertebrates and are the feeding grounds of fish and large numbers of overwintering waders or wildfowl, it replaces a more diverse pioneer plant community and produces dense swards which change the course and pace of succession and are replaced, in ungraded areas, by communities equally poor in species and which promote the reclamation of land for agriculture, thus destroying species-rich, high-level salt-marsh (Ranwell 1964, Davidson et al 1991).

Table 5.2: Examples of areas of historical land-claim on some estuaries around Britain

	Area lost (ha)	Period
The Wash	47,000	Since Roman
Severn Estuary	c 8,000	Since Roman
Dee Estuary	6,000	Since 1730
Humber Estuary	4,600	1600 - 1850
Greater Thames Estuary	4,340	mostly pre-1850
Tees Estuary	3,300	since 1720
Ribble Estuary	2,320	since 1800
Firth Forth (Inner)	2,280	since 1900
Morecambe Bay	1,320	1200 - 1900
Ore/Alde/Butley Estuary	3,640	since 1200
Deben Estuary	2,240	since 1200
Stour Estuary	1,600	since 1200
Blyth Estuary	1,280	since 1200
Orwell Estuary	980	since 1200
Southampton Water	690	since 1830
Poole Harbour	530	since 1807
Portsmouth Harbour	490	since 1850
Mersey Estuary	490	1800 - 1900
Tay Estuary	150	1800 - 1900
Total	91,250	

Source: Davidson et al 1991.

Historically estuarine habitat was reclaimed to develop as agricultural land, although in some cases the agricultural lands have been secondarily used for urban and industrial development. The Wash and Ribble Estuary form a good example of agricultural land -claim from estuaries. In the Dee estuary 6,000 ha of the over 22, 000 ha of the intertidal area has been removed since 1730 (Inglis and Kestner 1958). Estuaries reclaimed for industrial, urban and recreational purposes include those of the Severn, Orwell and Portsmouth harbour and the Solent. Estuarine land reclamation displaced many plant and animal species, and often deprives wading birds of feeding and roosting grounds (Gray 1979; Knights and Phillips 1979; Goss-Custard 1979b, Elkington 1977 and Coughlan 1979).

5.3 POLLUTION

Many estuaries have large conurbations and/or industrial complexes along their shores. While such place as London and Chester developed since at least since Roman times, places like Middlesbrough on the Tees Estuary, have grown up in the last 150 years as ports and heavy industry has moved downstream into estuaries. According to Davidson et al (1991), overall some 18, 186, 000 people live in large towns and cities adjacent to estuaries so at least one-third of Britain's population is associated with estuaries. In the United States, over 70% of the population live within 80 km of the coast (EPA 1987).

Effluent and waste from human populations and industry in the form of biodegradable organics, heavy metals, nutrients and radio active substances finds their way directly or indirectly into estuaries. This practice has resulted in polluting the estuary and damaging their resources (D.S.I.R. 1964, D.O.E. 1972). Table 5.3, presents the various types of pollution, its sources and effects on plants, animals and their environment.

Table 5.3: Type, source and effect of pollution on water.

Pollution	Sources	Effects
Organic matter	Sewage effluent; animal wastes; silage liquor; food processing waste	Dissolved oxygen removed from water; cannot survive.
Particulate material	Any disturbance of soil or rock; mining; sewage effluent; some industrial wastes, road run-off.	Smothering of all plants and animals; reduced light penetration; filter feeders cannot feed.
Acidification	Acid rain; air pollution; afforestation.	Reduction in pH: sensitive species cannot survive.
Toxic substances	Industrial wastes; pesticides.	Death or sickness of sensitive species
Plant nutrients (nitrate and phosphate)	Fertiliser run-off; sewage effluent	Eutrophication.

Sources : Furniss and Lane 1992

The organic and inorganic substances discharged into estuaries exert pressure in different forms on the estuary water quality and biota. The general effects that takes place could be classified as follows:

a) physical effects, such as are caused by suspended solid particles causing water turbidity, cooling water that raises water temperature, and oily films that restrict the reoxygenation of water.

b) oxidation effects caused by bacterial action or chemical oxidation of inorganic and organic substances, both of which significantly reduce the dissolved oxygen content of water.

c) toxic chemical effects caused by a range of substances that cause immediate or cumulative physiological changes in plants, animals, and humans.

d) chemical nutrient effects resulting from high concentrations of nitrates and phosphates.

e) pathogenic effects caused by micro-organisms, where bacteria and viruses are present in sufficient numbers to cause a health hazard.

f) radionuclide effects, caused by the accumulation of radioactive substances in food organisms, which produce human body changes.

a) Physical Effects

i) Inert wastes and suspended solids

Inert mineral wastes such as china clay or mining spoil and insoluble finely divided organic solids are a common waste found suspended in estuarine waters. The organic solids undergo slow biodegradation and cause a reduction of the dissolved oxygen in water. Inert solids are of varying particle size and density, and they settle out, or remain suspended according to their properties and the turbulence of the water. The extraction of china clay in Cornwall and west Devon gave rise to large quantities of waste much materials, a good portion of which finds its way into the estuaries and may cause substantial damage (Alabaster, 1972). The effects of such material have been little studied estuaries, however studies on rivers and creeks show that the water ways becomes chocked with the material causing great harm on the biota and facilitating accretion the water ways. The extrapolation of these effects from fresh water environment gives an idea of what will happen to estuarine biota and the general environment. Parts of South Francisco Bay became chocked due to debris of earth from hydraulic gold recovery in the Sierra Nevada . Siltation from the mines block Salmon spawning streams and obstructed navigation throughout the drainage basin (Nicholas et al 1986).

The mass movement of inert material is capable of covering partially or completely beds of invertebrates fauna and intertidal algae, for example, River Fal in Cornwall was filled with suspended solids of about 1 000 mg/l and the River Par even more heavily polluted with up to 5 000 mg/l as compared to unpolluted rivers containing about 60 mg/l. The unpolluted river support growth of normal trout (Salmo trutta) populations of about 30 / 100 m^2 and the contaminated rivers carried only about 3 / 100 m^2 each. The fish food in terms of biomass was about 615 g / 100 m^2 for the unpolluted river and about 195 and 39 for the Fal and Par rivers respectively. The adverse effects on fish include thickening and sometimes fusion of the epithelial cells of secondary lamellae of gills; abandoning of gravel by fish and the failure of their eggs to develop satisfactorily unless when a current of water is passed through the gravel (Herbert et al 1961). Movement of certain species of fish is affected by the quantity of suspended turbidity for example, the Eel (Angilla anguilla) increased with decreased turbidity and Minnows (Phoxinus phoxinus) moving down a clean tributary avoid entering a muddy stream (Moore, 1932). In St Austell Bay and Mevagissey Bay accumulated china-clay reduced drastically the fauna, reducing its productivity but yet increased productivity further seaward (Portman 1970). Saunders and Smith (1964), demonstrated that both the spawning and the standing crop of brook trout (Salvelinus fontinalis) that had been curtailed by heavy siltation in Ellerlsie Brook, returned within one season when deposit material was removed by scouring.

In addition it can be deduced that settlement layers reduce the solar energy absorption by plants and so lower the rate of photosynthesis, helping to produce low oxygen conditions on the river bed. This can prevent the development of salmon and trout eggs, and preclude the survival of bottom living invertebrate animals. Small suspended particles make water turbid, and this reduces light penetration, reduces photosynthesis, and restricts plant growth. Turbidity also reduces visibility in the water and limits the food gathering capacity of many animals. Fish and some invertebrates have their respiratory efficiency reduced because the gill surfaces become clogged with suspended matter. All these physical effects cause a disturbance of the balanced ecosystem.

Some animal species do not survive, others are reduced in numbers, and so food chains and nets are affected (Alabaster 1972).

ii). Thermal pollution

Some ecologist consider temperature as the primary control of life (Clark 1969; Barnett 1971).

In estuaries temperature varies naturally with variation in weather conditions. However cooling water from industries and power plant discharging directly into the estuarine system; the heat generated from decomposition of organic matter contained in effluent and waste discharged into estuaries and the discharge of worm domestic work water, significantly raise the temperature of the system and exert effects on the biology of the estuary (Clark 1969). Increase temperature speed up metabolic process for example every 10°C rise in temperature the rate may double (Clark 1969 and Brett, 1956). As each species has its own metabolic rate most aquatic animals can only exist within a specific temperature range. For example trout are killed by a temperature of over 25°C and their eggs will not develop in water above 14°C, but carp can withstand temperatures of up to 35°C (Dix, 1981). This difference in tolerance limits produces such effects that under certain temperature conditions only such species with wide tolerance range can survive. Clark (1969), chronicled effects of thermal pollution on aquatic life. Stress due to thermal pollution causes variation in the rate of heart beat in the fish (*Astacus*) from 30 beats per minute at water temperature of 4°C to 125 beats per minutes at 25°C and declining again to 65 beats per minute at 39°C. Increased heart beat increases the rate of oxygen consumption, for example the hardy carp at 1°C can survive on oxygen consumption as low as 0.5 m/l but will need more 1.5 m/l when the temperature is raised to 39°C. Other fishes can exist on 1 to 2 mg/l at 4°C but will require 3 to 4 to survive at 21°C and 5 mg for normal activity. In addition the haemoglobin of the blood in fish has a reduced affinity for oxygen at elevated temperature which makes it less efficient in delivering oxygen to the tissues and hence the dramatic increase. Increased temperature and oxygen consumption increases the feeding capacity of fish, at 11°C food took 18hrs through the alimentary canal of a young Carp but only 4.5hrs at 24°C. Brown trout consume more food between to 12 to 18°C but increase in weight is best achieved just below or just above this range, a vital consideration in fish farming. Diadromous fish like the Sockeye salmon (<u>Oncorhynchus nerka</u>) and Chinook (<u>O.tschawytscha</u>) become distressed when the oxygen concentration of the water is reduced to 3.5 ppm, death begins below 3 ppm and becomes rapid below 2.5 ppm (Dix, 1981).

Aquatic animals tend to move faster and show more spontaneous movement as the temperature rises, e.g. the Sock eye Salmon (<u>Oncorhynchus nerka</u>) cruises twice as fast at 18°C than it does at 2°C; above 18°C, the rate declines . The brook trout increases its spontaneous activity between 5 - 10°C, becomes less active between 10 - 21°C and increases again above 21°C until the lethal temperature of 28°C. In terms of reproduction, deposited eggs of the Atlantic Salmon hatch in 114 days at 3°C but take only 90 days at 8°C. The eggs of Herring hatch in 47 days at 0°C and 8 days at 16°C, Trout at hatch in 165 days at 3°C and 32 days at 14°C. Temperature affects fertility of aquatic animals as well, for example the banded sunfish fails to develop eggs at temperature 25°C and above. Among the crustaceans, Gammarus produces only female offsprings at temperatures beyond 9°C, the shrimp (Neomysis integer) is blocked from laying eggs at temperatures above 8°C and is usually not found in polluted waters (Green 1968). Daphnia can live for up to 108 days at 9°C but only 29 days at 31°C. In general terms, temperatures above 38°C are unbearable for most fish species however, coarse fish. Barnett (1971), in a study of effects of thermal pollution from the Hunterston Generating Station, Ayrshire, Scotland, observed higher mean specific growth rates in the most common species - Tellina tenuis da Costa, especially with the younger year groups. The species- Urothoe brevicornis, breeds earlier by about one month under the influence of raised temperature.

In the plant kingdom, high temperatures speed up growth. Above about 30°C, green algae tend to be less numerous, but there is an increased growth of blue-green algae and sewage fungus. This can eventually result in plant death and decomposition causing water stagnation.

Physical environmental conditions affects the degree of impact of thermal pollution, e.g. the effect will be greater in summer with an air temperature of over 28°C, and where there is reduced water volume flowing in a sluggish river. The resulting rise in water temperature will lower the oxygen saturation percentage and speed up the biodegradation of pollutant organic matter. Both these effects will result in a sharp increase in the oxygen sag, or deficit, in the water. A rise in temperature also increases the toxicity of some chemical pollutants.

The overall effect of heated cooling water discharges depends upon the volume and the temperature of the discharge, and the rate of flow and degree of pollution of the receiving river. The effect on the ecosystem will vary according to the interaction of both chemical and physical factors.

b). Oxidation Effects

Organic substances discharged into water courses undergo the processes of dilution and decomposition (Furniss and Lane 1992, Clark, 1989 and O'Sullivan, 1971). In decomposition there are two main types of oxidation, brought about by the action of bacteria upon organic pollutants, or through chemical oxidation of other pollutants present in industrial wastes. Both types of oxidation involve the use of dissolved oxygen, and so produce an increased Oxygen Demand and an dissolved oxygen deficit in water courses. Examples of chemical oxidation are the conversion of sulphide to sulphate in the sulphur cycle and ammonia to nitrite and then to nitrate in the nitrogen cycle. Another example occurs where drainage water from mines and spoil heaps enters streams and rivers. The drainage water often contains iron (II) sulphate and hydrogen carbonate. These iron salts are oxidized to iron (III) hydroxide, which is deposited as rusty red gelatinous masses. These deposits are often associated with filamentous bacteria, and if present in large quantities are toxic to biological life.

Depletion of oxygen has a damaging effect on the aquatic animals that depend on the dissolved oxygen to respire. Large quantities of organic matter in water may cause total deoxygenation, thus preventing almost all species of invertebrate and higher animals from surviving. Lack of oxygen in polluted waters generally decreases invertebrate species diversity and dominance of very few number of species (O'Sullivan 1971; Filice 1954 and Newell 1965, Barrett et al 1972). *Capitella capitata*, a polychaete is reported to be dominant when species like *Nereis diversicolor* and other members of the polychaete group are suppressed due to pollution (O'Sullivan 1971). Fraser (1931, 1932), recorded *Mya arenaria* as occurring in substrata of both stones and thick mud in a polluted area of the Mersey Estuary. Two mollusc: *Myrtea spinifera* and *Thyasira flexuosa* dominate the Loch Linnhe, Scotland, due to effect of wood pulp pollution (Pearson 1968).

Benthic fauna responds to organic pollution mainly in three ways. Certain species disappear or retreat from the polluted regions, such species include: *Nephthys hombergi*, *Eteone longa*, *Pectinaria (as Lagis) koreni*, *Diastylis rathkei*, *Polydora ciliata*, *Scolelepis fuliginosa* and most sponges, echinoderms and ascidians. *Halicryptus spinulosus* was one species that completely disappeared. This group of invertebrates are referred to as regressive species (O'Sullivan 1971).

The second group, transgressive species, spread in the direction of polluted regions or which now occur there but are scarce or absent before pollution began. Tulkki (1968) lists the isopods *Cyathura carinata* and *Idotea chelipes* and bivalve *Nacula nitida* in this category. In every polluted area could be added the polychaetes Capitella capitata, Polydora ciliata, Fabricia sabella together with nematodes.

The third group are indifferent species, their distribution does not change very much at the onset of pollution. Examples are Harmothoe imbricata, Cardium lamarcki, Mya arenaria and Corbula gibba. Corophium volutator, Eteone longa, Nereis diversicolor and Mytilis edulis may be included in this list of tolerant species (Alabaster, 1972).

The polychaete families Spionidae and Capitellidae, harpacticid copepods, nematodes and ciliates are strongly represented in the list of transgressive species. Most of these species are either detritus feeders (living on bacteria or organic detritus) or filter feeders (collecting suspended food particles out of the water).

The effect of pollution on fisheries starts with the loss of the more sensitive species, usually the salmon species, which passes through the estuaries to breed in fresh water, and latter the more resistant species as the degree of pollution increases. In the River Thames, commercial fishing went on fifteen years after the disappearance of salmon species (Wheeler 1979).

c) Chemical Toxic Effects

Some inorganic and organic chemical substances are toxic or poisonous to plants, animals, and humans. A toxin may be described as any chemical substance that is capable of causing injury, or impairing, or killing any living organism. Toxins are absorbed into the tissues from polluted water, and the effect produced varies with the type of chemical substance, the concentration in the tissues, and the metabolism of the organism. In water that is frequently polluted, the organism may be exposed to low concentrations over a varying length of time. Between a tolerable and lethal concentration there is an intermediate level of toxin, which occurs as the tissue concentration is increasing, but before any toxic effects are produced. This is the threshold concentration or threshold limiting value (TLV), and it is described as the maximum concentration of a toxin that an organism may be exposed to continuously, without suffering adverse effects (Dix, 1981).

i) Types of Chemical Toxins

Chemical toxins can be broadly considered under the four headings of metal and salts, pesticides, acids and alkalis, and other organic compounds such as PCBs, phenols, and cyanides.

ii) Heavy metals

The toxic or heavy metals include iron, lead, mercury, cadmium, zinc, copper, nickel and arsenic (Byran 1971; Robbe et al 1985; Hamilton 1990; Marcus and Thompson 1986; Duncan and Neil 1987 ; Lauenstein et al 1990, Arzul and Maguer,1990). Very small quantities or traces of some metals are required for normal growth and metabolism, for example copper, iron, nickel, and zinc. However if the TLV is exceeded, then these metals may start to cause a deleterious effect, and living organisms vary in this respect. For example, 0.3 mg/l of zinc, 0.02 mg/l of copper and

0.33 mg/l of lead are lethal to sticklebacks plant growth is retarded by zinc concentrations of 7 mg/l or more, but 0.5 mg/l of copper, or 0.01 mg/l of mercury will kill algae (Bryan 1971). Metals produce physiological poisoning by becoming attached or adsorbed on to cellular enzymes, causing inhibition of the enzymic control of respiration, photosynthesis, and growth (Anderson 1971). One of the most significant effects of metallic pollution is that aquatic organisms can absorb and accumulate in their tissues (Anderson 1971; Kimura 1988). Consequently increasing concentrations can build up in food chains and net (biomagnification) and they are highest in species of the secondary and tertiary trophic levels. For example, there may be up to 15 times as much mercury present in fish as in algae (Rees and Nicholson 1989).

In the plant kingdom, the algae, <u>Fucus vesiculesus</u>, was found to contain varying levels of toxic chemicals of Cu, Zn, Cd, Ni and Fe at different times reflecting variations of metals in the environment of the Humber estuary (Barnett et al 1989). The consumption of fish or vegetables material contaminated with heavy metals may affect human population as happened in Japan where about 100 people died and over 7 000 sustained various degrees ill-health from ingestion of fish or shellfish contaminated with methyl mercury compound discharged from a fertilizer factory located inland close to Agano River basin (Kimura 1988).

Similarly, the consumption of fish contaminated with organochlorine compounds affect development of fetus in pregnant mothers and children are smaller in size after birth (Swain 1988).

d) Chemical Nutrient Effects

Chemical nutrients are substances that are required by plants and animals for maintaining their growth and metabolism. Among these chemicals nitrogen and phosphorus are most important in water pollution. They usually occur as nitrates and phosphates. Small amounts of nitrates and phosphates occur in all natural waters, and these are sufficient to maintain balanced biological growth. Their concentrations rise slowly in estuaries and lakes as a result of biodegradation of dead organic material. This rise in nutrient is called natural enrichment or eutrophication (Fisher and Oppenheimer 1991).

The breakdown of domestic and industrial waste is accompanied by the release of nitrogen and phosphorus. This happen even where full biological treatment is given, such treatment merely oxidizes the organic matter and does little to remove nitrates and phosphates from the effluent. Removal of nitrogen compounds, in the form of suspended solids containing organic nitrogen, is much affected by the method of disposal of the sludge. Where the sludge is removed from the effluent disposed off, for example, on land, the amount of nitrogen discharged is considerably reduced; but where the sludge is treated anaerobically, nitrogen salts are released and returned to the sewage treatment plant (recycling process) to pass eventually into the receiving water.

The nutrients are assimilated into the system through the pathways of absorption by biota, and addition into the reservoir, in the sediment and in the water column. In those situations where nitrogen, for example has been limiting primary production, problem may arise when the limiting factor is removed, the nutrient is then used in the photosynthetic fixing of carbon dioxide and the production of organic matter as plant biomass.The extra plant biomass can affect the functioning of the system in two ways. Firstly when there is plenty of light during the day there is plenty of oxygen (Dissolve Oxygen in excess of 100 %) but during the night oxygen is consumed in respiration at greater than usual rate, and may accelerate the tendency of the system to anoxia. The second problem is that of primary production in excess of the energy requirement, the excess product enters the food chain via decomposer cycle, giving a situation not unlike that caused by direct organic matter loading. Riley and Chester (1971) reported primary production biomass as having potential BOD up to four times an average direct BOD load. In New Jersey oxygen depletion from excess nutrient loading caused massive fish kills and about $60 m loss in the commercial clam fishery (EPA 1987).

The excess algae can be a direct nuisance in the form of algal mats on beaches. They are unsightly and deter bathers, and to many people are an outward and obvious sign of pollution. Parry and Adeney (1901) establish the link between algal blooms and nutrient input. Phytoplankton blooms (red tides) particularly when the bloom is composed of the dinoflagellates Gonyaulax or Gymnodinium, some species of which contain a dangerous neurotoxin. These toxins can cause skin rashes or allergic complaints from those who come into contact with them. Some blooms produce toxins which can be accumulated in shellfish and may have severe or even fatal effects on the consumer e.g. birds. Areas regularly affected by toxic dinoflagellate blooms in summer include the coast of California and Florida, the Bay of Fundy in Nova Scotia and, in Britain, on the north-east coast of England (Clark 1989).

In Britain the concentration of nitrates and phosphates in water courses and seas has been increasing since the 1960s. For example in 1977, the Thames contained five times more nitrate than it did in 1948, and other rivers have shown similar increases (Robert and Holmes, 1984). The nutrient increase is associated with modern farming practices which involved increasing use of chemical fertilizers to increase crop yields. Farmers in Britain, used about one million tonnes of nitrogenous fertilizers in 1975-76, compared to 100, 000 tonnes some 40 years earlier, and the use is increasing at about 7 % per annum (Robert and Holmes 1984). In the same period, 175 000 tonnes of phosphatic fertilizer were also used. All the applied fertilizers are not absorbed from the soil by growing crops, and it is probable that up to 40 % of the applied nitrates enter water courses as run-off and leachate from agricultural land. Soil phosphate tends to be adsorbed, or bound to soil particles, so that probably only 20-25 % of phosphate is leached into water courses. Sewage effluent is another source of nutrients all of which are not removed during primary and secondary treatments. The quantity of phosphates present in sewage has been increasing since 1952, when the newly developed soapless detergents began to be widely used. Marjorie (1986) (USA) reported sharp declines in rockfish species and oyster species populations due to the production of toxins from the proliferating algae responding to high concentration of phosphorus and nitrogen contamination.

e) Micro-organism Effects

Faecal waste that is discharged into water contains pathogenic organisms that are capable of transmitting human diseases. Some bacteria are water borne, and these include types responsible for causing cholera, typhoid fever, bacillary dysentery, and gastroenteritis. In the mid-nineteenth century, well over 20 000 people died as result of cholera outbreaks from contaminated water in Britain (Wheeler 1979).

The alarming spread of cholera and evidences connecting it to pollution was responsible for the first serious approach towards to minimising the effect of pollution in estuaries and coastal waters. Plans were made to pipe the sewage away from London for instance, and discharge it well downstream (Wheeler 1979). This scheme and the introduction of secondary treatment of intercepted sewage before discharge resulted in water quality improvement as reflected in the records of annual minimum average dissolved oxygen levels for the tidal Thames as shown in Table 4 below.

Table 5.4: Percentage Dissolved Oxygen saturation in the Thames estuary

Year	D.O.percentage saturation
1968	5.5
1975	21.8
1976	30.0
1979	44.2

Source: Robbert and Holmes: 1984

f) Radionuclide Effects

The development of nuclear energy is producing more radioactive waste to be disposed off into the environment, and it contains various radionuclides with long half lives. The various radionuclides exhibit biological effects (Woodhead 1971).

At present low and medium activity wastes in Britain, are either stored on land or disposed of at sea. For example in 1976, there were 12 000 m^3 of solid wastes stored on land in the UK, and this contained nearly half a tonne of plutonium. Other wastes are sealed into containers and dumped into the North Atlantic at a depth of 4500 metres, at a location 900 km SSW of Lands End. In 1978, the DOE stated that about 66,000 tonnes of packages of solid low activity waste had been dumped at sea since 1949, and the scale of dumping was about 7,000 tonnes per year. At present it looks safe when these radioactive wastes are dumped at sea but the corrosive action of sea water and the effects of natural forces may eventually cause damage to, or leakage from containers. If this should happen, the escape and spread of radioactive nuclides would be uncontrollable, and some material may eventually enter the estuarine ecosystem.

Low level activity liquid waste are discharged by pipeline into coastal waters. In the UK, 75 % of the total waste is produced at Windscale in Cumbria, and liquid effluent is discharged into the Irish Sea. This contain such radionuclides as ruthenium-106, strontium-90, cerium-144, caesium-137, and various plutonium isotopes. These substances settle on to bottom sediments and become adsorbed on to the mineral particles. Isotopes that leak into the sea could be circulated by storms and ocean currents and eventually reach the coast regional and become incorporated in the ecosystem when absorbed by plants and animals. Since Man uses members of the higher trophic levels for food, for example fish, shellfish, and crustaceans such as crabs lobsters, and shrimps, we stand the risk of absorbing the elements through the tissues of the animal used as food (Kershaw et al 1992).

5.4 BARRAGES

Tidal barrages are constructed to provide electric power, control floods and to improve recreational activities. Along with these benefits are associated environmental consequences which if not carefully considered can outweigh the benefits. Such environmental consequences include:- permanent physical transformation; the inundating settled areas and the destruction of habitats; charging the ground water regime and water table; possible explosive aquatic weed growth; the decreased flushing time of pollutants, reduced tidal energy and delay in ocean ship transport (STPG, 1981, Jackson, 1977; Knights and Phillips, 1979, and Ferns, 1983). Barrages can interfere with fish migration and destroy bird feeding and roosting places. Few studies have been carried out the environmental effects of barrage construction and the methods of minimizing those effects that are undesirable (Ferns, 1989, Broyd et al 1984, Gilson, 1966).

At the construction phase, dredging operations generate sediment which increases water turbidity, along with the sediments there could be waste organic material and heavy metals. This causes a temporary deterioration in water quality and affects the living components of the ecosystem including fish and predatory birds. Construction noise impact may arise at the construction site.

During the operational phase, the main environmental effect may be the changing pattern of the existing tidal range, normally to the landward side of the barrage. For example in the Severn Estuary barrage the tidal range would be reduced by half to the landward side. The rate of exchange of water between the upper and lower estuary would be reduced and the whole of the existing intertidal area would be permanently inundated (Ferns, 1989). The halving of the tide range lowers current energy, a condition which would allow the partial settlement of the estuaries 10 million tonnes or so of sediment (on spring tides). This may then allow greater light penetration and consequently greater photosynthetic activity. This in turn may lead to algal blooms, especially in the early stages before the system stabilizes.

The Severn supports elvers and salmonoid fisheries in the order of about £0.5 million each per annum. The passage of the fisheries through turbines and sluices may affect productivity. The Estuary supports six species of wintering birds in numbers of international importance, viz. Grey Plover (Pluvialis squatarola), Curlew (Numenius arquata), Black-tailed godwit (Limosa), Redshank (Tringa totanus), Knot (Calidris canutus), and Dunlin (Calidris alpina) (Andrews and Davies) . The landward tidal movement will inundate vital feeding areas by birds and destroy fish breeding grounds. The impact may be significant in the case of birds but not so much with the fish for which the commercial value is small (Ferns, 1989).

Smies and Huiskes (1981) reported possible environmental impacts of storm surges on the barrier system of the Eastern Scheldt Estuary, which include: decrease in turbulence and turbidity with decreasing mean tidal current velocities, increase in mean water residence time and increase in particulate carbon which may result in increased sedimentation and consequent reduction in capacity of the estuary.

Overall changes in water regime due to impoundment lead to beneficial changes in terms of turbidity reduction, hardness reduction, oxidation of organic material, coliform reduction and flow equalization and detrimental effects of low re aeration, build up of organics, algal blooms, stratified flow and thermal stratification (Canter 1977).

Proposed barrages on the Wash, the Dee, Morecambe Bay, and the Solway Estuaries will involve the loss of most or all of the rich muds, leaving only the less fertile sands towards the sea. This will have very serious consequences since the Morcambe Bay, The Wash, Dee and Solway between them support as much as 30-35% of the waders present on the coastline of Britain which is in the range of 1.5 million birds (WRB, 1966, 1972; Corlett 1970). Tidal Power Barrage on the Strangford Lough will destroy rare floral fauna elements found in the largely unpolluted Estuary (Carter and Newbould, 1984)

5.5 POLLUTION INCIDENCE

The modern petroleum industry began in 1859, when E.L.Drake drilled a producing well on Oil Creek in Pennsylvania at a place that latter became Titusville (Anon 1985).

Today western civilization is heavily dependent on petroleum for motive power, lubrication, fuel, dyes, drugs and many synthetics.

Most of the oil used in the world industries is moved across large water surfaces. In the process of transportation leakages occur spilling out into the marine environment. From the 1960s to date, oceanic oil spills have become a major environmental problem, chiefly as a result of intensified petroleum exploration on the continental shelf and the use of suppertankers capable of transporting more than 450,000 metric tons of oil. Thousand of minor and several major oil spills related to well discharges and tanker operations are reported each year, with the total quantity of oil released annually into the world's oceans exceeding 907,000 metric tons (Anon, 1985). The costs of such spills are considerable in both economic and ecological terms. Oil on oceanic surfaces is harmful to many forms of aquatic life because it prevents sufficient amounts of sunlight for photosynthesis from penetrating into the water and also reduces the level of dissolved oxygen. Moreover, crude oil renders feathers and gills ineffective, so that birds and fish may die from direct contact with the oil itself. The impact of oil on the aquatic biota has been studied (e.g. Nelson-Smith 1968a, 1968b, and 1972b; Baker, 1971; Ranwell and Hewett, 1964 and MOSP, 1991). Accidents to supertankers and underwater wells and pipelines may be the cause for major, oil spills, but the unintentional or negligent release of used gasoline solvents and crankcase lubricants by industries and individuals greatly aggravates the overall environmental problems. More than 3,800,000 000 litres of oil are added to the world's coastal and inland waterways in this manner each year (Anon 1985).

5.5.1 Oil in the environment

Crude oil is an organic substance capable of being assimilated by the environment to a considerable degree and consequently there is no widespread and detectable accumulation of oil above background levels in the oceans.

Oil pollution occurs when the environmental load becomes excessive, usually in the form of accidental spillages, which can result in mass mortalities among seabirds, marine mammals and benthic and shoreline communities. Coastal amenities, such as sandy beaches, water abstractions, mariculture and marinas may also be affected and lead to serious economic repercussions

(Nelson-Smith, 1972b and Davies and Wolff, 1990).

Large spillages receive wide media attention, for example, in the Torrey Canyon incident in which 118,000 tonnes (26 million gallons of Arabian Gulf crude were spilled off Cornwall, March 1967, at least 18 000 tonnes of which were deposited on shore extending for 140 miles (225 km) from Trevose Head in the North to Manacle Point in the South and on some 75 miles (120 km) of coastline in Britanny. The total area contaminated amounting to 215 miles (345 km). Taking minor coastal indentations into account the area would be much wider (ACOPS 1990). In total representatives of species of at least 16 genera of algae, of some 20 species of lichens and of at least, 70 species of flowering plants were known to have been killed or so severely damage by oil pollution or emulsifier treatment that they were unlikely to survive. The coast of Cornwall is a prosperous inshore fishing ground. The fish were apparently not affected by the spillage. Fish landed on the port showed no reduction in weight when compared to two years before and two years after (Ranwell, 1968; Spooner, 1967; Stebbings 1967).

The Exxon Valdez tanker incident involved over 35,000 tonnes (11 million gallons) of oil spilled early on Good Friday 24 th, April 1989 in Prince William Sound. The accident occurred when the vessel carrying some 170,000 tonnes of oil from the port of Valdez, Alaska, U.S.A hit Bligh Reef in Prince Edward Sound at a speed of 12 knots. Prince William Sound is one of the world's richest fishing grounds. It is also a treasured wilderness area, encircled by wildlife refuges and national parks and forests

(ACOPS,1990).

Within a week the oil moved out of Prince William Sound into the Gulf of Alaska, and after a month the oil spill, oil had swept around Kodak Island and into the Lower Cook Inlet, while strong winds also pushed oil into the fjords of the Kenai Peninsula. The extent of the damage included 27,000 birds counted dead by mid July, large numbers of the mammal sea otters species were found dead and 120 of the already decreasing population of 5,000 of the American bald eagle were also reported dead.In the long term five salmon hatcheries which provide from 50 to 60% of the Prince William Sound peak salmon harvest worth as much as 35 million U.S. dollars a year were contaminated and it was feared that all the fish would be killed and that spawning grounds ruined and the salmon not return. The cleaning operation on the rocky shore involved at its peak 10,000 employees using water jets, rakes and shovels and paper towels. They were paid some $16.69/hour (about £10 then). The total cost of the clean up at the end of July come up to US $1,280 million. It was costing some $40 million per week. That included the costs of paying 10,000 clean-up workers, and renting and operating 1,000 vessels and 70 aircraft. The figure also included money to reimburse the Federal Government and States which contributed to the clean-up (ACOPS 1990).

In September 1983, the VLCC Sivand spilled 6,000 tonnes of Nigerian light crude oil in the Humber estuary as a result of a collision of the 218,000 deadweight tonne vessel with the jetty while berthing at the Immingham oil terminal. The incident occurred between midnight of 27 th Sept and early morning of the 28 th September 1983 (Mitchell et al 1986). The spill killed substantial numbers of invertebrates. The species most affected were Nereis, Cerastoderma, Macoma, Arenicola and Hydrobia. Some 200 birds were reported dead or dying and a minimum of 2,700 birds observed as being oiled to some degree (Mitchell, et al 1986).

The Amoco Cadiz spilled 223,000 tones (50 million gallons) of Arabian crude in March 1978 onto the Brittany Coast of France.The incident is known to have killed well in excess of 4,500 sea birds, destroyed fishing ground and contributed to a 25% drop in visitors to the Breton region in the following holiday season.The awards against Amoco for the pollution was originally Frs 261 million. On 21 February 1989 the award was adjusted with an additional sum of Frs 116 million. The sum was adjusted for two main reasons: firstly because clean-up equipment used by the French Government was rented, not bought, and hence a resale deduction was not valid; secondly, oyster growers affected by the disaster successfully argued that their compensation did not take into account the long-term effects from oil persisting in sandbanks (ACOPS, 1990).

In 1986, a Texaco refinery spilt oil on a complex of mangroves and coral reefs in Panama. The incident cause extensive damage to both the coral and mangrove . According to a study by The Smithsonian Tropical Research Institute of Balboa Panama (cited in ACOPS 1990,), before the spillage plants and animals covered the roots of mangroves in the study area, including algae and invertebrates, such as sponges, hydroids and other sessile organisms. In channels the roots supported oysters and barnacles as well as some mussels. After the accident oysters and barnacles in the channels and rivers disappeared from the reefs for 15 months (ACOPS 1990).

5.5.2 Fate of oil

Oil spilt on the surface of a body of water can be subject to a number of physical and chemical factors simultaneously. The actual fate of a particular spill is therefore the result of the specific combination of factors operating at the time. The factors with most influence are:-

i) The nature of the oil: in particular its viscosity, pour point, specific gravity and distillation characteristics.

ii) Spreading: the main driving force being the weight of the oil itself. Highly viscous oils such as TJP spread slowly; within a few hours the slick will begin to break up into windrows etc., and considerable spatial variation will occur in the thickness and distribution of oil within the slick.

iii) Evaporation: the volatile fractions of an oil will evaporate at rates depending on the surface area exposed, windspeed and ambient temperature. The residue after evaporation has an increased density and viscosity. Viscous heavy oil such as TJP undergoes only limited evaporation.

iv) Dispersion: turbulence and wave action on the sea surface will act on a slick to produce oil droplets in the water column. Theses may be carried away, break down (droplets have a greatly increased surface area to volume ratio) or re-coalesce to form larger droplets or a new slick behind the main one. Viscous oils show little tendency to disperse.

v) Emulsification: many oils absorb water to form water in oil emulsions - this can greatly increase (3-4 times) the volume of the pollutant. These emulsions are often highly stable and retard other processes which would tend to dissipate the oil (e.g. dispersion). Oils with Asphaltene contents higher than 0.5% tend to form stable emulsions which are often referred to as "chocolate mousse". After stranding emulsions often separate out into oil and water again.

vi) Dissolution: the heavier components of crude oils are not soluble while the lighter components, particularly the aromatics, are soluble. These are also the most toxic components and dissolution increases their contact with biotic systems. However, as these are the most volatile components, loss by evaporation usually exceeds dissolution by a factor of x10 to x1000 times. Dissolution is therefore, a very minor process in determining the fate of a spilled crude oil.

vii) Oxidation: oxidation is often enhanced by sunlight and leads either to the formation of lighter weight soluble fractions or persistent tars. In the case of a high viscosity oil or an emulsion tar formation dominates. Tarry residues are more likely to persist and may incorporate sediment in the outer layers to form tar balls with weathered oil-sediment outer crusts surrounding a softer, less weathered interior.

viii) Sedimentation: heavy residual oils have specific gravities greater than 1, and will therefore sink in fresh or brackish waters. If particulate matter becomes incorporated into the slick this can raise the density and lead to sinking.

ix) Biodegradation: oil can be broken down by bacterial/fungal action when oxygen and essential nutrients are available. This is so in sea water and on the surface of the sea bed. When oxygen and nutrients are limiting factors, oil incorporated into sediments may persist for a considerable time.

It should be realised that all these factors act together, thus it is difficult to predict the ultimate fate of a particular spill. In estuaries and near shore waters oil is likely to strand and interactions with the shore and its biota dominate.

5.5.3 Movement of oil

Empirical studies have shown that floating oil moves down wind at approximately 3% of the wind velocity (Taylor et al 1990). In the presence of surface water currents (river or tidal flows) an additional velocity, equal in magnitude and direction to that of the current, will be imposed on the oil. The oil therefore moves on a track that is the resultant of the current velocity and a wind vector composed of the wind direction and 3%

of the wind speed. These factors allow for prediction of slick movement in offshore waters and valuable resources in the path of the could be protected. In coastal waters and estuaries the slick is likely to strand before a response can be mounted.

5.6 SUMMARY

In the course of utilizing estuaries to maximize their natural advantages as centres for the bulk transport of goods, plentiful cooling water for heavy machinery, repositories of extractable minerals and their capacity to replace polluted water regularly, Man has often misused and abuse this treasure. The abuse and misused is accompanied by serious problems of pollution which virtually eliminate most sensitive biota and render estuaries unattractive. Fishing has been a centuries long practice in most estuaries at some point in history many them could not support any fish due to pollution. The Thames was one such estuary that lost its fish in the mid 19 th century.

Land claim along most estuaries converted the vital habitat of salt marsh and intertidal flats to Agricultural fields or in some cases concrete floor and walls. This loss of habitat in addition to loss of many species due to pollution lowers the conservation value of many estuaries, isplacing birds that visit the estuaries to feed and roost during the winter month and threaten many species in the long term to extinction.

The rapid growth of ports and docks plus accompanying industrial development attracted human populations to migrate to estuarine locations for jobs and business resulting in population explosion along most estuaries. It was sewage effluent from these populations and industrial effluent along the estuaries that contributed pollution of estuarine waters. Among the industrial wastes some are toxic and constitute a potential hazard to users of estuaries including Man.

Construction of barrages along the estuaries to provide electric power from tidal currents is a new idea being planned in many estuaries. This move is no doubt environmentally sound as it will help reduce gaseous emissions into the atmosphere. However, careful studies must be carried out before embarking on such projects because of [illegible] nature involving fundamental changes on tides which may cover important areas of bird feeding and threaten many species. Tidal alterations may also affect the sedimentation pattern and may lead to silting up of some estuaries.

Movement of oil tankers along estuaries is a major source of concern. Accidental spillages can destroy habitat and wildlife that had taken several years to develop. The degree of damage depend on the nature of oil, nature of the area of the spillage and prevailing environmental conditions.

Having discussed human impacts on estuaries in general, I now move on to discussed impacts in greater detail on the Mersey Estuary.

CHAPTER SIX

ECOLOGICAL IMPLICATIONS OF HUMAN ACTIVITIES ON THE MERSEY ESTUARY.

6.1 GENERAL CONSIDERATION

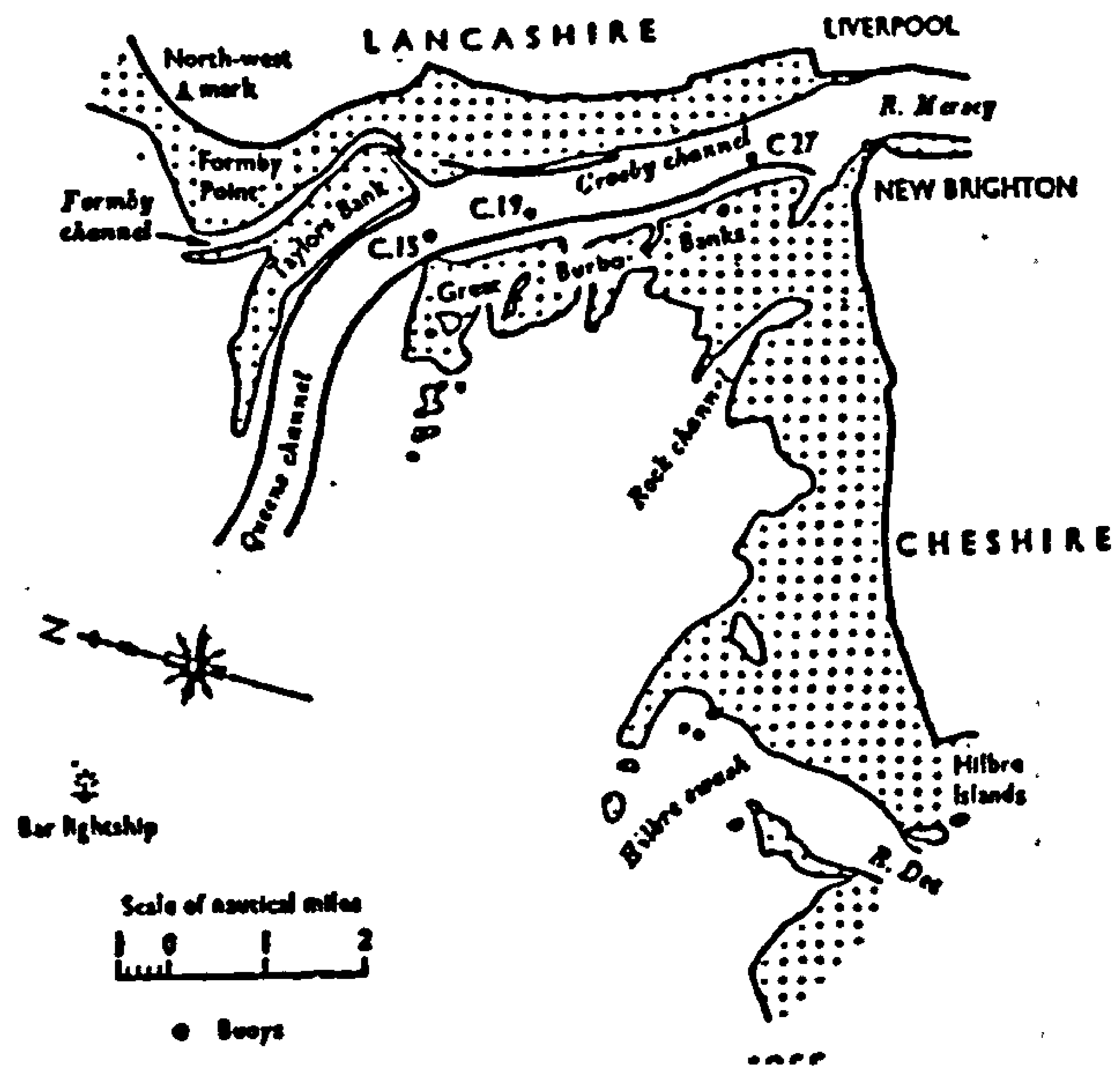
Studies on the effect of discharge of crude sewage on the amount and hardness of deposits in the Mersey Estuary (DSIR, 1938)

revealed that the major material that has contributed to the formation of extensive intertidal banks in the Inner Estuary, the general loss of capacity and siltation of navigation channels, which have to be dredged, cannot be accounted for by material entering the Estuary from fresh-water tributaries, or as sewage. The most probable source therefore, must be the bed of the Liverpool Bay and the Irish Sea. A large part of this material is sand, which will be transported in the layers close to the bed. Observations in the Narrows showed that the difference in salinity between the bed and surface-water is of the order of 1-2 parts per thousand (Price and Kendrick, 1963). Earlier studies on the Thames Estuary (Inglis and Allen, 1957) suggested that this range of salinity permits a landward drift of the more saline water in the layers close to the bed. There will therefore be a tendency for sand at the mouth to move upstream. Furthermore results from observations of transport of solids on the vertical in the Narrows indicated net landward drift of materials, the amount of material increases rapidly for tidal ranges above 60 cm, thus suggesting the influence of a density current. However it is considered that, round about the beginning of this century, the Mersey Estuary was in a state of long-term equilibrium. This condition implies that although quite large variations in the capacity of the Estuary might take place, they are of relatively short duration, little or no change being recorded in the general level when a longer period is considered. Since salinity/density currents were certainly also present when long-term equilibrium was established, providing a permanent means by which material may be transported up-river in the layers near to the bed, they cannot therefore be invoked to explain the rapid deterioration which has occurred since the turn of this century. Having arrived at this conclusion that the natural cyclic changes in the Estuary cannot provide sufficient explanation for its deterioration 90 years ago, I now use the anthropogenic interference in the natural dynamics of the Estuary to provide the most probable explanation.

Comparative analysis of field survey charts showing the shoaling and erosion that had occurred at three different periods 1833-1912, 1912-1936, and 1936-1955 indicated large movements of material in the bay and that certain areas are subject to greater changes than others, the extent of these changes diminishing with distance from the main shipping channel. Greater changes appear to have taken place during the years 1912-1936 than during the other two periods. These coincide with the construction of training walls, started in 1909 and virtually completed in 1936 and with large-scale dredging in the sea channels.

The most striking transformation took place in the Rock channel which at one time had been the main approach to the port of Liverpool. It deteriorated from a wide channel in 1833 (Figure 6.1), with depths of up to 9m at low water, to a narrow one today with depths of only 0.7-0.9m at low water. The channel shoaled from its western end at a rate of 0.6 million cu.yd a year between 1833 and 1912, 1.7 million cu.yd a year between 1912 and 1936, and 0.7 million cu.yd a year between 1936 and 1955 (Price and Kendrick 1963). As in the case of the Rock channel, the most rapid shoaling on the banks flanking the sea channels also took place during the period 1912-1936, although the high rate of shoaling continued into the period 1936-1955 over those regions of Great Burbo Bank (Figure 6.1).

Within this period (1833-1955) a total volume of shoaling of 272 million cu.yd, out of which 186 million cu. yd was between 1833-1912 took place from a total bay volume of 3770 cu.yd approximately (Price and Kendrick 1963). The portion of the Liverpool Bay containing this volume at the time is that lying below a level plane 9m above the L.B.D., and bounded by the coastline and by lines running approximately north from Hilbre island and west from the North West mark. It is worth noting that these figures can not form the sole basis for deduction of the changes in the Liverpool Bay. Firstly, because the early surveys are not as accurate as those of the present day, and secondly because the situation is complicated by large-scale dredging and dumping in the area under study. Some 119 million cu. yd of material dredged from the upper estuary have been dumped at sites well within the area, while 406 million cu.yd have been dredged from the sea channels and dumped outside the area. These figures cannot be summed algebraically, but when it is considered that during the period 1861-1955 the capacity of the Inner Estuary decrease by about 100 million cu. yd (Figure 6.2), a clear



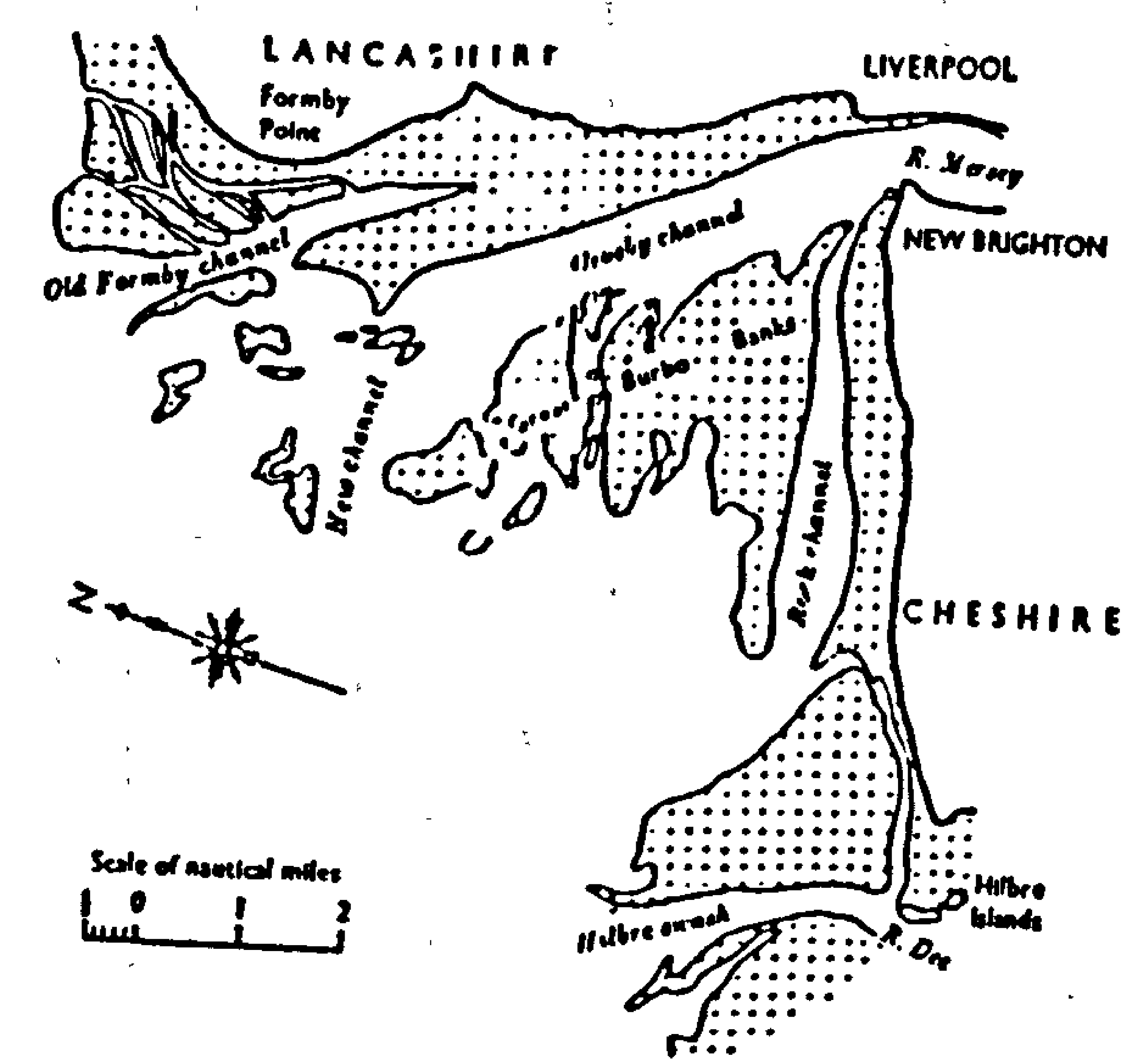


Figure 6.1: Position of low water channels in the Liverpool Bay after and before construction of the Crosby channel training wall

Source: Price and Kendrick 1963

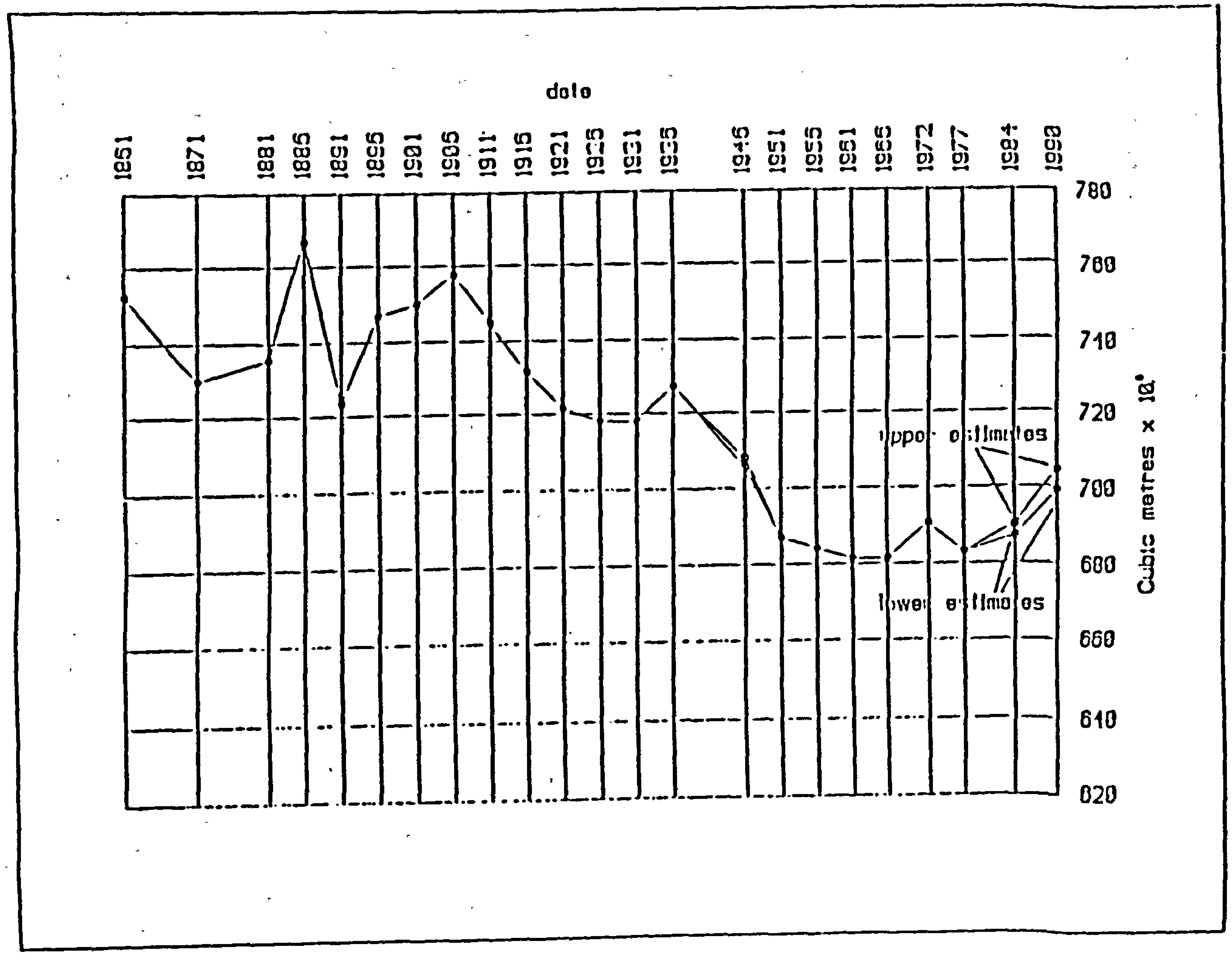


Figure 6.2: Fluctuations in the capacity of the Mersey Estuary between Rock Light and Warrington

Source: MBC 1992

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picture of an overall and large-scale movement of material into the Liverpool Bay during the period emerges. The total loss in the Inner Estuary during the period, if spread over the length of the Inner and Upper Estuary combined, would represent a reduction in depth of about 85cm.

Having established that Liverpool Bay is the source of supply of material entering into the Inner Estuary, I now discuss the impact of construction of training walls on the supply of material in the Liverpool Bay.

The semi-canalization of the main shipping channel in Liverpool Bay increased velocities and depths in the channel. The material that was eroded during the process of deepening was transported both upstream and downstream. The proportion moving upstream increased the sediment-load at the mouth and since tidal discharges at this section had remain unchanged, deposition occurred. However, the quantity of material eroded from the sea channels is not in itself enough to account for the total accretion in the Inner Estuary since the turn of the century. Progressive deterioration could only have been produced by the arrival at the mouth of a more-or-less constant supply in excess of that available before training.

At that time, water could flow freely into and out of the main channel at several points and at levels considerably lower than those imposed by the construction of training walls. For example, in 1900 the maximum depths of subsidiary channels through Great Burbo Bank, and the Rock Channel were -8 and -4.5m respectively. The drift pattern for 1911 illustrates areas of outward or ebb drift associated with these three channels, separated by tongues of flood drift. This drift pattern for the 1911 survey of the area suggests a fairly free exchange of material between the various channels. Sediment that entered the Crosby Channel on the flood tide could quite easily find its way out via the subsidiary channels, some of which were fairly deep at that time, and this state of affairs would tend to relieve the sediment-load in the main channel and limit the supply to the mouth of the Narrows leading to the Inner Estuary.

Construction of the West Crosby revetment increased the extent of the flood drift in the area behind the wall, toward the main channel, so that more material could now be brought up to the back of the wall than could be carried away by the ebb. Some of this material is carried over the wall and is likely to be retained in the channel since most of the sand is transported in the layers close to the bed, and the direction of the main ebb stream in these layers is down the channel parallel to the training walls: this leaves only surface water, carrying very little material in suspension, to flow out of the Crosby channel over the Burbo banks. Secondly, bed levels in the channel are considerably lower than the top of the revetment. For these reasons the training walls have had the effect of holding the load in the main channel, and because the discharges in this channel have increased, the supply of material to the mouth has also increased which would tend to cause progressive deterioration in the Inner Estuary.

Although training works in Liverpool Bay have achieved their three-fold aim of preventing erosion at Taylor's Bank, closing the subsidiary channel that threatened to form through Great Burbo Bank and deepening the main sea channel to Liverpool. It has been one of the main reasons for progressive deterioration of the Inner Estuary of the Mersey in greater than half of this century. Looking at Figure 6.2, it is clear that deterioration in the Inner Estuary started before training the Crosby Bank started in 1906 thus suggesting the involvement of other factors. The other main human activities on the Mersey Estuary are construction activities in the Inner Estuary and dredging. Discussion of the effect of these activities on deterioration of the Estuary now follows.

Alternate accumulation and erosion of deposits of silt cause rapid changes in estuaries like the Mersey. Meandering of low-water channel is the erosional process by which accumulations are kept in check and progressive deterioration is prevented. Where meandering is suppressed, the erosional process is also suppressed, resulting in loss of cubature. Records of the low-water channel above Eastham in the Mersey indicated that it frequently changes its course and often moves laterally over considerable distances (Figure 6.3). In the compartment between Runcorn and Hale Head the low-water channel could be found in any position between 1867 and 1891. After 1891, however, the picture changed completely. During the early part of that year the low-water channel moved across to within 180m of the Lancashire bank between Widnes and Ditton Brook. Between 1891 and 1893 that part of the channel move further downstream, between Ditton Brook and Hale Gate Marsh, also moved across to within 180m of the

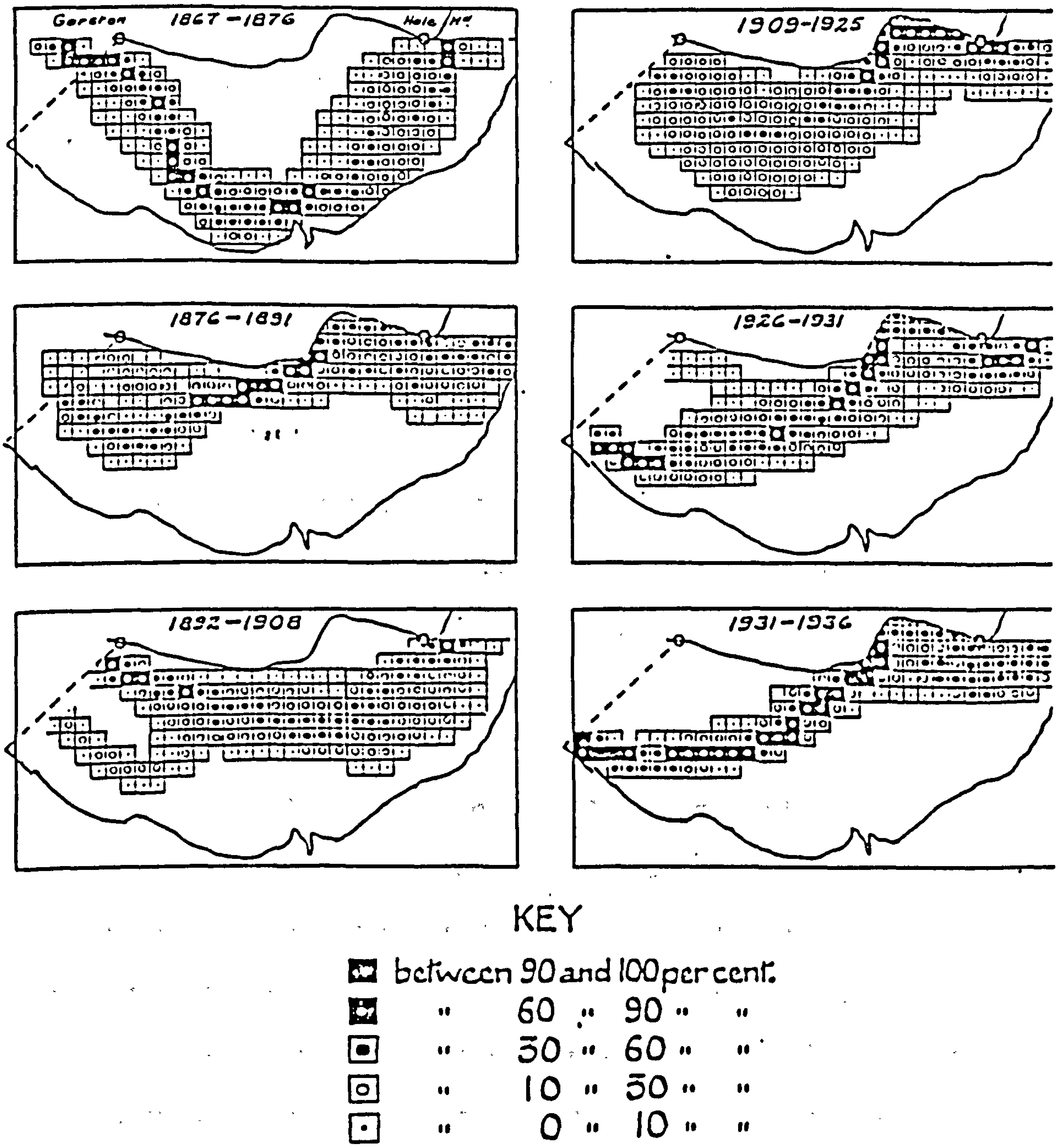

Figure 6.3: Changes in the position of Navigation channel in the Estuary basin, 1867-1936

Source: DSIR, 1938

Lancashire shore. The position since then has been relatively stable, the main low-water channel never returned to Cheshire side since then.

The stabilization of the low water channel in this relatively short reach at this time is probably caused by major engineering works that have been constructed in the area as follows:

(a) The River Weaver diversion scheme, completed in 1896.

(b) The bridge piers for the Runcorn railway bridge, completed in 1865.

(c) The construction of the piers of the Runcorn transporter bridge, completed in about 1902.

(d) The tipping of slag to form an embankment on the east side of the Estuary (1891-1896).

The level of influence exerted by each of the above developmental activities is difficult too determine, but it would seem that the tipping of the inerodible slag embankment on the Lanchashire side of the Estuary and the exclusion of the estuary of the Weaver from the Mersey were most important considering the time of the activities. The construction of the transporter bridge pier could also have contributed. Analysis of low-water channel movements from field survey charts reveals decrease in band-width of movement downstream of Hale Head between 1906 and 1931.

Chronological correlation of development activities with the pattern of siltation in the Inner Estuary revealed that between 1906 and 1931 the deterioration was rapid at first, but this tendency decreased towards the end of the period. Between 1931 and 1936 there was an increase in capacity, followed again by further deterioration. The stabilization of the low-water channel in the Inner and Upper Estuary, brought about by the construction of major civil engineering works toward the end of the last century, can be traced back to about 1906. The first training of the sea channels was construction of Taylor's Bank revetment in 1911, followed in 1923 by the West Crosby training wall. It is thus likely that during the period 1906 to 1931 the main reasons for the loss of capacity were the stabilization of the low-water channel in the Inner Estuary and the effect of training works constructed in the bay up to that time. After 1931, however, most of the deterioration is likely to have been associated with sea channel training.

One complication in the problems of shoaling in the main channels of the Inner Estuary is the progressive decrease in depth over Bromborough bar in the Eastham channel which run along the Cheshire bank from Bromborogh to Eastham, providing access to the Manchester Ship Canal through Eastham locks and serving the Queen Elizerbeth II oil dock and Bromborough dock (Figure 6.4).

In 1850 a continuous channel, 6m below L.B.D., extended upstream as far as the entrance to the Manchester Ship Canal, but by 1890 depths in the region of Bromborough-hereafter known as Bromborough bar had fallen to 1.2m below L.B.D. Fluctuations in depth of up 3m continued until 1953, more or less dredging being undertaken as occasion demanded, in an effort to maintain the channel at a minimum depth of 3.6m L.B.D. In July 1953 an attempt was made to deepen the Eastham channel and up to January 1954 this was successful, the average depth having increased by 1.2m. Progressive deterioration followed, in spite of continuous dredging at the rate of 3 million cu.yd a year, until by 1960 the minimum depth in the channel had fallen to 2.5m L.B.D (Price and Kendrick 1963). Persistence of the poor state of Brombrough bar was probably caused by movement of very large quantities of material.

However, availability of continuous supply of material from the sea seems to provide only partial answer to the problem. The short-period variation in conditions must be due to some other process, or a combination of process, which is necessarily variable. Another demonstration of this point is the fact that since 1906, conditions at Bromborough bar have been both good and bad, despite continued deterioration in the capacity of the Estuary during the period. It also indicates that even though material may be returning to the Inner Estuary from deposit sites in Liverpool Bay, there is no direct or immediate connexion between dumping in the Bay and silting on the bar. There have been periods in the past when dumping was taking place in the Bay and conditions at Bromborough bar were good (Price and Kendrick, 1963). Siltation of the bar is thought to be brought about by movement of sediment within the Inner Estuary due to erosion of the Middle Deep channel and the Poole Hall sands (Fig. 6.4).

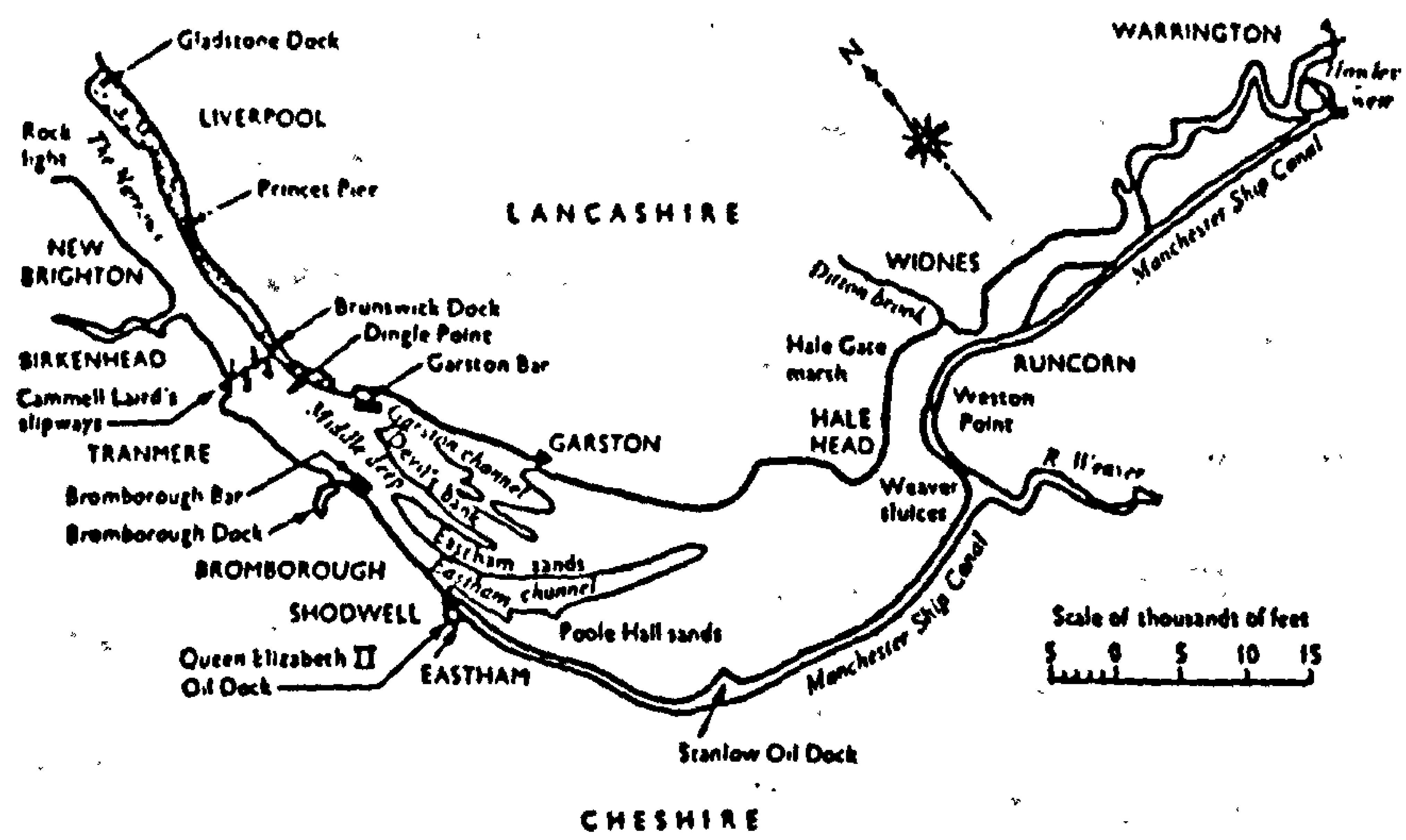

Figure 6.4: Position of low water channel and Bromborough Bar in the Inner Estuary

Source: Price and Kendrick 1963

From 1953, when depth over the bar started to deteriorate, the Middle Deep, at its upstream end, widened and deepened, the amount of material eroded in the way been considerable. Being a flood channel it must necessarily have transported the bulk of the eroded material landward into the low-water channel upstream. Findings from fluorescent tracer experiments indicated that a large part of the material would be transported down the Eastham channel on to Bromborough bar, the remainder travelling a short distance upstream before being transported down the Garston channel to the region of Garston bar. As the Middle Deep widened and deepened, the flood tide was able to attack Poole Hall sands again putting large amounts of material into suspension. It was estimated that between August 1958 and May 1959, 3 million cu.yd were eroded from this source alone (Price and Kendrick, 1963). A large proportion of this material must have contributed to the increased siltation experienced on Bromborough bar. In addition to the gradual, progressive increase in the silt content of the estuarine deposits, there is also a seasonal variation in the proportion of silt to sand dredged from Bromborough bar, and the quantity of silt in suspension. In the Mersey during the dry summer of 1959, it was reported that the water in the Eastham channel became unusually free of silt. Dredging on Bromborough bar, which had previously been done with bucket dredgers because of the high silt content of the deposits, was carried out by sand-pump dredgers. Surveyors reported that whereas normally they could read the figures on a tide-board only 15cm below the surface, during the summer of 1959 they could read these same figures 60cm below the surface. During the late autumn and early winter the deposits at Bromborough bar again became muddy, and the surveys showed quite a deep overlay of fluid mud which had previously been absent. This phenomenon is thought to have been cause by fluctuations in the level of available fresh water in the Estuary. During the dry summer of 1959 the freshwater flow over Howley weir and from other tributaries was low; hence salinity of the water upstream of Eastham was higher than normal and was conducive to maximum flocculation (electro-chemical process involving the neutralization of the charges on silt particle by an electrolyte-in this case sea water) of fine suspended material in this area. Under these conditions the silt would deposit on the banks upstream of Eastham, and thus the suspended silt content in the water would be reduced. As the freshwater flow from the tributaries increased during the late autumn the salt content of the water upstream of Eastham decreased. Under these conditions it is possible that the charges on the deposited silt could be restored, making it more readily available for entrainment and scour by the water. Vast quantities of silt could be released in this way which would collect as fluid mud in the Estuary downstream-notably Bromborough bar. The behaviour of the low-water channel in the Upper Estuary of constant change and the process of meandering which involves fretting away of large areas of sand and mud banks will undoubtedly contribute to sediment accretion downstream in the Inner Estuary.

Reduction in capacity of the Estuary caused by sedimentation due to construction activity increases the water retention time of the Estuary which means retaining polluted water for a long period within the inner estuary hence increasing the stress of pollution on water quality and the estuarine biota. The following section discusses pollution and its effect on the Mersey Estuary.

6.2 POLLUTION AND ITS EFFECT IN THE MERSEY ESTUARY

The Mersey Estuary has received discharges of domestic sewage and trade effluent for over 200 years from highly industrialized catchment of over 2 000 km^2 (Figure 6.5). At its tidal limit, Howley Weir in Warrington, the Estuary still receives severely polluted river water with a high Biological Oxygen Demand (B.O.D) and numerous discharges of domestic and trade effluent occurs in its tidal limits (6.6). The build of pollutants in the Estuary had already become a source of concern by 1930. Consequently the Mersey Docks and Harbour Board appointed a committee to investigate into the effects of the discharge of crude sewage into the Estuary. The Committee which investigated the problem concluded that the silting up and the consequent reduction in tidal capacity of the tidal basin, were the direct result of the discharge of crude sewage into the River Mersey. The committee also went on to adduce the presence of glutinous mud, similar in chemical and physical properties to that of the banks and deposits in the upper Estuary as coming directly or indirectly from the discharge of sewage into the Estuary. However, the Water Pollution and Research Board (DSIR, 1938), conclude that the rate of sedimentation and the composition of the mud were not appreciably altered by the discharge of sewage, alteration of tidal movement was responsible for the rapid silting up of the Estuary.

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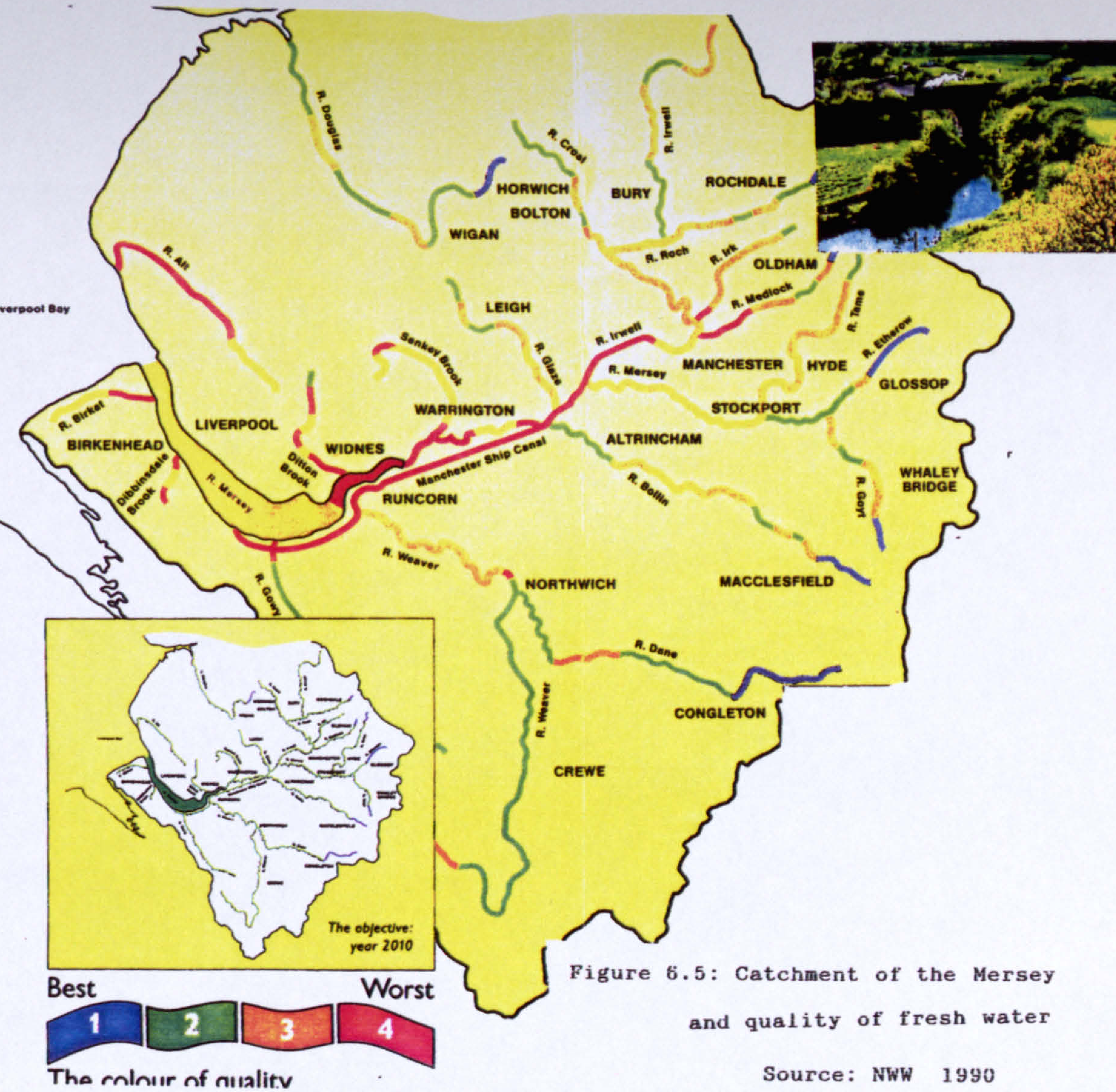


Figure 6.5: Catchment of the Mersey and quality of fresh water

Source: NWW 1990

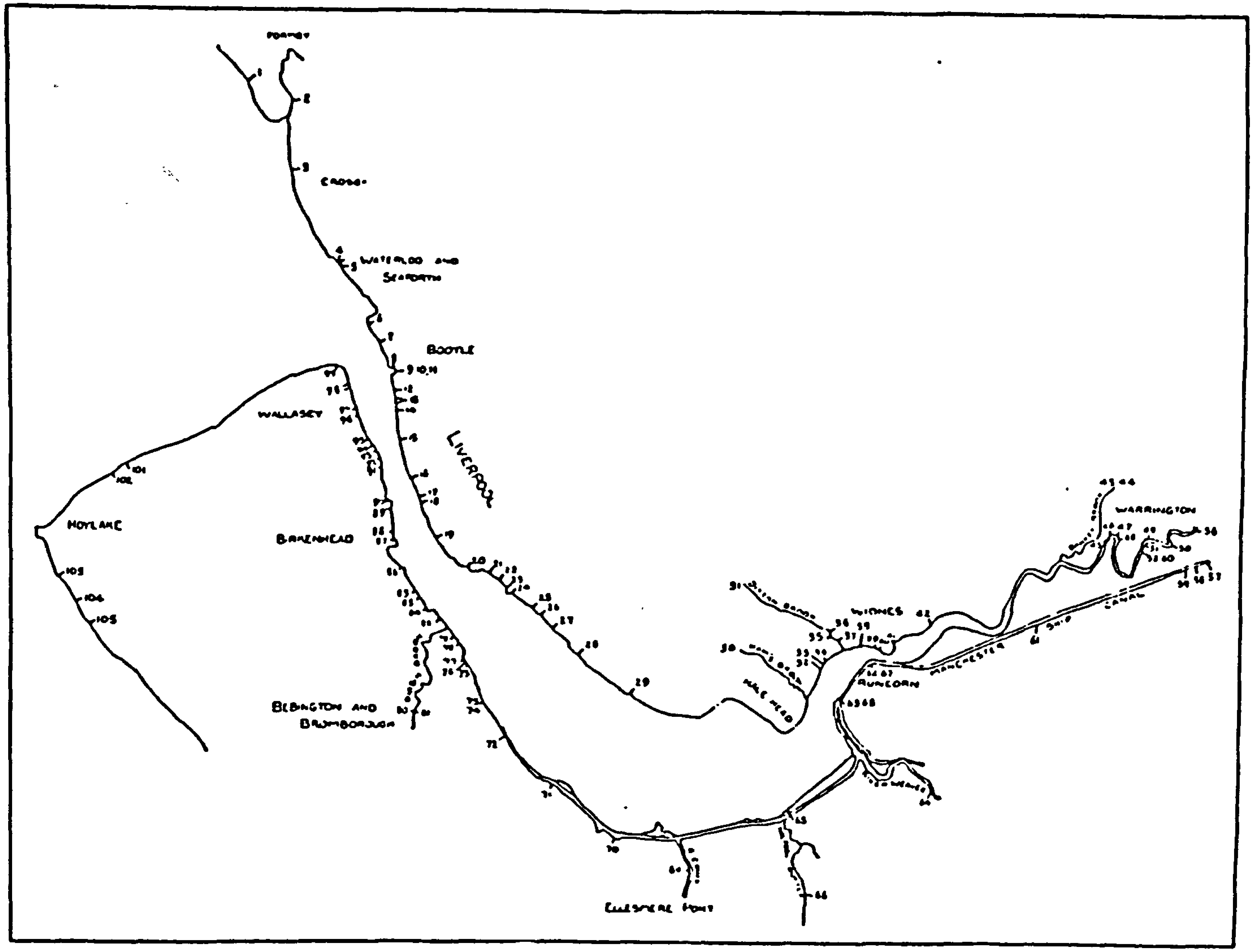


Figure 6.6: Sewage outfall discharge into the Mersey Estuary

Source: DSIR 1938

ewers in the region have become derelict.

A storm overflow running full

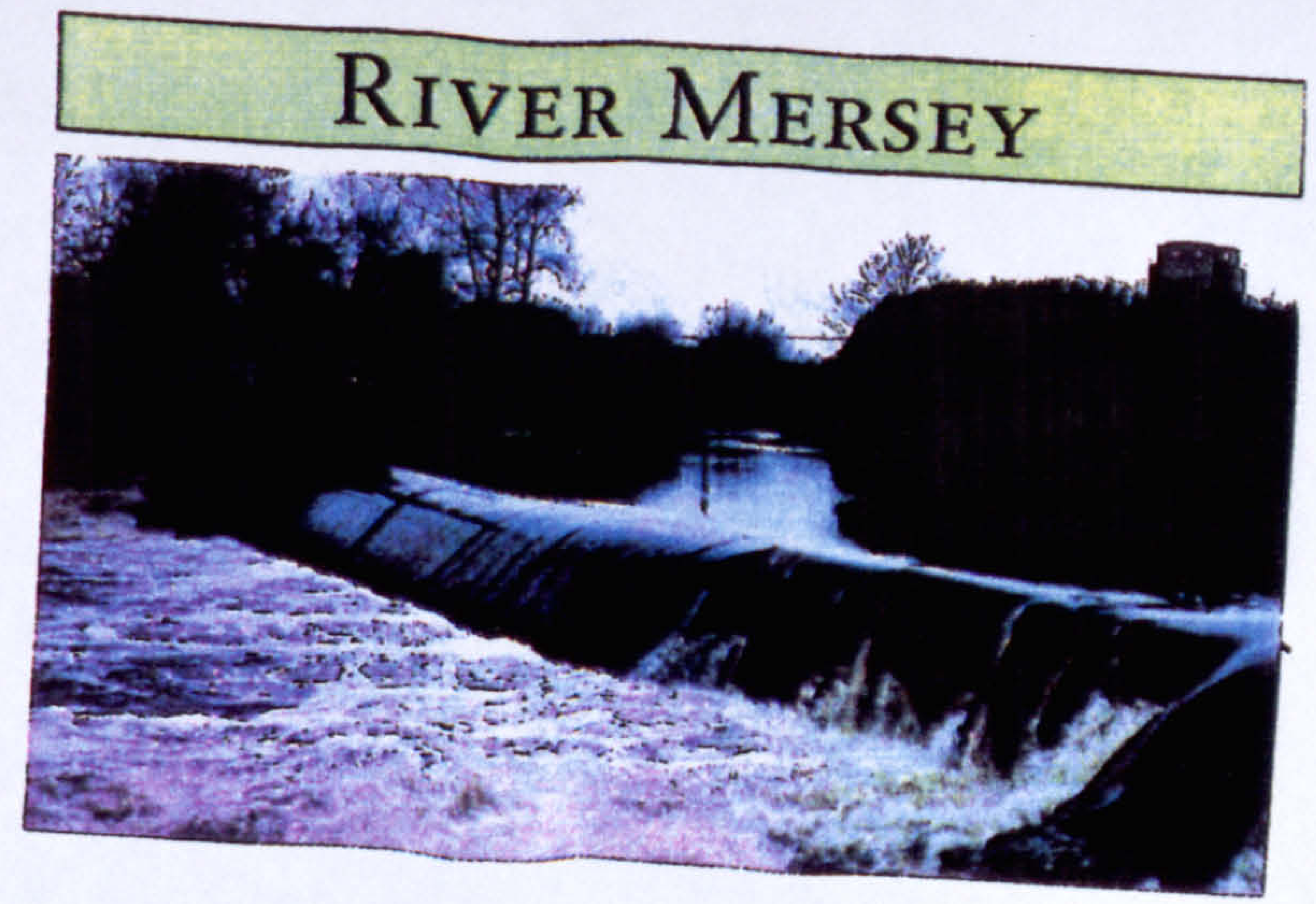


Figure 6.7: Pollution sources to the Mersey Estuary

Source: NWW 1990

Inputs to the Mersey Estuary still remain high after the 1985 clean up campaign drive has started. Dickson and Boelens (1988), presented inputs from various sources to the Estuary as shown in Table 6.1 below.

Table 6.1: Estimated inputs to the Mersey Estuary

Route	Flow (10 $m^3 d^{-1}$)	Tonnes per day				Grams per day			
		BOD	NH4-N	NO3-N	PO4-P	HCH	Drins	DDT	PCBs
River	5918	91	31	24.2	6.7	41-76	18*	34*	34*
Sewage	515	176	11	0.6	1.6	14-52	12-19	9-14	1-20
Trade	113	48	2.3	0.2	NS		NS	NS	
TOTAL	6546	255	44.3	25.0	8.3	55-128	12-37	9-48	1-54

Source: Dickson and Boelens, 1988 (ICES)

Key

BOD = Biological Oxygen Demand

DDT = Dichloro-diphenyl-trichloroethane

PCBs = Polychlorinated biphenyls

HCH,

Drins = Biocides

NS = Input not significant

A considerable input of heavy metals is discharged along with industrial effluents. These elements are potentially toxic and may be lethal where they accumulate in sufficient quantity especially in the upper hierarchy food chain. Compounds of copper (Cu), zinc (Zn), cadmium (Cd), Nickel (Ni) and iron (Fe) exist in quantities enough to cause concern (Table 6.2). Heavy metals have been implicated in heavy mortalities of waders and gulls recorded in the Estuary in 1979, 1980, 1981 and 1982. Concentration of trialkyl lead compounds in the food chain was thought to be responsible (Taylor et al 1990).

Table 6.2: Estimated inputs of metals to the Mersey Estuary

Metal	Load discharged to Mersey Estuary (kg/tide)			
	Rivers	Sewage	Industry	Total
Zn	107	328	21	456
Ni	29	51	0.6	81
Cu	30	67	41	138
Cd	1	0.9	0.3	2.2
Hg	1.8	0.1	0.005	1.9
Pb	116	98	5	219

Source: Dickson and Boelens, 1988 (ICES)

6.2.1 SOURCES OF POLLUTION

The catchment of the Estuary extends draining sewage and trade effluent, for the greater part of the south-west and south-east Lanchashire as well as most of Cheshire (Figure 6.5). The principal sources of pollution to the Mersey Estuary have tradionally been :- domestic sewage, industrial effluents, Industrial storm overflows and pollution carried by rivers (Figure 6.7).

Domestic sewage effluent is discharged into the Mersey Estuary through many outfalls along its entire length and on both the north and south banks and through the Manchester Ship Canal (Figure 6.6).The contribution at different points however vary greatly. Effluent discharged by Liverpool clearly dominate the total discharge into the Estuary (Figure 6.8). In addition to domestic sewage most sewers discharge trade effluent. Runcorn discharged some trade waste through the Manchester Ship Canal, but over most of the Merseyside area trade effluent reached the Estuary via the town sewers (Figure 6.6).

Industry based pollution comes mostly from the oil and petrochemical industries and the paper mills. The organic chemical industry and animal waste like tanneries effluent contain high carbon and nitrogen contents which contribute significantly to the heavy pollution load. The heavy chemical inorganic and metal industry contributed to water pollution with potential for poisoning the ecology. Other major contributors are the soap factories, galvanising works, and flour mills. Figure 6.9, presents the main types of industrial pollution load into the

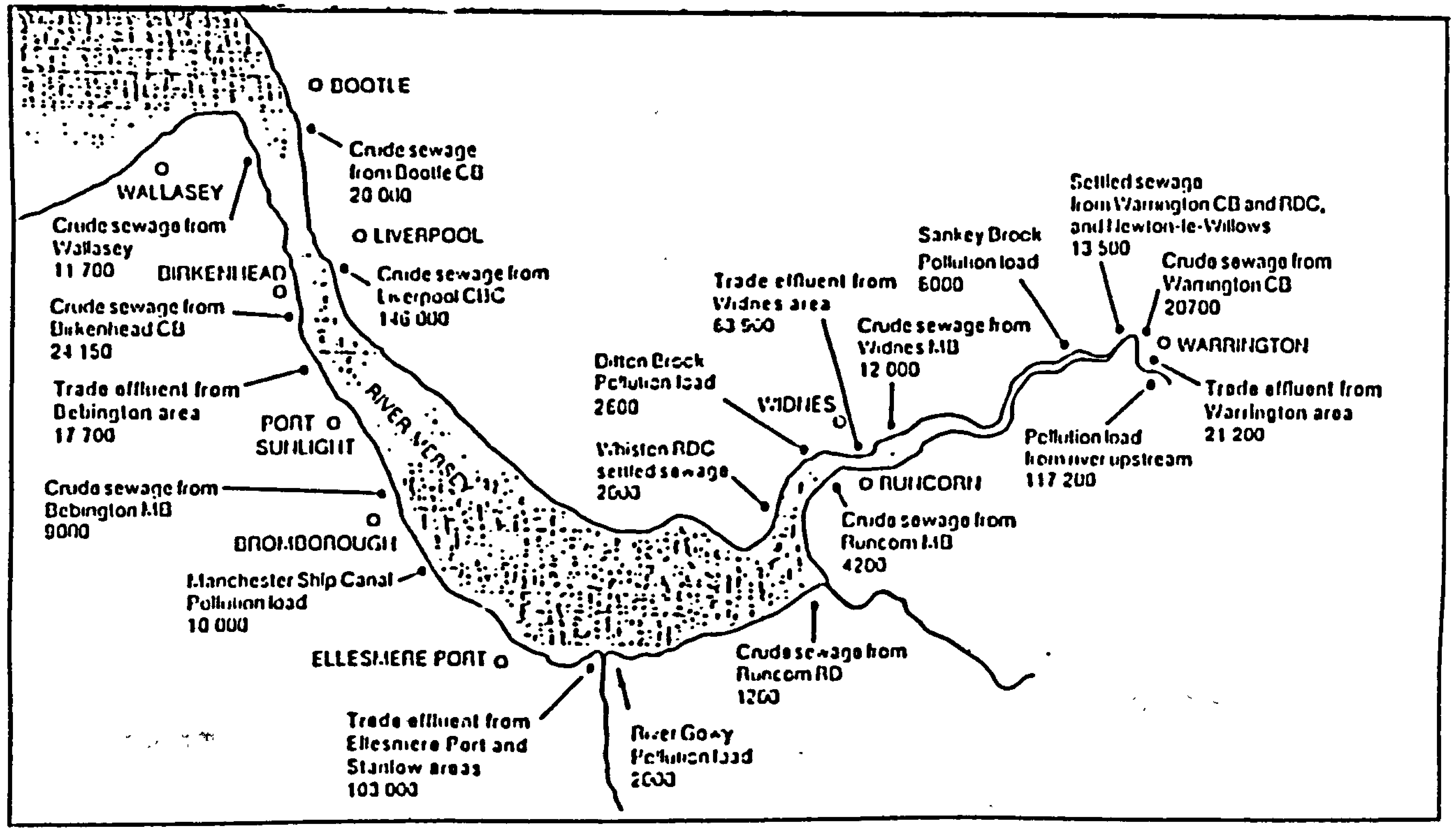
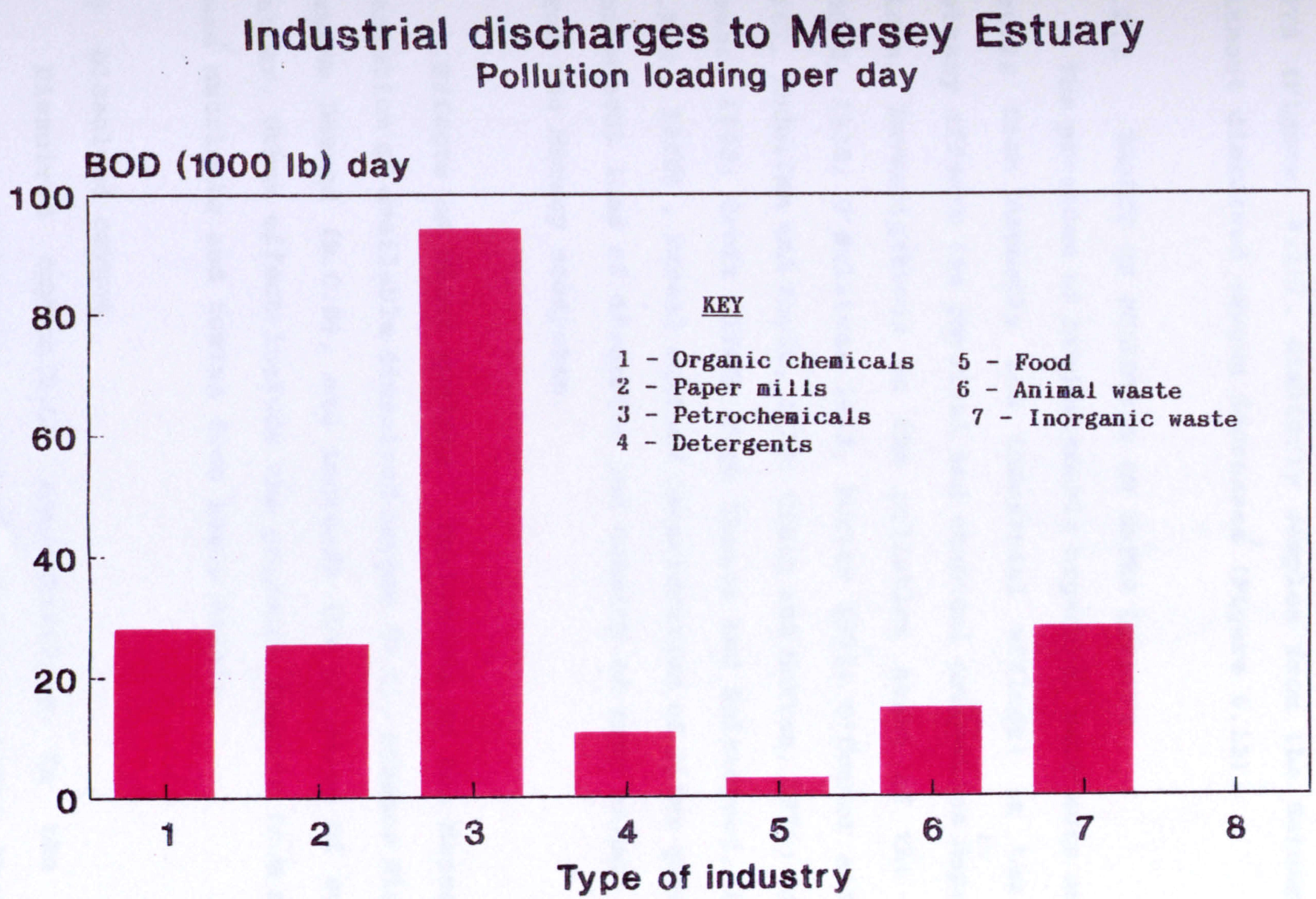


Figure 6.8: Pollution load discharge to the Mersey Estuary

Source: Clark, 1989

Figure 6.9



Industrial discharges to Mersey Estuary
Pollution loading per day
BOD (1000 lb) day
100
80
60
40
20
0
1
2
3
4
5
6
7
8
Type of industry
KEY
1 - Organic chemicals
2 - Paper mills
3 - Petrochemicals
4 - Detergents
5 - Food
6 - Animal waste
7 - Inorganic waste

Mersey.

Fresh water entering the Estuary was often severely polluted with high B.O.D and low D.O. but the situation improved after 1973 (Figure, 6.10). Similarly samples from the Estuary water without dissolved oxygen decreased (Figure 6.11).

6.2.2 IMPACT OF POLLUTION ON WATER QUALITY

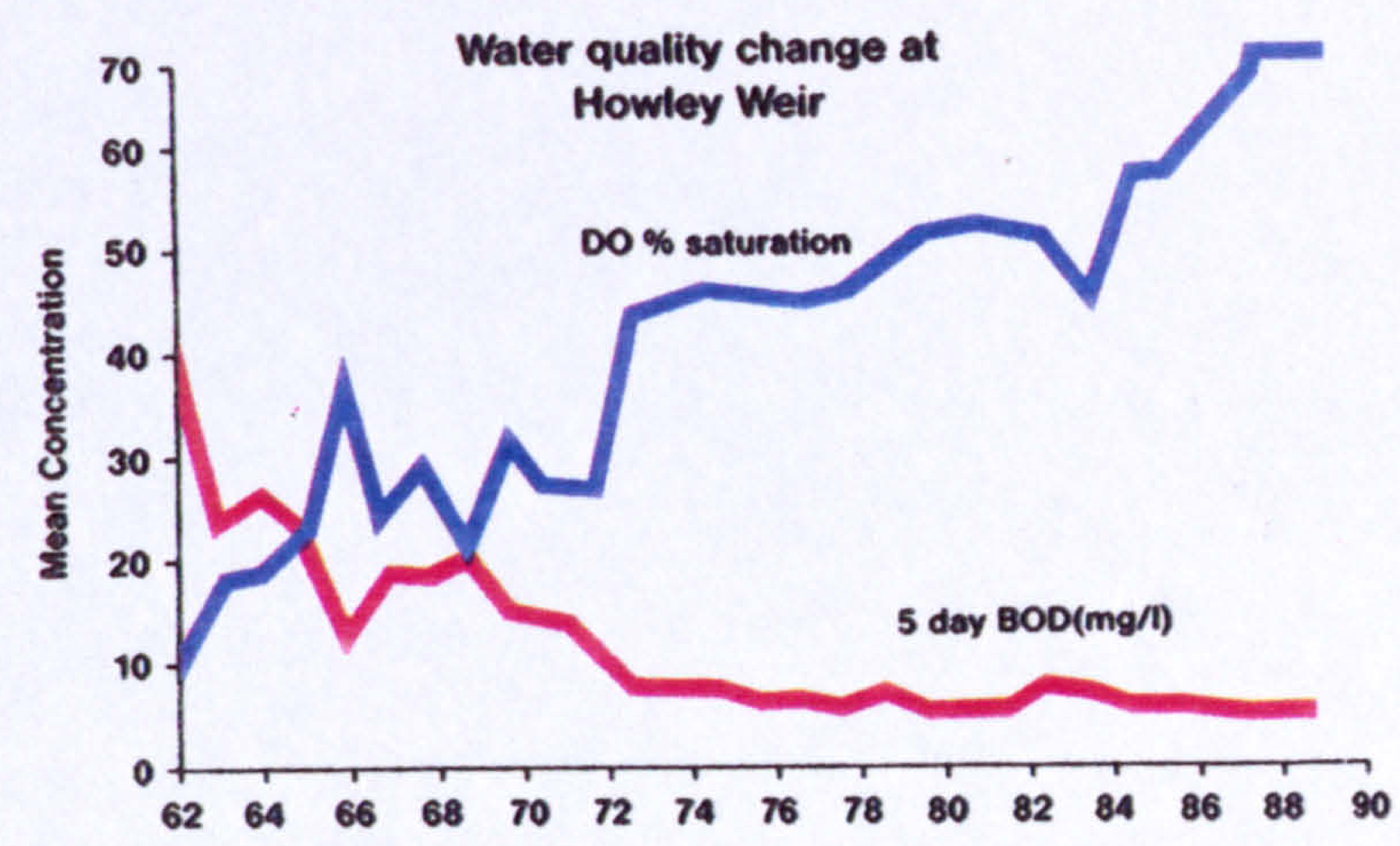
The presence of biodegradable organics, nutrients and toxic metals from domestic and industrial effluent in the Mersey Estuary affects its physical and chemical properties to depress its biota. Investigations on the pollution state of the Estuary (DSIR, 1938; O'Sullivan 1972, Porter 1973; O'Connor and Croft, 1967, Abdullah and Royle, 1973; Craig and Morton, 1976; Airey and Jones, 1982; Croft ,1965; Pugh Thomas and Sultanpour, 1980 and N.W.W., 1990) , reveal serious deterioration of water quality and consequent loss of diversity and density of many animal species from the Mersey ecosystem.

Effects on water quality - Pollutants in the Mersey cause depletion of available dissolved oxygen (D.O), enhance Biological Oxygen Demand (B.O.D), and increase the presence of suspended matter. Other effects include the presence of ammonia from nitrogen based nutrients and toxins from heavy metals.

a) Dissolved oxygen

Dissolved oxygen(D.O) concentrations in the estuary deteriorated rapidly and especially during the 1960s. Observation along the Estuary showed that organic pollutants were the main

Figure 6.10:


Water quality change at
Howley Weir
DO % saturation
5 day BOD(mg/l)
Mean Concentration
70
60
50
40
30
20
10
0
62
64
66
68
70
72
74
76
78
80
82
84
86
88
90

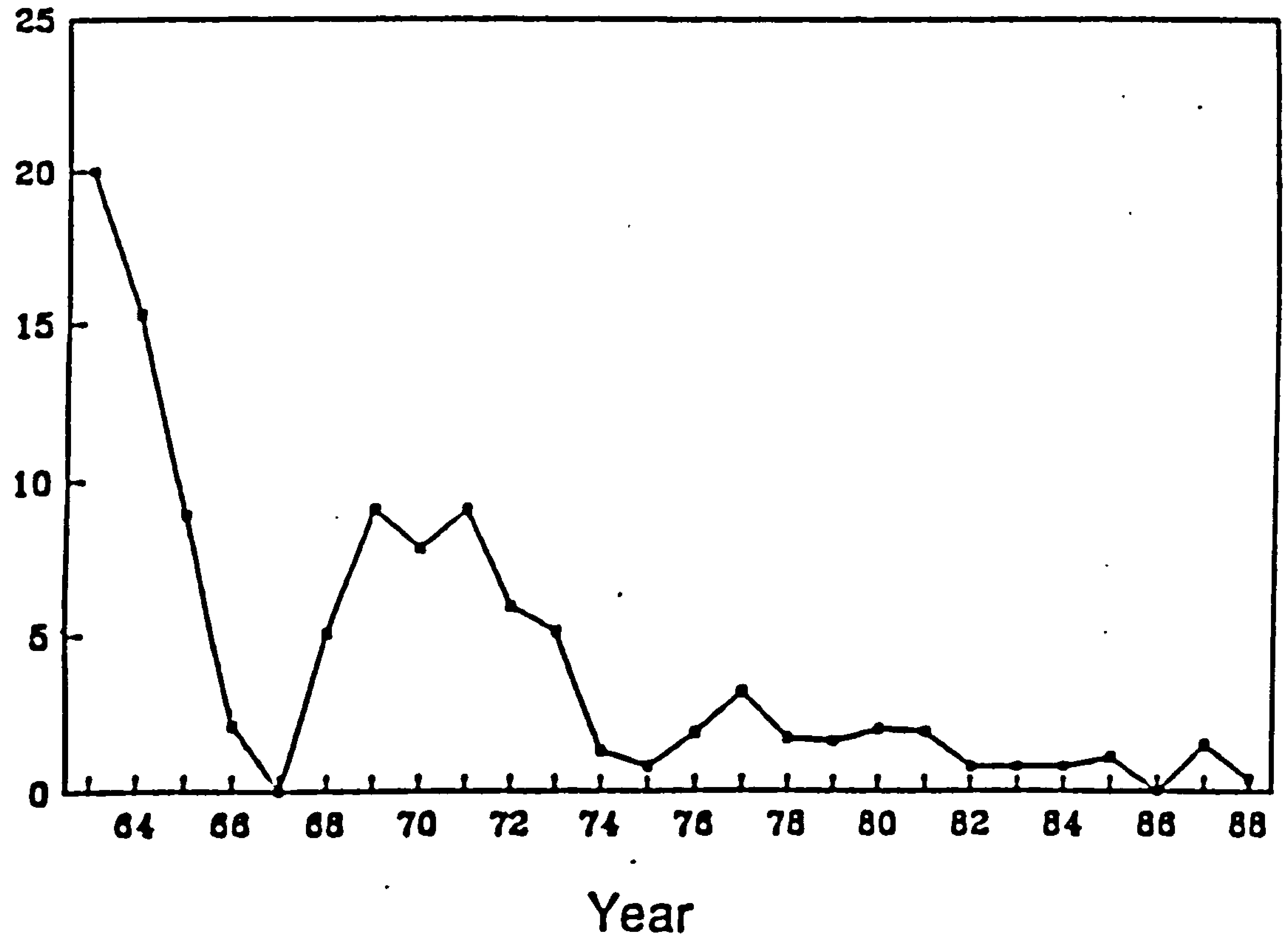


Figure 6.11: Percentage of Mersey samples without dissolved oxygen

Source: Holland 1989

cause of the fall in D.O. and had their greatest effect in the reach from Warrington to a point about eight kilometres below Widnes (Figure 6.12). In this reach the dissolved oxygen was usually less than 10% of the saturation value at low water, and occasionally it fell to 0%. Under most favourable conditions, at the high water of a spring tide, the value at Widnes rose to around 60% . Concentrations of free ammonium chloride, organic carbon and sulphide were also found to be highest between Warrington and Widnes. Because of the large volume of water available for dilution dissolved oxygen in the Outer Estuary remain high even at low water with values in excess of 60%. On each flood tide almost completely oxygen-saturated sea water entered the Narrows and increased the dissolved oxygen level still further.

b) Biological Oxygen Demand (BOD)

The amount of oxygen used up by bacteria over a period of five days. The BOD in the Mersey Estuary was correspondingly high when the dissolved oxygen content was low. Sewage contributed more than 50 % of total BOD entering the Estuary per day (Fig. 6.13). Other significant contributors were industrial discharges in to the River Mersey and its tributaries (Porter, 1973 and Ghose, 1980). Seasonal variations show that the month of April and September recorded the highest BOD in the Mersey (Curtis and Eyress, 1980).

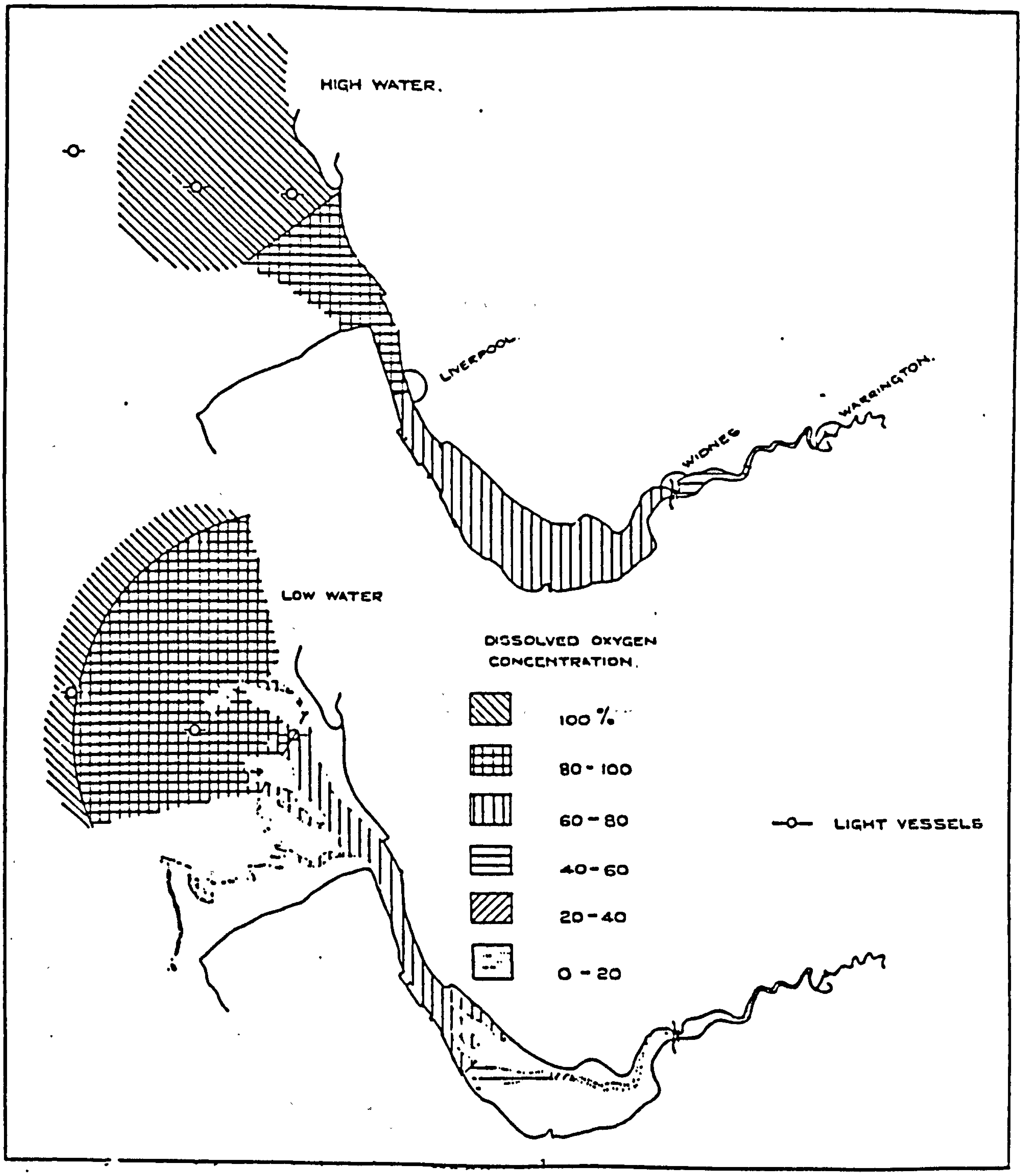
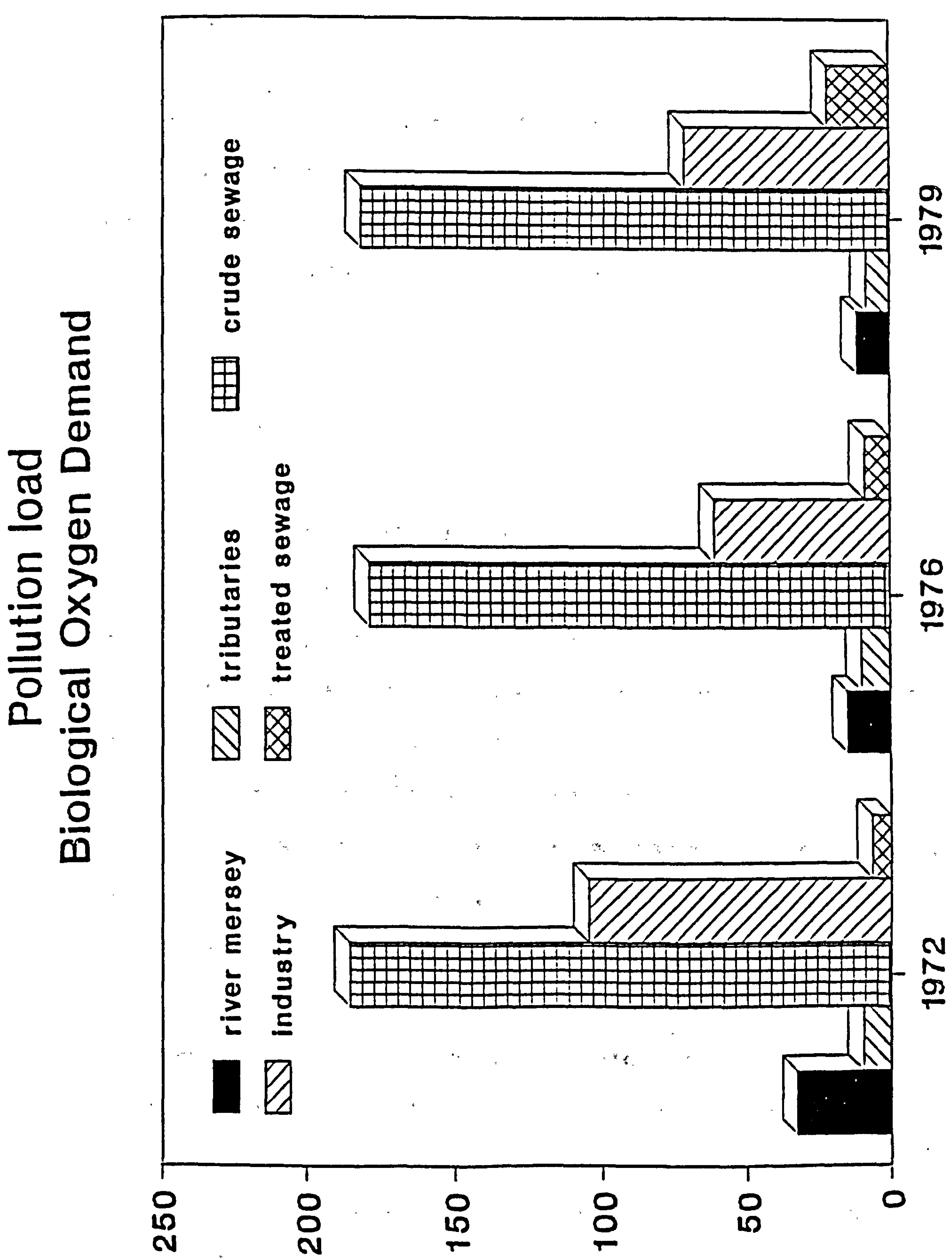


Figure 6.12: Dissolved oxygen concentration along the Mersey Estuary

Source: Croft 1965


Pollution load
Biological Oxygen Demand
river mersey
industry
tributaries
treated sewage
crude sewage
250
200
150
100
50
0
1972
1976
1979

c) Ammonical compounds

Presence of nitrogenous base compounds in sewage and other effluents contribute to the production of ammonia in the Mersey. The level of Ammonium nitrogen was high for the first 10 km from the tidal limit and decreases progressively to 30 km from where detectable level was insignificant. The trend since 1976 has been that of general improvement with figures expected to fall considerably by 1995 (Figure 6.14). Although the level of ammonia was not high enough to be toxic, it coincides with low D.O. and the combination could affect the biota synergistically.

d) Floating litter

Material discharged on the flooding tide any where upstream of the Rock Light house (which include much of the sewage and wastes from Liverpool, Wallasey and Birkenhead) will travel to the zone between Eastham and Widnes. During the ebb or at low water, conditions could go very bad with regard to suspended matter, in the Princes landing stage area of the Narrows section of the Estuary a layer of fine suspended matter ~~suspended matter~~ some 30 cm to 45 cm deep at least exists over all the bed at L.W. due possibly to the slack water conditions allowing all the suspended material being carried seawards by the ebb tide to be dropped the moment the tidal force falls below certain level. The rocky nature of the bed in this section of the Estuary support this suggestion. The large amount of matter in suspension present at low water is carried upstream again with the flood tide but this time is well distributed. For about 3 km. from Widnes a

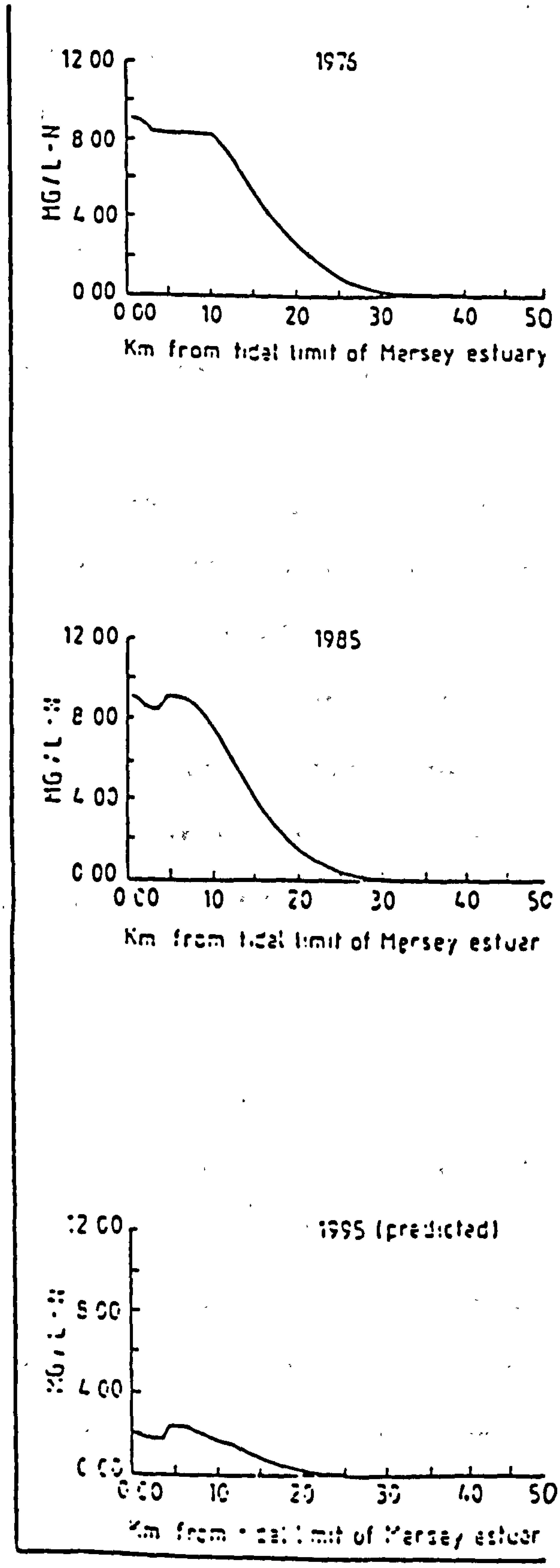


Figure 6.14: Concentration of Ammonium nitrogen in the Mersey Estuary

Source: Croft 1965

position of equilibrium exists with regard to concentration of suspended matter at both low and high water. The tidal and wave action in the Estuary tends to agglomerate crude sewage materials with grease, fat and oil into balls of various sizes which are then deposited on the shoreline both inside and immediately outside the Estuary.

6.2.3 IMPACT OF POLLUTION ON ESTUARY BIOTA

The poor water quality state of the Estuary has a major effect on its biology. All components of the ecosystem were affected and, by implication all those organisms such as wintering birds that make use of the ecosystem. Commercial fisheries were at one time lost completely from the Estuary. This section discusses effects of pollution on the pelagic and benthic biota, and on the salt marsh and fisheries.

a) Planktons.

There is little information on the effect of pollution on the pelagic ecosystem. Works of Ghazzawi (1933) and Gargari (1978, 1980) indicate an increase in phytoplankton numbers from early April to the end of June. thus suggesting an probable influence of temperature in promoting growth. The distribution of the diatom community as shown in chapter 2, seems to be according to habitat type with the sandy community distinct from the mud community.

b) Macrobenthic fauna

Invertebrate distribution in the Estuary reflects to a degree the level of pollution. In the outer Estuary 120 species were identified but only 26 in the Inner Estuary (Curtis and Eyres, 1980; Ghose 1980) . Eight of these species were exclusive to the Inner Estuary, the rest being found in both zones.

On a time scale Bassindale (1938) recorded 12 benthic species in the Inner Estuary : *Arenicola, Carcinus , Mytilus, Cardium, Macoma, Hydrobia, Mya, Nereis , Pygospio , Clitello , Crangon* and *Corophium*, of these, the first six had disappeared from the upper reaches where they were found in 1933. Holland, (1971b) did however record *Corophium* at Cressington and Eastham and *Mytilus* at the Pier Head.

Pygospio and *Macoma* moved little and *Hydrobia* was found to have moved further upstream since the 1932/33 survey of Bassindale. Holland reported seaward movement of some species since Bassindale published his list .

Comparison with the Dee reveals that inner estuarine species of this estuary are those which in the Mersey are typically restricted to the Outer Estuary. This would suggest that conditions in the Dee are not such as to limit the spread of euryhaline species wherever salinity is suitable. In the Mersey, however, the drop in fauna moving upstream is probably due to presence of substances which are inimical to the more sensitive species. In contrast, a wider range of species was found in the Outer Estuary which is more marine in character than the area studied in the Dee, thus marine species occur in the Mersey which are not present in the Dee (Curtis and Eyres 1980).

Popham (1966), in a survey of the Ribble Estuary, recorded 50 of the 70 species reported by Bassindale (1938) and most of the differences were attributed to different sampling method. *Clitellio sp.*, *Nereis diversicolor*, *Pygospio*, *Eteone*, *Hydrobia* and *Corophium* were recorded by Popham in the mud area at Fairhaven. The first three, and some *Hydrobia* are characteristic associates of the mudbanks of the Inner Mersey along with *Macoma* and several other oligochaetes. *Corophium* and *Eteone* were not found at all in this association, though Bassindale found the former to be a regular inhabitant of the Mersey mud banks in 1933. It was suggested that the condition of the Mersey mud banks in 1933 corresponded to that of the mud in the middle reaches of the Ribble in the 1950's and has since changed in such a way as to lead to the disappearance of *Corophium*.

The mollusc, *Macoma balthica*, was found in the Mersey to a maximum density of 10,400 /M^{-2}, whereas in the Dee estuary, a maximum density of 28,000 /M^{-2} was recorded (Ghose 1979). *Scrobicularia plana* was one of the abundant species on the Dee but was virtually absent from the Mersey and smaller numbers of *Eteone longa* occurred in the Mersey than in the Dee. These differences may be due to the pollution in the Mersey Estuary.

The destruction of the littoral habitat by the construction of docks and retaining walls probably accounts for a substantial proportion of the reduction in species variety in the Narrows. In the Inner Estuary the pollution load of the Mersey probably exerts a restricting influence on the species list. Large volumes of sediment moving into this part of the Estuary from the Irish sea after construction of the training walls may have destroyed invertebrate populations. Ghose (1980) reported on the growth and size of invertebrate species in the Mersey as follows: Pygospio elegans does not grow to the same size as in the neighbouring Dee estuary. Hydrobia ulvae was barely struggling to survive with growth slower in the Mersey than in the Lune and the Dee Estuaries. Macoma balthica and Cerastoderma edule showed a slow growth rate at New Brighton. Nephthys hombergii grew to a maximum length of 5.5 cm. at New Brighton, 7.0 cm. at Formby in the Mersey, whereas it grew to 6.0 cm. in the Dee Estuary. The growth rate and size attained by Nereis diversicolor was relatively slower in the Mersey as compared to the Thames Estuary.

If food supply is assumed to be adequate in both waters it may be that the smaller size of the a Mersey specimens is related to the level of pollution in the Estuary.

c) Impact of pollution on fish

The Mersey Estuary was once a nursery ground for soles, plaice, dab, codling and whiting (Johnstone, 1928). The availability of fish was such that around the beginning of this century as many as 53 boats with beam trawls were present at any one time in the Great Burbo Flats region and for a long time this area was a great attraction to fishermen from Southport, New Brighton and Hoylake; and up to 1910, about 40 fishing boats worked regularly in the Estuary. In the early 1930's shrimps, flounders and whiting were caught regularly in areas of the tidal basin, but by 1948 all these fish had disappeared (Porter, 1973; Srivastava, 1982).

Johnston (1910) recorded 106 species of fish, belonging to four orders, thirteen sub orders and thirty families from the local waters of Cheshire and Merseyside and the adjacent sea and observed that by then 'the Mersey had practically ceased to be a salmon stream'. In a sampling experiment between 1892 and 1970, the Lancashire Sea Fisheries Committee, showed that apart from shrimp, the main commercial fish were plaice, sole, dab and whiting mostly in juvenile stages. Corlett and O'Sullivan (1972), observed that the most important commercial fishing species in the Liverpool Bay area are : dabs, plaice, sole, cod, herring, whiting, skates and rays.

Srivastava (1982) recorded 31 species (30 species of fish and one lampern (see table 2.7), in the Mersey Estuary. Out of that number at least 29 species were in found in the outer Estuary from New Brighton outwards and only five were recorded in the Inner Estuary from the Narrows inwards. This indicates the effect of pollution on the distribution of fishes being largely limited to the Inner Estuary, which is unable to support any pelagic or demersal fishery due to low levels of dissolved oxygen (Srivastava, 1982 and Croft, 1965). Rees (1974) observed that although low levels can be tolerated for short periods, most active species need more than 80 % saturation and most sedentary species like flat fish need over 65 % saturation. Other stress factors such as raised temperature, silt particles in the gills and irritants that induce excess mucus production, also tend to raise their oxygen requirements. Lower salinity causes only slight stress until dilution reduce the salinity to one third of the sea water.

Many bottomfishes, e.g. suckers, darters and catfishes, decrease in numbers due to the destruction of feeding grounds by the siltation and high turbidity due to the suspended colloidal particles.

Since the food supply in the Outer Mersey Estuary is plentiful, slower growth and poorer condition of the Fishes in the Estuary has to be explained from other reasons than low calorific values of the food organisms (Srivastiva 1982). Other forms of the direct effects of pollution on fish include - tainting of catches with oil; the disabling of fishing boats by floating plastic, the closure of potential shell fish beds due to bacterial contamination, the fouling of trawling grounds by throwing over board of solid waste from ships and importantly by the disappearance of the benthic invertebrates which form the energy base of the fish species (Srivastava, 1982; Rice and Putwain, 1987; Curtis and Eyres, 1980 and Ghose, 1979). The findings of Srivastava put the overall diversity value as higher in spring and autumn than in summer; this is in contradiction with other findings. The low level of dissolved oxygen contents and high water temperature were identified as the cause of the decline in abundance of fish in summer.The environmental conditions for fishes were best in autumn.

d) Pollution and conservation in the Mersey

The location of the Mersey Estuary in a flyway way for wintering birds, the relative warmth of the area in comparison to other coastal areas in North West Europe and its position in relation to the Pennine and the Welsh mountains provide sufficient incentive to attract birds as a feeding and roosting ground. The Mersey, like other estuaries in Britain is, however, not a good roosting ground because of the risk of inundation of nests in the intertidal zone. The importance of most British estuaries is therefore mainly as wintering or passage stations for species which breed in northern latitudes.

Hodgson (1980), reported 46 breeding species in the Outer Estuary and 30 in the Inner. The Inner Estuary, however, attracted a greater range of visitors, 86 species compared with 68 in the Outer Estuary. Additionally, the Ship Canal Deposit Grounds on Frodsham Marshes attracted up to a further 19 species, many of these being very rare visitors.

Three groups of birds have been identified as being of importance in the Estuary, namely wildfowl, waders and gulls exerting their impact on the basis of numbers or biomass.

Studies of individual species indicate low bird numbers using the Mersey Estuary prior to 1970s. Among the swans and gees, the white fronted geese <u>Anser albifrons</u> was recorded in the Estuary as long ago as 1892 and was regularly counted in numbers between 1-2,000 and up to 5,000 during the hard winter of 1947. However, by 1967 this bird has became an infrequent visitor.

The pink-footed goose, <u>Anser brachyrhynchus</u> occasionally appears in the Inner and Outer Estuary. In the winter of 1974, between 400 and 500 birds were recorded in the neighbouring Alt estuary. In February 1959, 89 birds of mute swan, <u>Cygnus olor</u> were recorded and in 1967 100 birds were found on the Ince banks.

Mallard, <u>Anas platyrhynchos</u>, decreased in number during the 1950s but have shown dramatic increases (100 - 250%), since 1971 when compared to the previous five year average. Winter counts of Teal, <u>Anas crecca</u>, in the 1950s and 1960s were consistently 1-3% of the British population of the species but from the 1970s onward the figure rose to over 6% of the British population. Pintail, <u>Anas acuta</u>, was recorded at a maximum of 195 birds up to 1961 but in December 1966, 1,250 birds were counted and between 1971 /72 to 1975/76 an average of 8,000 birds were recorded representing 25% and 10% of British and North West European Population. Shelduck, <u>Tadorna</u>, were found ranging from 50 - 300 birds for 15 years (1961-65) with a maximum of 570 birds in March 1957. Between 1965 -70 the number of birds varied between 317 and 493 but in March 1976, 4,285 birds were counted amounting to 3.4% North West European population and 6.6% British population.

Curlew, Numenius arquata, is present all year round with the largest count in late summer (July to September) and winter (December to March). Between 1973 and 1974 both the Inner and Outer Estuaries supported numbers in excess of 1 % British population. Redshank, Tringa totanus, occurred in numbers greater than 1,250 in 1973 / 74 exceeding the 1% level of national population. This bird feed mainly on crabs and shrimps in summer and autumn and shellfish such as Macoma, Hydrobia, and Corophium at other times of the year. Dunlin, Calidris alpina, recorded a maximum monthly average of 26,000 birds in the Inner Estuary in December 1971 -76. In summer it roosts on the less disturbed Ince Bank. Wigeon, Anas penelope, was recorded in numbers of national significance in the 1970's and since then has been present in internationally significant numbers.

Seven species have been found to occur in numbers that are of international significance (present in numbers at least 1% of North Western European flyway population) (Table 6.3).

Table 6.3: Peak bird counts from the Mersey Estuary 1969-1990

	shduck	wigeon	teal	pintail	dunlin	Rshank	Curlew
1969/75	1762	3010	6380	7214	31654	NA	NA
1980/81	11800	15200	25850	18450	30500	NA	NA
1981/82	12170	10800	35000	11440	25400	NA	NA
1982/83	7110	9050	26100	13750	30000	NA	NA
1983/84	6800	5800	11050	8000	28000	NA	NA
1984/85	7605	10000	8,580	16000	34700	NA	NA
1985/86	4000	11650	4300	9000	25000	1620	1518
1986/87	2355	12000	8350	6000	12000	3300	1408
1987/88	2225	6000	12730	8950	16040	4100	1419
1988/89	2602	46030	9670	4288	22000	2930	NA
1989/90	4040	4000	123000	8000	17500	4458	NA
Mean peak	3434	7656	9470	8270	18508	3281	1180
NI	750	2500	1000	250	4300	750	910
II	2500	7500	4000	700	14000	1500	3500

NI - National Importance -1% of British wintering population
II - International Importance -1% of N.W.European flyway popln.

Source: Table produced by the author using information from: William, 1962; Williams, 1964; Hudgson, 1976 and MBC, 1992.

6.3 POLLUTION INCIDENTS

The Mersey Estuary had an average of approximately two accidental oil spills, greater than one tonne, per annum over the period 1979 to 1988 from all sources (Taylor et al 1990).

On Saturday, 19th August, 1989, there was an accidental spillage of 150 tonnes of crude oil into the Mersey Estuary. The heavy crude, Tia Juana Pesada (TJP), was originally loaded at Puerto Miranda, Venezuela and off loaded at Tranmere Shell oil terminal from where it was pumped through a pipeline buried along the foreshore to the Stanlow Refinery. During the pumping process, a fracture in the pipeline allowed approximately 150 tonnes (33,000 gallons) of the oil to escape into the Estuary (Davies and Wolf, 1990, MOSP; 1991).

6.3.1 CHARACTERISTICS OF THE SPILLED OIL

The physical and chemical properties of the spilled oil are shown in tables 6.4 and 6.5.

TJP crude is a high density, very viscous, bituminous oil with very low volatility and low wax content. Oil with such characteristics is less amenable to chemical dispersion. The crude contains substantial proportion of high molecular weight aromatics which are generally more persistent when spilled in the environment.

Table 6.4: Specification of various crude oils

Category	Country	Type	Specific Gravity	Viscosity (15 oC) c St.	Pour point oC
1. High wax content	U.K. U.K.	Dunlin Beatrice	0.850 0.835	12 20	3 27
2. Moderate wax content	Qatar Libya	Qatar Brega	0.814 0.824	3 5.5	-18 -18
3. Low wax content	Oman Saudi Arabia	Oman Arabian Light	0.861 0.851	27 17	-27 <-30
4. Very low wax highly viscous	Venezuela	Tia Jauna Pesada	0.987	50,000	3

Source: Taylor et al, 1990.

Table 6.5: The chemical composition of Tia Juana Pesada crude

Fraction	% mass/mass
Naphtha	1.1
Kerosine	2.9
Light gas oil	5.8
Heavy gas oil	7.6
Bitumen residue	82.6

Source: Taylor et al 1990

The very low proportion of volatile components in TJP crude meant that only a small amount of the oil would have been lost by evaporation. It is also unlikely that more than a very small amount was sufficiently water soluble to dissolve out. Oils with high viscosity tend to form coherent masses on the water surface with little tendency to disperse naturally, and hence are persistent. Chemical dispersants are designed to assist dispersion by promoting the formation of small, stable droplets. However, they are not generally effective against highly viscous oils at sea due to their limited ability to penetrate thick layers of oil. As a general rule, dispersants applied at sea progressively lose their effectiveness as the oil viscosity exceeds 2 000 centistokes (cSt.) and consequently TJP is one of the oils generally considered not to be amenable to chemical dispersion. However, in an onshore environment dispersant effectiveness can be enhanced by prolonged contact time and the use of brushes or other devices to promote mixing of oil and dispersant.

The spilt oil due to its very high viscosity, remained in thick floating masses even when moved by the tide, although there was also a widespread sheen in the Estuary. This was an oil film only a few molecules thick. The spill coincided with a period of high tide and strong southerly winds, a combination of circumstances which speeded up the movement of the stranded oil ashore on the north side of the Estuary. The movement of the slick is illustrated in Figure 6.15.

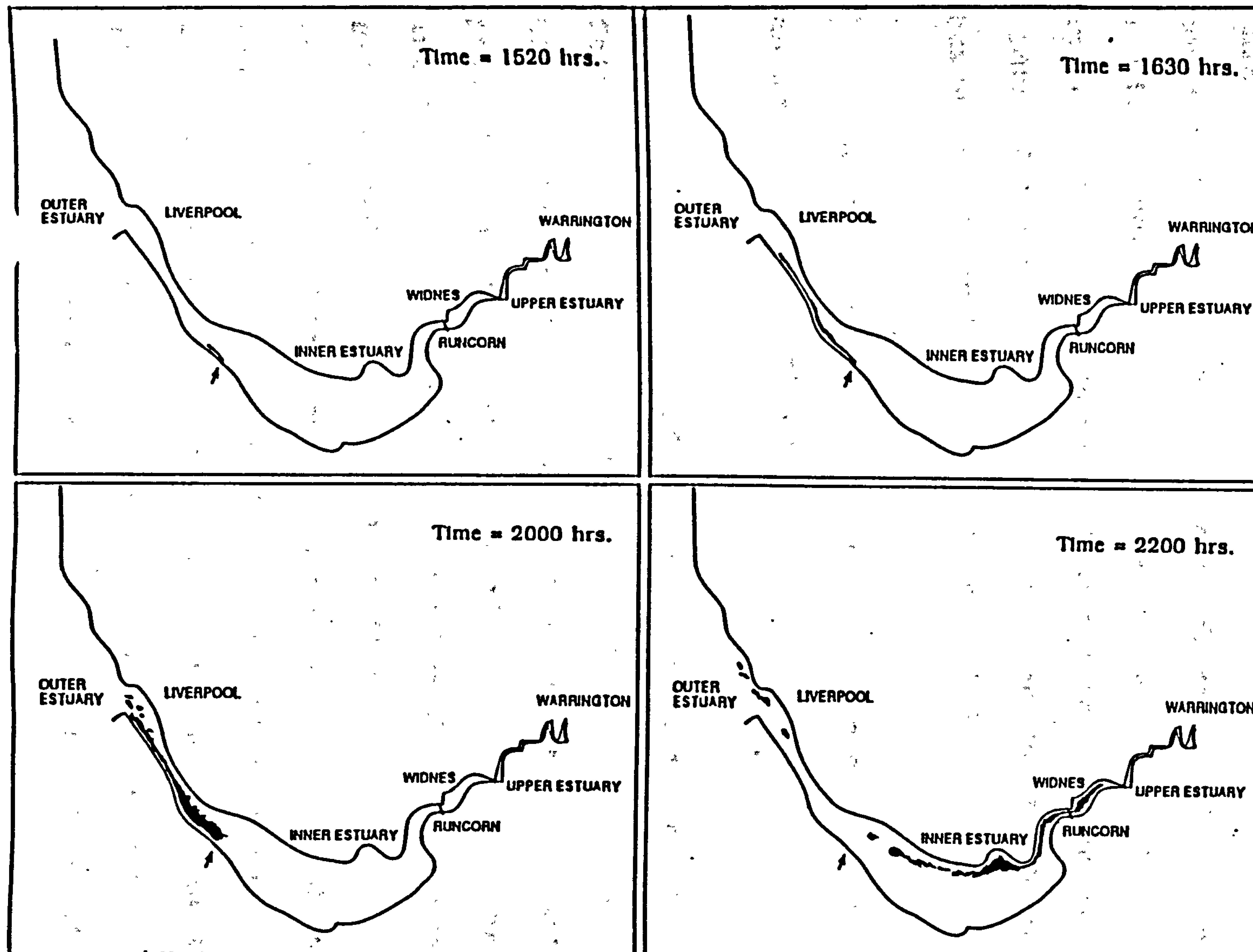


Figure 8.16: Movement of oil slick after August 1989 spillage in the Mersey Estuary

Source: MOSP 1991

Within approximately two hours of the spill, the slick was reported to be twelve metres wide and extended from Bromborough towards the Estuary Mouth. In the next half hour, the slick was approximately one mile long and half a mile wide. The wind at this time was from 190 (southerly) and at thirteen knots. Two hours latter (1825 hours), the slick was 10 miles long and half a mile wide. By 20.20, the slick was then reported to be approximately thirteen miles long and covering up to 70% of the width of the river between Eastham and New Brighton. The tide turned and began to flood at this period.

Overnight the flood tide carried the slick upstream as far as Howley Weir, Warrington.

By 06.30 hours Sunday morning, daylight revealed that the falling tide had left heavy oiling on some shores. The Central Electricity Generating Board at Fiddlers Ferry reported oil pollution on both banks of the river and on the power station intake screens. By noon, it was confirmed at the Merseyside Fire Brigade Headquarters, by Cheshire Fire Brigade crews that, with the exception of Stanlow and Ince Marshes, within Cheshire heavy contamination of the whole river had occurred. Coastguard reports at this time indicated no oil outside the Estuary but floating oil was still present in the Estuary and further deposition was predicted on the next high tide at 14.17 hours.

Around 1800 hours, heavy oil contamination extended from Hale to Warrington along both banks of the River. There was no further contamination in the New Brighton area but patches of oil were deposited from Speke to Southport.

On the Monday, 21st August, briefing at Merseyside Fire Brigade Headquarters at 1000 hours, it was revealed that there was still oil sheen on areas of the River. The pipeline leak had been sealed and there was no further danger from that source. During the evening, some oil came ashore at Grassendale, Liverpool such that about 20 tonnes was present on approximately 200 metres of the shore with deposits 30-45 cm deep in places. The source of this oil was unclear. Grassendale appears to be a natural collecting point for the Estuary and it is possible that a shift in the wind direction released oil previously held against docks in Birkenhead and Liverpool to be deposited here. Alternatively, given the specific gravity of this oil, it may have sunk in the fresh waters of the upper estuary and resurfaced as it was carried down river into denser saline waters.

6.3.2 IMPACT ON BIOTA

Detailed investigation of the spilled oil on algae, salt marsh vegetation, invertebrate fauna and sea birds using the Mersey Estuary were carried out after the spill.

a) algal populations.

Three different types of algal populations were identified: Intertidal macroalgae, Epilithic microalgae and Epipelic microalgae.

The intertidal macroalgae live attached to rocks or stones and are present in significant numbers in the Mersey Narrows, the North Shore between Garston Docks and Otterspool Promenade and at the Eastham Oil Terminal. The algae of greatest scientific interest due to its unusual and possibly hybrid features is the bladder wrack, Fucus vesiculosis along with associated microalgal flora, They provide a food source for many invertebrate grazers, which in turn are preyed upon by migratory fish and waterfowl (Jemmett, 1991).

The microscopic epilithic algae are found as a green film on sea walls in the Estuary, and were badly oiled at Grassendale and Otterspool and these algae were further affected by subsequent cleaning of the site. The significance of the micro-algae is poorly understood. The epipelic microalgae live in the surface (50mm) sediments. They are important in the nutrient cycling of the Estuary. They provide a source of food for many invertebrate grazers and provide a significant detritus input as well. The secretions of the epipelic algae play an important role in the stabilization of sediment surfaces and hence sediment deposition and transport (Jemmett, 1991).

Up to 90% of the areas covered by Fucus in the upper shore was contaminated with oil. Heavily oiled plants collapsed under the weight of the oil and became matted on the rock surfaces. The badly oiled individuals detached and fell off within six weeks and left oiled areas on the rock surface (MOSP, 1991). Moderately oiled plants in the upper to middle shore were lost during the February winter storms, leaving bare unoiled rock surfaces. In contrast, new sporelings appeared in large numbers on surfaces not affected by the oil.

Heavily oiled Fucus plants that survived the winter lost large amount of tissue but still become reproductive in April and May, 1990.

Although contamination was less in the middle shore Fucus population, it was widespread covering approximately 70% of the of the individual plants.

At Grassendale, much of the heavily oiled Fucus vesiculosus became detached prior to and during the winter storms. However, sufficient reproductively viable individuals remained to produce, in combination with the availability of suitable substrata and, a very high number of new individuals were in the early part of 1990.

There were no significant changes in the amount of chlorophyll present on untreated walls. Living specimens of algae were present to a depth of 5-10mm into the sections of stones. The spilled TJP is not able to penetrate deep into the rock because of its very high viscosity. Algal spores could not settle and grow on oiled rock surfaces. Epilithic algal populations recovered to their pre-spill level after six month in March 1990.

The epipelic algal populations at both Hale Head and Grassendale showed no significant differences between oiled and non-oiled areas. The populations at Hale Head showed no significant differences in species composition when related to historical records (MOSP 1991). The spilled oil has had no long term effect on this element of the ecosystem.

b) Salt marsh vegetation

Oil from the spill came ashore along the northern banks of the Inner Estuary, the southern shore of the Narrows and intermittently along both shores of the Upper Estuary (Figure 6.15). Due to tidal conditions at the time of the spill, the oil was deposited on the salt marshes of the northern shore at a high level, with some areas showing oiling restricted to the upper parts of [redacted] plants such as cord grass, Spartina anglica and sea aster, Aster tripolium while other areas showed more extensive oilings.The incident coincided with the flowering period of S.anglica, A.tripolium and hastate orache, Atriplex prostrata.

Prior to the storms of late February, 1990, all sites showed similar gradual , seasonal changes. The storm cleared some of areas of salt marsh to bare ground.

At Stanlow 77% of the substratum was laid bare by the storm. Similarly at Speke 86% bare and the lower and upper Olget shore sites. Brook Farm marsh was sheltered and only suffered a 28% reduction in cover. At Hale species such as Aster tripolium and Atriplex prostrata were heavily oiled but prostrate species such as Puccinellia maritima and Cochlearia anglica largely escaped the effects of the oil. In 1990, Atriplex prostrata and Aster *tripolium* seedling growth was much reduced, when compared to previous years, although *Aster* had spread vegetatively. *Cochlearia anglica* grew strongly in place of limited *Atriplex prostrata*. Although the spill coincided with the flowering period of *Spartina*, *Aster* and *Atriplex*, seed germination of *Spartina* and *Aster* was still comparatively high but *Aster* and *Atriplex* showed low germination due to oiling of the spikes and low viability of seeds in the following year. This low recruitment of seeds of the two species allow more space for the seeds of *Cochlearia* to proliferate more and cover a wider area. Seed germination of five selected species from the oiled Mersey marsh vegetation was compared with five similar species on the Dee where there was spill and the mean seed germination of species from the estuaries are generally comparable (Table 6.6).

Table 6.6: Seed germination record for five species at five sampling sites

SPECIES	% GERMINATION	MEAN GERMINATION	MERSEY MEAN	DEE MEAN
<u>Puccinellia</u>				
1.Speke	36			
2.Oglet	48	45.25	51.4	60.25
3.Oglet	42			
4.Oglet	55			
Stanlow (non-oiled)	76	76.0		
<u>Spartina</u>				
1.Speke	21			
2.Oglet	25	24.25	26.8	27.33
3.Oglet	26			
4.Oglet	25			
9.Stanlow (non-oiled)	37	37.0		
<u>Aster</u>				
1.Speke	42			
2.Oglet	33	31.25	34.2	44.75
3.Oglet	23			
4.Oglet	27			
9.Stanlow (non-oiled)	46	46.0		
<u>Cochlearia</u>				
1.Speke	25			
2.Oglet	-	30.0	32.7	45.6
3.Oglet	-			
4.Oglet	35			
9. Stanlow (non-oiled)	38	38.0		
<u>Atriplex</u>				
1.Speke	14.6			
2.Oglet	20.6	13.45	13.7	
3.Oglet	10.6			
4.Oglet	8.0			
9. Stanlow (non-oiled)	14.6	14.6		

Source: Heyslop, 1991.

Seeds oiled 50% or more, completely failed to germinate and those oiled 25% or more showed only low germination. Trials with seeds of Spartina demonstrated that clean seeds can germinate up to 72% while 25% oiled seeds showed only 12% germination (Table 6.9).

Table 6.7: Oiled Spartina germination results
(optimum temperature 25 C)

% OILED COVER	NUMBER OF SEEDS	NUMBER GERMINATING	% SUCCESS
100	25	0	0
75	25	0	0
50	25	0	0
25	25	3	12
0	25	18	72

Source: Heyslop, 1991.

One third of all the seeds collected from oiled sites were atleast 10% contaminated however, because only a fraction of the total salt marsh area were affected by oil, the total population of seeds affected was less than 10% (MOSP, 1991).

c) Invertebrate species

The immediate impact of the spilled oil on the invertebrate fauna was not recorded, There was however, little difference between the diversity of the oiled sites at Oglet and Hale and the comparable unoiled site at Stanlow (Stanlow) thus suggesting the variations of contaminated sites are more likely due to seasonal factors than to the oil spill.

The storms of February 1990 removed and re-sited large areas of substratum and the fauna record for March on the north shore, particularly at Speke and Oglet was impoverished.

Common species of annelids, molluscs and Crustacea showed a fairly steady increase in abundance from November 1989 until June 1990, with numbers falling sharply after this date. Reduction in numbers was observed during November 1989 as well as in autumn 1990 and hence could be attributed to natural population cycles (MOSP, 1991).

There was a great increase in the common ragworm Nereis diversicolor following the storms in February which continued through until June 1990. The increase was possibly due to sediment and vegetation changes resulting from the storms. It is known that Hediste are capable of migration and that mobilization by violent tides can remove and relocate large populations. Population pulses of Hediste are not unusual phenomena, and have been recorded by other workers.

Hydrobia (Mollusca) are capable of floating under the surface film of water. They can be transported great distances and may be deposited anywhere within the tidal range. During May 1990, spring tides re-deposited many thousands of Hydrobia especially at Stanlow but, subsequent spring tides appeared to reduce these numbers in many areas.

Gammarus are small 'shrimps' which inhabit salt marsh areas and survive tidal effects by living amongst the vegetation. These highly mobile amphipods can occupy a wide range of habitats and showed erratic population fluctuations and increases from winter to spring and summer. This is the expected pattern.

Observed reductions in the numbers of Hydrobia and Gammarus by November 1990 followed a period of minor storms and high tides, this further re-enforced the linkage between distribution abundance and normal estuarine events (Curtis, 1991).

d) Bird mortality and oiling

Oil spilled into estuarine environments directly affects birds by covering them or even killing them. Severely oiled birds die quickly but less affected individuals may stay alive for indefinite periods. Where several people are involved in the counting of the affected birds, records may be duplicated on occasion, with the same bird being counted by different persons at different times and in different locations. These difficulties make it impossible to simply add all the records together in order to establish an overall figure.

In the case of the TJP spill in the Mersey Estuary, an absolute minimum figure was arrived at adding the highest single time and place count to numbers of dead and rescued birds whose collection pre-dated these counts. It was possible, on occasions, to utilise counts from two observers if these were simultaneous and geographically discrete. These absolute minimum figures are considered the most accurate that can be calculated from the data. It should, however, be noted that these numbers are only approximate since it is not practically possible to know how many oiled birds left the area or died before they are counted.

Table 6.8 shows the absolute minimum numbers of birds observed to have been oiled following the oil spill. A minimum of 4,164 birds were oiled. Although only 172 affected corpses were recovered it is considered that many of the other affected birds died as a result of reduced insulation of feathers. The last oiled birds were seen around the time of the first frost of the winter and add credence to this supposition.

Of the 45 species involved in the incident, 80% were black-headed gulls, 12% were other gulls; the remaining 37 species accounted for only 8% of the casualties.

The vast majority of oiled birds were gulls or other water birds which encountered the oil as a slick on the water, hence the large numbers of birds that were oiled immediately following the spill. The gulls were typically contaminated on the breast and head, further evidence for them encountering the oil whilst floating on the water, rather than from contract with oiled vegetation which would have affected wings (MOSP, 1991).

The oil spill happened at a time of year when considerable movement of birds was occurring and many of the birds may have moved away from the area. Most oiled birds disappeared within a fortnight but some remained around the Mersey and associated roosts for many weeks. At the onset of colder weather in late October and November, all oiled birds disappeared. This indicates

Table 6.8: Numbers of each species observed oiled by the August 1989 oil-spill.

Common name	Latin name	Corpses	Oiled Total
Little Grebe	Tachybaptus ruficollis		11
Great Crested Grebe	Podiceps cristatus	4	5
Fulmer	Fumarus glacialis	1	1
Petrel	unidentified species	0	1
Cormorant	Phalacrocorax carbo	10	17
Shag	Phalacrocorax australis	0	1
Grey Heron	Ardea cinerea	0	3
Shelduck	Tadorna	1	13
Teal	Anas crecca	2	4
Mallard	Anas platyrhynchos	28	40
Pintail	Anas acuta	4	4
Scaup	Aythya marila	0	1
Quali	Coturnix	1	1
Water Rail	Rallus aquaticus	1	1
Oyster-Catcher	Haematopus ostralegus	0	11
Ringed plover	Charadrius hiaticula	3	48
Lapwing	Vanellus	0	2
Knot	Calidris canutus	1	2
Sanderling	Calidris alba	1	85
Dunlin	Calidris alpina	2	29
Bar-Tailed Godwit	Limosa lapponica	0	2
Curlew	Numenius arquata	0	18
Redshank	Tringa totanus	0	50
Common Sandpiper	Actitis hypoleucos	0	1
Turnstone	Arenaria interpres	0	1
Mediterranean Gull	Larus melanocephalus	0	2
Little Gull	Larus minutus	0	5
Black-Headed Gull	Larus ridibundus	49	3307
Common Gull	Larus canus	0	30
Lesser Black-Backed Gull	Larus fuscus	9	61
Herring Gull	Larus argentatus	31	351
Greater Black-Backed Gull	Larus marinus	8	
Kittiwake	Rissa tridactyla	2	28
Common Tern	Sterna hirundo	0	4
Guillemot	Uria aalgae	5	5
Feral/Racing Pigeon	Columba livia	4	4
Skylark	Alauda arvensis	1	2
Meadow Pipit	Anthus pratensis	4	4
Yellow Wagtail	Motacilla flava	0	4
Dunnock	Prunella modularis	0	1
Blackbird	Turdus merula	1	1
Linnet	Carduelis cannabina	1	1
Redpoll	Caruelis flammea	1	1
Budgerigar	Melopsittacus undulatus	0	1

Source: Adapted from MOSP, 1991.

that the insulation of the birds was affected by the oil and resulted in their death rather than the toxicity of the oil. Any other oiled birds that had moved to a similar climatic area can also be presumed to have died.

The combination of factors such as time of the spill, type of oil, tidal and meteorological conditions in the Estuary limited the impact on bird species. The worst affected individual species, was the black-headed gull with some 3,300 birds being oiled, this amounts to around 0.33% of the total population of western Europe. Such levels are unlikely to have any serious ecological impacts.

Had the oil-spill occurred during the winter, it would almost certainly have caused greater suffering and had a much larger impact on the total British and European populations of some species, such as pintail.

6.4 OTHER ACTIVITIES

6.4.1 RECREATION

Within the coastal strip of the Mersey there are a number of amenity areas which are adjacent to, or give access to, the shoreline. These include golf courses, country parks, nature reserves and National Trust land, as well as sites of interest such as antiquities.

Recreational water use includes ten sailing clubs situated near to the Dee and Mersey Estuaries and approximately eleven coastal and thirty inland yacht and powerboat clubs in the immediate vicinity whose members use the estuaries from time to time. There are also numerous individual boat owners who are not affiliated to a particular club. Organised club sailing is mainly at weekends and during evenings when conditions allow. The main season is from April to October, although some small dinghy sailing may take place in winter months when weather conditions are suitable. The Mersey is being promoted by local authorities as a location for waterbased events, such as the Tall Ship Race, which came to the River in 1984, and again in 1993 and the annual River Festival which incorporates a number of different events each year (Rice and Putwain, 1987). Berthing facilities exist in the South Docks of Liverpool and the use of the docks for water sports is actively encouraged. Transport across the Mersey Estuary is provided by the Mersey Ferries, operated by the Merseyside Passenger Transport Executive. These run from Seacombe and Woodside on Wirral Bank to Pier Head in Liverpool.

6.4.2 RESOURCE EXPLOITATION

Bait exploitation involves digging soil and turning up stones to uncover and take the animals. Digging up soil facilitates soil erosion by the widening of the dug areas into wider channels thus changing the pattern of water and sediment flow (Kennedy, 1980). Change in channel direction may result in the drying of certain areas and flooding other areas. If a usually moist area dries, most invertebrates species living there are lost by either death or migration. In flooded areas the macrobenthos become unavailable to their predators. In either case there is a risk to the wildfowl species using the Estuary for feeding and it can force birds to migrate to other estuaries with consequent enhanced competition and the possible death of some, thereby threatening the International and National importance of the Estuary as a wildfowl feeding area. In polluted estuaries such as the Mersey, digging stirs up sedimented heavy metals and may bring them into an active state which when taken into organisms accumulates biologically until it reaches a final host, which may be Man.

Sand for building is remove from the Estuary. In the process substantial damage is cause to the ecosystem due to the passage of heavy vehicles across the tidal marsh.

6.5 MITIGATION AND INITIATIVES

The concern for the pollution of the Estuary of the River Mersey started around 1930 when the Mersey Docks and Harbour Board set up a committee to investigate discharge of sewage into the Estuary. This baseline report was important in raising the level of awareness to the seriousness of the pollution problem in the Estuary. The passing of the Rivers (Prevention of Pollution) Act in 1951 with provision to prevent new industries from discharging harmful effluents into the river and the formation of the Mersey River Board, marked a significant turning point in the post industrial Mersey. In 1961 a second Act was passed empowering the River Board to impose limits on pollution load and the power to prosecute illegal discharges was conferred on the Mersey and Weaver River Authority by the 1963 Water Resources Act. The Authority also issued consents to local authorities and industrialists which set limits on the quality and quantity of effluent discharges.

In 1971 a steering committee of Local Authorities and industry was set up to investigate pollution and consider treatment options. The Control of Pollution Act of 1974 further augmented the clean up effort. The Environmental Protection Act of 1990 and Water Resources Act of 1991 consolidated enactments relating to the National Rivers Authority and encouraged conservation of natural habitats and the enhancement of recreation.

The combined effect of all this legislations has been a gradual improvement in the quality of Estuary as river discharges were coming under control. The improvements were manifest in the improvement of the biota using the Estuary including fish and wading and visiting birds in 1970-80. Lloyd and Oldfied (1977), and Levenson (1987) reported on the concepts and organization of cleaning up pollution in estuaries.

A fifteen-year programme of works costing £170 million and aimed at cleaning up the Mersey Estuary was initiated in 1980. Then in 1985, the Mersey Basing Campaign was launched to clean up the Estuary and all its tributaries. The programme is estimated to cost four billion pounds (£4 billion). The effort of the campaign was already beginning to bear fruits, by 1989 the organic pollution load on the Estuary had dropped by 30% of 1972 level (Clark, 1989). Remarkable improvements have been recorded in fishing, conservation and recreation in the Mersey (MBT, 1993). In fact activities of the Mersey Basin Campaign to clean up the Estuary are now almost on daily basis. I have endeavoured to follow up the progress made on the condition of the Estuary but it is virtually impossible to keep track of all the developments.

Measures have been taken by Shell U.K. Ltd., to prevent oil spillage similar to what happened in August 1989. Among such measures was replacing the 40 year-old oil pipeline which ran between Eastham and Stanlow in Cheshire with a new one of higher specification and the more comprehensive monitoring of oil flows. The pipeline which leaked in 1989, was an insulated 21" diameter pipe which carried heated fuel oils, heavy residues and unheated gas oils. The new pipeline will be 6,715m long and have an external diameter of 12.75". The wall thickness will be 0.406" except under the canal where the thickness is 0.5" in order to provide added protection. This is above the standard specification for fuel oil pipelines which is only 0.330" (Millett, J.C., Personal communication)

Several measures have been outlined to help ensure pipeline safety. Thirty five expansion loops will be spaced at even intervals along the pipeline. ~~These will be spaced at even intervals along the pipeline.~~ These will be capable of allowing the passage along the pipe of a monitoring tool, known as an 'intelligent pig'. Block valves positioned at five locations along the pipeline will allow isolation of certain sections of the pipeline for routine maintenance and in the case of an emergency. Under the canal, cathodic protection will be installed to prevent corrosion. In addition, a sophisticated loss monitoring system will be installed which will allow any leaks to be quickly identified. To avoid corrosion, the pipeline will be insulated with 50 mm of high density polyurethane foam before being wrapped with heavy gauge alloy sheeting. The section of pipeline under the canal will not be insulated but will be coated with neoprene rubber. The pipeline will have a normal operating pressure of 35 bar, at a maximum temperature of 70 °C, allowing a throughput of 450 cubic metres per hour.

6.6 PROPOSALS FOR NEW PROJECTS

As the quality of the environment of the Mersey Estuary improves, there are pressures for new development, which may lead to further substantial changes. Key proposals include the construction of the Mersey Barrage, expansion of Liverpool Airport, development of new Oil and Petrochemical related industries and road across the Estuary. These proposals if carried out, could significantly alter flow, quality and water level. Internationally important areas for birds could be lost. On the positive side, New job opportunities may be created, new opportunities for tourism and recreation may also be open.

6.6.1 THE MERSEY BARRAGE

Construction of a barrage across the Estuary will exert impacts on the landscape, physical and chemical features of the Estuary. These impacts will generate a series of impacts on the biology, amenity value and soci-economic environment of the estuary.

a) Construction phase

The construction phase would involve land reclamation, dredging of sediments, relocation and construction operation, Impacts associated with this phase include loss of intertidal habitat, increase water turbidity and then possibly raising toxic substances in the dredging operation.

Reclaimed areas will be needed to create the lock at New Ferry and the Cofferdammed construction area for turbine and sluice caissons will result in the reclamation of about 30 ha of land of which about 20 ha would be from existing intertidal areas (MBC, 1992).

The muds at New Ferry are particularly rich in invertebrates and support a number of wildfowl among which five species would be affected significantly. These species are :

i) Teal - numbers in excess of 2% of the Mersey total frequently use the areas that would be reclaimed should the barrage go ahead.

b) Pintail - which regularly use the central areas of New Ferry in numbers exceeding 2% of the Mersey total. The other species are Knot, Dunlin and Redshank.

Longer retention period would mean retaining pollution load for within the estuary longer than the present level and that could destroy what has been achieved so far in the cleaning exercise making a waste of the £170 million invested in the programme.

Large amounts of dredging are required as preparatory work for construction of the temporary works casting basin in the New Ferry area and for the foundations of the structures forming the line of the Barrage. The deepest level of dredging will be for the power unit caissons with a founding level of -22.85 m OD. The sluices, to be located on placed granular materials, will require dredging to levels between -11m. OD and -19m OD. The New Ferry Lock approach channels will be dredged to a level of -13 OD. Dingle approaches will not require dredging as the existing riverbed is below the proposed Lock sill level.

The dredged materials will be disposed off in the main reclamation areas between New Ferry Lock and the Wirral Shore and between Dingle Lock and the Liverpool Shore. Retaining bunds of rockfill construction with a central sealing zone will be formed initially to contain the dredged materials. The impact of dredged material will the same as land reclamation stated above.

Dredging materials up to a depth of -22.85 OD has the risk of resuspending sediments and toxic substances that they may contain. According to results of the sediment analysis, impacts to water quality during construction will be minimal. Hence water quality and the ecosystem will not be adversely affected.

Several discharges would have to be diverted at Wirral Barrage land fall. A pumping station will be required at Port Sunlight on the River Dibbin and further new pumping stations will be required at Warrington and Widnes. On the Liverpool side major works will be required on three large outfalls.

Nine of the eleven main rivers discharging into the Mersey will require new works. Major engineering work is necessary on the River Gowy and River Weaver. Engineering works can be carried out during a major shut-down of Stanlow Oil Refinery for other purposes.

Two hundred piped discharges enter the River system above the proposed Barrage comprising sewer outlets, surface water outfall, storm sewerage overflows and treatment work' outfalls. Some 150 of these discharge points will be so slightly affected as to require negligible attention whilst, of the remainder, 20 will require major accommodation works and the remaining 30 require work of a moderate scale (MBC 1992).

b) Operational phase.

i). <u>Physicochemical</u>

The effect of the barrage on the hydrology of the Estuary will extension of the upstream duration of high water levels and reduction in time during which water levels would fall below open river mean tide levels. The impact on these is saline water intrusion into the sandstone aquifer which will increase ground water salinity. There are five abstraction points for ground water along the Mersey for industrial use. Another impact is on the drainage system of the Estuary and possible flooding as result of increased High Water levels upstream of the Barrage.

The impoundment will result in the reduction of overall tidal currants in the Estuary and increased duration of the high water slack period. The combined impact of reduced current energy is decrease in efficiency of effluent initial dilution and dispersion.

ii) <u>Biological</u>

Increased stability and reduced turbidity of the impounded water enhance the growth of phytoplankton, while this has the advantage of increased primary productivity, excess growth could lead to population crush and consequent anoxia, scum formation and algal toxins . This deteriorated water condition will have adverse impacts on the zooplanktons, fish and predatory birds that feed on them.

Increase in water residence time may restrict the movement of zooplantons between the Estuary and Liverpool Bay. Selective feeding by zooplankton may indirectly promote growth of unpalatable phytoplankton which could grow to excess level and crash.

The invertebrate fauna is will increase in diversity due to more suitable condition interms enhanced sediment stability and improved water quality. The range of habitat also increases upstream due to increase in mean salinity and decreased salinity range. Increased primary productivity also will promote increase biomass of the benthic fauna.

Hydrological changes such as compression of tidal range, displacement of tidal curve further up the shore, concentration of wave action over a compressed tidal range and greater duration of high water slack combine to affect the salt-marsh vegetation in as follows: The upper marsh zone is compressed,middle and upper marsh species are displaced by the characteristic lower marsh species such as Puccinnelia, Salicornia, Spartina and Sueda species. The chances of terrestrial grasses (e.g. Elymus), invading the salt-marsh vegetation will be minimised due to frequent inundation as a result increased high water.

Decrease in duration and extent of intertidal mudflat exposure result in decrease in productivity and spatial distribution of intertidal epipelic algae in the inner and upper Estuary.

Due to increase in water slack period and reduction in flushing time, the risk of fish accumulating contaminants increase. The barrage sluices constitute physical barrier to seasonal and daily migrations of fish and Ichthyoplankton. Barrage plants such turbine may constitute a hazard due to physical collision and pressure and shear stress effects. Apart from the direct effects, the barrage may indirectly affect fish by making an easy prey to both birds and predatory fish, when disoriented during both turbine and sluice passage. fishery could be affected due to loss of intertidal habitat used by juvenile brown shrimp as nursery ground.

iii) Conservation value

Impact on birds will be mainly due to loss in feeding area as a result of reclamation and submergence under extended hugh water. Changes in the frequency and periods of exposure of favoured feeding areas affect certain species. Indirectly, changes in salt-marsh flooding patterns affects feeding time of birds and changes in feeding patterns could lead to induction of new behaviour pattern in significant species.

iv) Socio-Economic

From the socio-economic point of view the barrage is expected to provide cleaner water, which will boost recreational facilities and attract tourism. The barrage will simultaneously act a flood control barrier. It is expected to provide some 600 new jobs and increase the regional income by 0.3%. This benefit may not be fully realised in the Merseyside area since the job is highly technical and it is not likely that the area has man-power sufficient to take most of the jobs.

6.6.2. EXPANSION OF THE LIVERPOOL AIRPORT

Proposals have been considered to expand Liverpool Air Port from its present capacity of less than half a million passengers a year, to the status of a major airport with the capacity of 40 million passenger per year. The proposal if carried out would claim about 1,000 hectares of the Estuary. This would affect the appearance, water regime and hydraulics of the Estuary. It would also require extensive importation of bunding and fill material with all the attendant impacts in the environment. Reclamation of bird feeding areas and potential of Bird strike by air craft would cause a significant damage to the conservation value of the Mersey. Birds displaced from the Mersey might be lost to Britain completely. Communities such as at Hale, Runcorn and Widness would be affected by air craft noise and risk to safety of concentration of hazardous installations in the Mersey Basin including the Castner Kellner works with large stores of chlorine and the Nuclear Fuels site at Capenhurst. Additional land requirement to locate airport servicing firms, business parks and industries would add to the pressure on the estuarine and surrounding areas. Up to 30, 000 jobs could be created when fully operational and most of the jobs would come from the Merseyside area. At least as much or more jobs would be created in the region in businesses and servicing and supporting the airport as well as new firms attracted solely by the presence of a major international airport.

6.6.3. EXPANSION OF OIL AND PETROCHEMICAL INDUSTRIES

In the 1980s, studies were undertaken of the feasibility of reclaiming part of the Southern bank marshes for new oil and petrochemicals development. Result of the studies indicate that the Manchester Ship Canal silt deposit grounds alongside Frodsham Score were unsuitable for large scale development. The presences of important bird feeding areas on the Stanlow Banks and because of the detrimental effect on the hydraulic regime of the river, makes the Banks undesirable for development. Development the Helsby, Frodsham and Lordship Marshes may have adverse consequences on the environment of the nearby communities, principally Helsby and Frodsham. The Ince Banks are of high ecological value as an Internationally important site for overwintering wildfowl, any development on this site would reduce its conservation value. In view of the these environmental considerations and the relatively high financial risk associated with any speculative development, attempt to develop industry on the southern Mersey Banks requires a full Environmental Impact Assessment studies (Gilfoyle, 1991).

6.6.4. THE MERSEY CROSSING

There are proposals to look into the possibility of building a new crossing on the Mersey. Since neither the form nor the location of the crossing is yet determined, it is difficult to assess its environmental impacts. With a bridge, there are aspects such as airborne and water run-off pollution, scour, siltation and channel shifting, and possible effect on bird habitat. In case of a tunnel, which is unlikely due to cost differences, the impacts of turbidity and erection of concrete walls would have little impact on the overall environment.

6.6.5 RISK ASSESSMENT OF DEVELOPMENT PROPOSALS

Analysis of probable risks associated with development proposals are presented in Table 6.9, below.

Table 6.9: Risk assessment of the proposed developments.

RISK EXPOSURE	RISK EVALUATION		
	BARRAGE	AIRPORT	CROSSING
<u>Pre-const.</u> excavation to ascertain bedrock form and type	stir up toxic substances, turbidity - reduce primary productivity, impair health or kill biota	~~destroy~~ disturb salt marsh and intertidal habitat - reduce primary and secondary productivity, diminish bird number.	similar effect to Airport but to a lesser degree.
<u>Construction</u> Relocation of existing structures- Transmission lines / cables and pipes.	Spillage and shocks - destroy habitat, kill biota.	Spillage - destroy salt marsh, reduce productivity.	Spillage - destroy ecosystem, kill biota.

Having discussed the changes brought about by human action on the structure, hydrology and biology of the Mersey Estuary, I now move to apply EIA techniques to assess these impacts which will be the subject of the chapter following.

7 APPLICATION OF EIA TECHNIQUES

7.1 GENERAL CONSIDERATION

The principles and techniques of EIA have been described in chapter four. Impacts of various human activities on estuaries in general and in the Mersey Estuary in particular, have been described in chapters five and six respectively.

This chapter involves the selection of appropriate EIA methods and their application to bring into focus impacts of human activities on estuaries.

7.2 SELECTION OF EIA TECHNIQUES

From Table 4.4, it can be seen that all EIA techniques have certain merits and drawbacks. The criteria for selection therefore depend on the nature of the project. In the case of estuaries it is worth noting that various development activities take place at different times thus exacting impacts on the ecosystem as individual projects and cumulatively. For this reason, I consider it appropriate to use a simple checklist method to identify all possible impact parameters of each major project on the ecosystem. The fact that the checklist method, however, does not provide links between initial and high order impacts. The impact network method is therefore suggested to show links between one impact and another along the energy flow line in ecosystems. Nevertheless, these two methods do not give an idea of the extent and importance of identified impacts. To quantify impacts, a modified Leopold matrix is suggested to assess impact magnitude and importance. Finally, a classification into positive and negative impacts is presented in the form of a summary matrix.

Although estuaries such as the Mersey have a linear dimension, the application of the Overlay Technique to categories habitats according to sensitivity and importance to pollution incidence, such oil spills, seems to be of little or no practical importance because estuarine processes such as tidal movement, wind speed and direction and the time of the incident will most likely outweigh the importance of any such map produced as a warning device. The oil spill incident in the Mersey of August 1989 as discussed in chapter six is a case in point. Strong wind after the spillage almost completely modified the situation of the impact and damage caused by the spilled oil.

The general points to notes however, are that spillage during the winter period is likely to have more adverse impacts because of the presence of large numbers of sea birds on the inter tidal mud flats and salt marsh which provide the bulk of their food. Hence incidents affecting the Ince and Stanlow marshes are likely to show more adverse impacts than those occurring elsewhere.

The development of computer technology has undoubtedly enhanced the value and accuracy of modelling and this makes it a very important tool in impact prediction and evaluation. The methodology is not however, applied in this thesis because of the limited Information on estuaries and the fact that in the area where the research is to be applied, Nigeria, computer facilities are virtually non existent. The other difficulties of application of this technology due its high technical nature, the lack of experts with sufficient skill to interpret the results and its high resources requirement have been explained in chapter four (4.1.4, f) and in Table 4.4.

7.2.1 CHECKLIST

Based on my work in chapters five and six, a simple checklist of impact of human activities on estuaries is produced as follows.

TABLE 7.1: Simple check list of impacts of human activities on activities on the ecosystem of the Mersey Estuary.

A) Impacts of training wall (refer 6.1)

-change in current and tides

-change in sedimentation pattern

-change in estuary bed level and composition

-change in low water channel position

-change in position and extent of intertidal mud flat

-change estuary water replacement time

-change in total water capacity of the Estuary basin

-change fresh water scour

B) Dock wall (refer 5.2.1 & 6.1)

-destruction of intertidal habitat

-destruction of salt marsh habitat

-change in tidal range

-change in fresh water flow and scour

-change in landscape

C) Dredging (refer 6.1)

-change in channel depth

-turbidity

-toxic material in suspension

-change in volume of pollutants

-dredge landfill

-Infauna habitat

E) Pollution (refer 6.2)

i) Water quality

-change in biological oxygen demand (BOD)

-change in dissolved oxygen level (DO)

-change in nutrients status

-change floating material

-change in turbidity

-change temperature

-change in pathogen

- change in heavy metal concentration

b) Sediment contamination (refer Table 5.1

- change concentration of toxins
- change in organic content
- change in nutrient content

c) biological (refer 6.2)

- change plant and animal species
- diversity
- plankton community
- vegetative community
- invertebrate community
- fishes
- productivity
- nutrient cycling

} birds, humans

<u>Visual quality</u> (refer Table 5.1)

- visual content
- area and structure coherence
- apparent access

7.2.2 IMPACT NETWORK

From the above checklist I have developed a network to show the link in impacts between the physical and biotic component of the ecosystem and how they affect estuary resources including fisheries, conservation and recreation. I found it more convenient to present the impact of construction activity separate from that of pollution and hence the respective networks are presented in Tables 7.2 and 7.3.

To illustrate the complexity of the network I will briefly discuss some of the effects of dredging and dock construction. Effective use of an Estuary for Navigation can only be maintained where the channels through which ships sail are of sufficient depth to that ships are able to unload and load as close as practicable to the industry where raw materials are required or finished products transported. In the Mersey Estuary increases in ship size during the 19th and early parts of the 20th century reached such a level that the natural navigation channels in the Liverpool Bay and within the Estuary basin were no longer of sufficient depth to ensure smooth sailing. To alleviate this problem the Crosby Sea Channel was trained with stone walls and regular dredging has since been carried out in the Estuary channel to maintain sufficient depth for ships (Ref. chapter 6). Docks were built along the Lancashire Banks of the Narrows and the Inner Estuary, the Wallasey and on the Cheshire banks at Bromborough and the Manchester Ship Canal. Hence the interaction of Shipping with Training walls, Docks and Dredging as indicated by "x" in Table 7.2. Industrial bases are located behind training

TABLE 7.2: Network of impact of construction activity on the Mersey Estuary

a)		b)			d)	e)	f)
-SHIPPING -IND.LOC.	X	X X		X	INITIAL EFFECT	SUBSEQUE-NT EFFECT	FINAL EFFECT
	TRAINING WALL	DOCK WALL		DREDGING			
c) **<u>HYDRAULIC / SEDIMENT</u>**	X	X		X	i) TIDES/ CURRENT	-deposit sediment -accrete low water channel -raise mud flats -decrease capacity -decrease tidal range -delay flushing -burry shellfish -remove fresh water scour	COMM. FISHING CONSERVA-TION RECREA-TION SHIPPING
					ii) Remove material	-ground water salinity -remove shellfish bed -remove benthic plants -suspend dredged -remove sediment	+SHIPPING +RECREA-TION COMM. FISHING

					iii) Material disposal	-destroy bird habitat -produce island - pollutant seepage.	CONSERVA-TION

<u>Key</u>
IND.LOC. : Industrial location
x : possible impact

TABLE 7.3: Network of impacts of pollution on ecosystem of the Mersey Estuary

SOURCE	INITIAL IMPACT	SUBSEQUENT IMPACT	FINAL IMPACT
	BOD	Physiological stress, change population, change community.	CONSERVATION, SPORT AND COMMERCIAL FISHING.
Industrial effluents	D.O.	-do-	-do-
	Nutrients	Eutrophication, increase productivity.	SHELLFISHING, CONSERVATION.
	Floatables	Nuisance,	RECREATION.
Sewage effluents			
	Turbidity	Increase stress, Decrease productivity.	COMMERCIAL FISHING, RECREATION.
Industrial effluent	Temp.	Change physiology, change productivity	CONSERVATION, RECREATION, COMMERCIAL FISHING.
	Pathogen	-	RECREATION
Cooling water discharge	Odour	-	RECREATION
	Toxicity	Change physiology, biomagnification.	COMMERCIAL FISHING, CONSERVATION.
	Radioactive.	Change physiology, decrease productivity.	COMMERCIAL FISHING, CONSERVATION

and dock walls where tidal influence and erosion are limited and therefore, there is a link between Industrial location on the one hand and Training wall and Docks on the other.

These activities of training the sea channel, building dock walls and regular dredging of the navigation channels generated impacts that alter the hydraulics and sedimentation of the Estuary. Thus the link "x" connecting Hydraulic / Sedimentation and the three construction activities.

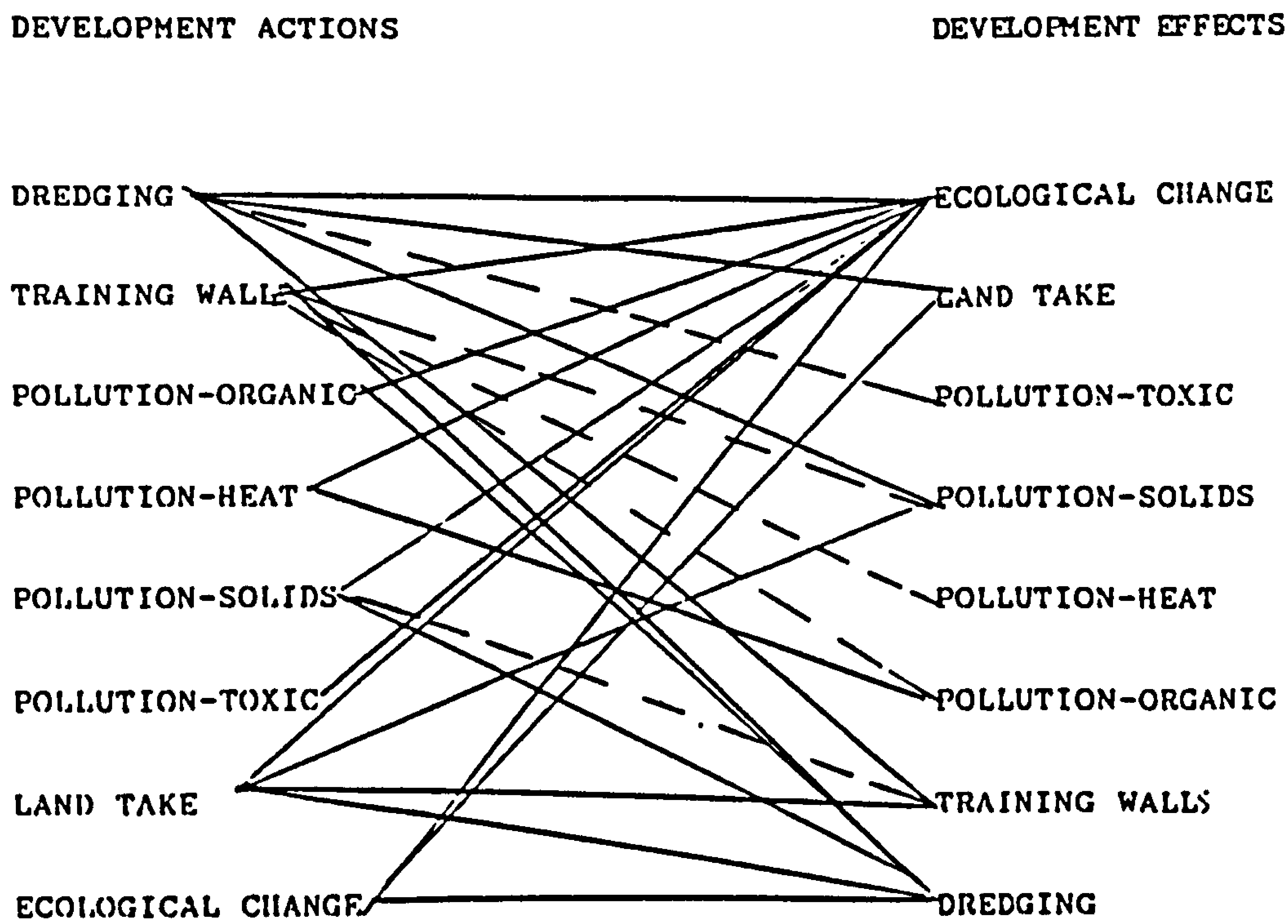
The first impact resulting from change in hydraulic and sedimentation was the alteration of tides and currants in the Liverpool Bay so that there was a net drift change from seaward to landward (see chapter six). Consequently, more silt material is brought from the sea and is carried by the tide into the Estuary.

Dock walls along the Narrows enhance tidal scour and do not allow settlement of the sediments in this region of the Estuary. On reaching the expanded basin of the Inner Estuary the current is slackened thus allowing deposition of sediments in this region. The depositing sediments accrete in the Inner Estuary basin, and especially in the low water channels. It raises the Estuary banks levels to a position where they are only covered by high tide. Accretion of the Estuary bed resulted in an overall reduction in water volume up to 4% between 1906 and 1931 and it also reduced it flushing frequency. Another secondary effect is the possible smothering of shellfish and other of invertebrate habitats in general. The plankton community may also have been smothered and deprived of the necessary sunlight for primary production thus weakening the base of the food chain. The final effect arising from all of these impacts was the decline of commercial fishing, so much so that by 1948 all fishing activities had stopped. Accretion of channels create navigation difficulty and turbidity in water lowers it's recreational potential. Conservation importance is in jeopardy by destruction of habitats and by weakening energy base of the ecosystem.

Dock walls and similar construction, sever salt marsh and intertidal mud from the estuary and subsequent construction work inside the wall then destroys the biota and alters the landscape. Outside the wall silt accretes which may subsequently be colonised by marsh vegetation thus further decreasing the size of the estuary. Dock walls also alter or dam up river flow and remove the dilution effect of fresh water and also remove fresh water scour. Absence of the fresh water scour may minimize erosion and facilitate accretion. In the Mersey lack of freshwater scour promotes stabilization of the Inner Estuary navigation channel and the accretion of mudflats on the Cheshire bank. The construction of the Manchester Ship Canal destroyed large areas of salt marsh and diverted river flows through sluices which thus removed their scouring effect.

Dredging removed some of this depreciated sediment and increased current strength and facilitated navigation. In the process, sediments are sometimes resuspended which if containing toxins increase the chances of them being consumed by invertebrates and getting incorporated into the food chain. Bio-

Figure 7.1: Network of Interaction of Causes and Effects of Development Activities on Estuaries

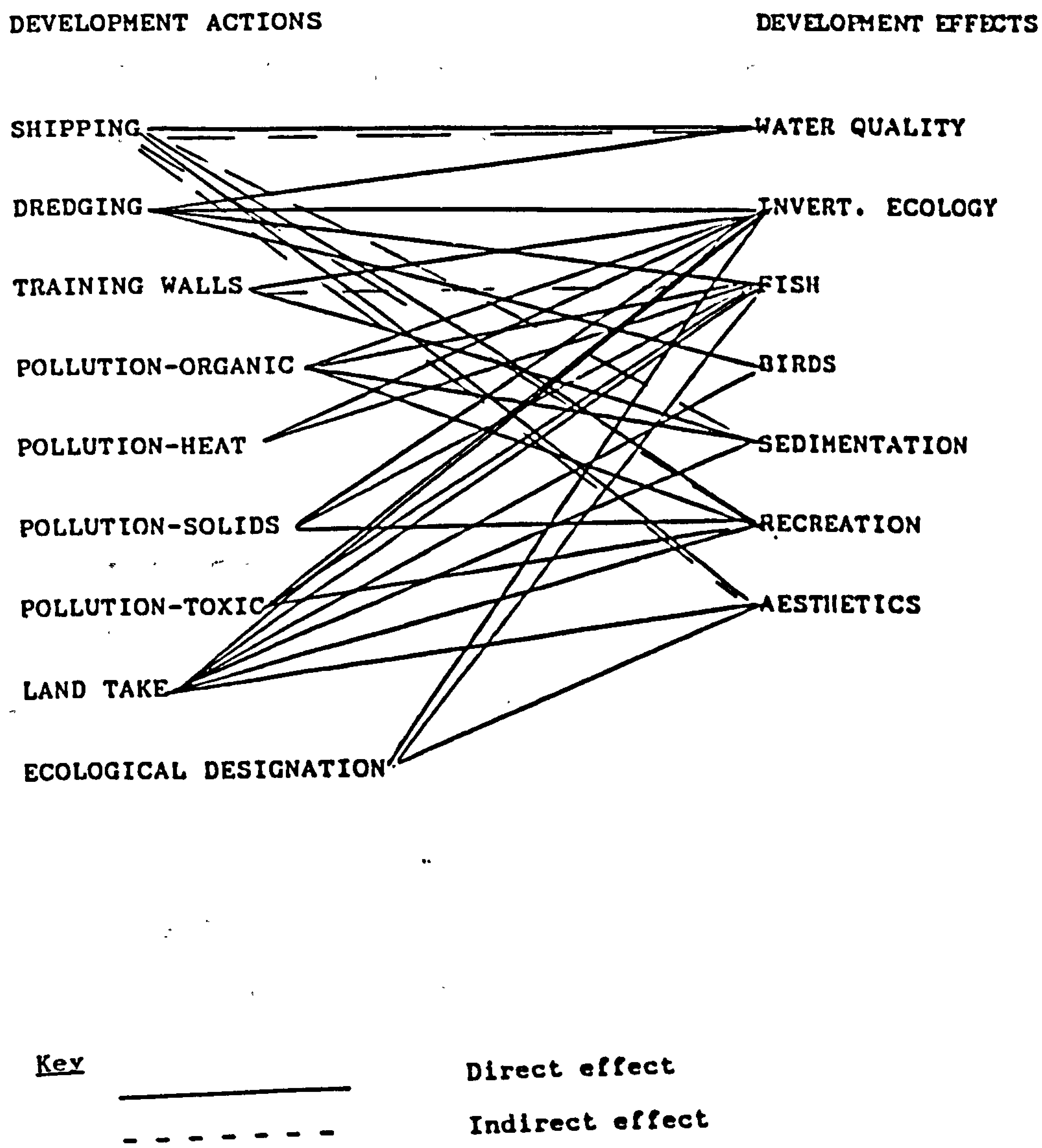


Key

———— Direct effect

- - - - Indirect effect

Figure 7.2: Network of Interactions: Causes and Effects of Development Actions and Environmental Factor'



accumulation of toxins along the food chain could lead to food poisoning and possible death of high order consumer' including Man. Disposal of dredged materials from the Ship Canal into fresh water pools has also destroyed bird feeding sites.

Using the information provided by Tables 7.2 and 7.3, I then produced figures 7.1 and 7.2 which give a visual impression of the interaction between various forms of development and related impacts of the environment.

7.2.3 IMPACT MATRIX

Having identified the impacts of development activities and their interactions on the environment, which provide qualitative information, I then went on to produce a matrix so as to be able the assess these impacts quantitatively, using the information provided in earlier tables and figures. A modified Leopold matrix was used to assess the magnitude and importance of impacts (as define in chapter four). The weights assigned are on a scale of 1-10 as follows:

1-3 = low impact

4-6 = moderate impact

7-10 = high impact

Table 7.4: Modified Leopold Matrix of Impact of Development Action and Environmental Effects on estuaries using the Mersey as an example

DEVELOPMENT ACTION / ENVIRONMENTAL EFFECTS	SHIPPING	DREDGING	TRAINING WALL	POLLUTION				LAND TAKE	ECO. DESIGNATION
				ORG.	HEAT	SOLIDS	TOXIC		
WATER QUALITY	4/7	2/2		5/7	2/2	4/3	3/4		
INVERT. ECOLOGY		2/2	3/3	6/6	1/1	2/2	1/1	6/6	+2/3
FISH		3/4	4/3	7/5	2/2	3/3	1/2	1/2	+3/5
BIRDS							1/1	3/3	+3/3
SEDIMENTATION	1/1	+5/5	5/5	2/2				2/2	1/1
RECREATION	2/2			3/3		3/4	1/1	2/2	1/1
AESTHETIC	1/1								+2/2

WEIGHT JUSTIFICATION

The weights assigned in the Table 7.4 above are analyzed and justified. Each impacts is broken into Magnitude and importance: Magnitude is considered to be a measure of the "degree, extensiveness or scale" of an impact and is assessed on the basis of information from the text. Importance is considered as the significance of an impact and is a subjective judgement on the part of individual investigator.

In the Table above, the magnitude of the effect of shipping on water quality is judged 4 and importance 7. The reason is that water quality effects resulting from shipping are in form of accidental spillages of oil which is usually rare. In the Mersey an average of two accidental spillages greater than one tonne are recorded every year (chapter 6.3) but so far the most damaging effect was recorded after the August 1989 accidental discharge and even on that occasion the extent of the damage was not very high because of the prevailing weather conditions.

However, the Torry Canyon incident in Cornwall, March 1967, contaminated a total area of 345 km^2; the Exxon Valdez, 1989 incident result in a spillage which spread out of Prince William Sound into the Gulp of Alaska, the Lower Cook Inlet and the fjords of Kenai Peninsula. Salmon hatcheries which provide over 50% of the Prince William Sound peak salmon harvest amounting to $35,000,000 a year was destroyed. In addition large numbers of sea otters and birds were destroyed. Clean up operation cost up to $1,280 million (chapter 5.1.2). In France the Amoco Cadiz spillage of March 1978 on the coast of Britanny killed in excess of 4,500 sea birds and cost 25% drop in visitors to Breton region in the following holiday season. The huge cost involved in oil spillages justify the high rating for importance of impact of shipping on water quality.

The impact of dredging on sedimentation is judged 5 in magnitude and 5 in importance. In the Mersey Estuary the level of dredging was moderately high for instance between 1891 and 1931 a yearly average of 1.9 million cubic yards was removed from the Estuary. In terns of navigation, the impact is positive since dredging alow ships to sail and importance of 5 is attached.

The effect of training walls as discussed in chapter 6.1, promote sedimentation by altering current and tides as the case of training the Crosby Channel in the Liverpool Bay or they may remove fresh water scouring as in case of construction of the Manchester Ship Canal. The degree of sedimentation promoted by this process in the Mersey is considered to be high and assessed as 5 in magnitude. Sediments accrete navigation channels and smother organisms such fish and invertebrates and hence the importance is assessed as 5.

Organic pollutants raise the level of B.O.D and lowers that of D.O. thus making conditions inhabitable for most living organisms. Lack of dissolved oxygen in waters of the Mersey Estuary reached a very critical level particularly in Upper Estuary especially in 1960s as illustrated in the last chapter. The high B.O.D and low D.O. in Mersey are judged 5 in magnitude and 7 in importance. The magnitude is judged so because the situation has since improved greatly and importance of 7 is in view of the role played by oxygen in life as further illustrated below.

The presence of some 120 species of invertebrates in the Outer Estuary where dissolved oxygen remain in excess of 60 % and only 26 in the Inner Estuary with 10% or less D.O. shaw how far organic pollution may restrict species diversity and is judged as 6 in magnitude. The position of this group of animals in the food chain is important particularly for birds and is also assessed as 6.

Fish are even more sensitive to organic pollution than invertebrates, as for instance by 1948 all commercial fish disappeared from the Mersey, and hence the magnitude is judged 7. At its peak period the fish industry supported up to 53 boats. The loss of all of these is considerable and is assessed 5.

Land take from estuaries displace many plant and animal species, and often deprives wading birds of feeding and roosting grounds. In the Wash Estuary 47,000 hectares have been lost since Roman time and 8,000 ha have been lost from the Severn. The Mersey Estuary has lost over 500 ha since 1800 and the neighbouring Dee over 6,000 ha since 1750. In San Francisco Bay on the Pacific coast of USA only 6% of the original 2,200 Km^2 remained as at 1986 (Chapter 5.2). Since most of the area lost is the invertebrate habitat, the magnitude of this impact is assessed 6 and its importance also 6 because most areas claimed from the Estuary are permanently lost (Fish are similarly affected by loss of habitat but to a lesser degree than the invertebrates and is assessed 4 in magnitude and 5 in importance).

Ecologically, designated areas permit the growth of fish in hatcheries, for instance as in the case of Prince William sound. Although the number of such designation is limited, assessed 3, their importance is moderately high and assessed 5. Using the information in Table 7.4, a summary matrix identifying all major activities and categorization of key impacts generated into adverse and beneficial is presented in Table 7.5.

Table 7.5: Impacts of construction activities on water quality of the Mersey Estuary.

CONSTRUCTION ACTIVITY	RELATIVE QUANTITY RELEASED BY CONSTRUCTION							EFFECTS OF POLLUTANTS	
	SEDIMENT	NUTRIENTS	HEAVY METALS	BIODEG. ORGANICS	REFR. ORGANICS PESTICIDES	OILS & SYNTHETIC CHEMS	HOT WATER DISCHARGE	+ve	-ve
OUT-OF-STREAM ACTIVITIES (EARTH MOVING)									
. AREAL (Suburban Devm't - Business/ Commercial Devm't; residences, streets, shopping centres, parking lots, public buildings; Reclamation Land fills, dredging spoil on-land, earth dams. bridges, tunnel and rail).	L	M	L	H	L	M	L	MSC protect Ince and Stanlow marshes which are important bird feeding sites.	Remove river scour and promote siltation of inner estuary, results in costly losses of flora and fauna.severe deterioration of water quality.
IN-STREAM . Training nav. channel, dredging operation, dock walls.	H	L	L	L	L	L	L	accretion of intertidal banks which support invertebrates and salt marsh, stabilize low water navig. channel, remove heavy metals and other toxins.	siltation of inner estuary and navigation channel, smother invertebrates and fish, disorient fish, reduce flushing frequency.

Key (Degree of impact)
H: High L: Low
M: Medium

8 SUMMARY, DISCUSSION AND RECOMMENDATIONS

8.1 SUMMARY

My studies have shown that estuaries are highly productive ecosystems with very high potential for commercial and sport fisheries, are nursery grounds for a number of migratory none-estuarine fishes, such as Salmon and feeding grounds for large numbers of a variety of birds (Barnes, 1972 ; Wilson, 1988, Wheeler, 1979, Clark, 1989; Odum, 1971 and Hodgson, 1980).

In Chapter One, I outlined the various forms in which estuaries exist and their variable salinity distribution. I also described deposition of sediment from the sea and rivers and its accretion within estuaries and how the erosion of sediments from one part of an estuary and deposition in another part and the movement of the eroded sediment out of estuaries together with the strength and direction of tides and currents are all factors which influence the shape of estuaries.

I have also shown that the coast of Britain is the most indented with estuaries in Europe, a factor that may be due to the location of the Island surrounded by seas such as the Irish Sea and the Atlantic Ocean and to the geomorphological formation of the land (Gresswell 1964).

The physicochemical dynamics of estuaries exert a significant influence on their economic usage by Man. For example, the siltation of the Dee Estuary in the early 17th century caused the decline of trade to Chester and its ultimate transfer to Liverpool on the Mersey Estuary.

The Mersey Estuary, its origin, extent, location, physical and biological characteristics have been described in Chapter two. The Estuary is classified along its length into four sections : the Outer Estuary linked to the Liverpool Bay, in the Irish Sea, the Narrows and the Inner Estuary, where it expand after the Narrows and the Upper Estuary ending at the tidal limit in Warrington.

Tidally induced water movements dominate the Estuary due to presence of a large tidal range. The Narrows records the highest tidal current speed exceeding 2.5 m/sec. A factor attributable to its width and configuration.
Ghose (1979) recorded a total of 135 species of invertebrates in the Estuary (Table 2.3). The diversity of the species increases towards the Outer Estuary. In the Inner Estuary only 26 species were recorded, 38 species in the Narrows and 120 species in the Outer Estuary. This increase in diversity correspond with level of dissolved oxygen along the Estuary. In the Dee Estuary, the inner estuarine species correspond with those which in the Mersey are typically restricted to the Outer Estuary. Thus showing factors other than salinity, which in the case of the Mersey are pollutants, as being responsible for the distribution of the benthic organisms.

In terms of density, the up to 28, 000 / m^2 of Macoma were recorded in the Dee whereas in the Mersey a maximum of only 10, 000 / m^2 were recorded as at 1979. Scrobicularia plana was one of the abundant species in the Dee during the 1970s but was not found in the Mersey (Ghose 1979). Studies of individual species revealed that the growth of Pygospio elegans and Hydrobia ulvae was retarded in the Mersey when compared with growth of similar species in the Dee and Lune Estuaries (Ghose 1979)

Commercial fishing start to decline in the Mersey 1930s and had completely ceased by 1948. The rapid rate at which fishing activity diminish at that time when there were no major construction activities in the Estuary suggest influence of deteriorating water quality during the period and since fish are generally more sensitive to pollution, commercial species disappeared even before the 1960s when oxygen levels start to fall to 0 % level.

Changes in the diversity and fish species in the Mersey Estuary were described. Johnston (1910, 1928) reported a very prosperous fish industry along the Mersey in 1908, forty years latter the fish had disappeared and since then the Estuary was thought to be devoid of fish until 1972 when Corlett and O'Sullivan reported fishing by small trawlers on the banks of the Outer Estuary. Investigation by Srivastava (1982), revealed that the Estuary is gradually recovering some of its lost fish species. She recorded a total of 31 species (Table 2.7). Twenty nine of these species were found in the Outer Estuary and only five in the Inner Estuary. This distribution also correspond with level of dissolved oxygen along the Estuary suggesting that the

Inner Estuary was still not clean enough to support most of the fish species. Holland (1989) reported further improvement in the Estuary recording a total of 51 fish species including 11 fresh water species found drawn to the Manchester Ship Canal. The other 41 species include marine, estuarine and migratory fish. Also, he reported the presence of mullet as far upstream as Eastham, whiting were found at Hale Head in 1988 and dead salmon species found on the banks at different points.

The Mersey is one of the most important estuaries in the U.K. today in terms of the conservation importance for populations of bird species with at least six species in numbers of international importance and seven of national importance (Table 6.5). One, however, notes that high numbers of birds started to appear from around 1970. This correspond with improvement in Estuary water and increase diversity and density of biota and especially the benthic invertebrates, which constitute the bulk of the bird prey.

Before the advent of industrial revolution, estuarine dynamics was dependent on changes in the natural environment. However the advent of the industrial revolution attracted manufacturing industries and large human populations to live around estuaries. In chapter three the growth of population and industry around the Mersey Estuary was described. Liverpool is identified as the most important town in the Merseyside area. The population of the town rose dramatically from 78,000 in 1801 to 223,000 in 1841.

Environmental Impact Assessment (EIA) has been used as a tool in the assessment of impact of human activities on estuarine environment. The development, process, techniques and problems of EIA have been described in chapter four. The requirement for EIA in Britain was legalised in 1985, although other forms of environmental regulations existed for over a century. Checklists, Matrix and Network methods have been found very helpful in assessing human impact on Estuaries.

A general view of human impacts on estuaries is presented in the fifth chapter. Land claim, mineral extraction, pollution and tidal barrages have identified as the main human activities. Impact generated by land-claim includes habitat loss, accretion and recolonisation by salt marsh vegetation and alteration of the landscape visual quality. Similarly the extraction of material and to a lesser extent bait collection destroy habitat and contribute to pollution.

Other forms of human use which caused adverse impacts on the estuarine ecosystem are summarised in table 5.1. Land claim for agriculture as in the case of the Wash and Ribble (Davidson et al 1991) and for building and construction in the Wadden Sea in the Netherlands (Vranken et al 1990). Land claim by sea defence may influences the estuarine environment by changing salinity and sedimentation pattern where current flows of streams and river discharge to estuaries were restricted, thus reducing the volume of fresh water and its scouring effects. Habitat modification by severing tidal influence prevent sea water from reaching some part of the estuarine habitat and in some cases the habitat has been completely destroyed (McLusky et al 1990; Vranken et al 1990 and Beeftink 1975). Biological land claim by for instance the spread of the Spartina results in rapid modification of estuarine habitat by change in plant community and also promotes sediment accretion (Ranwell 1964).

In Chapter five I also describe the effect of organic and inorganic pollution in estuaries. Generally organic pollution lead to lack of dissolved oxygen and consequent loss of biota including commercial fisheries. Inorganic pollutants, such as Mercury are known to cause death of algae at level as low as 0.01 mg/l (Bryan, 1971). Other elements with toxic potential such as Cu, Pb, Cd are also known to accumulate along the food chain and could cause death among the high order consumers, e.g. fish which may can contain up to 15 times as much mercury as in algae (Anderson, 1971 and Rees and Nicholson, 1989). The presence of excess nutrients causes primary production in excess of energy requirement and the excess product when decomposed may lead to oxygen depletion. The occurrence of such a situation caused massive fish kill in New Jersey with a loss amounting to $60 m in the commercial clam fishery (EPA, 1987).

High temperature in estuaries caused by pollution, change the metabolic rate of many aquatic animals and can lead to their death when the limit is exceeded (Clark, 1969 and Brett, 1956).

The practice of discharging liquid nuclear waste by pipeline into coastal waters posses potential hazard to estuarine environments in the event of leak or accidental spillage. In the

UK, waste water produced at Sellafield is discharged into the Irish Sea (Kershaw et al 1992). Hence there is a possible hazard to the Mersey and its neighbouring Dee and the Ribble Estuaries.

The transportation of large volumes of oil is another hazard affecting the estuarine ecosystem. Several cases of oil spillages have been reported, for example the Torrey Canyon in Cornwall, resulting severe damage and death of about 70 species of flowering plants, 20 species of lichens and at-least 16 genera of algae (Ranwell, 1968). The Exxon Valdez tanker spillage on the very rich fishing grounds, the Prince William Sound, causing an estimated damage of over US, $35 m from fisheries alone, Killed over 27 000 birds and several of other wildlife species including large numbers of sea otters and over 0.2 % of the 5, 000 strong American bald eagle. The total cost of the clean up operation involving 10,000 workers, 1,000 vessels and 70 aircrafts came up to US $I,280 million. The Amoco Cadiz incident on the Britany Coast in 1978, cost the company a total of Frs 377 million.

The construction of barrages across estuaries carries a possible risk of loss of vital fishing grounds and bird feeding sites as predicted in the case of Severn Estuary . Intertidal feeding areas will be lost by permanent inundation for such birds as the Grey plover, Black-tailed godwit, Redshank, Knot and Dunlin. Other effects anticipated from the Severn Barrage are the reduction of tidal range by half on the landward side and change in flushing. Barrage proposals on the Wash, the Dee, Morecambe Bay, and Solway will involve inundating most of the rich intertidal muds, leaving only the less fertile sands towards the sea. This situation constitutes a very serious hazard to over 1.5 million wading birds which constitute about one third of the total of such birds present on the coastline of Britain. The Construction of a barrier system on the Eastern Scheldt Estuary caused a reduction on mean tidal current velocities, increase in mean water residence time and increase in particulate carbon which may enhance sedimentation, followed by reduction in total capacity of the estuary.

In chapter six, my research showed that the construction of training walls along the navigation channels within the Estuary of the River Mersey caused an increase in flow of sediment into the Inner Estuary from the Irish Sea. The construction of the Manchester Ship Canal in 1894, limited river flows and removed their scouring effects by channelling fresh water via sluices and the diversion of the River Weaver after reclamation of the marshes in 1896 block the river from tidal influences resulting in loss of substantial intertidal area. The overall impact of these construction activities has changed sedimentation pattern in the Estuary leading to increase bed hight, reduction in volume and consequent change in flushing as well as changes in the position of low water navigation channels. The sediment material deposited in the Estuary is in approximate proportion of 3:1:1 for sand, muddy sand and mud (Head 1990). The sandy material is normally poor in organic matter and nutrient and hence does not support abundant biota. The other reason for poor biota in the Estuary since 1930s is the probable smothering effect of sediments, as large volume of sand move into the Estuary.

Discharge of domestic sewage, industrial effluents; industrial storm overflow into the Mersey Estuary resulted in severe deterioration in water quality and loss of its fishes and other organisms.

In chapter seven Environmental Impact Assessment (EIA) was used to assess impact of construction activities and pollution in Estuaries. The checklists method, Impact network and modified Leopold matrix have been found to be most useful in assessing human impacts in estuaries. Application of EIA and the results obtained are discussed in the following section.

8.2 DISCUSSION

Environment Impact Assessment technique has become a widely accepted tool in various part of the world for the identification and prediction of impacts and precede any approval for major developments but was rarely applied for estuarine environment. Hence this attempt is made as part of pioneer effort in application of EIA in estuarine management.

It is remarkable to learn that the available EIA techniques can be satisfactorily applied to assess the environmental impact of human activities on estuaries. In particular, the use of checklist help to identify all the major impacts as illustrated in Table 7.1. The network method define the link in cause and effect relationship between activity and the natural environment, it also identify the link between one activity and another and how several activities affect one environmental component (Table 7.2 & 7.3 and Figures 7.1 and 7.3). Application of leopold's matrix helped in quantification of magnitude and importance of impacts within a given scale (Table 7.5).

The network of interaction of causes and effects relationships of development activities and environment (Figure 7.1 & 7.2) form the basis of this discussion. Dredging of the Estuary navigation channels leads to a number of effects including increase in depth of the channels thus creating extra space to be filled by water. Filling the additional area without a corresponding increase in the volume of water that flows into the Estuary would mean reduction in tidal range so that areas that are normally covered by tidal water or now exposed. Depending on the extent of exposure corresponding physical and chemical changes occur which inturn affect the biota inhabiting the exposed area. Thus changing the ecology of the Estuary and affecting its conservation value.

In the course of dredging solid suspension is raised in the water column. This reduce the depth of solar radiation and inturn reduce primary productivity in the Mersey Estuary, phyton plankton population increases dramatically with improvement in water quality (see chapter two). Also suspended solids are inimical to fish movement. In addition toxic heavy metal incorporated in sediments are now released in water column indirectly adding to the pollution problems. In Mersey, the level of heavy metals in sediment very with the exception of Mercury and therefore dredging does not pose a serious pollution hazard.

Dredging channels can promote erosion especially in sandy bottom channels. Training walls are then erected to check erosion and to direct water flow. Ecological changes follow on either side of the wall. Increase water flow within a narrow confine of the training wall will increase its speed and can alter sedimentation pattern as happened in the Mersey after training the crossby channel. Pattern of sediment movement change from seaward to landward direction as already explained in chapter six. Increase flow of solid material in estuaries can lead to smothering of biota and destruction of fish habitat. In the Mersey Estuary low water channels were filled with sand and fish habitat destroyed with loss in commercial fishing. Movement of sand in the Inner Estuary of the Mersey and in the Navigation channels necessitate large scale dredging.

Organic pollution in estuaries decrease the level of dissolved oxygen leading to death and disappearance of many animal species including fishes and invertebrates which are important for commercial and conservation use of an estuary. Disappearance of species of organisms will lead to changes in the food chain leading to ecological readjustment. Organic effluent mix up with sediment and accrete in estuary channels and where the level of accretion is high it makes dredging necessary.

The effect of heat pollution on estuarine organisms is discussed in chapter five. such changes either of increase production or death of organisms will affect the overall ecological balance. Increased production could lead to over production and eventual population crush, thus increasing organic pollution. So ecological imbalance is likely to result due to increase heat in an ecosystem. Hot water discharge in the Mersey is not likely to cause significant changes due to limitation in area at the discharge point. The effect of pollution depend on the level of water available, in well dredged channel the impact of the heat pollution is less.

Land take from estuaries reduces the extent of estuarine habitats for instance in the wash (Figure 5.1). Ecological changes flow after land take. Accretion is promoted on the seaward direction and further squeezing of the estuary. Where waste disposal take place, as is often the case, organic and toxic pollution can result due seepage.

Ecologically designated sites may require some form of land take to protect them and dredged channels to ensure flow of estuarine water.

Causes and effects of development actions and environmental factors is shown in Figure 7.2. Shipping exert both direct and indirect effects on water quality in estuaries. Direct effects are mainly from accidental spillage as in the case of Torrey Canyon, Exxon valdez discussed in chapter five and the Mersey August 1989 spillage discussed in chapter six.

Removal of sediments from estuaries directly effect invertebrate and fish habitats that are destroyed in the process. Water quality is affected by suspending sediments and toxic heavy metals. The effect of pollution on fish and invertebrates is already discussed. Fish eating birds find it more difficult to predate in turbid waters. Deposition of dredged materials create islands around the estuary which diminish its aesthetic quality.

Apart from impact on the ecology, solids waste effluents brought a shore by tides on the beeches, destroy their recreational value. Sources and effect of pollution in the Mersey are described in chapter six. In chapter five a more general view of different estuaries is given.

In conclusion, I would like to draw readers attention to the very variable nature of estuaries. This variability derives from two sources of natural circumstances and differing sources of economic development. In chapter one of my thesis I demonstrated how geological factors affect the morphology of estuaries and so the water regimes within them. I have also discussed how differing tidal height affects water regimes and such be added the differing effects of climatic factors such as temperature and rainfall. The thesis has estuaries in temperate regions but it must be remembered that in tropical areas climatic factors may vary extensively over a twelve months period.

The natural variability of estuaries outlined in the thesis and summarised above means that even without human interference no two estuaries are like. Each estuary must be regarded as a special entity.

Onto this natural variation is superimposed the effects of economic development, which are also very variable in terms of both time and space. In the context of the Mersey I have shown that economic development has varied historically with a peak in adverse effects probably being reached in the period 1950-1970.

I have also demonstrated that some form of economic development have greater environmental effect than others. The situation is probably most dramatically illustrated using the example of organic pollution. Again, using the estuary of the Mersey as an example, pollution levels are now falling and the effects of pollution on the estuarine ecology is diminishing. In terms of ecological impact the construction of dock walls and land take will have long lasting ecological effects. This situation in the Mersey illustrates an important point. Traditionally, the public has perceived that "POLLUTION" has been the main cause of ecological/environmental disruption in the Estuary. In the long term this view can be seen to be incorrect.

In terms of space, economic development also varies from estuary to estuary. This situation can be seen by comparing the levels of urbanization between the neighbouring Dee and Mersey. In addition whereas development on the Mersey has been industrial, on the wash, it has been land reclamation for agriculture.

A common place saying is, "Estuaries are very variable". I have demonstrated that it is nevertheless a true comment.

In the context of environmental impact assessment this variability means that each development on each estuary must be regarded as being unique and so be subject to a level of investigation above that which may be acceptable for most purely terrestrial development. An additional problem in this context is that although general estuarine processes are now well understood few estuaries are as well known environmentally as those of the Thames and Mersey. This lack of knowledge means that the environmental impact assessment of economic development projects on many estuaries is likely to be a difficult procedure. A greater understanding of all estuarine processes is therefore needed and detailed information on estuaries which may be subjected to economic development needs to be collected.

Nevertheless, I believe that I have demonstrated that standard environmental impact assessment techniques could be applied to estuarine environment and that by so doing the adverse effects of economic development may be reduced.

8.3 RECOMMENDATIONS

1. In view of the limited information on most estuaries, I recommend that EIA be conducted on all major development activities on estuaries before the implementation of project.

2. I suggest that the checklist and weighted matrix method are probably the most practicable EIA methods applicable to estuaries and I recommend the two techniques for any attempt to carry out EIA on estuaries.

3. There is the need more research on estuaries to generate the information necessary for clearer understanding of their dynamics and ecology. This information is very vital for any attempt to conduct EIA on estuaries.

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