SEDIMENT REDISTRIBUTION IN THE UILKRAALS ESTUARY AS A CONSEQUENCE OF HUMAN DISTURBANCE

BY

J. CROWTHER

A research report submitted in partial fulfilment of the requirements for the degree of Master of Science in the Department of Environmental and Geographical Science
University of Cape Town
September 1988

ABSTRACT

The construction of bridge embankments and other physical obstacles in estuaries has often resulted in the redistribution of sediments, which ultimately leads to detrimental impacts in these environments. The aim of this study is to investigate how the sediment distribution and dynamics within a specific estuary, the Uilkraals estuary, have been affected by human disturbance; focusing on the impacts arising from construction of two temporary embankments and a permanent bridge and embankment.

The Uilkraals estuary is situated in the south-western Cape, approximately 60 kilometres north-west of Cape Agulhas. Human impact has been extensive and engineering projects of various sizes and permanence have marked the recent history of this estuary. A bridge and embankment which cross the estuary 800 m from the mouth were built in 1973. In 1978 an embankment was built between the bridge and the estuary mouth. A second embankment which replaced the first in 1980, was removed before the end of that year. Extensive dune reclamation occurred on the left bank between 1938 and 1973.

The techniques used in the study include: (i) a quantitative analysis of all available aerial photographs from 1938 to 1987 (ii) a ground survey and (iii) core and surface sediment sampling. The quantitative analysis reveals that the major changes in estuarine characteristics have been in response to human disturbance. The contour map and cross-sections drawn from the ground survey indicate a build up of sediment downstream of the bridge and scouring of the channel upstream. The latter suggests the dominance of the flood-tidal current in the estuary. The core sediment analyses are unable to distinguish any real difference in the modes of sediment deposition on either side of the bridge embankment. The embankment has, however, affected deposition by acting as a "hydraulic shelter" to sediment accumulated downstream of the bridge during high run-off events and by initiating deposition of sediment upstream of the embankment. The surface sample analyses indicate that there has been an increase in flow velocities in the vicinity of the bridge since its construction and that the major agents which bring marine sediment into the the estuary are flood-tidal currents and wind.

It is concluded that the sediment distribution and dynamics of the Uilkraals estuary have been affected by human disturbance. Recommendations for future management of the estuary are that no further embankments should be constructed in the estuary and that the construction of a culvert or culverts under the existing bridge embankment would alleviate a number of problems presently experienced in the estuary.

ACKNOWLEDGEMENTS

The author is indebted to the former National Research Institute of Oceanology at Stellenbosch for the use of equipment, and for the help and assistance given by staff during the course of this study. Special acknowledgement must be given to the following people:

* Dr. Harry Swart for his help in initiating the project and permission to use equipment and personnel for the study

* Mrs Joe Perry for her help and guidance with the aerial photographic work and enthusiasm throughout the study

* Mr Laurie Barwell and Mr Piet Badenhorst for giving up their valuable time to take the core samples, and for much advice and many discussions about the project

* Mr Willie Daniels for undertaking the settling tube analysis and for help with the sampling of the cores

* Mr Pat Morant and Mrs Helene Heydorn for their assistance in obtaining literature and information

* Mr Leon van der Merwe for additional surveying of the datum heights

Survey data supplied by Mr B. Kingwell of Escom is gratefully acknowledged.

Many thanks must go to Jerome Barrit for the survey work, Mike Reaper for assisting with the surface sediment sampling, Susie Brownlie for constructive critism of the document, and Louis de Villiers for help with obtaining the core samples and continuous support during the writing of the report.

The assistance of Mrs Linda Lavery with MS Word and Lotus, and Mr Andy Vinnicombe with cartographic advice and diatyping, is acknowledged with gratitude.

Final thanks must go to Dr Mike Meadows for his supervision and guidance throughout this study.

All figures that appear in this report, unless otherwise stated, have been drawn by the author.

CONTENTS

PAGE

LIST OF FIGURES

Page

LIST OF TABLES

Page

LIST OF PLATES

CHAPTER ONE

INTRODUCTION

PAGE

CHAPTER ONE

INTRODUCTION

1.1 INTRODUCTION TO THE STUDY

In recent years there has been much discussion in South Africa and in other countries about the importance of either maintaining estuaries as close as possible to their natural state, or exploiting them as areas for recreation and development. Day & Grindley (1981) write that the protection of the estuarine environment in the long term is essential if the natural resources provided by estuaries and the quality of human life near them are to be maintained. While the need to preserve estuaries has been stated by several authors, engineering projects which lead to detrimental impacts are continually being carried out in these environments.

One such type of engineering project which has led to considerable debate between engineers and planners on the one hand, and scientists on the other, has been the construction of embankments and bridges across estuaries. Ecological problems result from the common practice of building the major part of bridges on embankments and allowing only relatively narrow passages for the throughflow of water under spanned sections. Embankments can have highly detrimental ecological impacts by restricting water flows, either during daily tidal exchange cycles or during floods when they tend to act as dam walls (Heydorn & Tinley, 1980). Heydorn & Tinley (1980) state that there are many estuaries where consequent damage in the form of siltation, sanding up, erosion or ecological degradation can be demonstrated. Despite these problems, transport planners and engineers, in stressing the need for good transport links along the South

African coast, believe that the only cost effective way to cross many estuaries is by building long embankments. These often entail inadequately short spanned bridge sections. Very few planners and engineers seem to appreciate the environmental impacts of such structures.

The sedimentation in many of South Africa's estuaries has been affected by bridges and embankments built across them. Begg (1978) and Heydorn & Tinley (1980) point out that there are numerous examples where bridge construction has resulted in the build-up of sediment in estuaries. In Natal for example, a 480 m embankment across the Mdloti river has resulted in increased sedimentation upstream of the structure (NRIO, 1986). Beaumont and Heydenryck (1980) discuss how construction works across the Diep river system have been partly responsible for the silting up of what was once a tidal lagoon to form a large dry pan.

On the other hand Rooseboom (1979, cited in Grindley & Heydorn, 1979) contends that bridges are relatively innocent structures in initiating estuarine sedimentation, and that the greatest changes in estuaries are caused by changes in the character of the water and the land-use in the catchment. Several other studies (Bruton & Appleton, 1975; Weaver, 1977; Begg, 1978; Esterhuysen & Rust, 1987) indicate that, in the absence of the external influences mentioned by Rooseboom, bridges and embankments have, to some degree, initiated sedimentation and changed the natural functioning of the estuarine environments.

This study examines a specific estuary of the south-western Cape, namely the Uilkraals estuary. The main aim of this study is to investigate how the sediment distribution and dynamics within the estuary have been affected by human disturbance. The study concentrates specifically on the influence that a bridge embankment and two temporary rubble embankments have had on the sediment distribution within the

Uilkraals estuary. The direct impacts of the embankments as well as the secondary impacts which have arisen as a result of the sediment redistribution are examined. Many of the secondary impacts have been noted by other researchers.

1.2 SELECTION OF THE STUDY SITE

The Uilkraals estuary was chosen for this study as it is ideally suited to illustrate the impacts of embankment construction on an estuarine system. The bridge, with a spanned section of 100 m and an embankment of 120 m, was built in 1973 and appears to have changed significantly the morphology and dynamics of the system (Heydorn & Bickerton, 1982). Flow in the estuary has been restricted to a narrow channel under the bridge, while a significant amount of sediment has been deposited on either side of the bridge embankment. Problems have subsequently arisen in trying to control the channeled waterflow which is presently threatening to erode a sand promontory carrying holiday bungalows.

A rubble embankment was constructed by the local divisional council in early 1978, with the intention apparently of reclaiming part of the estuarine area as beach adjoining the caravan park and camp site (Gaigher, 1978). This was removed in early 1980 and a second embankment built in May/June 1980 in order to rectify the problem of a stagnant pool and a series of sand dunes which had formed in front of the holiday bungalows. The second embankment, from the opposite bank, was built to force the river back into its original position. Before December 1980 this embankment was removed by the divisional council on the advice of personnel from the CSIR at Stellenbosch, as it was feared that this would increase the possibility of flooding in the caravan park.

In addition to the history of engineering projects in the estuary, there are several other reasons for having chosen the Uilraals for this study. These are:

- that there is a good set of aerial photographs of the estuary. The earliest dates back to 1938 and the most recent was taken in February 1987. Of the seven photographs available for analysis, three were taken in 1980, thus giving excellent coverage of the impacts of the temporary embankments during that year

- the estuary is of an appropriate size for this type of study and

- the estuary is within easy access of the University of Cape Town.

1.3 RATIONALE FOR THE STUDY

The study meets the main criteria of the South African National Committee for Oceanographic Research (SANCOR) Estuaries Programme for the period 1982-1991 and this is "...to provide a scientific understanding of estuaries - in particular of the interactive physical, chemical and biological processes within them, of their inter-action with the fringe areas and with their adjacent marine and terrestrial environments and finally of human impacts upon them - thereby contributing information required for their wise management " (SANCOR, 1983, p.3). In the SANCOR Newsletter (1986, p.2) the working group appointed to investigate the future Estuarine Programme highlighted, among other points, that " human influences in and manipulation of estuarine systems are of the utmost importance and should receive sufficient attention in the planning of research ". Further information of the Estuaries Programme is given in Appendix I.

This study adds to the limited research which has been conducted on sediment redistribution in estuaries as a result of embankment construction. Information gained from the study will also be useful for the future management of the estuary.

1.4 OBJECTIVES OF THE STUDY

The objectives of this study are:

1. To describe the temporal changes in sediment distribution which have occurred in the Uilkraals estuary since 1938.

2. To describe the present sediment distribution and dynamics of the lower Uilkraals estuary.

3. To determine the significance of the impacts of bridge construction and the temporary embankments on the sediment morphology and dynamics of the Uilkraals estuary.

4. To provide recommendations for the future management of the Uilkraals estuary.

1.5 APPROACH TO THE STUDY

Three techniques have been employed to meet the objectives set out above. These are:

- a quantitative analysis of aerial photographs
- a ground survey of the sediment topography and
- core and surface sediment sampling and analysis.

The quantitative analysis is aimed at measuring changes that have occurred in selected estuarine characteristics between the dates of photography and provides an understanding of the long term functioning of the estuary. Diagrams illustrating the selected characteristics have been drawn for each of the seven photographs. The quantitative analysis meets the first objective set out above.

The ground survey was conducted using a standard survey method. The contour map and cross-sections drawn from these data illustrate the present sediment distribution and assist in the interpretation of the sediment dynamics in and around the estuary.

Statistical analysis of the core samples reveals information on contemporary sedimentation in the estuary. The surface sample analysis gives information on surface processes operating at present. The ground survey and the sediment analyses will meet the second objective of the study.

Results from all the techniques have been used to determine the impact of the bridge and permanent embankment, while the impact of the temporary embankments is gauged from the quantitative analysis and past work only. Additional information from the literature and other sources has also been drawn upon. Guidelines for the recommendations are then made on the basis of all the data gathered in the study.

The structure of the report is as follows. Chapter Two provides a theoretical background to estuarine sediments and their behaviour, discusses briefly the uses and degradation of estuaries and outlines some research work that has been conducted on the impacts of bridges and embankments in South Africa. Chapter Three consists of a site specific and regional description of the study area. The techniques used, namely aerial photography, ground survey and sediment sampling are described in Chapter Four. In each section the relevant background to the techniques is discussed. Chapter Five presents the results and in Chapter Six they are discussed. Conclusions to the study and recommendations for future management of the estuary are made in Chapter Seven.

CHAPTER TWO

ESTUARINE SEDIMENTS AND HUMAN INTERACTIONS

Page

CHAPTER TWO

ESTUARINE SEDIMENTS AND HUMAN INTERACTIONS

This chapter begins by defining the term "estuary" as it is to be applied in this study. This is followed by a general description of estuarine sediments, including the source and nature of sediments, their deposition, sediment circulation, and the importance of sediments in the estuarine system. Thereafter, there is a general discussion on the uses of estuaries to mankind and how humans have been responsible for their degradation. The final section examines impacts that bridges and embankments have had on South African estuarine ecosystems.

2.1 DEFINITION OF AN ESTUARY

Prichard (1967,p.3) defines an estuary as "...a semi-enclosed coastal body of water which has a free connection with the open sea and within which sea water is measurably diluted with fresh water from land drainage." Day (1980) however, notes two major difficulties with Prichard's definition in its application to South Africa and other dry regions. The phrase "...a free connection with the open sea ..." would exclude those estuaries which are temporarily cut off from the sea during the dry season. Secondly, the phrase "... diluted with fresh water ..." would exclude estuaries which, far from being diluted sea water, become hypersaline when evaporation exceeds fresh water inflow. Day (1980, p.18) thus modifies Prichard's earlier definition and defines an estuary as "...a partially enclosed coastal body of water which is either permanently or periodically open to the sea and within which there is a measurable variation in salinity due to the mixture of sea water with freshwater derived from land drainage."

2.2 ESTUARINE SEDIMENTS

Source and nature

The primary sources of estuarine sediments are the river itself, offshore and littoral areas, and the shorelines of the actual estuary (Meade, 1972). McLusky (1981) has listed examples of each. In many North European estuaries the main source of sedimentary material is the sea, and the material is carried into the estuary in the bottom inflowing currents that characterize salt wedges. In Breton estuaries, fine material is available on the banks of the estuary, and these banks are the main source of estuarine sediments. In the estuaries of Loire (France) and Apalachicola (USA), rivers carrying large quantities of silt and clay are the main source of estuarine sediments. Day (1981) however, points out that sediments of both a marine and terrestrial source are present in most estuaries. The examples above represent extreme cases, while normally there is a predominance of fine silts and clays of fluvial origin at the head of the estuary grading to medium or coarse sand of marine origin at the mouth.

The sediments are composed mainly of mineral particles derived from the breakdown of rocks of the drainage basin, local cliffs or the nearby sea-bed (Guilcher 1967, in Buller and McManus, 1979). The fragments vary greatly in composition, shape, and size and respond differently to the movement of water. The magnitude of coastal and estuarine flows is such that the majority of sediment in motion is composed of medium to fine sand, silt and clay particles (O'Connor, 1983).

Deposition

The deposition of sediments within an estuary is controlled by the speed of the currents and the particle size of the sediments (McLusky, 1981). The current velocity itself is affected by river discharge, tides and the wind (Meade, 1972). The relationship between current speed and the erosion, transportation and deposition of sediments initially described by Hjulström in 1935, and modified by Postma (1967) is shown in Fig 2.1.

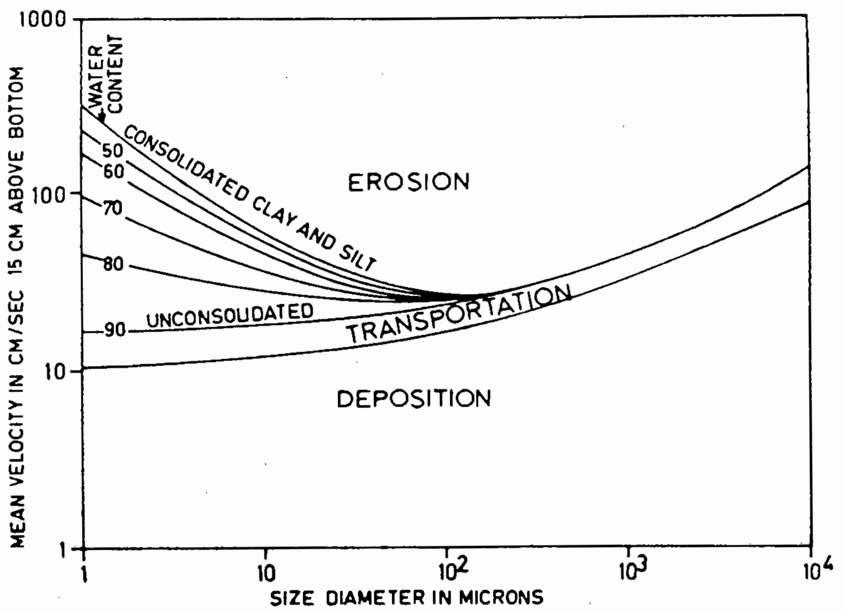


FIG 2.1 MODIFIED HJULSTROM CURVE SHOWING EROSION, TRANSPORTATION AND DEPOSITION VELOCITIES FOR DIFFERENT GRAIN SIZES. THE DIAGRAM INDICATES POSSIBLE VALUES FOR VARIOUS STAGES OF CONSOLIDATION (AFTER POSTMA, 1967).

As can be seen in Fig 2.1, for each grain size there exists a certain critical velocity below which it is deposited, while above a certain velocity, called the critical scour velocity, it is eroded. For coarse sediments, such as sand and gravel, the forces resisting motion are caused by the weight of the particles. Finer sediments that contain appreciable fractions of silt, clay or both, tend to be cohesive and their resistance to entrainment is due to cohesion rather than the weight of the individual grains.

The consequence of these relationships for estuaries has been reported by McLusky (1981). In the fast-flowing rivers and strong tidal currents at either end of the estuary, all sizes of sedimentary particles may be eroded and transported. As the current slackens, so the coarser pebbles and sands are the first to be deposited, and the finer silts and clays remain in motion. Only in the calmer, middle reaches of an estuary, where the river and tidal currents meet, and especially in the slack water at high tide overlying the intertidal areas, are the currents slow enough for mud to be deposited.

The pattern of sediment distribution is further affected by the uneven distribution of tidal currents (Dyer, 1979). Local constrictions in an estuary create coarse patches and increases in width result in the deposition of mud. There can often be large lateral variations in the sediment type associated with bends and junctions, especially in the lower part of an estuary where lateral variations in velocity can be large.

Vegetation plays an important role in the deposition of sediments in the intertidal and supratidal areas during high flow conditions. When fine sediments are deposited they are rapidly stabilized by the roots of saltmarsh vegetation (Day, 1981). The stems and leaves of aquatic vegetation further reduce current velocities and, as deposition continues, the build-up of sediment results in an elevation of the saltmarsh.

Circulation

The circulation of sediment in the estuarine environment closely follows the movement of water in the system (O'Connor, 1983). Sediment is moved into an estuary on the flood tide from coastal sources and mixed with bank and terrestrial sediment. At highwater, fine sediments are deposited on the high inter-tidal flats while the coarser, sandy material is deposited in the deeper flow channels.

On the ebb tide, sediments flow out of the estuary. The lower ebb velocities may not be able to move all the material settled by the previous flood tide except in the deeper parts of the flow cross-section. In the lower reaches of the estuary the reduced period of the ebb tide near the estuary bed traps material in the estuary. Fine sediment progressively moves upstream to accumulate at a point where the near-bed flood and ebb tidal excursion of fluid is equal. The accumulation point is not fixed but moves landward as tides increase from Neap to Spring and seawards as they decrease from Spring to Neap.

Large increases in river flow rate will also move the accumulation point seawards. Major rivers, such as the Amazon, produce so much freshwater and sediment that the gravitational circulation is flushed completely out of the estuary. The importance of a single severe flood event in flushing estuaries has been pointed out by many workers (Day, 1981). The distribution of sediments and the location of shoals and channels resulting from sorting and resorting during many years of normal flow may be washed away and a completely new system established in a single severe flood. Thus when studying the distribution of estuarine sediments and estuarine dynamics in a single time period it is important to know previous run-off conditions as this will largely determine the state of the estuary at the time of the study.

Fine clay, which stays undisturbed on the estuary bed for a few weeks, especially if deposited with sand, can consolidate rapidly. However, the consolidation of inter-tidal banks is restricted by lateral movement of the flow channels. Side erosion of the ebb tide, as flow is concentrated in the deeper channels, increases the concentration of sediment on the ebb tide and helps to balance out the landward flux of sediments in the shorter, higher velocity flood tide.

An estuary can thus exist in a state of dynamic equilibrium due to the lateral movement of the channels on the ebb tide and the periodic flushing by high run-off during storms.

The general effect of engineering works in a estuary is to change the boundary conditions for a particular study area (O'Connor, 1983, p.326). River diversion schemes may reduce the amount of water and sediment entering an estuary while the construction of breakwaters for a new harbour scheme may starve the coast and channel system at the mouth of the estuary.

Sediments - importance in the estuarine system

The preceding discussion clearly indicates that sediments in transit through and deposited within estuaries vary greatly from locality to locality. Since the deposited material forms the substrate upon and within which many of the estuarine organisms live and from which many draw their food supply, the sediment serves as an important factor in the estuarine ecosystem (Buller & McManus, 1979, p.87). The fine particulate material derived from the land or the sea and passing into the estuary may undergo substantial changes in chemical state, and may entrap pollutant materials. The geochemical gradients frequently detected in the uppermost zones of deposited muds and silts because of the mobilization of certain elements and enrichment at the surface indicate the importance of this part of the sediment column. The sand and gravel-size sediments may be of economic significance as building materials. All sizes of material are potentially important in the siltation of navigable waterways and harbours.

Besides the relationship of sediments with water dynamics, bed particles also exert a control on the distribution of benthic organisms. The range of sizes present at one site determines the packing of the particles and the availability of pore spaces through which interstitial fluids may pass.

In this way the sediments strongly influence the nature of both organic and chemical activity in the bed (Buller & McManus, 1979, p.87).

2.3 USES AND DEGRADATION OF ESTUARIES

Estuaries, situated at the interface between land and sea, are extremely susceptible to processes operating within both marine and terrestrial environments. They are highly dynamic environments, where conditions can change rapidly, radically, and frequently (Saeijs, 1982). Any changes in the processes operating, whether natural or human induced, will be reflected in a readjustment of the estuarine system. Human-induced changes, often resulting from the lack of knowledge concerning the nature of the processes operating, seem to create the most noticeable and deleterious impacts.

Estuaries have long been important to society; simple evidence being the fact that many of the world's largest cities are situated on or adjacent to them. Land in the vicinity of estuaries has always been highly esteemed because of the opportunities available for agriculture, fishing, trade, communication and in the present century, for industry and recreation (Saeijs, 1982).

With the growth of human populations, increasing pressure is being placed on estuaries for their use. Water sports, among the fastest growing outdoor sports in many parts of the world (Day & Grindley, 1981), have resulted in tremendous demand for the development of holiday resorts adjoining estuaries. A conflicting demand on estuaries is for their use as repositories for industrial effluent and domestic waste. Biologists have stressed the natural functions of estuaries as vital feeding grounds for many birds, such as waders and wildfowl. They are important for coastal fishing and, because of their variability, are also fascinating areas which challenge our understanding of the adaptation of plants and animals to their environment (SANCOR, 1983).

These multiple uses have understandably led to much conflict of interests (Begg, 1978), this often being to the detriment of the estuarine system. Grindley and Heydorn (1979, p.1) noted that " in South Africa, as in many other countries, widespread disruptions of the natural functioning of estuarine ecosystems have been caused by human activities".

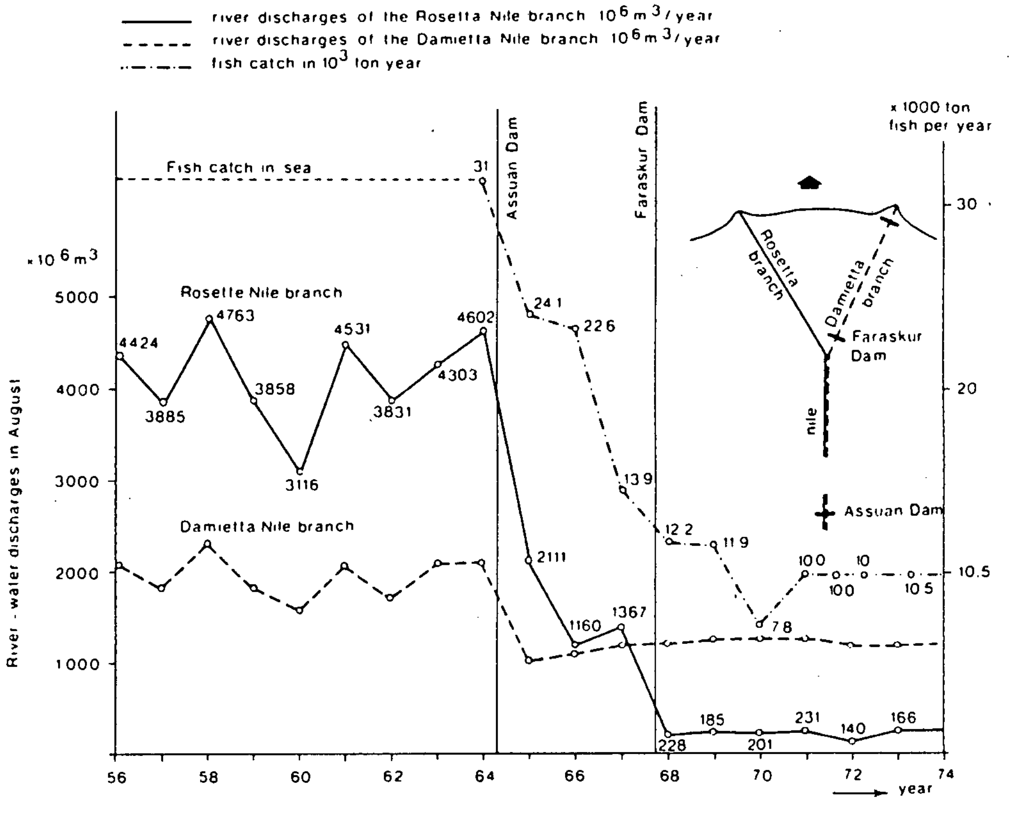


FIG.2.2 RIVER-WATER DISCHARGES OF THE ROSETTE, AND THE DAMIETTE NILE BRANCHES IN M^3, IN THE MONTH OF AUGUST, AND THE FISH CATCHES IN THE MEDITERRANEAN, NORTH OF EGYPT, IN TONS PER YEAR. IN THAT TIME THE WATER MANAGEMENT OF THE NILE WAS DRASTICALLY CHANGED WITH THE CONSTRUCTION OF THE ASSUAN AND FARASKUR DAMS (AFTER SAEIJS, 1982).

Examples of river pollution and engineering projects in an estuary are appropriate to illustrate the variability of such impacts: The vast number of people living along the banks of many estuaries, e.g. the Thames, has resulted in major sewage disposal problems. The disposal of unpurified material has added bacterial and other forms of pollution, which increases the danger of infection and risk of epidemics. Cholera outbreaks in Great Britain in 1849 and 1854 may have been caused by inadequate drainage of the Thames (Dart & Sheldon, 1980).

Engineering projects have been carried out in estuaries for many centuries and have led to undesired as well as desired effects. In the last few decades, the use of new technologies has increased human influences on estuaries so greatly that their systems are in serious danger of dysregulation and even destruction (Saeijs, 1982). The Nile delta, for example, has been transformed for agricultural purposes to such a degree, by the construction of the Assuan and Faraskur Dams, that the formerly estuarine character of the system has been replaced by the presence of a few lagoons with no connection to the sea (Fig 2.2).

2.4 BRIDGES AND EMBANKMENTS IN SOUTHERN AFRICA

Along the 3000km coast of southern Africa from Kosi Bay to the Orange river there a total of 296 estuaries which enter the sea (SANCOR, 1983). Of these, not one has been left untouched by human activity of some sort.

One of the main agents producing impacts in estuarine environments in South Africa has been the construction of embankments across floodplains. In coastal communication networks, where road and rail bridges are constructed over estuaries, the main part of the bridges are on embankments and only a relatively narrow passage is allowed for the throughflow of water under spanned sections (Heydorn & Tinley, 1980). While the short term economic advantages of constructing embankments in preference to bridges with more spans are clear, the embankments can have highly detrimental ecological effects by restricting water flows, either during daily tidal exchange cycles or during floods when they tend to act as dam walls . Heydorn & Tinley (1980) note that there are many examples on the Cape coast where consequent damage in the form of siltation, sanding up, erosion or ecological degradation can be demonstrated. The Diep River system, for example, has undergone major changes as a result of different farming activities in the upper catchment and construction works across the lower reaches. Beaumont & Heydenryck (1980, p.10) note that "...the lower reaches have silted up creating a large dry pan in an area which was once a tidal lagoon". They conclude that road embankments, bridges, a weir and dredging operations have radically altered the river system. Farquharson (1970) has discussed how the coastal road in the Eastern Cape (from Alexandria eastwards) has affected estuaries which it has crossed. Flow restrictions have occurred in the Bushmans, Kariega, and East and West Kleinemonde estuaries, the overall impacts of which are difficult to determine. However, by calculating flow rates Farquharson was able to conclude that the embankments result in considerable scouring and deposition; thus causing significant changes in sediment dynamics.

In his studies of the Natal coast, Begg (1978) cites 23 out of a total of 73 estuaries which have suffered severe impacts due to the presence of transport-related facilities. Of these, 21 have been directly affected by embankments across floodplains. Begg (1978, p.612) lists four impacts that embankments across the floodplains of Natal`s estuaries may have, namely:

i) reduced tidal exchange (Mgobezeleni)

ii) a damming effect upon flood waters which leads to siltation and in turn results in losses of storage capacity and water area (Mzumbe)

iii) reduced scour (Lavu)

iv) instability in the mouth position (Mtwalume).

In another study, Perry (1985) has indicated that fifty-one of the lower reaches of the rivers in Natal have been affected by embankments across floodplains. Perry cites the damming effect as listed by Begg(1978) as the cause and adds that the impacts have become increasingly important since the 1950`s.

The national road bridge constructed over the Mdloti river illustrates how the dynamics of an estuary can respond to embankments built on a floodplain (NRIO, 1986). The 480m embankment on the floodplain, restricting the former channel by about 70%, has resulted in increased sedimentation upstream. The river's response to the increased bed-level has been to increase the thalweg and sinuosity of the channel.

The Mtwalume estuary gives one of the most startling pictures of the changes that can and have occurred in response to human disturbances. The estuary, which once extended 4km upstream and hosted 35 varieties of fish (Thorpe, in Begg 1978) has been degraded to such an extent that it is presently regarded as being barren of fish. As with many other estuaries in Natal (Begg, 1978) this has resulted from the expansion of sugar cane farming in the catchment, the construction of a railway and, later, a road bridge over the floodplain.

Studies which look specifically at the impacts of bridges and embankments on single estuarine systems have been conducted by Howard-Williams *et al.* (1975), Bruton & Appleton (1975), Weaver (1977), and Esterhuysen & Rust (1987). Howard-Williams *et al.* (1975) conducted a preliminary ecological survey of the lower Swartvlei estuary with special reference to the area spanned by a road bridge. Their survey found that there was no appreciable effect on the ecology of the lower estuary. They did note, however, that the study took place when the mouth was open and that conditions may be different when the mouth is closed.

Bruton & Appleton (1975) surveyed the Mgobezeleni lake-system in Zululand and note the effect of a bridge on a mangrove swamp. The bridge, consisting of eleven one-metre diameter pipes and a raised foundation, crosses the estuary immediately seaward of a mangrove forest and impounds a pool 50 cm deep. Below the bridge the stream is under direct tidal influence. Since completion of the bridge, most of the larger trees previously reported have died. The authors note two effects that the bridge has had on the mangrove swamps. Firstly, most tides are prevented from reaching the swamp and secondly, the mud flats are always flooded due to the raised water level above the bridge. The latter factor, which has been noted elsewhere in Natal, is probably responsible for extensive mangrove mortality. The slight drop in water level since the construction of a second section of the bridge at Mgobezeleni has resulted in some regeneration of the mangroves.

Weaver (1977) considers the effects of flow restriction on selected grain size parameters of the sediment of the Bushman's River estuary. The dredging of rubble from the western arch of the Bushman's river bridge provided an ideal opportunity to study the effects of flow restriction on estuarine hydraulics. The results obtained from the study show that a reversal in sedimentation trends occurred in the study area due to human induced changes in channel geometry. The work by Weaver (1977) is the only study that specifically examines the redistribution of sediments in an estuary due to human impact.

In a study of the lower Swartkops estuary Esterhuysen & Rust (1987) show how a railway causeway and the embankments of Wylde Bridge exercise an important control on the configuration of the channel downstream of these restrictions. With respect to the 100-year flood level the cross-sectional area for the pristine flood-plain of 1735 m^2 has been reduced to 612 m^2 in the area below the Wylde bridge. The higher flow velocities which have been generated as a result, have caused accelerated erosion of the channel bank downstream of the Wylde bridge, as well as affecting the depositional patterns downstream of the bridge. The development of a longitudinal intertidal sand bar opposite the Swartkops village is "... almost certainly as a consequence of the artificial constriction of estuarine and fluvial flow by the Wylde bridge ..." (p. 523). The migration of this sand bar downstream appears to be in equilibrium with the southward migration of the meander in which it is situated.

This chapter in discussing various aspects of estuarine sediments, has illustrated the importance of estuaries to people, and how, due to pressure of increasing populations, they may become progressively degraded. The impacts of bridges and embankments on various estuarine systems in South Africa have been noted. Sediment distribution in estuaries changes as a consequence of these impacts and this often results in adverse effects on the systems. Moving on to the specific problem of this study, the following chapter describes the important characteristics of the Uilkraals study area.

CHAPTER THREE

THE STUDY AREA

Page

CHAPTER THREE

THE STUDY AREA

This chapter describes the characteristics of the Uilkraals estuary and catchment which are pertinent to this study. After a description of the location and boundaries of the study area, natural features are described, including geology and physiography, river and catchment, morphology, vegetation, and climate. The succeeding section then describes estuarine uses, in terms of land-use, recreation, and the wetland habitat. The final section briefly describes the history of bridge and embankment construction in the estuary.

A complete description of the environmental characteristics of the Uilkraals estuary can be found in Heydorn & Bickerton (1982). It is not the intention in this report to exhaustively repeat their findings, but rather to highlight those features of importance to the research problem.

3.1 LOCATION AND BOUNDARIES OF THE STUDY AREA

The mouth of the Uilkraals estuary is located at $34^{0}36^{\prime}$ South and $19^{0}24^{\prime}$ East. It is situated approximately 60 kilometres north-west of Cape Agulhas and six kilometres south-east of the small fishing village of Gansbaai. The location of the study area is indicated in Fig 3.1.

The physical boundaries of the study area are depicted in Fig 3.2. The upstream boundary of the study area is at the limit of the sandflats, approximately 2,1 kilometres from the sea. This area has been selected as it is between here and the coast that most changes can be observed. A

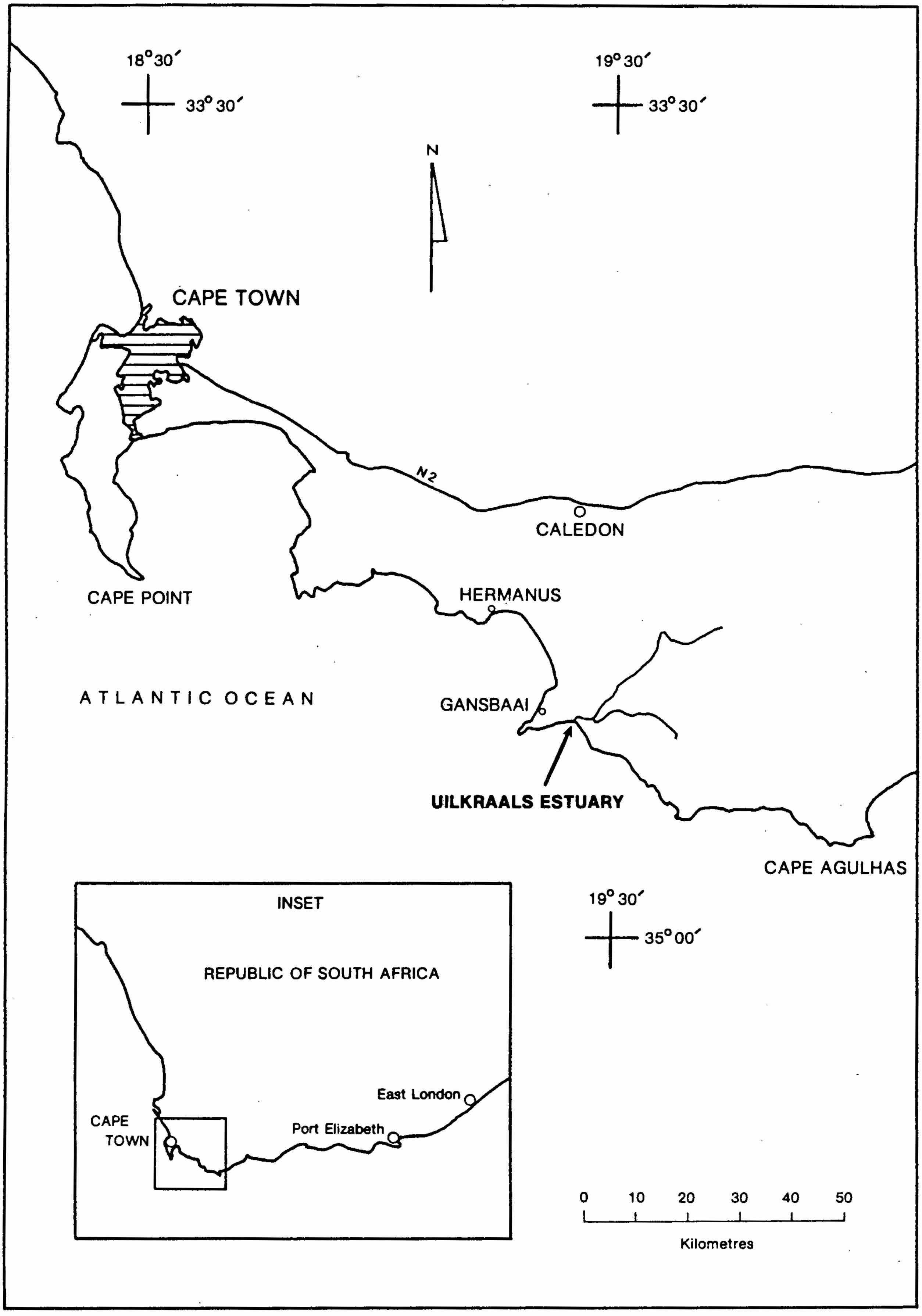


FIG.3.1 LOCALITY MAP OF THE STUDY AREA.

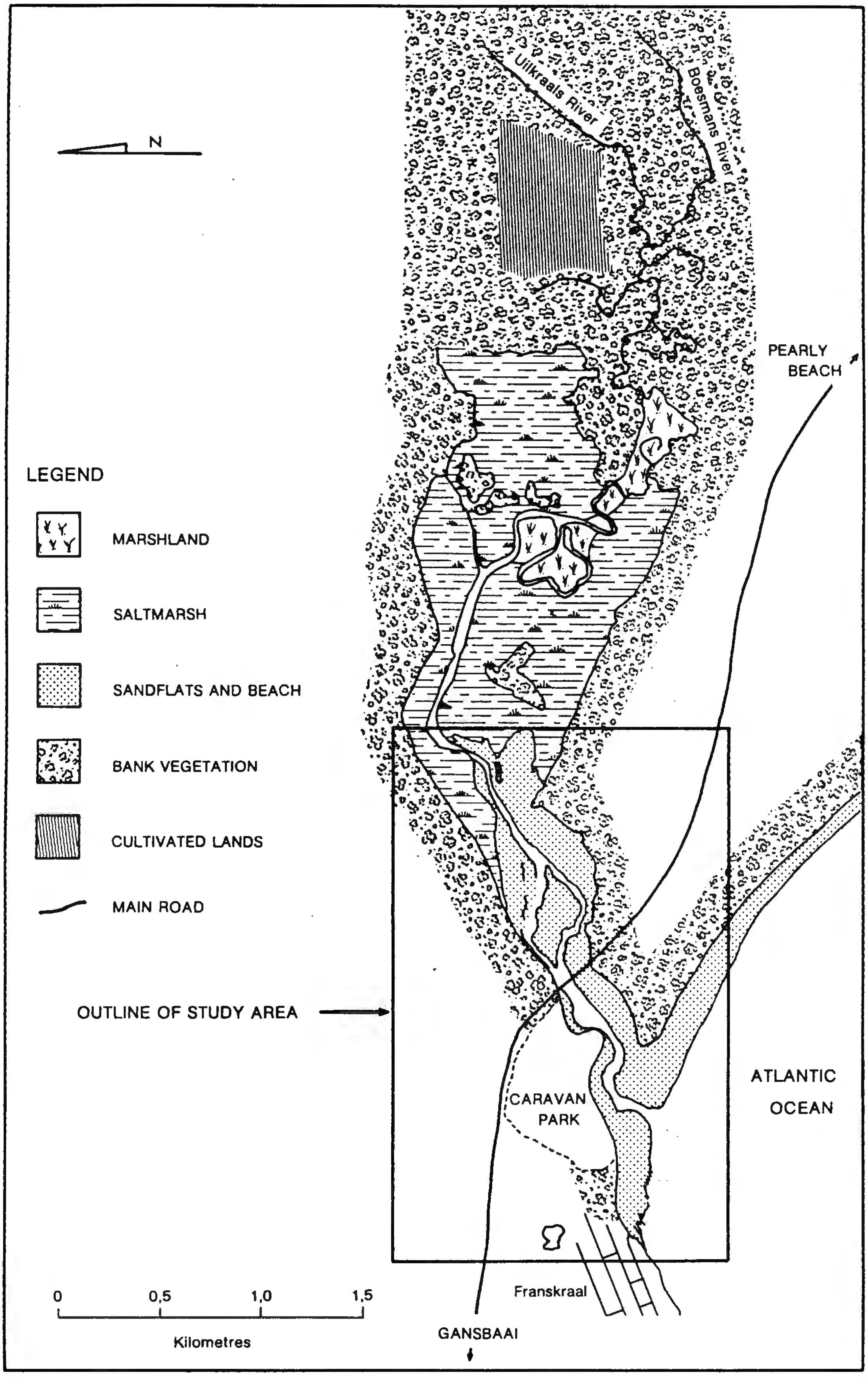


FIG 3.2 OUTLINE OF THE STUDY AREA AND MORPHOLOGY OF THE ESTUARY (DRAWN FROM AERIAL PHOTOGRAPH 498/148, 1980).

preliminary study of all the aerial photographs indicated that above this point there have been no changes in the channel positions over the relevant period.

3.2 NATURAL FEATURES

Geology and physiography

The geology of the region has been described by Spies *et al.*(1963) in their explanation of the geological sheets 3419C and 3419D (Gansbaai) and 3420 (Bredasdorp). Details of the geology to the north of this area have been extracted from the 1:1 000 000 Geological Map of Southern Africa. The geology is depicted in Fig 3.3.

In a river valley around Papiesvlei (20 km upstream) the oldest rocks in the area, those of the Malmesbury Formation, outcrop. These consist of sheared shale and fine grained-greywacke. A small outcrop of pre-Cape granite is found about 12km upstream of the mouth.

Table Mountain Group rocks predominate throughout the area. In the upper catchment they produce the highest peaks such as the Tafelberg(845m) and, along the coast, the resistant rocky outcrops which are prominent in the area. The rocks consist of sandstones, quartzites, shale layers and conglomerates. Thin persistent Table Mountain Group shales are found within the above rocks.

Shales of the Bokkeveld Group are found to the west of the estuary and form a lower gently undulating plain between the more resistant Table Mountain Group rocks.

The coastal plain, at an elevation of approximately 40 m, varies in width between 1 and 9 kilometres and consists

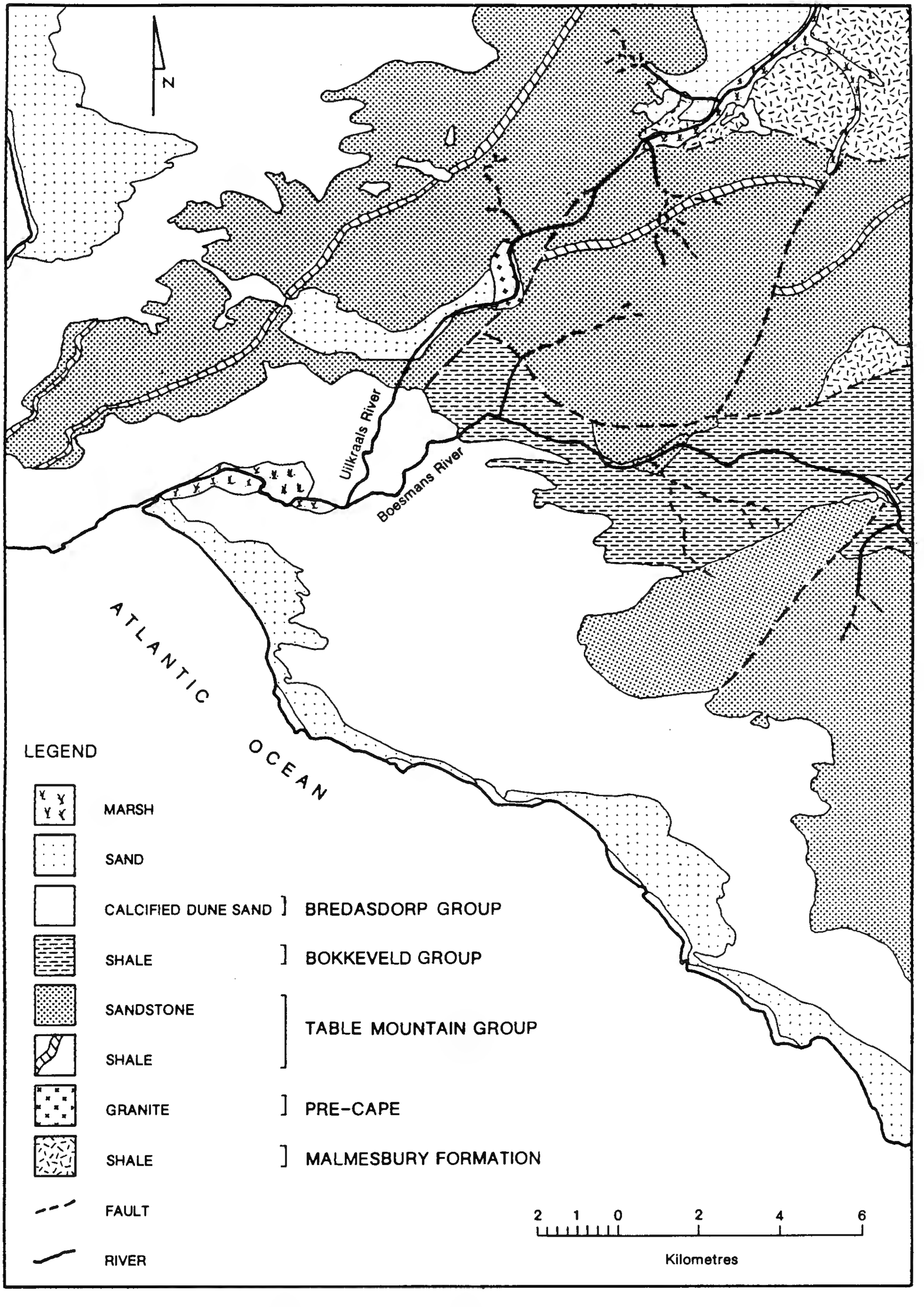


FIG 3.3 GEOLOGY OF PART OF THE UILKRAALS CATCHMENT AREA (AFTER SPIES ET AL., 1963).

mainly of limestones of the Bredasdorp Group (Malan, 1987), with recent blown sand at the coast. These Tertiary coastal limestones (Siesser, 1972), consist of calcified dune and marine sands, containing greatly varying proportions of quartz grains and comminuted shell fragments. The estuary itself is situated directly on these limestones. To the south-east of the mouth, a once shifting belt of dune sands has been stabilized by extensive reclamation by the Department of Forestry (Heydorn & Bickerton, 1982).

River and catchment

In the upper catchment the Paardensberg and Sondagskloof, rivers which rise in the Perdeberg/Tafelberg and Van Der Bijlberg Mountains respectively, join at about 30 km from the mouth. The major tributary, the Boesmans River rises in the lower relief area to the east and joins the Uilkraals approximately 6 km from its mouth. From here the Uilkraals meanders to the coast where it is bordered by broad, marshy vleis.

The river, with a maximum length of 49.5 km and a source elevation at about 620 m has a gradient of 1: 80 over its length. The Uilkraals estuary has a catchment area of 390 km^2 with a mean annual run-off (M.A.R.) of 18,13 $m^3 \times 10^6$ (Pitman *et al.*, 1981). The average sediment yield for the catchment is 150 t km^{-2} yr^{-1} (Rooseboom, 1975) which would yield a total of 58 500 tons per year. From a report on the 26 Cape South-West estuaries (NRIO, 1987) the above data on the Uilkraals system can be compared with that of other rivers (Table 3.1). The river gradient for the Uilkraals is low, with only five other estuaries in the south-western Cape being lower. Other rivers with similar gradients are the Duiwenhoks and Ratel. The mean annual run-off is low and, when compared to other rivers with catchment size taken into consideration, is very similar to the Klein and Bot rivers. The average catchment sediment yield is low and is

River	Average catchment sediment yield		MAR ($m^3 \times 10^6$)	MAR (mm)	Catchment area (km^2)	River gradient (1:)
	tons/year	tons/km^2/yr				
BUFFELS (WEST)	150	50	0,59	197	3	18
ELSIES	850	50	3,33	196	17	26
SILWERMYN	1 300	50	5,09	196	26	18
SAND	4 150	50	10,43	126	83	35
SEEKOE	4 650	50	11,68	126	93	639
EERSTE	86 645	122	195,12	275	710	40
LOURENS	12 939	92	121,99	871	140	22
SIR LOWRYS PASS	7 350	150	30,28	618	49	18
STEENBRAS	11 100	150	45,73	618	74	36
ROOIELS	3 150	150	9,65	460	21	13
BUFFELS (EAST)	3 600	150	11,03	460	24	12
PALMIET	80 250	150	200,92	376	535	62
BOT	138 000	150	46,52	51	920	54
ONRUS	8 850	150	3,10	53	59	18
MOSSEL	750	150	0,26	52	5	8
KLEIN	135 900	150	40,00	44,15	906	113
UILKRAALS	58 500	150	18,13	46	390	80
RATEL	60 750	150	7,05	17	405	78
HEUNINGNES	210 000	150	37,57	27	1 400	163
KLIPDRIFSFONTEIN	4 050	150	0,51	19	27	25
PAPKUILS	200	200	0,02	20	1	18
BREë	2 382 720	192	1 751,34	141	12 384	189
DUIWENHOKS	226 534	169	89,73	67	1 340	68
KAFFERKUILS	275 717	178	106,42	69	1 550	48
GOURITZ	20 010 486	438	539,05	12	45 715	217
BLINDE	5 400	150	0,56	16	36	56

TABLE 3.1 AVERAGE CATCHMENT SEDIMENT YIELD, MEAN ANNUAL RUN-OFF (MAR), CATCHMENT AREA, AND RIVER GRADIENT, FOR RIVERS OF THE SOUTH-WESTERN CAPE (FROM NRIO, 1987).

the same as most rivers in the south-western Cape. From Table 3.1 the average catchment sediment yield in t yr^{-1}, M.A.R. in mm, and catchment area for the Uilkraals can be compared with other estuaries of the south-western Cape.

With all these values being low it can be expected that the riverine sediment input into the Uilkraals estuary will be small. Heydorn & Bickerton (1982) also noted that there is little evidence of sedimentation from fluvial erosion in the Uilkraals catchment.

Morphology

The shape of the estuary is illustrated in Fig 3.2. From the confluence with the Boesmans river, the Uilkraals follows a tortuous channel through marshland and is characterized by a number of cut-off meanders and ox-bow lakes. Further downstream the river is flanked by saltmarsh and follows a much straighter course. On entering the large broad sandflats above the road bridge, the river splits into numerous channels that traverse across the whole area. The sandflats are illustrated in Plates 1 and 7. The embankment across the estuary has restricted the channel to the right (west) bank along which the major channel now enters the sea. After flowing around the promontory carrying the holiday bungalows the river may enter the sea in any of a number of positions. The positions depend on the direction of the longshore current and the prevailing run-off conditions.

Vegetation

The catchment area falls into Acocks' Veld Types 47, Coastal Macchia and 69, Macchia (Acocks, 1975), the latter occurring in the more elevated source regions. A more detailed description of the Cape Floral Kingdom by Moll *et al.*(1984) identifies three major vegetation types in this region. In the elevated area of the upper catchment, heathlands of Mesic Mountain Fynbos dominate, while lower lying areas consist of Elim Fynbos heathlands. The coastal plain consists of broad-leaf shrublands of the South Coast Strandveld. In recent years areas of pristine vegetation have been reduced by grazing, especially in the lower reaches, and by the encroachment of alien vegetation, especially *Acacia cyclops*. These aliens have produced dense thickets throughout large parts of the area and are especially prevalent around the estuary. They do not, however, appear to have had any impact on the sediment distribution within the estuary.

A detailed description of the vegetation in the immediate vicinity of the estuary is given by Heydorn & Bickerton (1982) and is illustrated in Fig 3.4. Ten main plant communities were identified of which three are of importance to this study as their areal extent has changed quite substantially over the study period. The structure and species composition of each community as recorded by Heydorn and Bickerton (1982) can be seen in Appendix 2. The *Sporobolus virginicus / Juncus acutus / Salicornia meyerana* Floodplain Herbland covering a large area of the floodplain consists of a mosaic of vegetation with different species dominant in patches. Typical saltmarsh species (e.g.*Salicornia meyerana*) occur on the floodplain. *Restio eleocharis / Metalasia* sp. (Parsons 123) Low Shrubland covers an extensive area on the east (left) bank, south of the Pearly beach road. *Chrysanthemoides monolifera* Low Dune Shrubland is found in a narrow strip along the coast on the eastern bank.

The significance of vegetation to this study is that because plants are restricted to certain areas by environmental factors, any increase or decrease in a plant community will reflect changing conditions within the system. Vegetation changes may also affect sediment dynamics within the system.

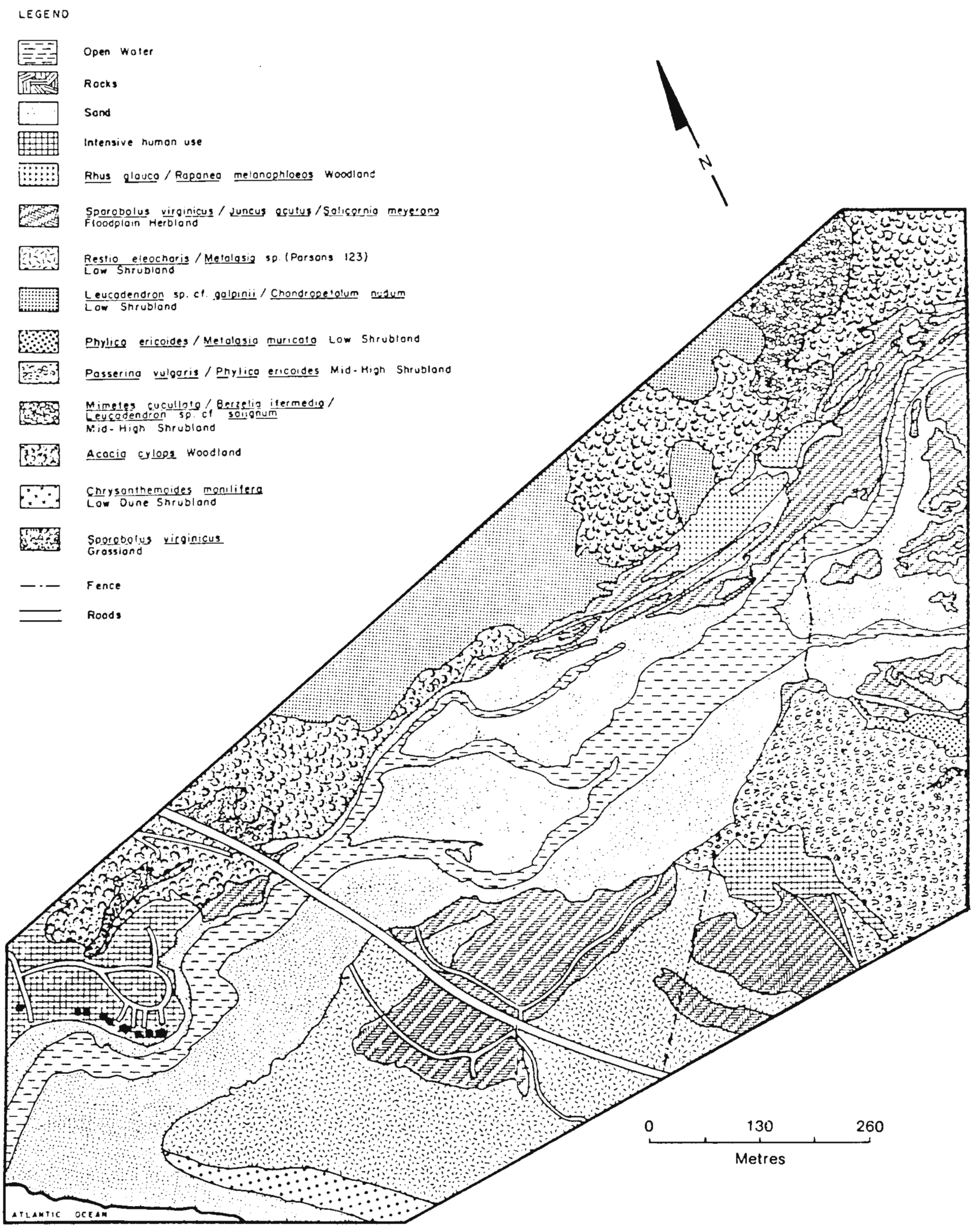


FIG 3.4 VEGETATION IN AND AROUND THE ESTUARY (AFTER HEYDORN & BICKERTON, 1982).

Climate

The Uilkraals estuary and catchment fall within the temperate Mediterranean region of the south-west coast (Heydorn & Tinley, 1980, p.20). Dry summers are characterised by strong easterly and south-easterly winds while in the winter wet westerly to north-westerly winds dominate. Figure 3.5 illustrates a wind rose for Danger Point (two kilometres away) between 1921 and 1949.

More recent wind roses obtained from visually observing ships (Swart & Serdyn, 1984) show similar patterns (Fig 3.6). Wind directions are important as they determine aeolian transport into and around the estuary. One can expect summer sediment supply to be supplemented by airborne material from the SE and in winter from the NW.

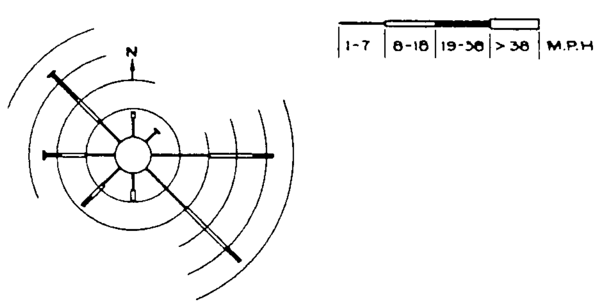


FIG 3.5 WIND ROSE FOR DANGER POINT (FROM WALSH, 1968).

The mean annual rainfall for most of the catchment ranges between 500 and 600 mm (Heydorn & Tinley 1980, p.27). Walsh (1968) gives a mean annual rainfall value of 503 mm for Danger Point, while Pitman *et al.* (1981) give a value for the catchment of 606 mm. Maximum rainfall peaks occur in June and July, the average monthly values being 73 and 65 mm, respectively (Walsh, 1968).

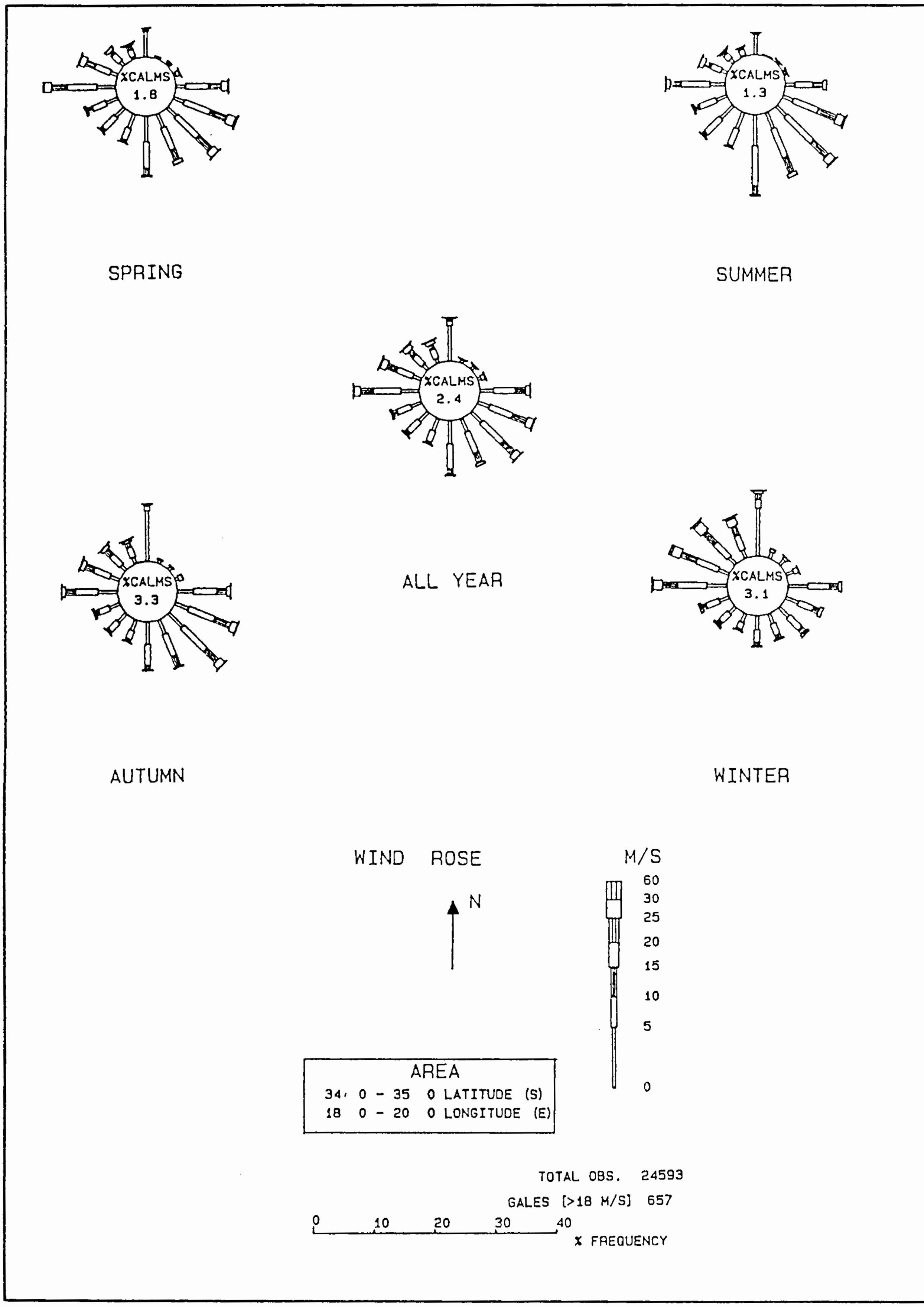


FIG 3.6 WIND ROSES FROM VISUALLY OBSERVING SHIPS (FROM SWART & SERDYN, 1984).

3.3 ESTUARY USES

This section briefly describes land-use in the catchment and estuary. It also looks at the use of the Uilkraals estuary for recreation and the importance of the wetland habitat for estuarine associated bird species.

Land-use

Agriculture is the main land-use in the catchment and consists of both cultivated and grazing lands. At the mouth of the estuary on the west bank is a caravan park which has a few bungalows and approximately 1 000 caravan sites. To the east of the mouth lies the stabilized dune field of the Duinefontein Sands Forestry Reserve. An extensive part of the flood plain upstream of the bridge is used for grazing by cattle.

Recreation

The estuary is used for swimming, canoeing and bait gathering. The Uilkraals is the main swimming beach for people from Gansbaai and for holiday-makers who stay at Franskraal (a holiday village 2 km west of the estuary) and the Uilenkraalsmond caravan park. The caravan park superintendent Mr. Van Skalkwyk indicates that between 5000 and 6000 people stay at the park in peak season (pers.comm.). During Easter the area is well visited but for the remainder of the year the estuary is utilised only on weekends. The gathering of sandprawns (*Callianassa kraussi*) and mudprawns (*Upogebia africana*) by local fishermen occurs throughout the year but increases during the holiday season.

Wetland habitat

The wetland habitat is utilised by many estuarine-associated bird species. Heydorn & Bickerton (1982) list 38 bird species which have been recorded at the estuary. Siegfried

(1981, p.235) has presented data which suggest that the Uilkraals is of particular importance to migratory waders utilizing the estuary in the summer months. In 1981, Ryan *et al.* (in press) counted a total of 6755 birds at the estuary, which included 11 species of waders and 13 non-waders. They indicate the importance of the Uilkraals as one of a group of 12 estuaries which support 74% of all wetland birds and 86% of all waders in the south-western Cape..

3.4 CONSTRUCTION IN THE ESTUARY

The first bridge across the estuary was a wooden footbridge which was situated approximately 150 m upstream from the position of the present road bridge. The footbridge, built prior to 1961, had no apparent impact on the dynamics and sedimentation of the estuary.

The construction of the present bridge, by the Caledon Division Council, was completed in 1973 and replaced the wooden footbridge. The 220 m bridge spans the estuary approximately 800 m from its mouth. An embankment 120 m in length supports the eastern road access to the bridge while the remaining 100 m is spanned and supported by concrete pylons (Plates 1 and 5). Gaigher (1978) notes that building rubble left under the bridge prevented the natural drainage of the estuary above the bridge. However, after some delay the rubble was removed so that the normal drainage could occur. The effect of the bridge embankment has been to concentrate river and tidal flows against the western bank.

In 1978 a rubble and rock embankment (Plate 2) about 150 m long was built, protruding from the promontory on which the holiday bungalows are situated. The purpose of this embankment was to force the river mouth eastwards, that is away from the beach in front of the holiday bungalows and caravan park where it entered the sea at that time. The intention apparently was to increase the size of the beach in front of the holiday bungalows (Gaigher, 1978). Within a few months the embankment was badly eroded by wave and tidal action and partly covered by sand. Further, a shallow stagnant pool of water (Plate 3) and a series of small sand dunes had formed on the beach in front of the bungalows.

To rectify this situation, the Caledon Divisional Council removed the western embankment and in May/June 1980 constructed a new embankment extending from the eastern bank (Plate 4). This was to force the river mouth westwards to its original position. The latter embankment was soon removed as it was feared that this could increase the possibility of flooding in the caravan park. The embankment was also visually obtrusive and rubble from the breakdown of the embankment could have proved hazardous to recreation. The mouth soon returned to its natural position between the east and west bank. Up until the time of writing there has been no other interference with the natural position of the river or mouth.

Having described the pertinent characteristics of the study area, the following chapter describes the techniques employed to determine how bridge and embankment construction has effected sediment redistribution within the Uilkraals estuary.

CHAPTER FOUR

TECHNIQUES

Page

CHAPTER FOUR

TECHNIQUES

This chapter describes the techniques used in this study; namely aerial photography, ground survey, and sediment sampling. In each section the appropriate theoretical background to the technique is discussed, followed by a description of the methodology.

4.1 AERIAL PHOTOGRAPHY

This section firstly describes aerial photography in general, noting its major features and applications. This is followed by a discussion of aerial photography in coastal studies which examines research conducted by different workers and advantages and disadvantages so noted. This leads to a discussion of aerial photography in South Africa and describes the method upon which this study is based.

4.1.1 General introduction to aerial photography

Aerial photography is a small section in the broader category of remote sensing. The process of aerial photography involves capturing earth images, normally within the visible spectrum, on black and white or colour film from a position some height above the ground.

Despite the advent of satellite imagery and other forms of non-spectral remote sensing, aerial photography has remained very much in use today. The cost is low compared to the other remote sensing techniques and it is relatively easy to organize flights over study areas at short notice. Photographs can be obtained from any height depending on the scale required and give a very high resolution image (Strahler, 1975).

Aerial photographs are useful in that they may provide data from three different viewpoints. Firstly, they offer a holistic view of an image because of the altitude at which they are taken (Gutkind 1956, cited in Bayne 1984). Patterns and interfaces are more readily apparent and it is often easier to appreciate the significance of system components from the wider perspective lent by distance. Secondly, aerial photographs may provide a range of data (Bayne, 1984) in any one image. Thirdly, a temporal perspective can be gained from sequential images of the same area at different time periods. The insidious changes which escape detection on the ground often are unambiguously evident on sequential aerial photographs of the same area (Bayne, 1984, p.11). Repetitive observation gives an overview of earth dynamics over time previously difficult or impossible to obtain (Schanda, 1976).

4.1.2. Coastal studies

The idea of using aerial photographs in the study of coastal features and coastal processes is not a new concept (Stafford & Langfelder, 1971). Since the 1930s, aerial photographs have been used in the study of coastlines and in coastal engineering to an increasingly large extent. A detailed review of the literature on the applications of aerial photographs to coastal studies has been presented by Stafford (1968). Other findings that have arisen from work conducted in coastal studies are now briefly outlined.

El-Ashry & Wanless (1967) point out that an aerial photograph provides an excellent record of the pattern of features that existed on a coastline at the time of photography. The size of waves, direction of wave fronts, the direction of littoral drift and, of importance to this study, the distribution of shallow water sediment accumulations may easily be determined. From sequential aerial photography, El-Ashry & Wanless (1967) note that it is possible to observe and measure changes resulting from sediment shift during the interval between the dates of photography.

Stafford & Langfelder (1971) and Klemas (1976) have also suggested the use of sequential aerial photography for monitoring changes of the coastal zone. In devising a method of comparing beach locations along the North Carolina coast, Stafford & Langfelder (1971) have found the technique to be a very effective and efficient means of collecting information on coastal erosion trends over an extensive section of the coast. Klemas (1976) points out that this technique is ideal for studying wetlands as the uniform flatness of their topography eliminates variations in reflectance due to sloping surfaces.

The advantages and disadvantages of sequential aerial photography noted by the writers above are worthy of comment. El-Ashry & Wanless (1967) note that the greatest advantage of sequential aerial photography, especially when supplemented by older surveys and charts, is its recording of long-term trends in shoreline changes. Stafford & Langfelder (1971) list other advantages, namely the permanent record of data on the photographs, the infinite amount of ground detail in contrast to maps and charts, the frequency of aerial photographs in the last 30 years, and the economic savings over ground surveys.

In interpreting the changes, the greatest problem encountered is the lack of continuous daily photographic coverage (El-Ashry & Wanless, 1967). Hence, all that can be said of the changes is that they occurred between the dates of photography. Expanding on this point, Stafford & Langfelder (1971) note that the photographs, recording conditions and locations at a specific time, may not be typical of mean conditions. Two other limitations are noted by Stafford & Langfelder (1971). Only data on horizontal changes in beach location and areas can be determined and not volumes of materials eroded or accreted. The second limitation is the inherent errors that exist in the photographic image. The most important errors are scale variations between photographs caused by altitude variation of the photographic aircraft, scale variation within photographs caused by camera tilt at the instant of exposure, and relief distortions caused by elevation differences within the terrain depicted on the aerial photographs. The errors in the photographic image are, however, of little significance to this study firstly because each photograph has been reduced to the same scale, and secondly, there is little elevation difference in the study area - hence scale distortions due to camera tilt and elevation differences are small.

Notwithstanding these problems, aerial photographic study of wetlands is clearly a fruitful means of identifying long term changes in the sediment characteristics of estuaries.

4.1.3. Aerial photography in South Africa

Aerial photographic research and the use of aerial photographs in South Africa has been reviewed by Bayne (1984). Bayne points out that the earliest major use of aerial photographs in South Africa was in 1929 . In 1934 the Union government awarded the first contract for photographs which was to form the basis for the 1:50 000 topographic series. Up until 1972 the major use of aerial photographs was for cartographic purposes. The first multi-temporal study was conducted by Ward in 1971 and since then Weisser (Weisser 1979; Weisser & Marques 1979; Weiser & Parsons 1981; Weisser & Ward 1982; Weisser *et al.*, 1982) appears to have been the major researcher in this field. Much of his work has involved vegetation changes in dune and lagoonal environments.

Major research in multi-temporal aerial photographic studies of estuaries is being undertaken by the National Research Institute for Oceanology (NRIO) at Stellenbosch. The Sediment Dynamics Division of this Institute is conducting hydrological and hydraulic studies of Natal and Cape estuaries. The method developed, quantitatively comparing historical aerial photographs, is aimed at acquiring an understanding of the long-term functioning of estuaries (NRIO, 1983). Aerial photographs are analysed to reveal changes in features such as channel widths, sand spits, open water areas, and surrounding land-use. From this information a description of the condition of the rivers and estuaries can be produced, interpreted and evaluated against the background of simulated run-off data (no actual run-off data exist for many rivers), marine processes and changing land-use in the catchment.

The quantitative analysis of multi-temporal aerial photographs which has been used in this study is in principle identical to the method developed by NRIO (see 4.1.4 below) . The method developed has removed many of the scale problems listed by Stafford & Langfelder (1971) and it is also ideal for recording long term changes. As was noted by El-Ashry & Wanless (1967), however, the method reveals nothing about changes that may have occurred between the dates of photography.

4.1.4. Methods

This section lists the source of the aerial cover and outlines the method used in the quantitative analysis of the multi-temporal aerial photographs.

Aerial cover

The major source for the aerial photography was the Department of Survey and Mapping at Mowbray. From here five

Year	*Day/Mnth*	*Job*	*Strip*	*Number*	*Scale*	*Time*	*Source*
1938	23/12	130/38[1]	49	20489	1:20 500	13h35	Trig
1961	3/12	461[1]	7	8888	1:36 000	12h07	Trig
1973	3/10	719[1]	9	2698	1:57 000	12h15	Trig
Apr80	8/04	[1]498/148	7	1019	1:36 000	15h00	Trig
Jul80	2/07	820[1]	7	10123	1:150 000	11h40	Trig
Dec80	-	374[1]	-	240	1:20 000	10h56	U.N.
[2]1987	23/02	-	-	50	1:10 000	11h00	NRIO

1 ORTHOPHOTO SERIES BASED ON SAME JOB NUMBER.
2 COLOUR PHOTOGRAPH.
TRIG - DEPT. OF SURVEYING AND MAPPING, MOWBRAY.
U.N. - UNIVERSITY OF NATAL.
NRIO.- NATIONAL RESEARCH INSTITUTE OF OCEANOLOGY.

TABLE 4.1 DETAILS OF AERIAL PHOTOGRAPHS.

black and white aerial photographs between 1938 to July 1980 were obtained. The December 1980 photograph was obtained from the University of Natal and the 1987 photograph from the National Research Institute of Oceanology in Stellenbosch. A list of the aerial photographs with full details is given in Table 4.1.

Quantitative analysis

The first task involved identifying permanent features which were common to all the photographs (Fig.4.1) and then drawing a tracing of these features taken from the 1:10 000 orthophoto map. The photographs were then reduced to the same scale. This entailed making negatives (from diapositives of the aerial photographs) and printing them on a scale of 1:10 000 using the tracing drawn from the orthophoto to obtain the best possible fit. Pre-selected data to be used in the comparison were then copied from the

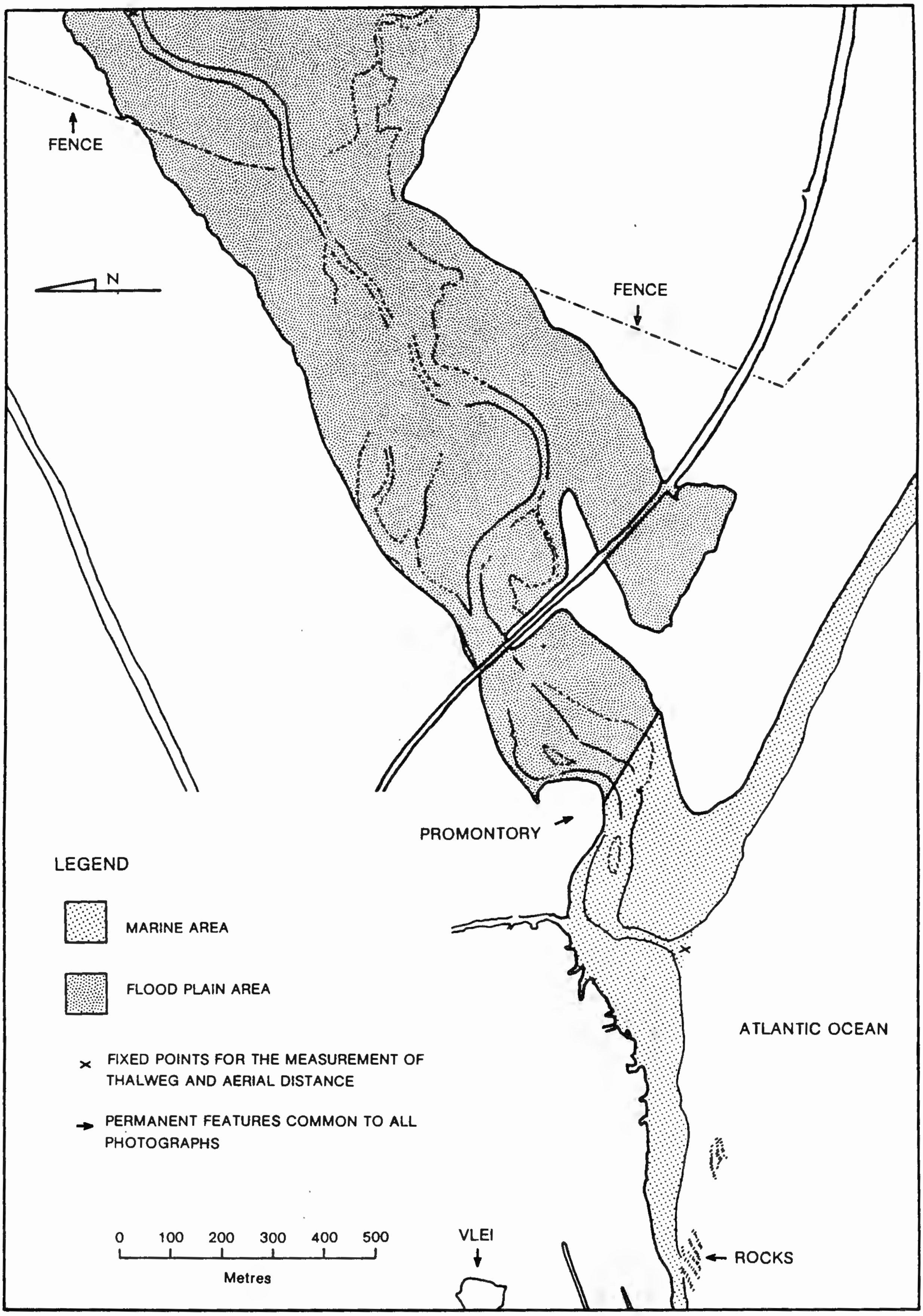


FIG 4.1 PERMANENT FEATURES COMMON TO ALL PHOTOGRAPHS, FIXED POINTS FOR THE MEASUREMENT OF THALWEG AND AERIAL DISTANCE, AND THE DEMARCATED FLOODPLAIN AND MARINE AREAS (DRAWN FROM ORTHOPHOTO 498/148, APRIL 1980).

photographs onto the tracing paper for each year. Measurements were then extracted directly from the tracings.

The 1987 colour photograph did not go through the reduction procedure, as it was already adjusted to the orthophoto series during its initial printing.

Measurements and data recording

The photographs have been studied with regard to (i) the river, (ii) the floodplain and (iii) the marine area (Fig.4.1). Linear, areal and angular measurements of features within the above subdivisions were made using a Hewlett Packard flat-bed digitiser. River widths and lateral stability for the period under review were also determined. Measurements of these were taken manually with a steel ruler.

A table based on work by Kellerhals *et al.* (1976) has been compiled by NRIO (1983) to facilitate the observation and recording of salient points. The NRIO classification has been further modified for this study in that parameters were selected and added to illustrate better the changes in sediment distribution and other human impacts in the Uilkraals estuary. Parameters measured are listed in Table 4.2.

River characteristics measured include thalweg and aerial distance. Thalweg is a measure of the actual length of the deepest channel between two fixed points. Thalweg changes in position and length with changes in flow, the thalweg slope is therefore not constant but is related to flow (Alexander, 1979). The aerial distance is the direct distance between the same two points used to measure thalweg distance. The two points were selected as follows (see Fig 4.1): the upstream point is in the centre of the channel at the border of the study area; the lower point is in the centre of the channel at the mouth and is in line with the high tide mark. Thalweg was also measured for the floodplain area described below. For the floodplain area the upper point of measurement is the same as above, while the lower point was taken where the channel crosses the separating line between the floodplain and marine areas. The sinuosity, a measure of the curvature of a river channel, is calculated by dividing the thalweg length by the aerial distance. A sinuosity value of 1 would indicate a straight river channel. The greater the value above 1, the more curved is the river.

RIVER
Thalweg(m)
Aerial distance(m)
Sinuosity
FLOODPLAIN
Total area(Ha)
Open sand(%)
Herbland sand (%)
Herbland mud (%)
Dry sand(%)
MARINE AREA
Open sand(Ha)
Vegetation
Left bank change(Ha)
Right bank change(Ha)

% - Percent
Ha - Hectares

TABLE 4.2 DIGITISED PARAMETERS MEASURED FROM THE AERIAL PHOTOGRAPHS.

For areal measurements of estuary characteristics, the estuary was subdivided into a floodplain and a marine area. This division was made because the large changes in the area of vegetation along the coast due to dune stabilisation would offset values for the subtle changes that have occurred in the area above the caravan park. The selection of the position for the line separating the two was arbitrary. The position of the line, the floodplain area, and the marine area can all be seen in Fig 4.1. No areal measurements were taken from the July 1980 photograph because of the lack of clarity after scale enlargement.

The total area of the floodplain, in hectares, was measured for each year of photography. Subdivisions include open sand, herbland sand and herbland mud. The initial measurements in hectares for the subdivisions were converted to percentages of the total floodplain area. Dry sand was measured separately as a percentage of the total floodplain area. Open sand constitutes all sand areas, whether sub-tidal, inter-tidal or supra-tidal, which are not vegetated. Herbland sand and herbland mud are vegetated areas with substrates of sand and mud, respectively. Mud is a rather loose term but has been used to signify herbland with a high clay content, rich in organic matter and well compacted. Dry sand areas are sand areas which are either inter-tidal or supra-tidal on which the sand appears dry at the time of the photograph. Dry sand is somewhat of an arbitrary characteristic: However, it does give a good idea of where larger sand bodies may have stabilized or changed between the dates of photography.

Open sand and vegetation changes were measured in the marine area. Open sand is the area between the dune vegetation and the high tide mark at the time of the photograph. The vegetation change is a measure of the increase or decrease in the area of dune vegetation from the previous photograph. The 1938 photograph was used as a baseline against which changes in later aerial photographs were compared.

As the tidal level has a large influence on the area of the measured parameters it must be taken into consideration when comparing the aerial photographs. Only photographs which were taken at similar tide levels can be directly compared. Subtle changes in area may only be apparent changes that occur due to the difference in tide levels between the photographs. However, tide level will only noticeably affect measurements for the floodplain dry sand areas and the marine open sand areas. Tidal data at the time of photography, where available, are given in Table 4.3.

Date	*Photo time*	*Tide* High	*Tide* Low	*Tidal level*
1938	13h35	no data available		mid/low
1961	12h07	12h00	19h00	high-incoming
1973	12h15	06h37	12h54	low-outgoing
Apr80	15h00	08h17	14h53	low-outgoing
Jul80	11h00	05h49	11h57	low-outgoing
Dec80	10h57	no data available		mid/low
1987	11h00	11h22	18h17	high-incoming

TABLE 4.3 TIDAL DATA AT THE TIME OF AERIAL PHOTOGRAPHY. WHERE NO TIDAL DATA ARE AVAILABLE, THE TIDE LEVEL HAS BEEN ESTIMATED FROM THE PHOTOGRAPHS THEMSELVES (TIDAL DATA TAKEN FROM SOUTH AFRICAN TIDE TABLES).

The method outlined by NRIO (1983) was used to quantify river widths and lateral stability of the river. An envelope of mobility was compiled by superimposing river courses for each year and tracing the maximum outer position from each. Over the envelope of mobility, lines of measurement were marked at regular 200 metres intervals from the mouth to the limit of the study area (see Fig 4.2). By placing this tracing over the detailed tracing for each year, readings of river widths and lateral stability were taken along the lines of measurement. Wherever a line of measurement crossed a channel, the width of the river perpendicular to the channel was noted, and where there was more than one channel the average river width was calculated. From these values means, standard deviations, and coefficients of variation were determined. Distances of lateral stability were taken from the maximum left bank position to mid-river (along the lines of measurement) and where there was more than one channel, a weighted average was calculated. Means, standard deviations, coefficients of variation and maximum minus minimum distances from the left bank were calculated.

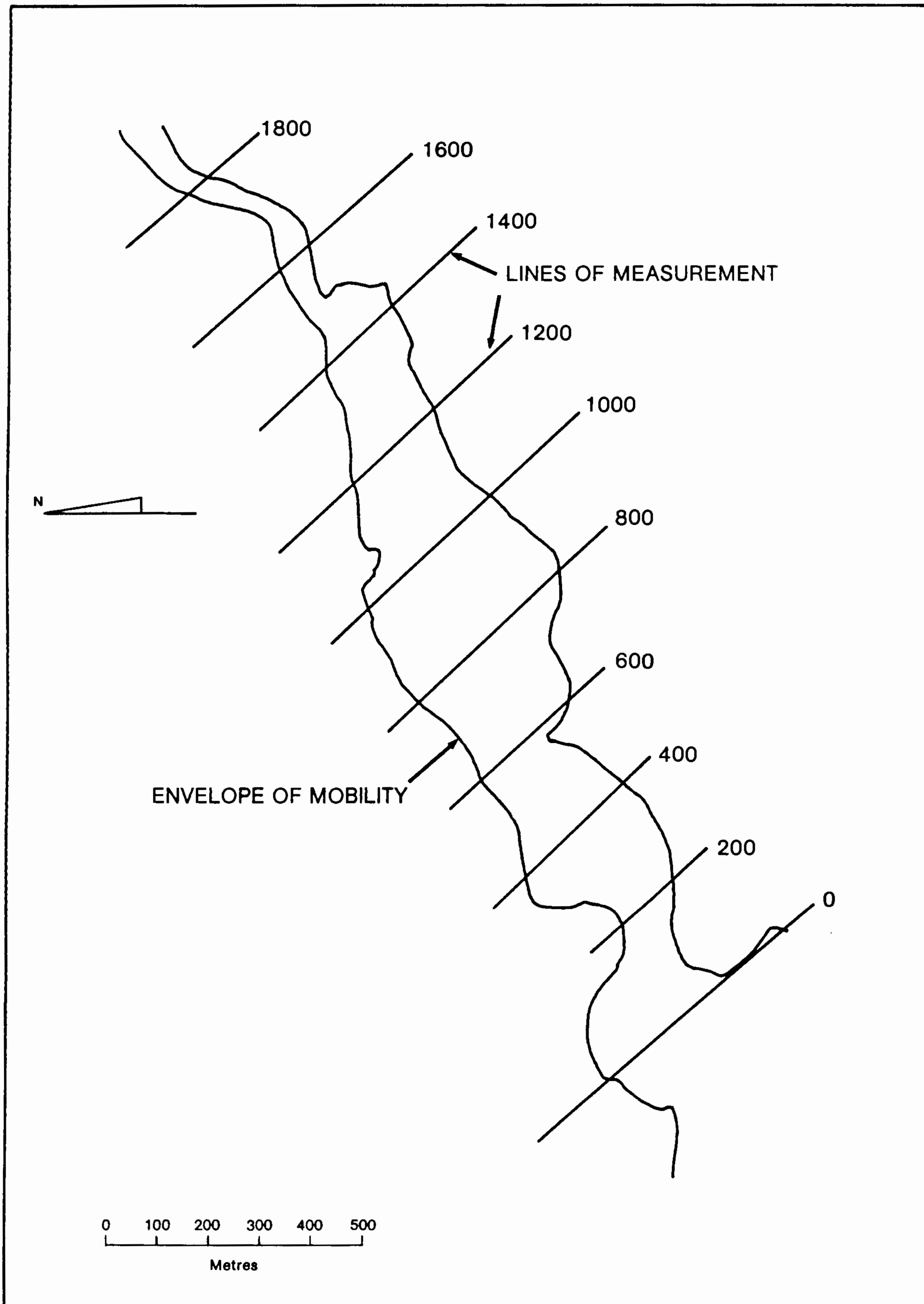


FIG 4.2 ENVELOPE OF MOBILITY AND LINES ALONG WHICH MEASUREMENTS WERE TAKEN. LINES ARE AT 200 M PARALLEL DISTANCE INTERVALS AND INDICATE DISTANCE FROM THE MOUTH.

As past flow conditions will affect parameters such as thalweg, aerial length and channel positions, knowledge of antecedent run-off and rainfall conditions must be considered for each of the time slices covered by the aerial photographs. These data are presented in Table 4.4.

Date	*Antecedent run-off and rainfall conditions*
1938	Preceded by one year with below average mean annual run-off. Previous three months near average monthly run-off, this following five months of below average monthly run-off.
1961	For two years previous below average mean annual run-off. For five months previous, near or below average monthly run-off.
1973	Preceded by an extremely dry six years with mean annual and monthly run-off below average.
Apr 1980	Previous four years average to below average mean annual run-off. Five months previous above average monthly run-off followed by four months of below average run-off. The event five months previous corresponds to above average monthly catchment rainfall of 103 mm in November 1979.
Jul 1980	From April to June average monthly run-off with a river flood between the 27th and 29th of June (average monthly catchment rainfall 60 mm).
Dec 1980	From July to December highest average catchment rainfall of 87 mm in November.
1987	Above average annual rainfall for preceding two years. High average catchment rainfall events in July 1985 (130 mm) and August 1986 (183 mm).

TABLE 4.4 ANTECEDENT RUN-OFF AND RAINFALL CONDITIONS PRIOR TO EACH DATE OF PHOTOGRAPHY.

Simulated run-off data (NRIO, 1987) are not available beyond 1980 (hydro year 1979), therefore from 1980 onwards catchment rainfall data (supplied by the Weather Bureau, Pretoria) are given to indicate high flow events. Simulated run-off and rainfall data have been used because no flow gauge data exist for the Uilkraals river.

4.2 GROUND SURVEY

The ground survey involved mapping of the estuary on either side of the Uilkraals bridge and embankment. Data from the mapping were used to produce a contour map and cross sections of the estuary.

Field work

The initial field task undertaken was to obtain datum heights at the estuary on which all other survey work would be based. Positions to which datum heights would be fixed were selected at deck level on either side of the bridge. Heights were brought in from bench-marks which had been surveyed by Escom and from Trigonometric beacons.

Method	*Station*	*Co-ordinates* Y	X	*Height*
Escom	Uil 1	-38 093,60	3830315,33	5,73
	Uil 2	-38 138,54	3830349,03	5,68
	22/4/87			
Height Accuracy: (B. Kingwell, pers.comm.) 0.25 metres, therefore height for both stations taken as 5,7 metres				
Trig.	Uil 2 06/4/87	Height 5,02 metres		
Trig.	Uil 2 25/8/87	-38 139.10	3830349,20	5.28

TABLE 4.5 CO-ORDINATES AND HEIGHTS FOR DATUM POINTS.

The co-ordinates and heights can be seen in Table 4.5. The second method was used because of the measurement inaccuracy in the Escom values (Mr. B. Kingwell, pers.comm.), and as the calculated height of 5,7 m was greater than the actual measured height from the road deck to water level.

The height of 5,02 m obtained from Trig. beacons was selected as it best approximated the measured height from road deck to water level. Results from a later survey conducted by Mr. L. Van der Merwe (pers.comm.) of NRIO tallied closely with those of the latter method above .

The area on either side of the bridge was surveyed using an electronic distance measure (EDM) and prism. This equipment was supplied by the Department of Surveying at the University of Cape Town. Lines were walked at right angles to the current direction at approximately 40m intervals. Ranging rods were used to fix the directions. Along each traverse, readings were taken where there was a break in slope. To facilitate the drawing of the contour map, the maximum distance between points was 45 metres. A total of 428 points was read over a distance of 700 m, with roughly half of the points being taken on each side of the bridge.

Data analysis

The measurements for each reading were entered into a mainframe computer and a programme made available by NRIO was used to draw a contour map of the estuary. The map was drawn at a scale of 1: 2 500 with a contour interval of 0,2 metre (see Fig 5.13). Cross-section depth profiles of the estuary were drawn from the contour map.

4.3 SEDIMENT SAMPLING AND ANALYSIS

This section describes the techniques used in vertical core sampling and surface sediment sampling. For each technique, field and laboratory work is described. The following section on data analysis describes and discusses the methods used for size and statistical analysis.

From the analysis of sediment samples the character of both the vertical and surface samples in the estuary can be described. Comparisons of the different statistics calculated for above and below the bridge enable the impact(s), if any, to be determined. Surface samples also supply useful data for understanding the sediment dynamics in the area around the bridge and for the whole estuary.

4.3.1. Core sampling

Field

Core samples of the estuary sediments were obtained by using a vibracore sampler developed by NRIO. Simply, the sampler works as follows: an aluminium tube is filled with water and vibrated using a simple air generator. At the same time water is pumped from the top of the tube to produce a pressure which draws sediment into the tube as the tube drops into the sand. When the required length has been obtained, or the tube will penetrate no further, it is pulled out with the aid of a winch, connected to a tripod, and sealed. The maximum depth of the holes depends firstly on the estuary stratigraphy, as any rocks or pebble horizons will not allow any further penetration of the tube. Secondly, the equipment is only capable of handling pipes of up to approximately 6 metres in length.

The selection of the core sample localities was based on the following criteria. Firstly, sites had to be positioned on either side and within close proximity of the bridge. This enabled the vertical character of the sediments above and below the bridge to be compared, the aim being to see if any differences exist as a result of the bridge. Secondly, localities were selected where past aerial photographs indicated the presence of previous channels. If an old channel could be identified and intercepted, a better idea of the pattern of sedimentation over the period could be determined. The actual positioning of the sample sites was dependent on the presence of water which is needed by the vibracore sampler. The final number of cores obtained was limited to one sampling day because of financial constraints. In total, five core samples were obtained, three taken upstream of the bridge and two downstream. Sample positions can be seen in Fig 4.3.

Pegs were placed in the core sample holes to mark the sample positions. At a later date collar heights of the holes were levelled-in using a dumpy-level and staff. Table 4.6 lists the depths of the holes, the loss or gain of core during recovery, and the collar heights for the samples C1 to C5.

Hole No.	*Depth* (m)	*Loss or Gain* (m)	*Collar Heights* (MSL)
C1	4,60	0,3 loss	0,00
C2	2,70	0,5 loss	0,11
C3	2,50	No change	0,13
C4	2,40	0,3 gain	0,25
C5	2,00	No change	0,34

TABLE 4.6 CORE SAMPLE DATA INDICATING HOLE NUMBERS, DEPTH OF HOLE, LOSS OR GAIN OF CORE DURING RECOVERY, AND COLLAR HEIGHTS OF THE CORE SAMPLES.

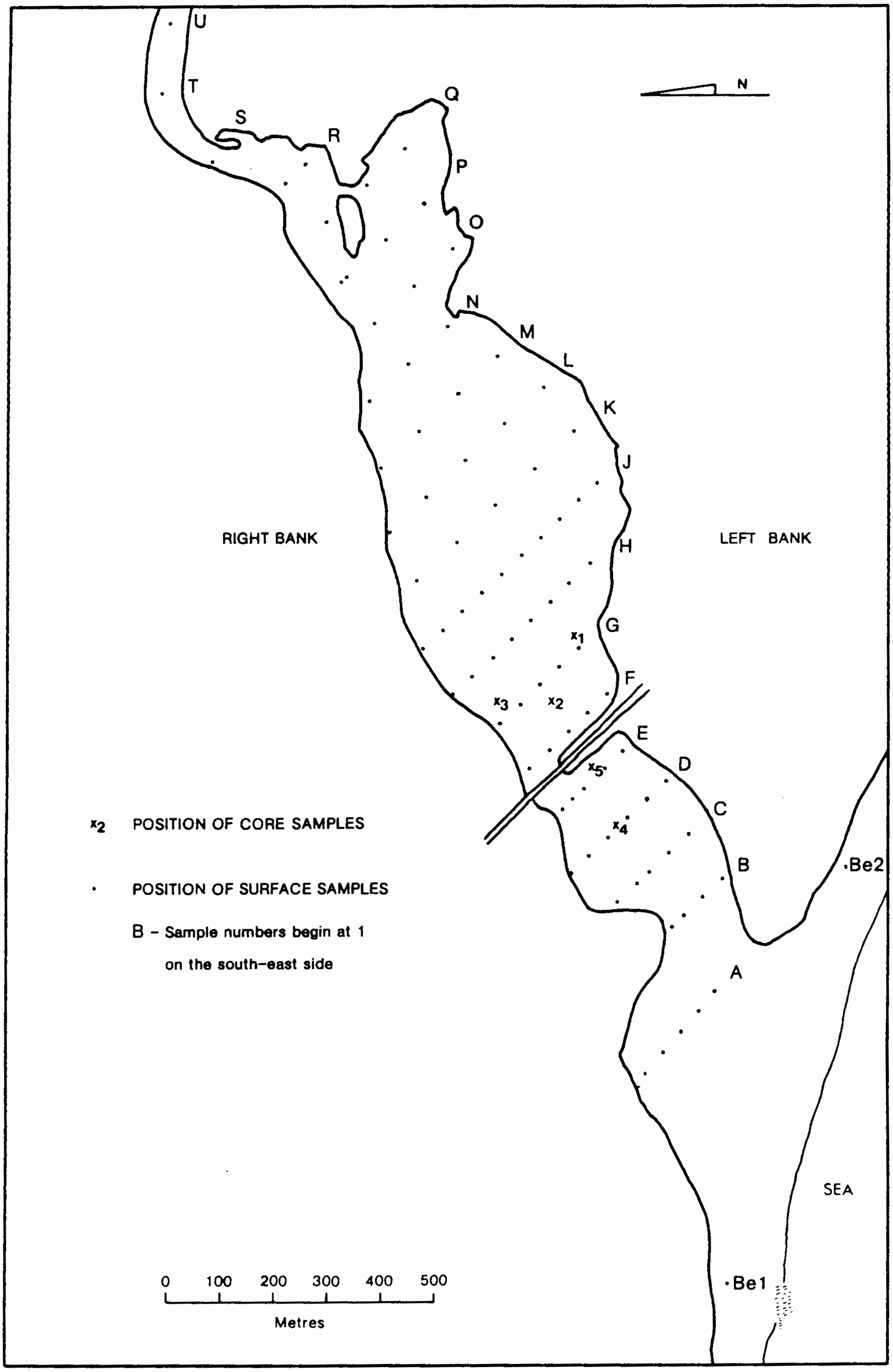


FIG 4.3 POSITIONS OF CORE AND SURFACE SAMPLES.

Laboratory

In the laboratory, the cores were split and sampled. Samples of approximately 50 g samples were taken at 10cm intervals over the length of the core. The cores were logged to record the sedimentary stratigraphy and photographed. No further preparation of the core samples took place before they were analysed. The settling tube method used for the analysis is described in section 4.3.3.

4.3.2. Surface sampling

Field

Sediment sample positions were set out using a parallel arrangement of ranging rods with the sample lines placed at 100 metre intervals. Sample lines and positions are depicted in Fig 4.3. Along the first 9 lines (A to J) samples were taken at approximately 50 metre intervals. As the distance was measured by pacing, the points are accurate to within 4 metres. For the next 7 lines (K to R) samples were obtained at 100 metre intervals. This reduction in sampling density was done to reduce time both in field sampling and in sample preparation and analysis. With the gentle topography, the expected changes in sediment size characteristics of this area is small. The remaining samples (S to U) were taken in the deepest part of the channel. Where the major channel was missed on this grid extra samples were taken. Thus lines E, Q, and S have some sample points that are located closer together. A total of 82 samples was collected. Beach samples were taken at localities Be1 and Be2. Sediment samples, weighing roughly 0,5 kilogram, were collected from the top 5 cm of the sediment surface using a small plastic container. Samples were taken from the upper sediment surface as this best reflects the energy conditions in which they were deposited.

Laboratory work

The initial laboratory work involved determining the clay content of selected samples. Nine samples were selected from the suite to give a good representation of the clay content of the sediment in the study area. The percentage clay content was determined using a wet sieving process based on the British Standard 1377 (1975) method. Samples selected for analysis are listed in Table 4.11.

The next stage in the sample preparation was to let the samples stand so that the major portion of water (caught during sampling) would evaporate. Samples were not oven dried, in order to prevent caking (Buller & McManus, 1979, p.94) and crust development (Briggs, 1977, p.67) which occurs when the clay content of samples is more than a few percent. Particle aggregation (Buller & McManus, 1979, p.96) is also avoided in this way. As a conventional splitting procedure e.g. Buller & McManus (1979, p.96), could not be conducted with a wet sample, a simple alternative method was devised by the writer. This involved repeated wet splitting until a sample size of 10 to 15 g remained. From this roughly 4 to 5 g were used for the detailed sedimentation analysis.

4.3.3 Data analysis

Size analysis

A sedimentation tube was used to conduct the size analysis of the sediment. Sediment tubes have been developed and have gained popularity because they provide a more rapid analysis than sieves and because it is believed that settling velocity has a greater dynamic significance than size determined by sieving (Blatt *et al.*, 1980). The sedimentation tube is based on Stokes' Law (Buller & McManus, 1979) and operates on the principle that samples are introduced at the top of a tube and the particles settle to the other end at rates proportional to their fall characteristics - dominated by size. Some limitations of the settling tube for analysis of sand have been noted by Blatt *et al.* (1980), Buller & McManus (1979), and Fromme (1977). Blatt *et al.* (1980) note that despite the limitations, several investigations have shown that settling tubes can give results of reasonably high precision. Schlee *et al.* (1964), in studies at Cape Cod, and Flemming (1977) in his analysis of sediments from Saldanha Bay and Langebaan Lagoon, have obtained accurate results using sedimentation tubes.

The settling tube used by the Sediment Dynamics Division at NRIO was made available for this study. Measurements of settling velocities were plotted automatically in a recorder and converted to grain sizes in an "on-line" computer system. For each sample the diameter is given in microns for 11 weight percentages which have been labelled D5, D10, D16, D25, D35, D50, D60, D75, D84, D90, and D95. For the core samples C1 to C5 the programme also plotted grain size against depth in the holes.

This tube calibrated using beach sediments is ideal for the measurement of sand size particles. A limitation of the tube however, is that it does not analyse sediment of a size smaller than approximately 105 micron or 3.25 phi. The effects that this may have on the statistical analyses are noted at the end of the following section.

Statistical analysis

A plethora of measures is available in sedimentary statistics (Buller & McManus, 1979). As it is beyond the scope of this project to discuss these in detail, the reader's attention is drawn to some of the literature available in this field. Some classic papers have been written by Krumbein (1934), Inman (1952), Folk & Ward (1957), McCammon (1962), and Folk (1966). Some well known books on the subject have been written by King (1966), Griffiths (1967), Folk (1968), Pettijohn (1975), Briggs (1977), Dyer (1979), and Blatt *et al.* (1980).

The first task in statistical analysis of sediments is to convert grain size recorded in millimetres into phi(Ø) scale (Krumbein, 1934) which is presented as;

$$\text{phi} = -\log_2 \text{diameter (mm)}.$$

This simply expresses the particle size as the negative logarithm, to the base two, of the diameter in millimetres. The phi scale converts data which are non-normal when measured on a simple arithmetic scale to a normal distribution (Briggs, 1977). Table 4.7 lists some of the phi equivalents to millimetre size.

mm	Phi	Grain type[a]	Microns	Phi	Grain type[a]
3.36–4.00	−1.75 to −2	Granule	74–88	3.75–3.5	
2.83–3.36	−1.5 to −1.75		62.5–74	4–3.75	
2.38–2.83	−1.25 to −1.5				
2.00–2.38	−1 to −1.25		53–62.5	4.25–4	C silt
			44–53	4.5–4.25	
1.68–2.00	−0.75 to −1	VC sand			
1.41–1.68	−0.5 to −0.75		31.2–44	5–4.5	
1.19–1.41	−0.25 to −0.5		15.6–31.2	6–5	M silt
1.00–1.19	0 to −0.25		7.8–15.6	7–6	F silt
			3.9–7.8	8–7	VF silt
0.84–1.00	0.25–0	C sand			
0.71–0.84	0.5–0.25		1.95–3.9	9–8	C clay
0.59–0.71	0.75–0.5		0.975–1.95	10–9	M clay
0.50–0.59	1–0.75		0.487–0.975	11–10	F clay
			0.243–0.487	12–11	VF clay
0.42–0.50	1.25–1	M sand			
0.35–0.42	1.5–1.25				
0.297–0.35	1.75–1.5				
0.250–0.297	2–1.75				
0.210–0.250	2.25–2	F sand			
0.177–0.210	2.5–2.25				
0.149–0.177	2.75–2.5				
0.125–0.149	3–2.75				
0.105–0.125	3.25–3	VF sand			
0.088–0.105	3.5–3.25				

[a] VL, very large; L, large; M, medium, S, small; VS, very small; VC, very coarse; C, coarse; F, fine; VF, very fine.

TABLE 4.7 PHI EQUIVALENTS TO MILLIMETRE SCALE FOR A RANGE OF SEDIMENT SIZES (FROM GRIFFITHS, 1967).

For simplicity and speed of operation, graphic measures have been favoured to moment measures. Although moment measures are the most mathematically elegant in obtaining parameters of a frequency distribution, for natural sediments there are some serious drawbacks (Folk, 1966, p.78). For example, moment measures assume a centre of gravity at the halfway mark of the class, an assumption which is often quite erroneous. In a summation of a discussion of moment and graphic measures, Folk (1966, p.80) concludes that "... the method of moments measures a slightly different property than the graphic methods, but that it has no specially sacred aura of fundamentality; each method has its advantages and its drawbacks, and each is equally valid for comparing a suite of samples. Presumably the same geologic conclusions would be reached no matter which method is used, because sample-to-sample variation in most geologic suites is so large as to outweigh precise hair-splitting over details of statistical orthodoxy ".

Graphic measures developed by Folk & Ward (1957) were used to determine the mean grain size, sorting, and skewness of the sediments. The measures of Folk & Ward were selected because of their frequent citations in the literature (e.g. King, 1966; Pettijohn, 1975; Buller & McManus, 1979; Weaver, 1977; Blatt *et al.* 1980), their ease of use, and their statistical efficiency (McCammon, 1962).

Mean grain size has been calculated using the formula ;

$$\text{Mean} = \frac{(\phi 16 + \phi 50 + \phi 84)}{3}$$

Mean grain size is the best measure of the overall average size of a sample (Folk, 1966, p.80) and best represents energy conditions during deposition. Relative energy conditions as reflected by mean grain size have been suggested by Solohub & Klovan (1970) and can be seen in Table 4.8.

Mean grain size (phi)	*Energy conditions*
Less than 0	High
0 to 2	Medium
Greater than 2	Low

TABLE 4.8 RELATIVE ENERGY CONDITIONS AS REFLECTED BY MEAN GRAIN SIZE (AFTER SOLOHUB AND KLOVAN, 1970).

Sorting was calculated from the equation;

$$\text{Sorting} = \frac{(\phi 84 - \phi 16)}{4} + \frac{(\phi 95 - \phi 5)}{6,6}$$

Sorting is a measure of dispersion or scatter and is an expression of the standard deviation of the size distribution. It is theoretically independent of values of central tendency and skewness, but in the case of sediments it seems to be correlated frequently with the mean; very coarse or very fine deposits tend to have a high standard deviation (are poorly sorted), whereas sands have a relatively low standard deviation (are well sorted). Sorting plots for the Tay Estuary (Fig 4.4b) indicate this relationship. The best sorted sediments (0,0 to 0,5) are found in the same area as fine sand (2 - 3 phi, Fig 4.4a), with a decrease of sorting into the finer and coarser sediments which border the broad central area. Sorting is related directly to the ability of the transporting agent to segregate its load according to size. In some environments this sorting process is very efficient - for instance, beach or windblown sands display a very narrow range of particle sizes. In other cases, such as in glacial till, the sorting

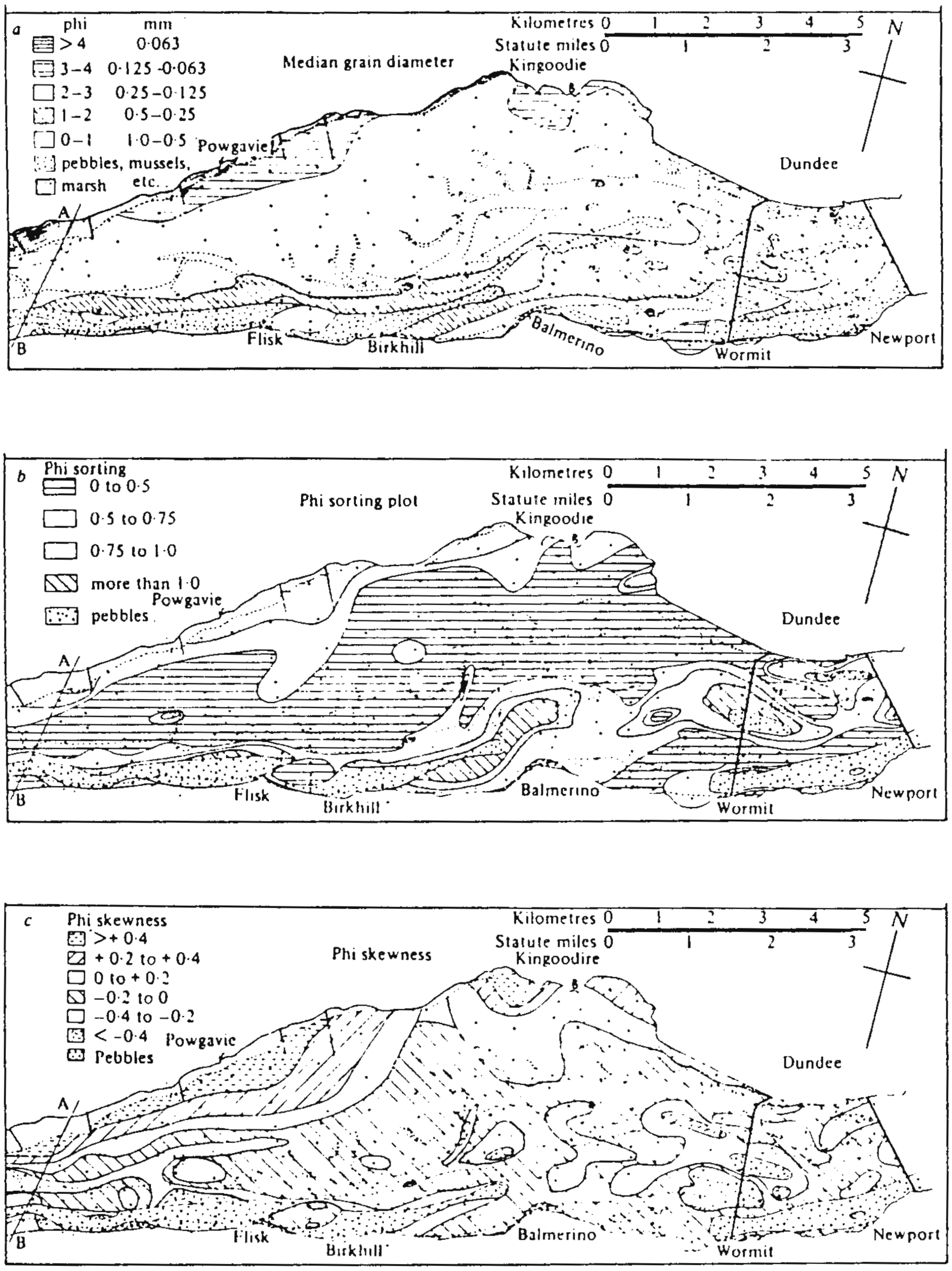


FIG 4.4 A. DISTRIBUTION OF MEDIAN GRAIN DIAMETER IN PART OF THE UPPER TAY ESTUARY. B. SORTING CHARACTERISTICS OF SEDIMENTS IN PART OF THE UPPER TAY ESTUARY. C. SKEWNESS VARIATIONS OF SEDIMENTS IN PART OF THE UPPER TAY ESTUARY (AFTER BULLER & MCMANUS, 1979)

process is comparatively inefficient and, as a result, the sediment is a mixture of very different particles (Briggs, 1977). A "verbal" sorting scale as suggested by Folk & Ward (1957) which facilitates description of the measurement, is shown in Table 4.9. Sorting is also useful as an index of current conditions; well sorted material indicating consistent conditions and poorly sorted material indicating inconsistent conditions (Stephenson, 1970).

Extremely poorly sorted	> 4.00
Very poorly sorted	2.00-4.00
Poorly sorted	1.00-2.00
Moderately sorted	0.50-1.00
Well sorted	0.35-0.50
Very well sorted	< 0.35

TABLE 4.9 VERBAL SORTING SCALE IN PHI VALUES (AFTER FOLK AND WARD, 1957).

Skewness, a measure of the asymmetry of a distribution, is calculated from the equation ;

$$\text{Skewness } (Sk_I) = \frac{\phi 84 + \phi 16 - 2\phi 50}{2(\phi 84 - \phi 16)} + \frac{\phi 95 + \phi 5 - 2\phi 50}{2(\phi 95 - \phi 5)}$$

Symmetrical curves have Sk_I = 0,00 and the measure varies from -1,00 to +1,00 (although natural sediments with skewness values beyond $\pm$ 0,80 are very rare). Positive values indicate distributions which are dominated by the finer grades, and negative values reflect dominance of coarser grades. In the Tay Estuary (Fig 4.4c) the upper tidal flat sediments are strongly positively skewed, the distributions are symmetrical lower on the flats, and become weakly negatively skewed on approach to the channel. Many sedimentologists have observed that negative skewness is often associated with sediments deposited in environments dominated by wave activity or by strong current action (Buller & McManus, 1979). A "verbal" scale of skewness (Folk & Ward, 1957) is shown in Table 4.10.

Very Negative-skewed	-1.00 to -0.30
Negative-skewed	-0.30 to -0.10
Nearly-symmetrical	-0.10 to +0.10
Positive-skewed	+0.10 to +0.30
Very positive-skewed	+0.30 to +1.00

TABLE 4.10 VERBAL SKEWNESS SCALE IN PHI VALUES (AFTER FOLK AND WARD, 1957).

As noted in a previous section, the settling tube does not measure sizes smaller than approximately 105 microns (3.25 phi). This affects the statistical analyses in the following way :

- the mean value will be higher than expected (the lack of fines will push up the value)

- sorting will be better (the lack of fines will reduce the variation around the mean)

- skewness will be more negative.

These effects, however, are likely to be small as the sample clay and silt content (< 63 microns or 4 phi) is low. This has been determined by conducting a Spearman's Rank Correlation test on eight samples previously analysed for their weight percent clay and silt. The test showed that a high correlation (r=0,78) exists between the clay content and distance from the estuary mouth. It can therefore be expected that the clay content at any sample position in the estuary will be below the highest calculated clay and silt content of 9,40 weight percent. Table 4.11 shows the test used and gives the weight percent clay and silt for the selected samples. The expected error in the statistical analysis will be of the same order as the values in Table 4.11.

Sample No	*% Clay* (c)	*Distance(m)* (d)	*Rank*$_c$	*Rank*$_d$	*Diff.*(D)	D^2
U	6,06	1900	5	8	3	9
T	9,40	1800	8	7	1	1
S	6,15	1700	7	6	1	1
Q3	4,66	1500	4	5	1	1
O3	6,09	1300	6	4	2	4
L1	2,90	1000	3	3	0	0
E3	1,96	400	1	2	1	1
B2	2,59	100	2	1	1	1

D2 = 18

$$r_s = 1 - \frac{6 \times 18}{8^3 - 8} \quad = 0,78$$

TABLE 4.11 RELATIONSHIP BETWEEN CLAY/SILT CONTENT (< 63 MICRON) AND DISTANCE FROM THE MOUTH DETERMINED USING SPEARMAN'S RANK CORRELATION TEST. A PERFECT CORRELATION R_S WOULD YIELD A VALUE OF 1.

No weight percent has been obtained for samples between 63 and 100 microns. This will have an effect on the statistical parameters but, because of the narrow weight range, the effect will be small.

These effects on the analyses make direct comparisons of the statistical parameters with those of other environments difficult and may result, therefore, in misleading interpretations. However, for statistical comparisons of sediments **within** the Uilkraals estuary, these errors will have little effect and can be largely overlooked.

The results of the analyses have been presented, firstly, by plotting in plan view each of the statistical measures against position in the estuary as has been done by Buller & McManus (1979). This is a common way of presenting such data and enables easy visual comparisons to be made with other statistical distributions and with the physical characteristics of the estuary. The second method of presenting the results has been to use bivariate scattergrams. These are graphs of two size parameters (e.g. mean and sorting) which are plotted against each other to show the distribution of distinct fields of sediment textures. Briggs (1977) notes that they are of particular value in palaeo-environmental studies, where the aim is to identify the depositional environment of sedimentary deposits, and are also used as an aid to classification and correlation of sediments. They are based on the principle that each process of transport and deposition tends to produce sediments with a characteristic range of particle size distributions. Friedman (1961) for example, plotted standard deviation (sorting) against skewness for sands from aeolian dunes, beach and river channels, and found a clear distinction between beach and river sands (Fig 4.5).

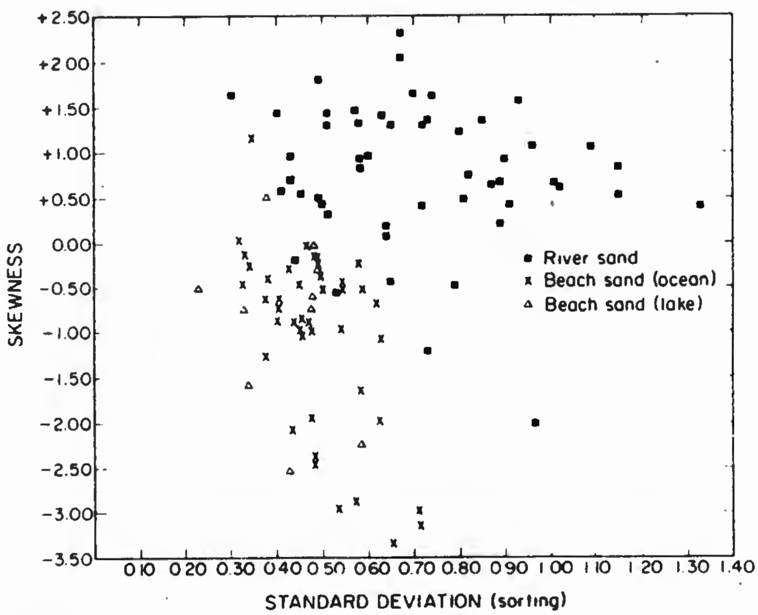


FIG 4.5 BIVARIATE SCATTERGRAM ILLUSTRATING THE DISTINCTION BETWEEN BEACH AND RIVER SANDS ON THE BASIS OF SKEWNESS AND STANDARD DEVIATION CALCULATED FROM MOMENTS (FROM FRIEDMAN, 1961).

In this study, statistical values above and below the bridge have been separated in order to detect possible differences in transport and depositional processes on either side of the bridge.

This section has outlined the various techniques used in this study and has described the advantages and disadvantages of each. Of the techniques described, some appear to be more appropriate to determine the impacts of bridge and embankment construction in the Uilkraals estuary than others. However, by employing a combination of the results, a clearer picture of the impacts may be gained. The following chapter presents the results of the study.

CHAPTER FIVE

RESULTS

Page

CHAPTER FIVE

RESULTS

This chapter outlines the results of the study, examining firstly the quantitative analysis of aerial photography, secondly the results of the ground survey and thirdly the results of the core and surface sampling.

5.1 AERIAL PHOTOGRAPHY

Diagrammatic representations of the aerial photographs used in this study are shown in Figs 5.2 to 5.8. Plate 7 shows the actual 1987 aerial photograph.

River characteristics

Examination of aerial photography has produced a series of measurements on thalweg and aerial length, the results of which are depicted in Fig 5.1 and Table 5.1. Thalweg lengths for the time slices studied vary from a high of 2864 m in December 1980 to a low of 2338 m in April 1980, a variation

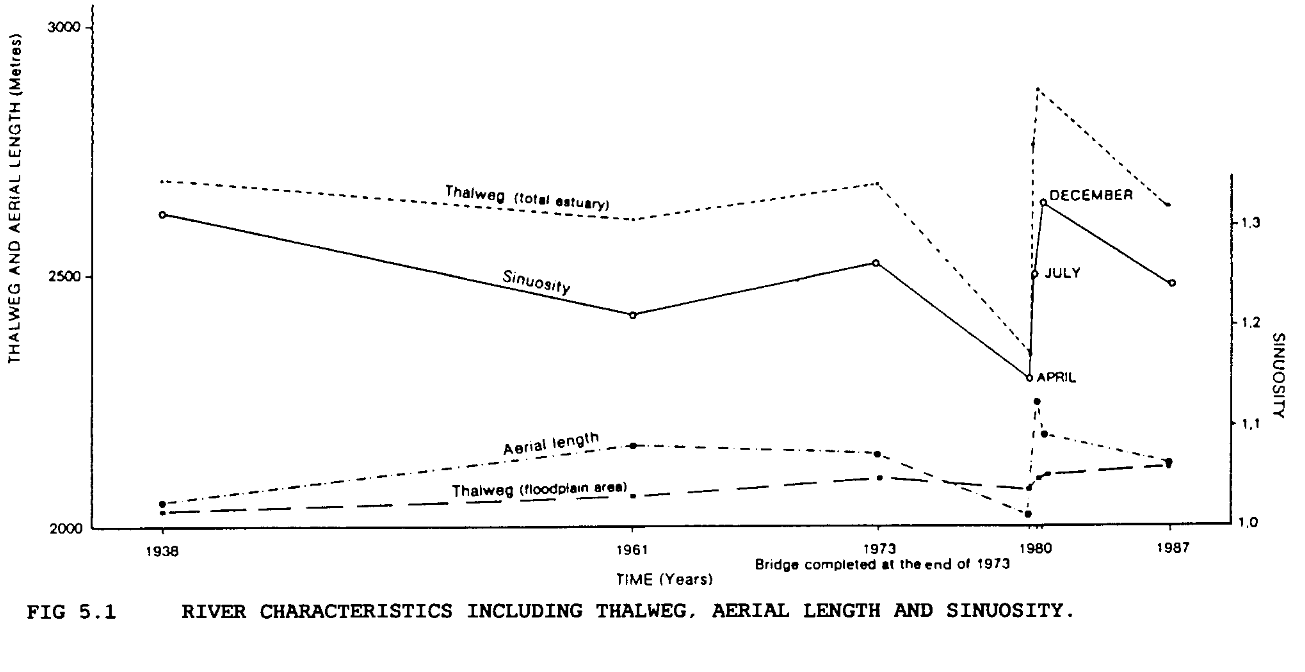


FIG 5.1 RIVER CHARACTERISTICS INCLUDING THALWEG, AERIAL LENGTH AND SINUOSITY.

of 18 %. Prior to April 1980 thalweg lengths for the preceding three photographs were similar; around the 2600's. The July 1980 photograph shows an increased thalweg length of about 400 m from that of the April 1980 photograph. The December 1980 photograph shows a further increase in thalweg length of approximately 100 m (Fig 5.7). In 1987 (Fig 5.8) there is a drop in thalweg length of over 200 m from December 1980 to 2632 m, which is very similar to the lengths in the first three photographs. Above the separating line between the floodplain and the marine area, thalweg lengths vary much less. A high value of 2116 m occurs in 1987 with the lowest value of 2027 m occurring in April 1980. Thalweg lengths and their changes for above and below the separating line are presented in Table 5.2. Above the line thalwegs change by a maximum of 65 m or 3,1 %

	1938	*1961*	*1973*	*Apr80*	*Jul80*	*Dec80*	*1987*
<u>River</u>							
Thalweg (m)							
- total length	2678	2610	2682	2338	2756	2864	2632
- above line	2029	2054	2092	2027	2090	2101	2116
Aerial dist (m)	2049	2162	2144	2018	2205	2174	2128
Sinuosity	1,31	1,21	1,25	1,16	1,25	1,32	1,24
<u>Floodplain</u>							
Total area (Ha)	74,0	79,4	78,0	77,8	-	78,1	77,4
Open sand (%)	65,3	64,8	67,3	68,2	-	68,0	63,2
Herbland Sand (%)	29,9	32,8	30,0	28,4	-	29,1	33,7
Herbland Mud (%)	4,9	2,4	2,9	3,4	-	3,0	3,1
Dry sand (% of total area)	3,1	6,1	7,4	6,3	-	5,6	6,3
<u>Marine</u>							
Open sand (Ha)	32,9	23,2	21,3	22,9	-	19,4	14,3
Vegetation							
L.B. change (Ha)	-	17,8	2,5	0,3	-	-0,1	-0,1
R.B. change (Ha)	-	4,3	-0,2	0,7	-	same	same

TABLE 5.1 QUANTITATIVE MEASUREMENTS AND DATA RECORDINGS OBTAINED FROM THE AERIAL PHOTOGRAPHS.

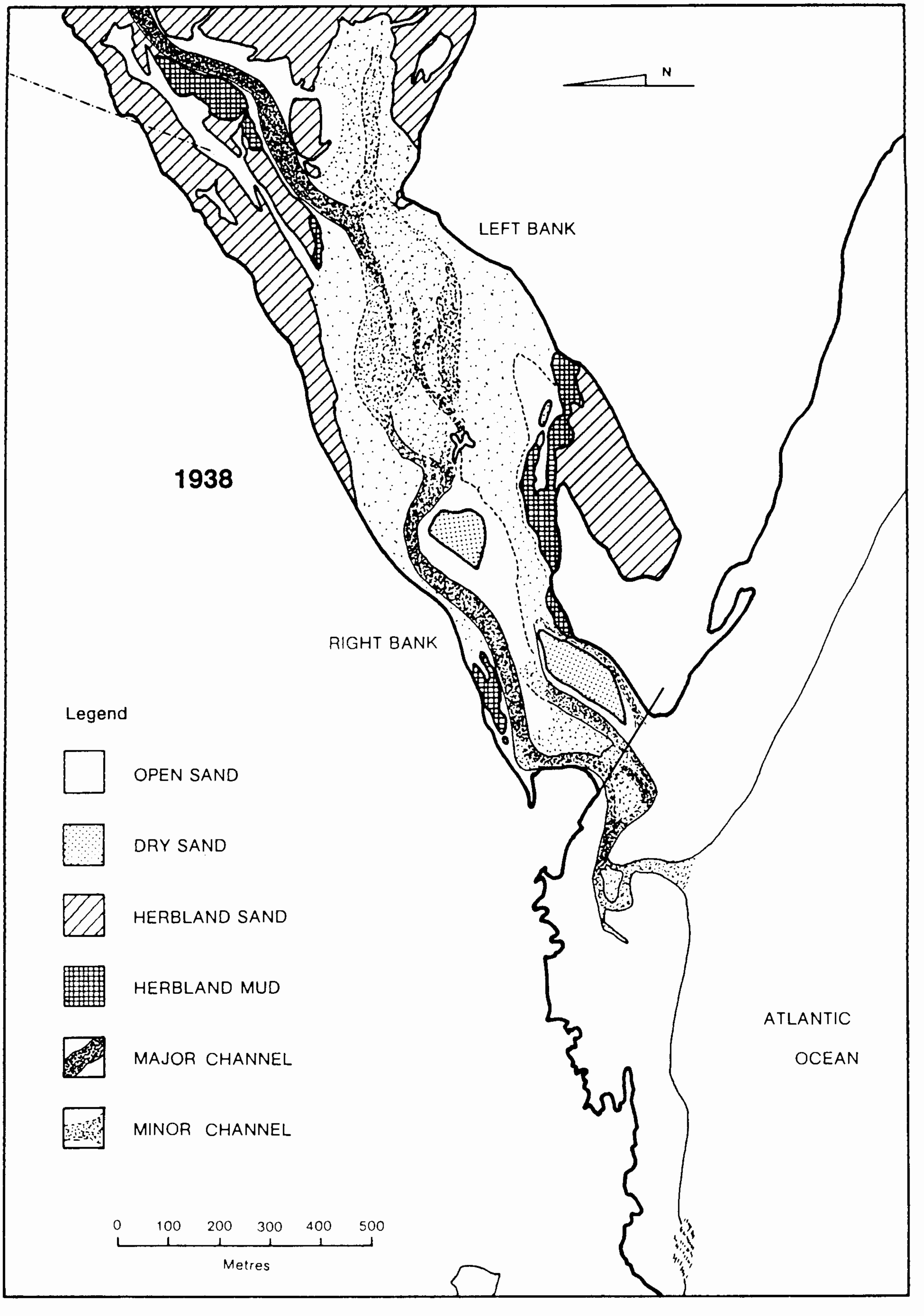


FIG 5.2 DIAGRAMMATIC REPRESENTATION OF 1938 AERIAL PHOTOGRAPH.

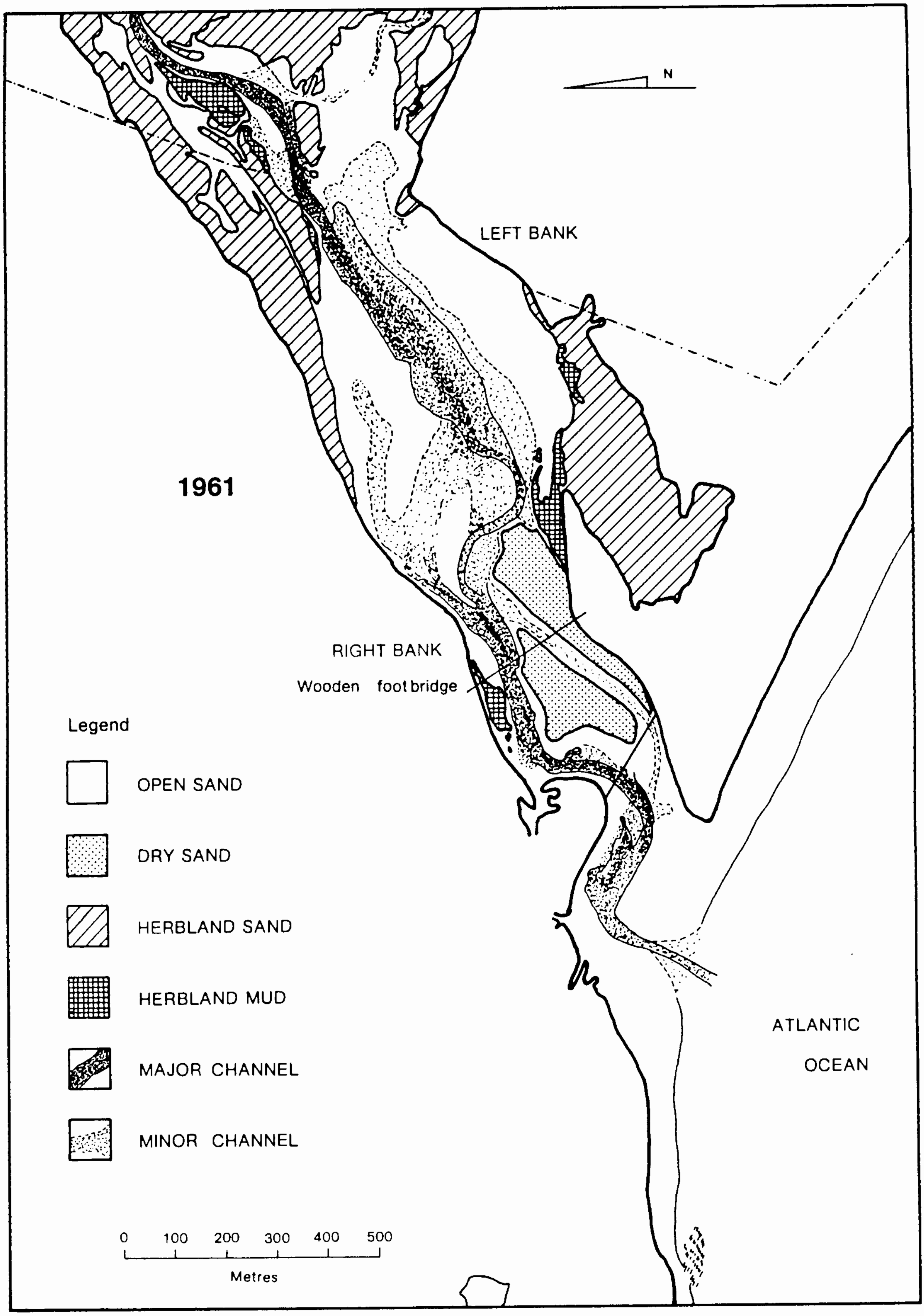


FIG 5.3 DIAGRAMMATIC REPRESENTATION OF 1961 AERIAL PHOTOGRAPH.

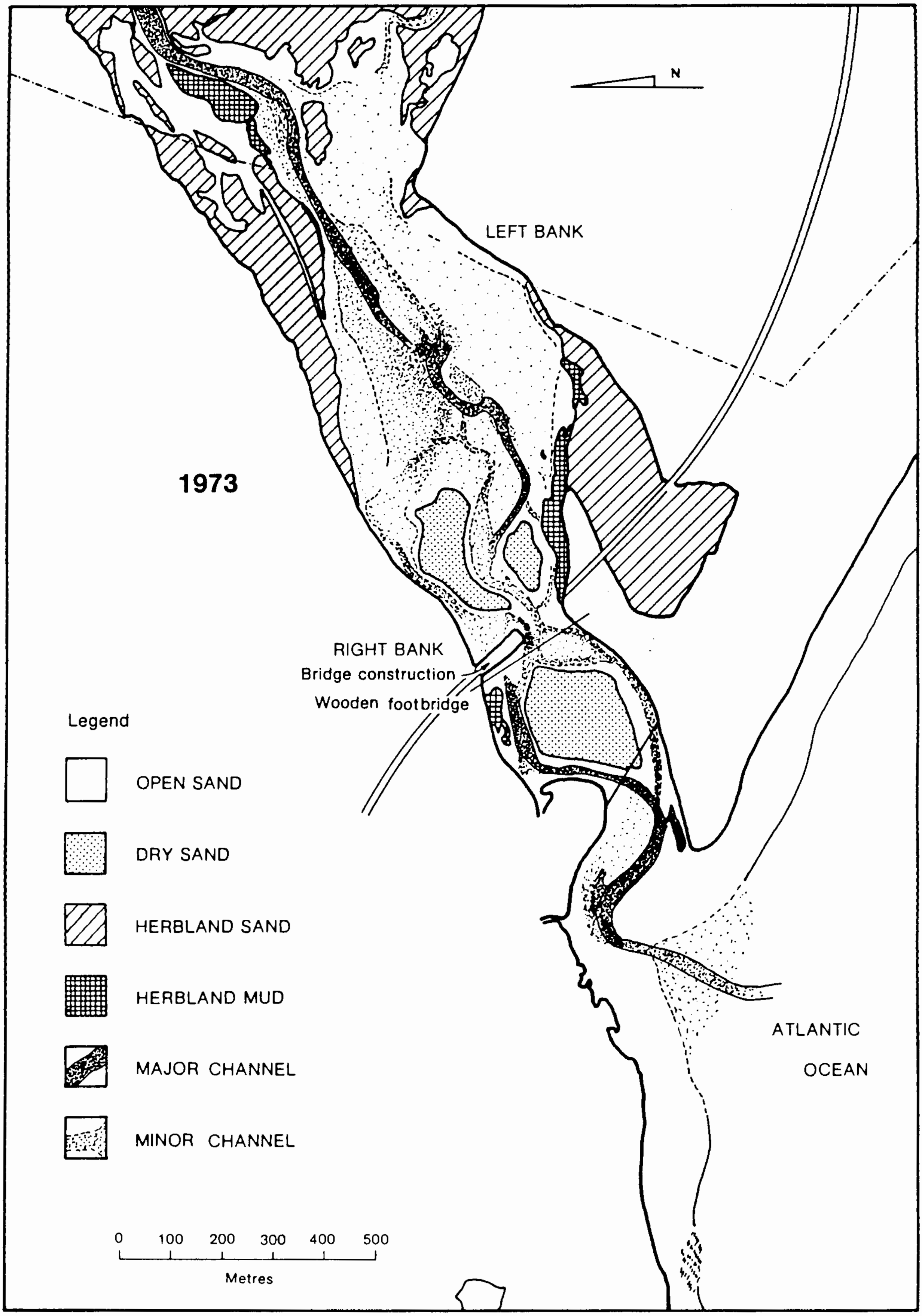


FIG 5.4 DIAGRAMMATIC REPRESENTATION OF 1973 AERIAL PHOTOGRAPH.

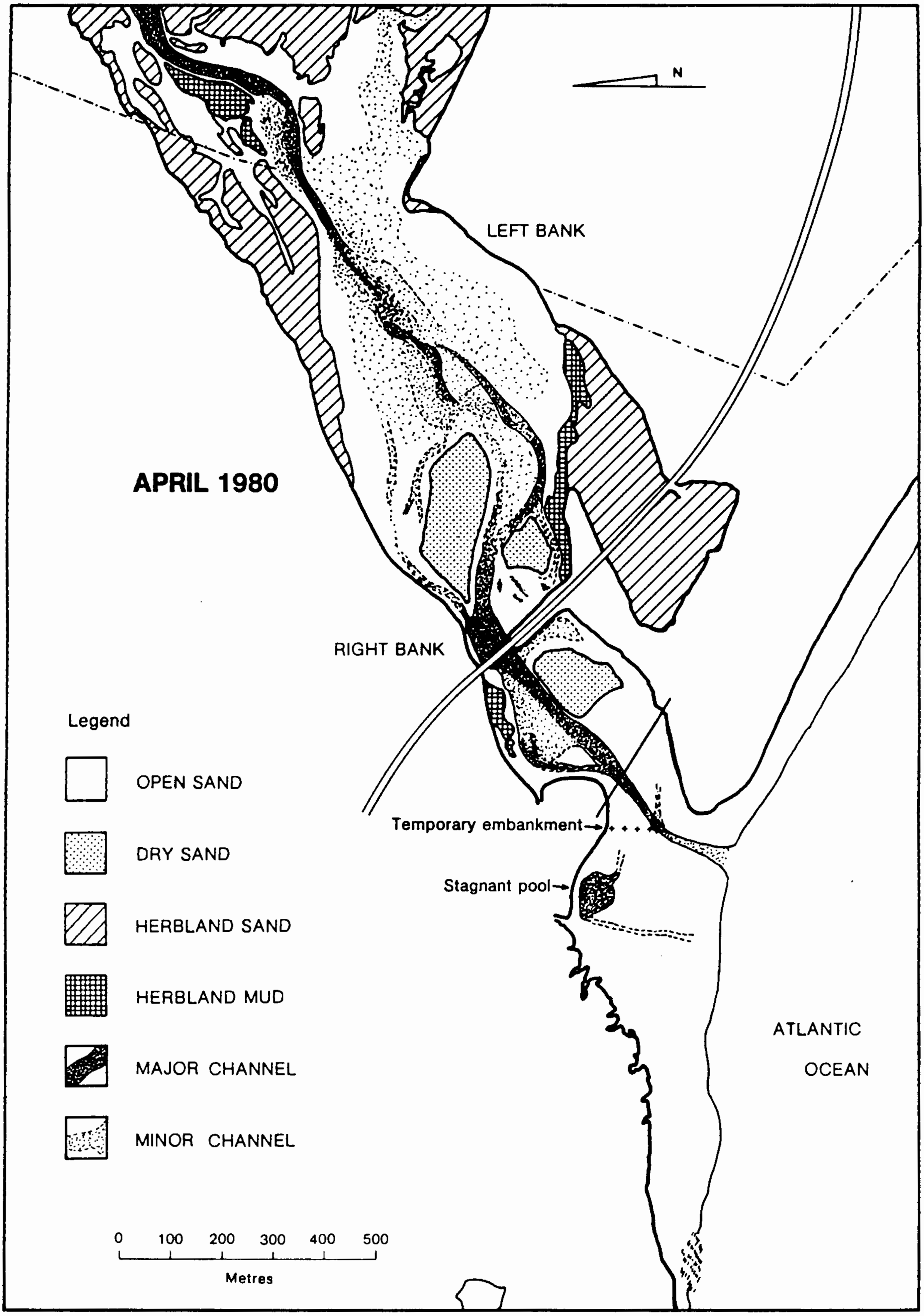


FIG 5.5 DIAGRAMMATIC REPRESENTATION OF APRIL 1980 AERIAL PHOTOGRAPH.

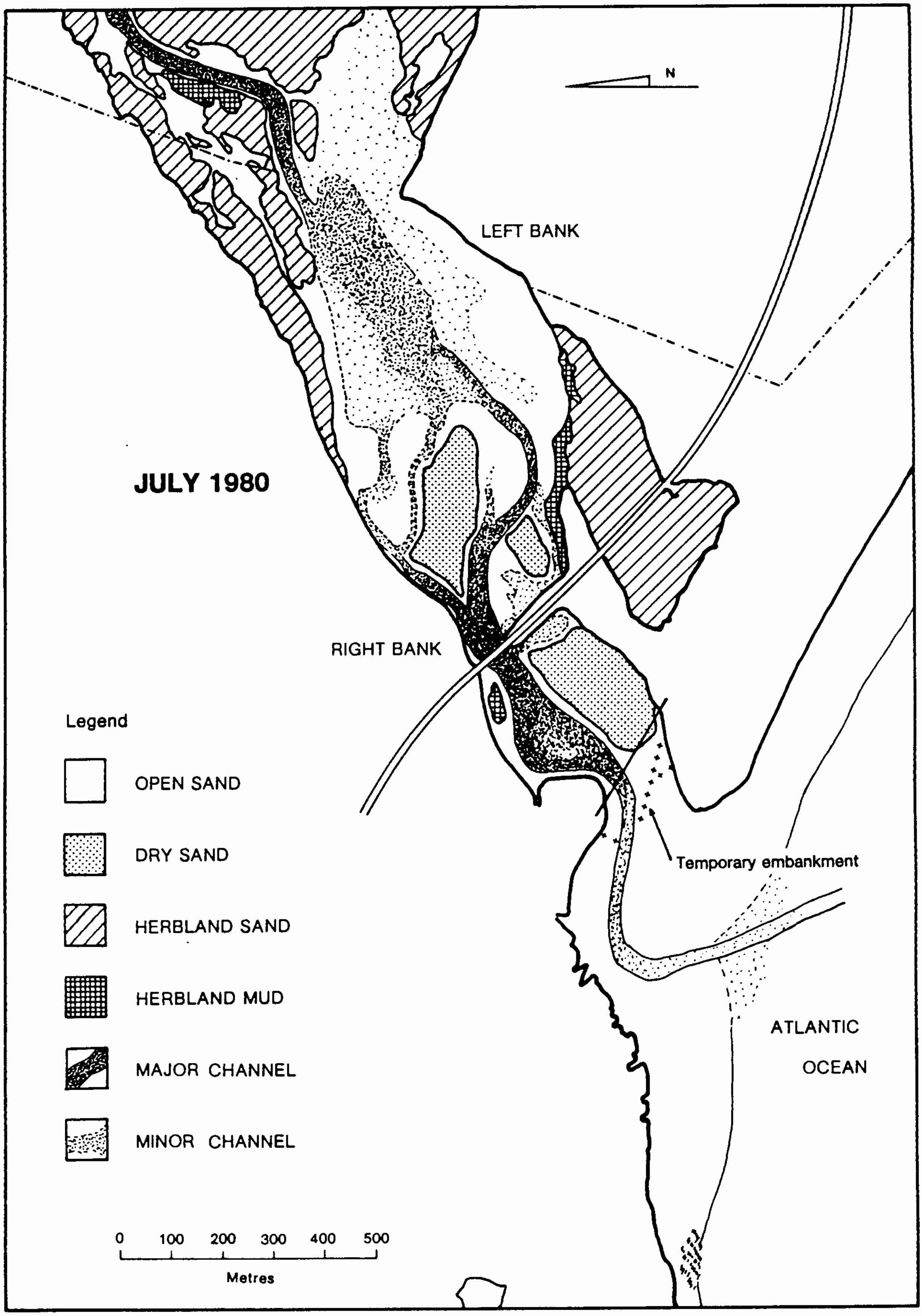


FIG 5.6 DIAGRAMMATIC REPRESENTATION OF JULY 1980 AERIAL PHOTOGRAPH.

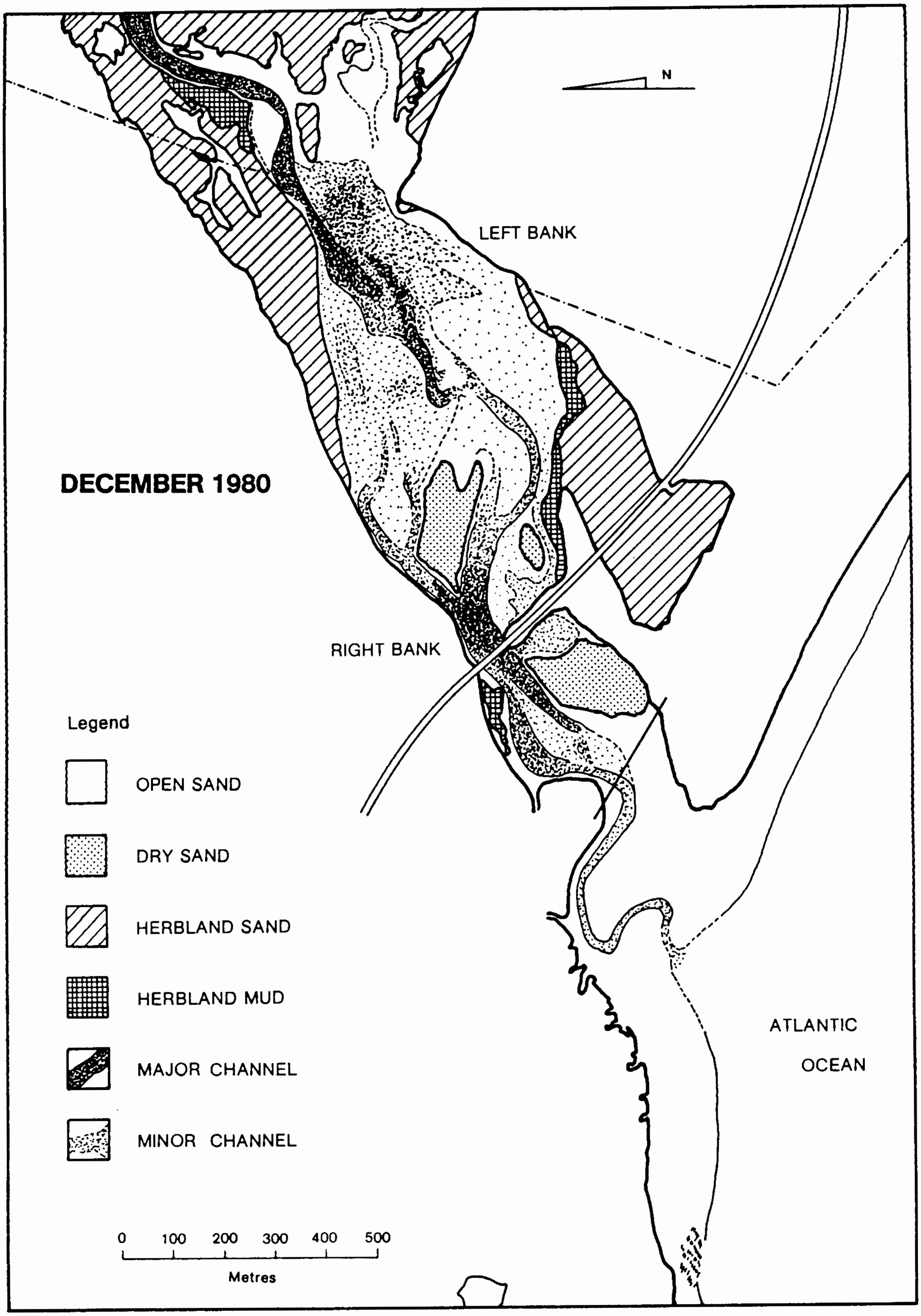


FIG 5.7 DIAGRAMMATIC REPRESENTATION OF DECEMBER 1980 AERIAL PHOTOGRAPH.

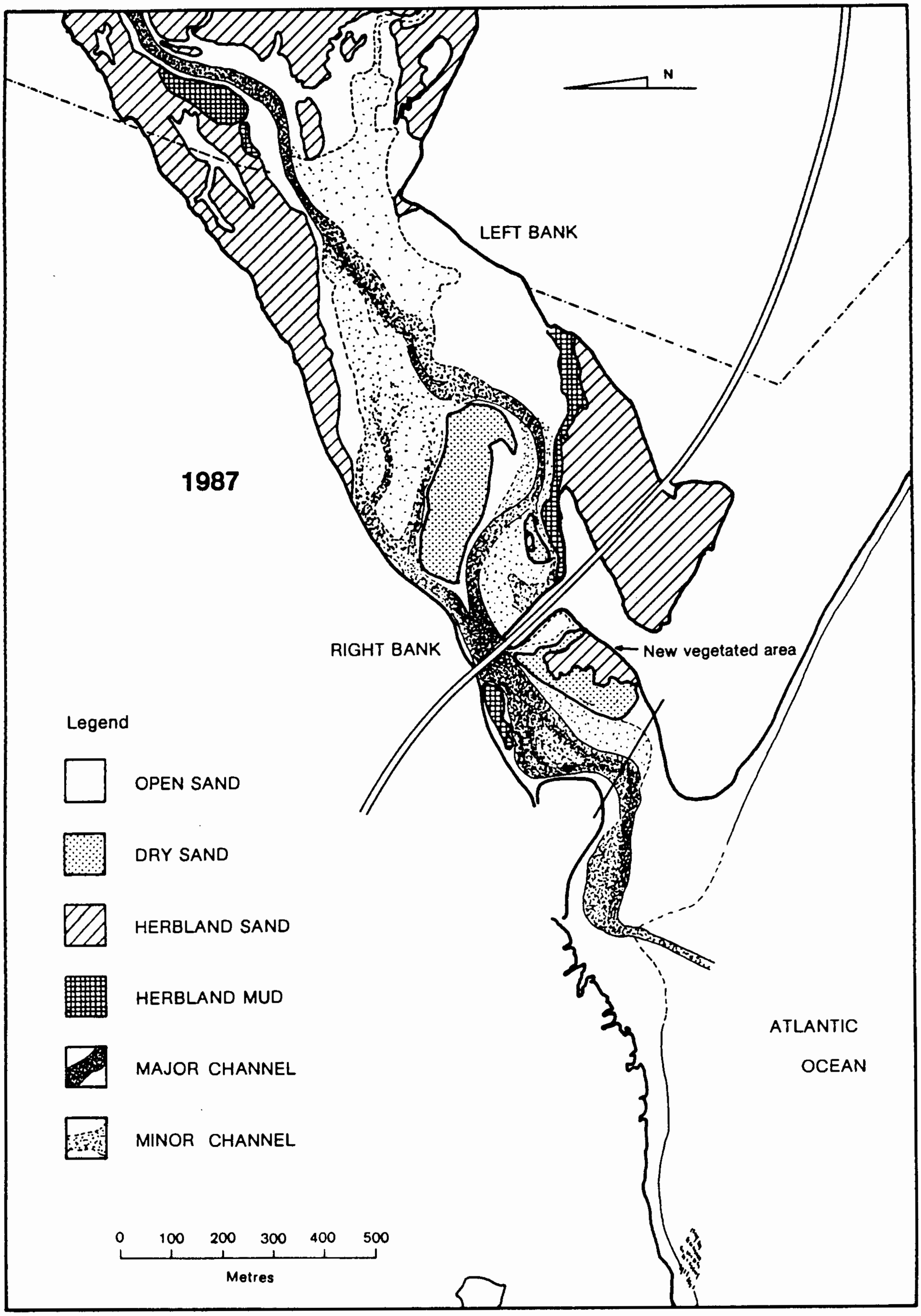


FIG 5.8 DIAGRAMMATIC REPRESENTATION OF 1987 AERIAL PHOTOGRAPH.

between photographs, with a maximum total change for the period of 89 m or 4,2 %. By comparison, thalwegs below the line have a maximum between photograph change of 359 m or 53,6 % and a maximum total change for the period of 452 m or 59,3 %.

The changes in the aerial distance for the period are much less marked than those of the thalweg distances. The smallest distance of 2018 m occurred in April 1980 (Fig 5.5) and another low value of 2049 m in 1938 (Fig 5.2). The highest value of 2205 m occurred in July 1980. The remaining values for December 1980 and 1987 are similar to those of 1961 and 1973.

The sinuosity varies from 1,16 to 1,32 and because of the small change in aerial length in comparison to thalweg length, reflects the trend of the thalweg distances (Fig 5.1). The lowest sinuosity of 1.16 corresponds to April 1980 and the highest value of 1.32 to December 1987. Sinuosity for the other photographs varies from 1,21 to 1,31.

Year	*Thalweg* (above line)	*Change* (m)	*Thalweg* (below line)	*Change* (m)
1938	2029		649	
1961	2054	+25	556	-93
1971	2092	+38	590	+34
Apr80	2027	-65	311	-279
Jul80	2090	+63	670	+359
Dec80	2101	+11	763	+93
1987	2116	+15	516	-247

\+ increase
\- decrease

TABLE 5.2 THALWEG LENGTHS AND CHANGES BETWEEN YEARS OF PHOTOGRAPHY FOR ABOVE AND BELOW THE LINE SEPARATING THE FLOODPLAIN FROM THE MARINE AREA. NOTE THE LARGE CHANGES BELOW THE LINE.

Floodplain measurements

Floodplain measurements for each photograph are illustrated in Fig 5.9. In 1938 the total floodplain area was 74 ha. Of the total area, open sand constitutes 65,3 % and herbland sand and mud 29,9 and 4,9 %, respectively. In 1961 the total area increased to 79,4 ha of which 64,8 % was open sand, 32,8 % herbland sand and 2,4 % herbland mud. The increase

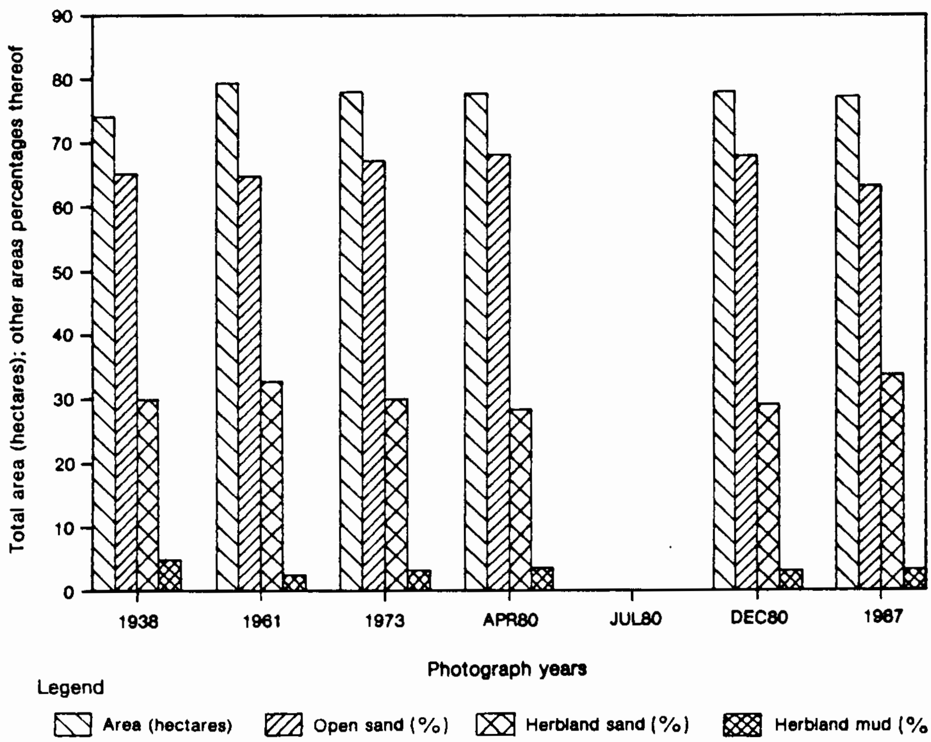


FIG 5.9 FLOODPLAIN MEASUREMENTS.

in herbland sand occurred in the protruding area on the left bank. In 1973 the total area had changed very little from 1961. However, an increase in open sand occurred from 64,8 to 67,3 % at the cost of a decrease in herbland sand from 32,8 to 30,0 %. Herbland mud had increased only slightly from 2,4 to 2,9 % of the total area. In April 1980 there is little change from 1973 with only a small increase in open sand and decrease in herbland sand. Herbland mud increased slightly to 3,4 %. The December 1980 photograph shows very little change from April 1980 (no data were obtained from the July photograph because of the loss of clarity during enlargement). At 77,4 ha, the total area for 1987 is very much the same as in December 1980. However there has been a notable decrease in 1987 in the open sand area from 68,0 % in December 1980 to 63,2 %, and an increase in herbland sand from 29,1 to 33,7 %.

Dry sand areas show an increase in size from 1938 to 1961 of 3,1 to 6,1 %. For the other years the dry sand areas changed little with the highest value being 7,4 % in 1973 and the lowest, 5,6 %, in December 1980.

Marine area

The decrease in the open sand area and the coincident increase in bank vegetation have been the only major changes in the marine area (Table 5.1). From 1938 to 1961 vegetation on the right bank increased by 4,3 ha and on the left bank by 17,9 ha. The coincident decrease in open sand area was by about 16 ha, down to 23,2 ha. In 1973 the open sand area decreased further to 21,3 ha, while the left bank vegetation increased by 2,5 ha. Over the remainder of the period there have been only minor changes in bank vegetation. Open sand areas decreased from 22,9 ha in 1973 to 14,3 ha in 1987.

River widths

Results of the river width measurements can be seen in Table 5.3. As depicted by the mean values, river widths are narrow at the mouth and in the upper part of the study area but become much wider over the large shallow open sand area upstream of the bridge. The coefficients of variation (which relate the standard deviation to the mean) indicate that the variation in river width is most marked in the open sand area (stations 5 and 8) and decreases towards the mouth and upper study area.

Station	Distance from mouth(m)	River widths(m) 1938	1961	1973	Apr80	Jul80	Dec80	1987	Mean	Std.Dev	Coe.Var %
1	0	48	25	20	18	25	43	27	29.4	11.5	39.1
2	200	75	40	20	27	27	29	56	39.1	19.7	50.4
3	400	57	42	45	100	106	105	103	79.7	30.1	37.7
4	600	35	45	45	60	70	70	67	56.0	14.2	25.4
5	800	25	135	37	30	40	76	45	55.4	38.8	69.9
6	1000	85	152	205	97	142	168	78	132.4	47.4	35.8
7	1200	112	100	142	95	127	142	59	111.0	29.6	26.7
8	1400	92	75	39	10	118	162	32	75.4	53.3	70.7
9	1600	45	15	40	35	35	62	25	36.7	14.9	40.6
10	1800	27	17	20	24	28	31	22	24.1	4.9	20.2
Mean		60.1	64.6	61.3	49.6	71.8	88.8	51.4	63.9		
Std.Dev		29.6	49.2	61.8	35.4	46.9	52.7	26.4			
Coe.Var		49.3	76.1	100.8	71.4	65.3	59.3	51.3			

TABLE 5.3 RIVER WIDTH MEASUREMENTS FROM AERIAL PHOTOGRAPHY FOR THE PERIOD 1938 TO 1987.

The horizontal mean values depict changes in river width for each year of photography. The mean widths changed little between 1938 and 1973. Narrow values occurred in April 1980 and 1987 with greater widths in July and December 1980. The mean river width for the period is 63,9 m.

Station	*Dist.from mouth* (metres)	*Pre-bridge* 1938-1973	*Post-bridge* 1980-1987	*Change* (%)
1	0	31	28	- 10
2	200	45	35	- 22
3	400	48	104	+ 54
4	600	42	67	+ 37
5	800	66	48	- 27
6	1000	147	121	- 18
7	1200	118	106	- 10
8	1400	69	81	+ 15
9	1600	33	39	+ 15
10	1800	21	26	+ 19

\- Decrease in river width
\+ Increase in river width

TABLE 5.4 MEAN RIVER WIDTHS FOR THE PERIOD PRE- AND POST-BRIDGE CONSTRUCTION.

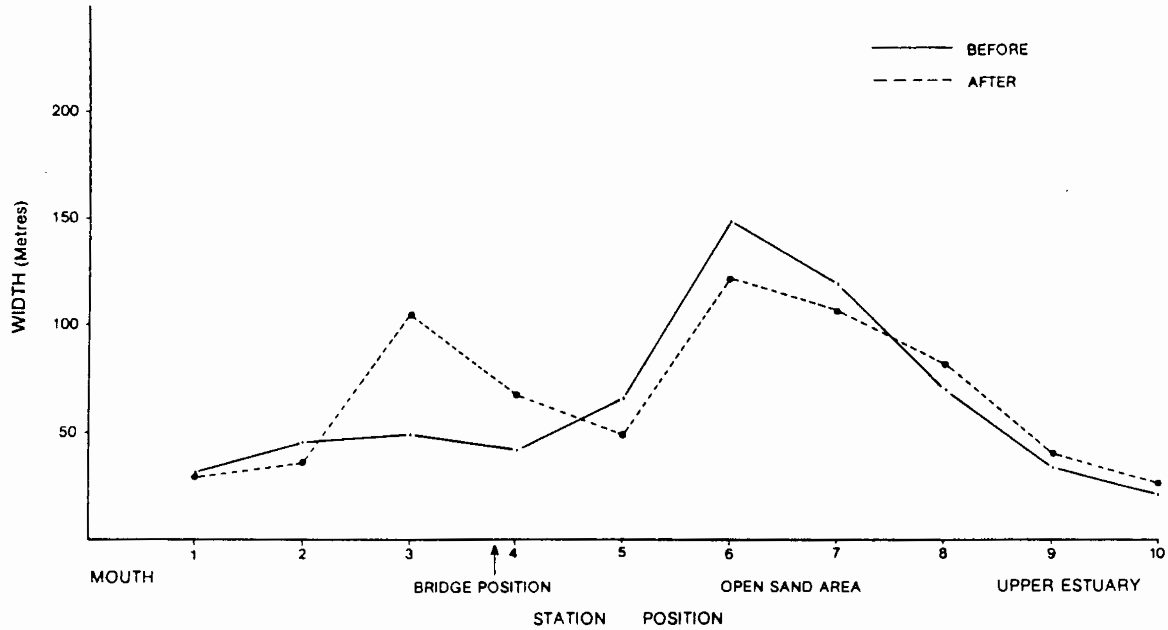


FIG 5.10 MEAN RIVER WIDTHS BEFORE AND AFTER BRIDGE CONSTRUCTION. NOTE THE INCREASE IN WIDTH AT STATIONS 3 & 4.

Mean values before and after bridge construction (Table 5.4), calculated from the data presented in Table 5.3, are illustrated in Fig 5.10. At five of the ten stations widths decreased, while at the other five, widths increased. At the two stations nearest the mouth (stations 1 & 2) there has been a decrease in river width. On either side of the bridge (stations 3 & 4) there has been a marked increase in river width, with percentage changes of 54 and 37 for the two stations, respectively. At stations 5, 6 and 7 widths decrease while for the remaining 3 stations widths increase.

Lateral stability

Lateral stability results can be seen in Table 5.5. Lateral channel displacement within the Uilkraals estuary is controlled largely by the geomorphology of the estuary, in such a way that where the floodplain widens lateral displacement increases, and vice versa. In the upper part of the study area however (stations 9 & 10), the stable channel

Station	Distance from mouth	Distance from maximum observed left bank position to mid-river (m)							Max-Min	Mean	Std.Dev	Coe.Var %
		1938	1961	1973	Apr80	Jul80	Dec80	1987				
1	0	148	230	235	35	270	257	215	235	198.6	82.1	41.3
2	200	85	95	53	95	100	100	80	47	86.9	16.7	19.2
3	400	185	220	163	200	198	197	202	57	195.0	17.5	9.0
4	600	115	155	95	175	180	175	175	85	152.9	34.1	22.3
5	800	335	170	160	154	139	209	239	196	200.9	68.5	34.1
6	1000	113	104	135	137	95	97	70	67	107.3	23.6	22.0
7	1200	85	67	105	80	63	109	92	46	85.9	17.6	20.5
8	1400	55	112	150	138	116	81	128	95	111.4	33.2	29.8
9	1600	45	17	26	30	30	40	26	28	30.6	9.3	30.6
10	1800	14	24	25	32	25	20	25	18	23.6	5.5	23.3
Mean		118.0	119.4	114.7	107.6	121.6	128.5	125.2	87.4	119.3		25.2
Std.Dev		91.2	74.1	67.3	62.3	77.4	77.4	78.5	72.0			9.0
Coe.Var		77.3	62.0	58.6	57.9	63.7	60.2	62.7	82.4			35.8

TABLE 5.5 LATERAL DISPLACEMENT MEASURED FROM AERIAL PHOTOGRAPHS FOR THE PERIOD 1938 TO 1987.

is restricted by well developed herbland sand and mud rather than by the floodplain. With the exception of stations 1 and 5 the lateral channel displacement varies between 46 and 95 m for the estuary. The large displacement of 196 m at station 5 can be accounted for by the long distance (335 m) to mid-river in 1938. At station 1 the high lateral displacement of 235 m is due to the various mouth positions. With the exception of April 1980, all photographs show the channel entering the sea towards the western side of the beach with a minimum distance to left bank of 146 m. In April 1980 with the river against the left bank, the distance was reduced to 35 m. The highest displacement of 270 m was recorded in July 1980. Coefficients of variation also show the most marked change in displacement at stations 1 and 5 with values of 41,3 and 34,1 % respectively. Variation in lateral stability for the other stations is much less marked with the coefficients of variation for stations 8 and 9 around 30 % and for all other stations 23 % and below.

In Table 5.6 and Fig 5.11 results of lateral displacement before and after bridge construction are shown. At station 1 the post-bridge lateral shift of 235 m is three times greater than for pre-bridge displacement and has been

Station	*Dist.from mouth* (metres)	*Pre-bridge* 1938-1973	*Post-bridge* 1980-1987
1	0	87	235
2	200	42	20
3	400	57	5
4	600	60	5
5	800	175	100
6	1000	31	67
7	1200	38	46
8	1400	95	57
9	1600	19	14
10	1800	11	12

TABLE 5.6 LATERAL DISPLACEMENT (MAXIMUM - MINIMUM) FOR THE PERIODS PRE- AND POST-BRIDGE CONSTRUCTION.

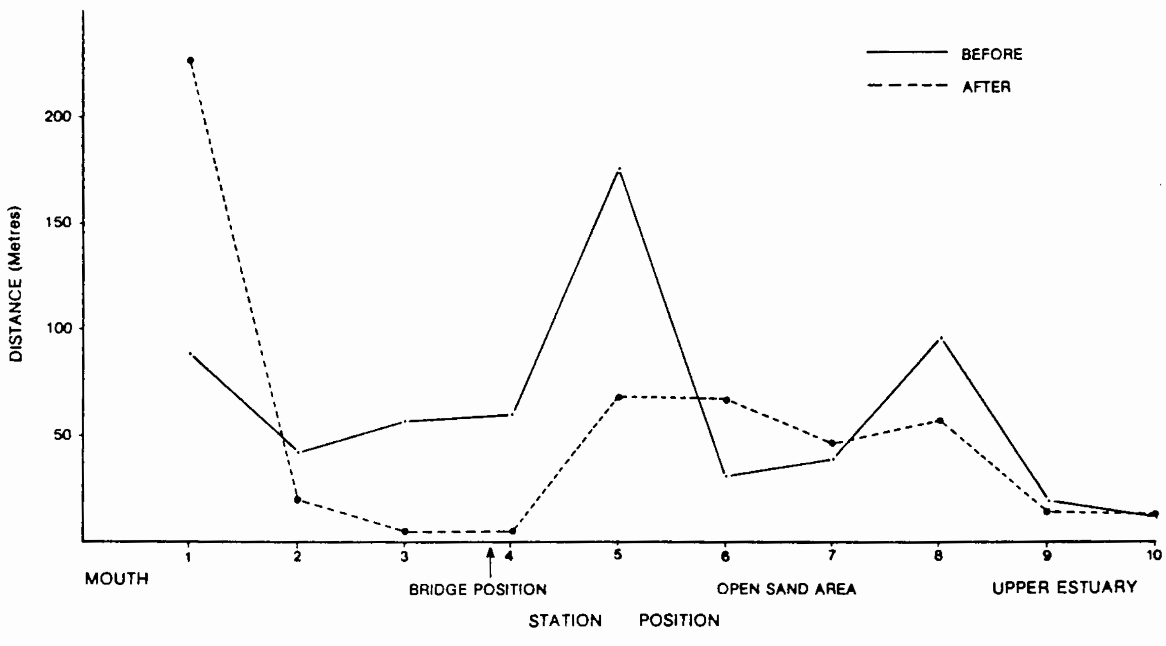


FIG 5.11 LATERAL DISPLACEMENT BEFORE AND AFTER BRIDGE CONSTRUCTION. NOTE THE LOWER LATERAL DISPLACEMENT THAT OCCURS AT STATIONS 2, 3, 4 AND 8 AFTER BRIDGE CONSTRUCTION.

affected largely by the temporary embankments. At stations 2 to 5, the lateral channel displacement after bridge construction decreased markedly (Fig 5.11) with the low values of 5 m at station 3 & 4 indicating that there is very little lateral channel movement. On the large open sand area (stations 6 & 7) displacement has increased in the period since bridge construction. At station 8 displacement has decreased while the values for channel position in the upper part of the study area (stations 9 & 10) have changed very little.

Mean channel positions before and after bridge construction are shown in Table 5.7 and are illustrated in Fig 5.12. Mean positions at the mouth are remarkably similar if one considers the vast difference in lateral displacement. At stations 2 to 4 the increased values indicate that the river is further towards the right bank, with the highest displacement of 54 m occurring at station 4. At stations 5 and 6 the mean values are lower showing that the channel is closer to the left bank. For the other years the mean channel position has varied little. The positioning of the main channel towards the right bank in the vicinity of the bridge is clearly visible in Figs 5.5 to 5.8.

Station	*Dist.from mouth* (metres)	*Pre-bridge* 1938-1973	*Post-bridge* 1980-1987
1	0	204	194
2	200	78	94
3	400	189	199
4	600	122	176
5	800	222	185
6	1000	117	99
7	1200	86	86
8	1400	106	116
9	1600	29	32
10	1800	21	26

TABLE 5.7 MEAN CHANNEL POSITIONS (METRES FROM LEFT BANK) FOR THE PERIODS PRE- AND POST-BRIDGE CONSTRUCTION.

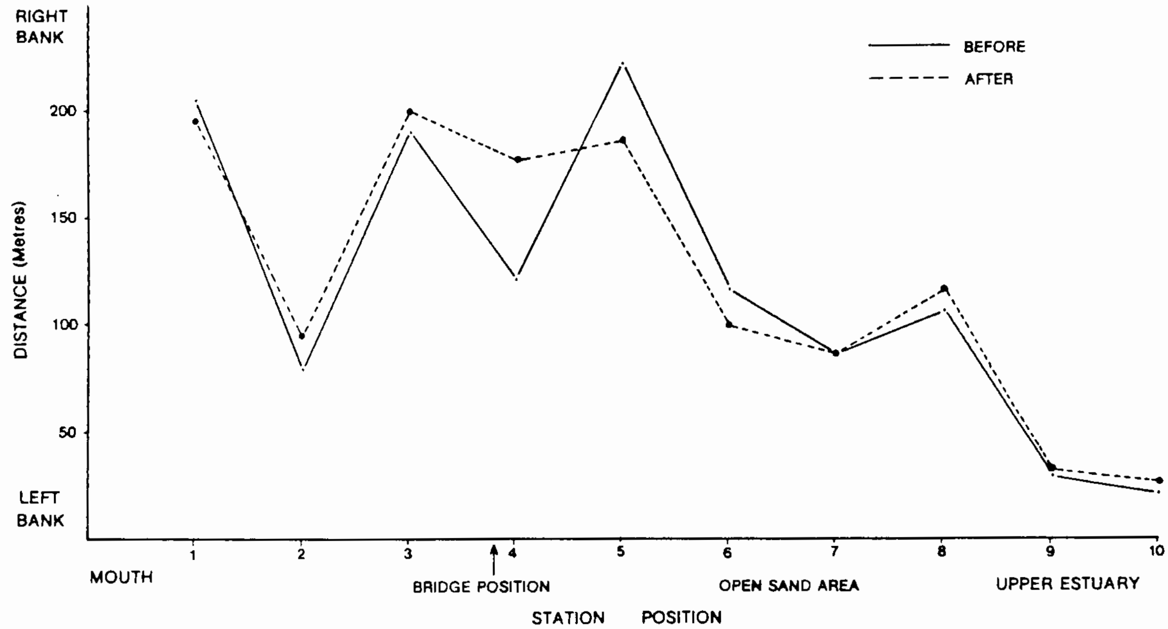


FIG 5.12 MEAN CHANNEL POSITIONS (MEASURED AS DISTANCE FROM THE LEFT BANK) BEFORE AND AFTER BRIDGE CONSTRUCTION. NOTE THAT SINCE BRIDGE CONSTRUCTION, THE CHANNEL HAS BEEN PUSHED TOWARDS THE RIGHT BANK SEAWARD OF STATION 4, AND TOWARDS THE LEFT BANK UPSTREAM OF STATION 4.

5.2 GROUND SURVEY

The contour map of the estuarine topography in the vicinity of the bridge and cross-section depth profiles are depicted in Figs 5.13 and 5.14 respectively. Approaching the bridge from upstream, the estuary has two major channels, one near to the left bank and one near to the right bank (station 5). The large area between the channels is very flat and varies in elevation from 0,5 to 0,8 m above mean sea level (MSL). From where the channels meet, to just upstream of the bridge (stations 4 to 4a), the deepest depths in the estuary were measured; the maximum being -0,7 m below MSL. The adjacent sand bank (left bank) which abuts the road embankment, has an elevation of between 0,3 and 0,5 m above MSL, which increases towards the embankment.

Below the bridge, the estuary has one main channel which is narrow near the bridge and mouth, but widens in the intermediate area (stations 2a & 3), where at low tide a

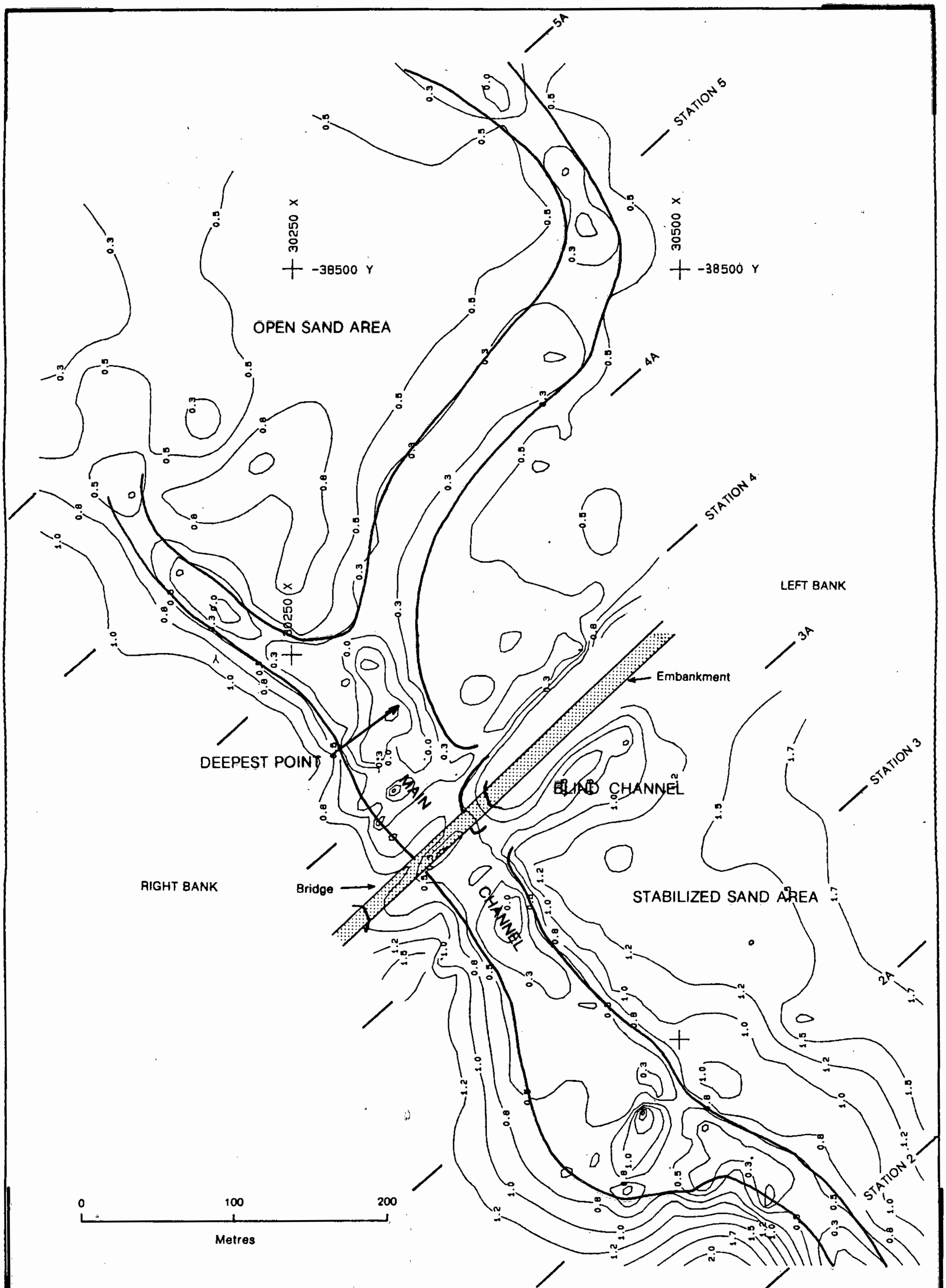


FIG 5.13 CONTOUR MAP OF THE AREA AROUND THE BRIDGE. STATIONS DENOTE THE POSITIONS OF THE CROSS-SECTION PROFILES.

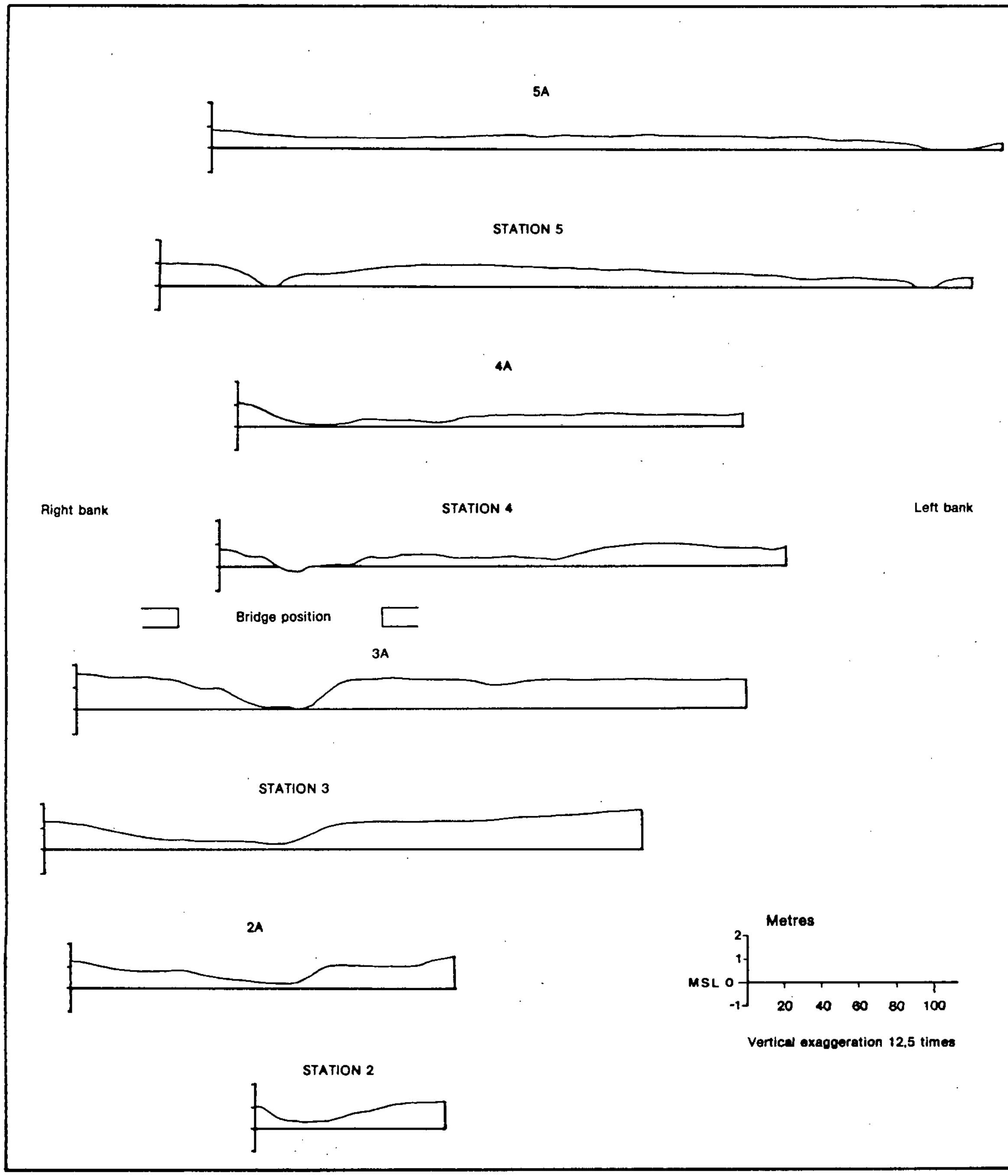


FIG 5.14 CROSS-SECTION DEPTH PROFILES DRAWN FROM THE CONTOUR MAP LOOKING UPSTREAM FROM THE MOUTH. SECTION LINES ARE ILLUSTRATED IN FIG 5.13.

small sand bank is exposed in the centre of the channel. The channel here is much shallower than upstream, with the maximum depth being -0,16 m below MSL. Adjacent to the embankment on the downstream side is a small blind channel which becomes inundated at high tide. The left bank sand area, stretching from the blind channel to the end of the survey area (new vegetated area, Fig 5.8) varies in elevation from 1,0 to 1,5 m above MSL. Below the bridge there is a steep drop of approximately 1 m (stations 2a-3a) from the left bank stabilised sand area into the main channel. Upstream the drop into the channels is less marked.

Channel positions and the area above MSL are clearly illustrated on the cross-section depth profiles (Fig 5.14). A comparison of the first two sections upstream and downstream of the bridge show that downstream, the amount of sediment above MSL is substantially greater than that of upstream. The deeper channel depth upstream is also clearly visible.

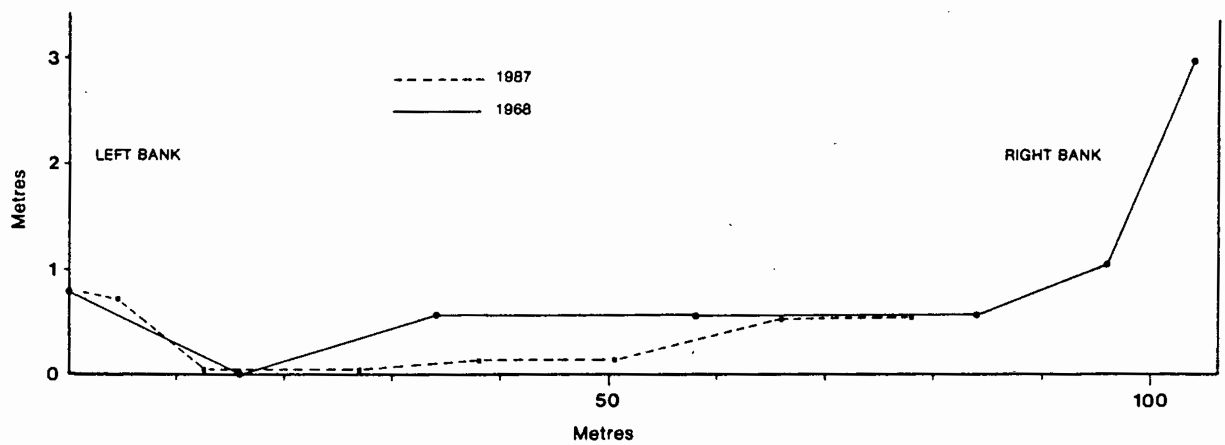


FIG 5.15 CROSS-SECTIONS OF THE SEDIMENT SURFACE UNDER THE UILKRAALS ESTUARY BRIDGE IN 1968 PRIOR TO CONSTRUCTION, AND IN 1987. SECTIONS ARE VIEWED LOOKING DOWNSTREAM.

In Fig 5.15 cross-sections of the sediment surface under the bridge in 1987 and 1968 have been drawn from the ground survey and the site plan for the initial bridge construction

(Cape Provincial Administration, 1968), respectively. A comparison of the cross-sections shows that in 1987 the sediment surface had dropped by up to 0,5 m below the 1968 level.

5.3 SEDIMENT SAMPLING

5.3.1 Core stratigraphy and analysis

Core logs (Fig 5.16) show that the upper 5 m of the estuarine sediment consists mainly of massive (unstratified) fine sand and lesser lag deposits which consist of varying amounts of pebble and shell material. The fine sand is creamy yellow in colour and is frequently interspersed with fine pebbles and shell material. Laminated mud and mud balls are less frequently present. The cores are darker at places due to the presence decaying carbonaceous material.

Results of the core sediment analyses are depicted in Fig 5.17, with the actual values for mean grain size, sorting and skewness being listed in Appendix III. In Fig 5.18 grain size (in microns) for each weight percentage is plotted against core depth. Although not showing any of the calculated analyses, this figure does highlight depths in the cores at which there are significant changes in size (especially in the coarser sediments) and aids in the interpretation of the grain size analyses depicted in Fig 5.17. Thus, in the following discussion of the results shown in Fig 5.17, Fig 5.18 can be referred to continually.

As indicated by the mean grain size, cores consist mainly of fine sand (2 to 3 phi) with minor amounts of medium and coarse sand (0 to 2 phi). Based on the verbal description of Solohub & Klovan (1970) these sizes reflect low to medium energy conditions of deposition. Verbal sorting values (Folk & Ward, 1957) indicate sediments that are moderately to well sorted, but which become poorly sorted in places. Verbal skewness (Folk & Ward, 1957) indicates that the core sediments are negatively to very negatively skewed.

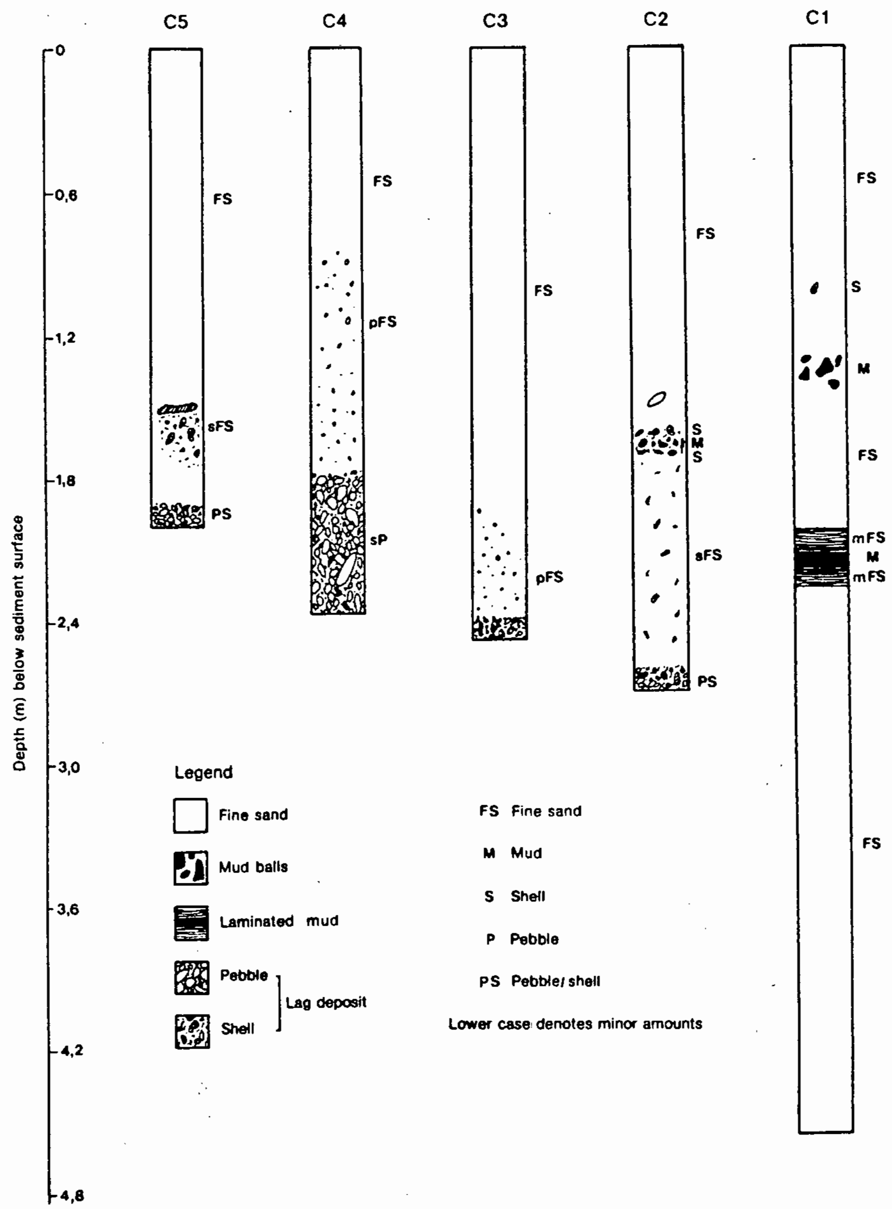
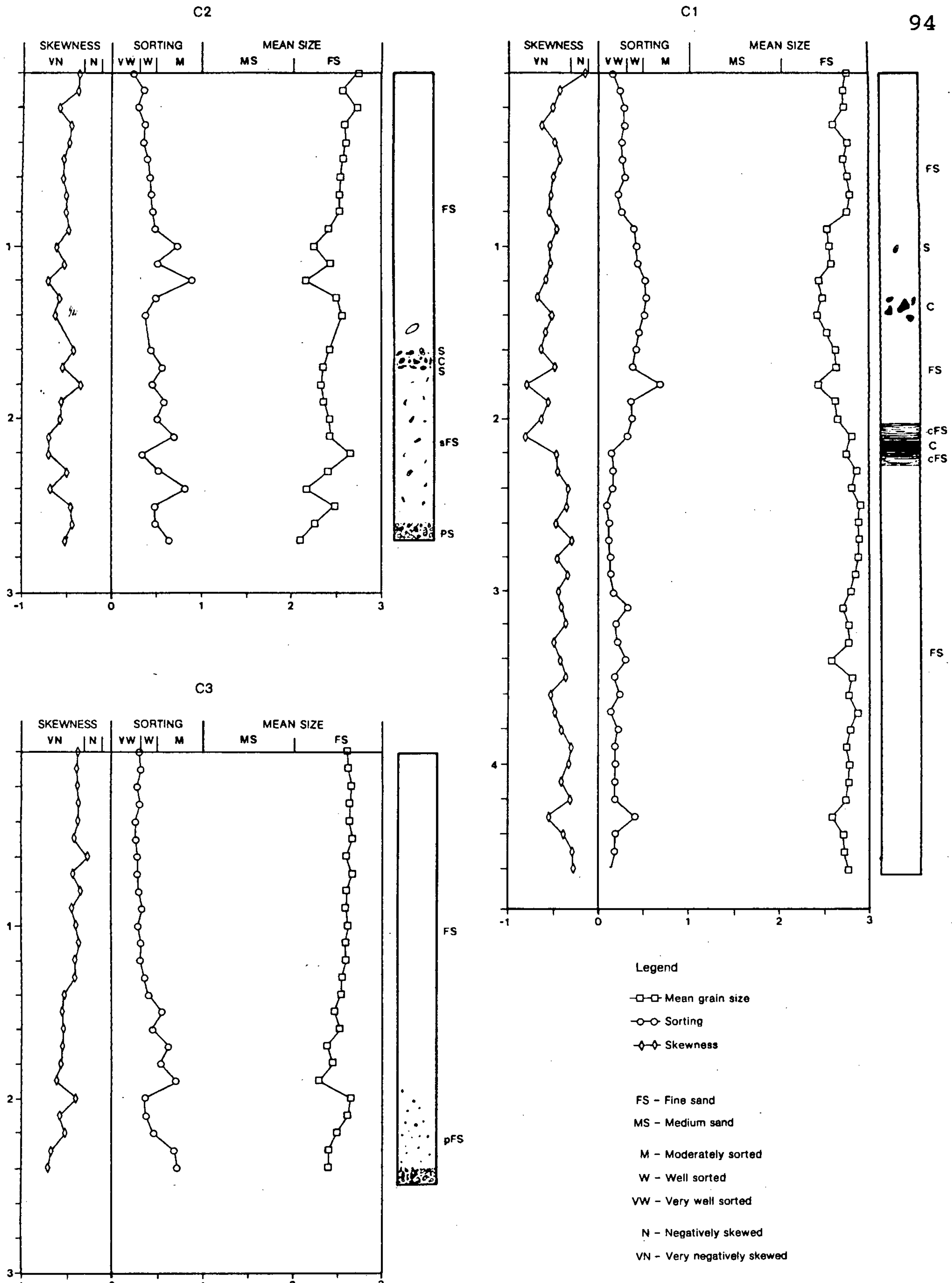


FIG 5.16 CORE STRATIGRAPHY AS REVEALED FROM VISUAL OBSERVATION. THE SEDIMENT SURFACE LEVEL RELATIVE TO MEAN SEA LEVEL FOR EACH CORE IS: C1 = 0,00 M; C2 = 0,11 M; C3 = 0,13 M; C4 = 0,25 M; C5 = 0,34 M.

In core C1 the mean sample size consists mostly of fine sand smaller than 2,5 phi (177 microns). From the bottom of the core to the laminated mud layer, samples are consistently small (Fig 5.17), very well sorted and negatively to very negatively skewed. Above the laminated mud layer, from 2,1



Legend

- Mean grain size
- Sorting
- Skewness

FS - Fine sand
MS - Medium sand
M - Moderately sorted
W - Well sorted
VW - Very well sorted
N - Negatively skewed
VN - Very negatively skewed

FIG 5.17 CORE SEDIMENT SAMPLE ANALYSES. FOR EASY REFERENCE THE RESULTS HAVE BEEN PLOTTED AGAINST CORE STRATIGRAPHY. VALUES ALONG THE SIDE INDICATE DEPTH (METRES) FROM THE SURFACE.

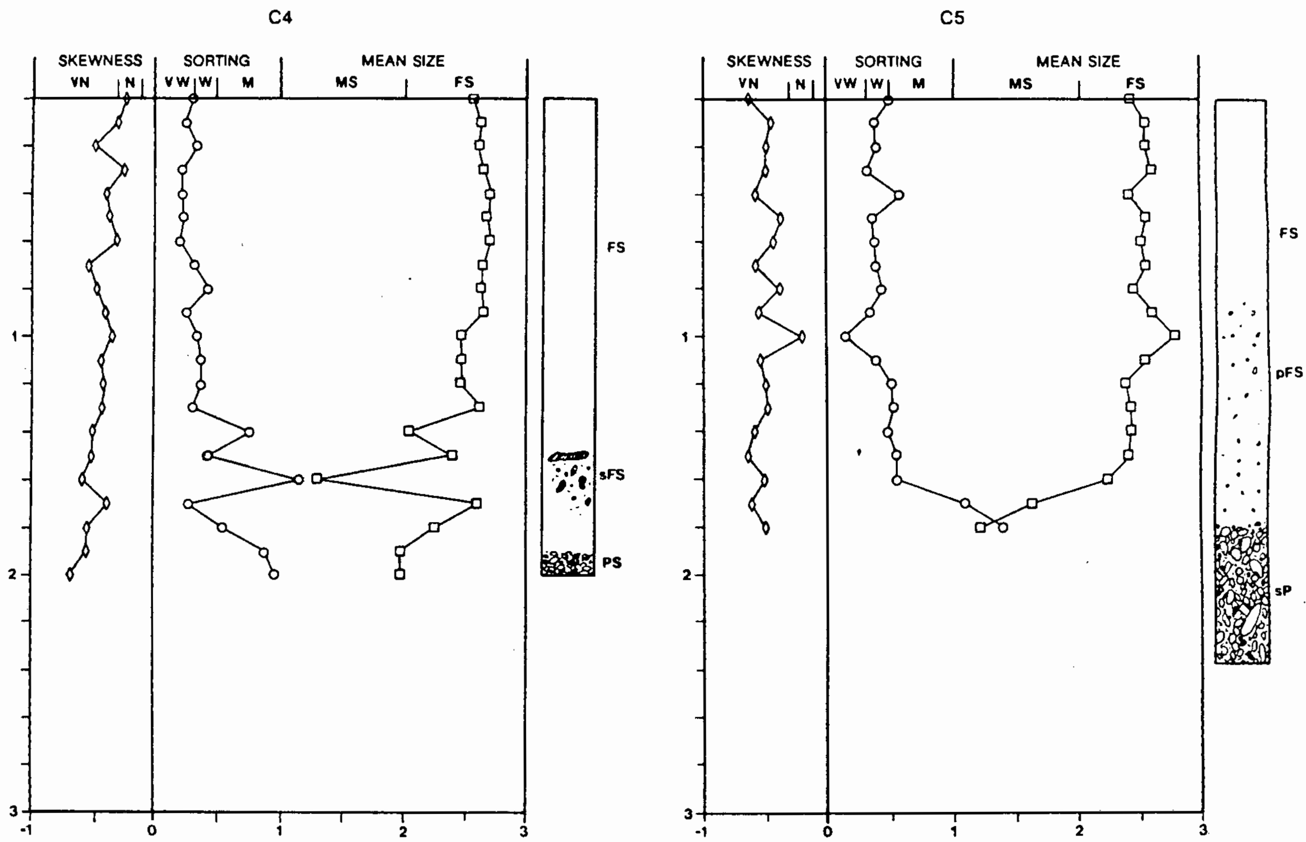


FIG 5.17 CONTINUED.

to 0,9 m, the mean sample size increases slightly (note the change in Fig 5.18), with a corresponding drop in sorting and increase in skewness. The upper samples show a reversal of that described above, with a decrease in mean size, better sorting and less negative skewness. From a depth of roughly 1,4 m (mud ball layer) upwards, the analyses show a decreases in mean grain size, increase in sorting and decrease in skewness.

In core C2 mean grain size between 0,8 m and the bottom of the hole is coarser than that of C1. Sizes are between 2 and 2,5 phi (177 and 250 microns) with the coarsest samples corresponding to the bottom pebble/shell layer. Over the same depth, samples are moderately to well sorted and very negatively skewed, with an evident variation between samples which can be accounted for by varying proportions of shell material in this section of the core. From 0,8 m upwards the mean sizes are less than 2,5 phi and decrease towards the

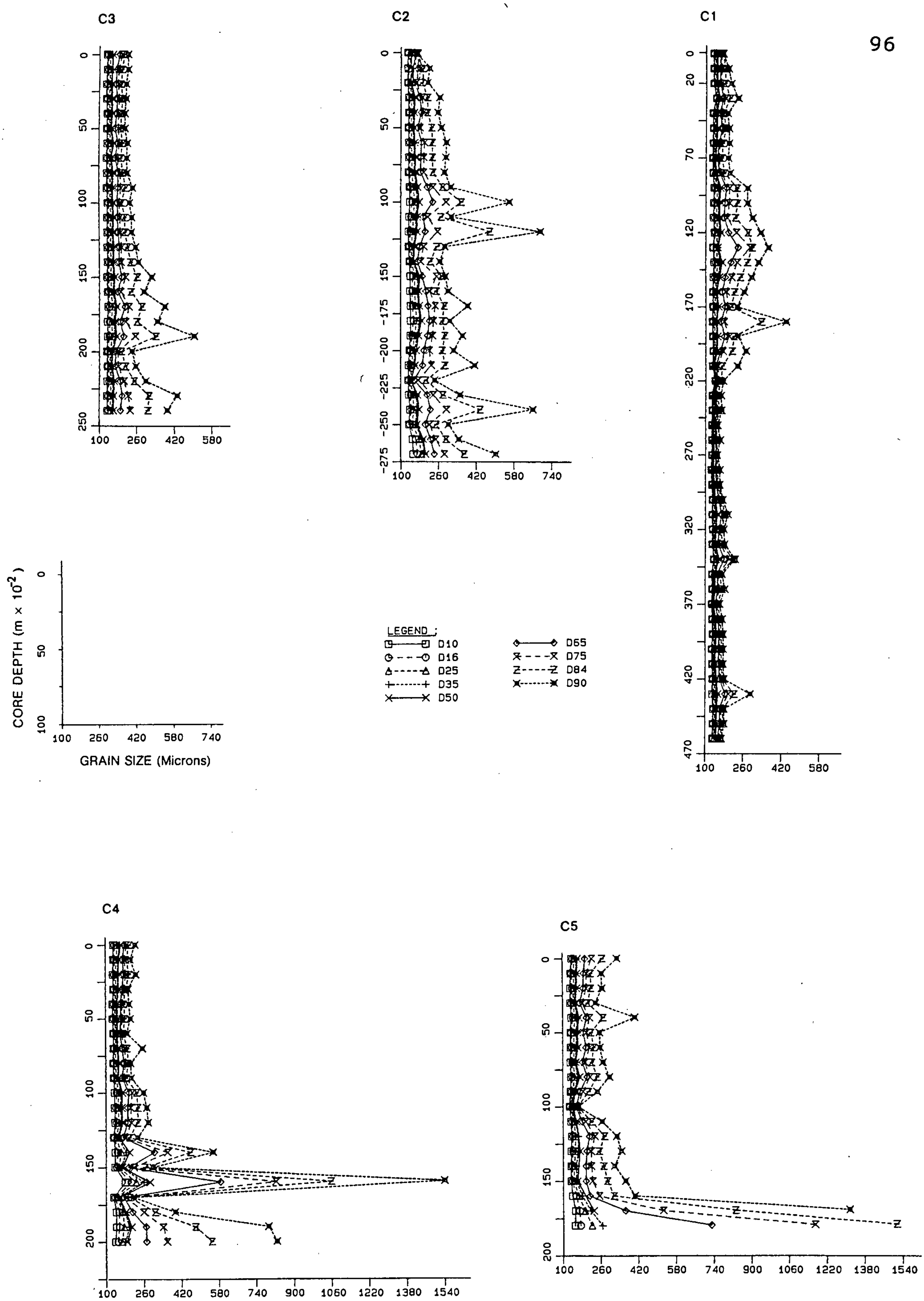


FIG 5.18 GRAIN SIZE ANALYSIS FOR DIFFERENT WEIGHT PERCENTAGES OF THE CORE SAMPLES.

mean sizes are less than 2,5 phi and decrease towards the surface. Sorting improves and skewness decreases over the corresponding section.

In core C3 mean sample sizes towards the bottom of the hole become slightly coarser than 2,5 phi due to the pebble material in the sand. From 1,4 m upwards mean sample size is less than 2,5 phi, with sample to sample variation being remarkably small. Samples are moderately sorted in the lower section becoming well to very well sorted above 1,4 m depth. Skewness decreases upwards but remains very negative.

Mean sample size for the lower section of of core C4 reaches medium sand size in the pebble/shell and shelly fine sand layers. Fig 5.18 illustrates that the coarser fractions reach up to 1540 microns (1,54 mm) in size. Corresponding sorting values drop markedly to moderately sorted. Above 1,3 m mean sample size is below 2,5 phi, samples are well sorted and skewness decreases slightly upwards. From 0,6 m upwards mean grain size increases slightly.

Core C5 is similar to C4, with the overall grain size decreasing from bottom to top. Medium, poorly sorted samples characterize the lag deposit and immediately above. From 1,5 m upwards sample sizes remain similar and centre around 2,5 phi, with a slight increase in size in the upper section. Samples are well sorted and again very negatively skewed.

5.3.2 Surface sample analysis

Results of the surface sample analysis are shown in Appendix IV and are depicted in Figs 5.19, 5.20 and 5.21. Mean grain size (Fig 5.19) is mostly fine sand varying from 2,1 to 2,9 phi (233 to 133 microns), with one medium size sample obtained from J10. To emphasize the subtle changes in the

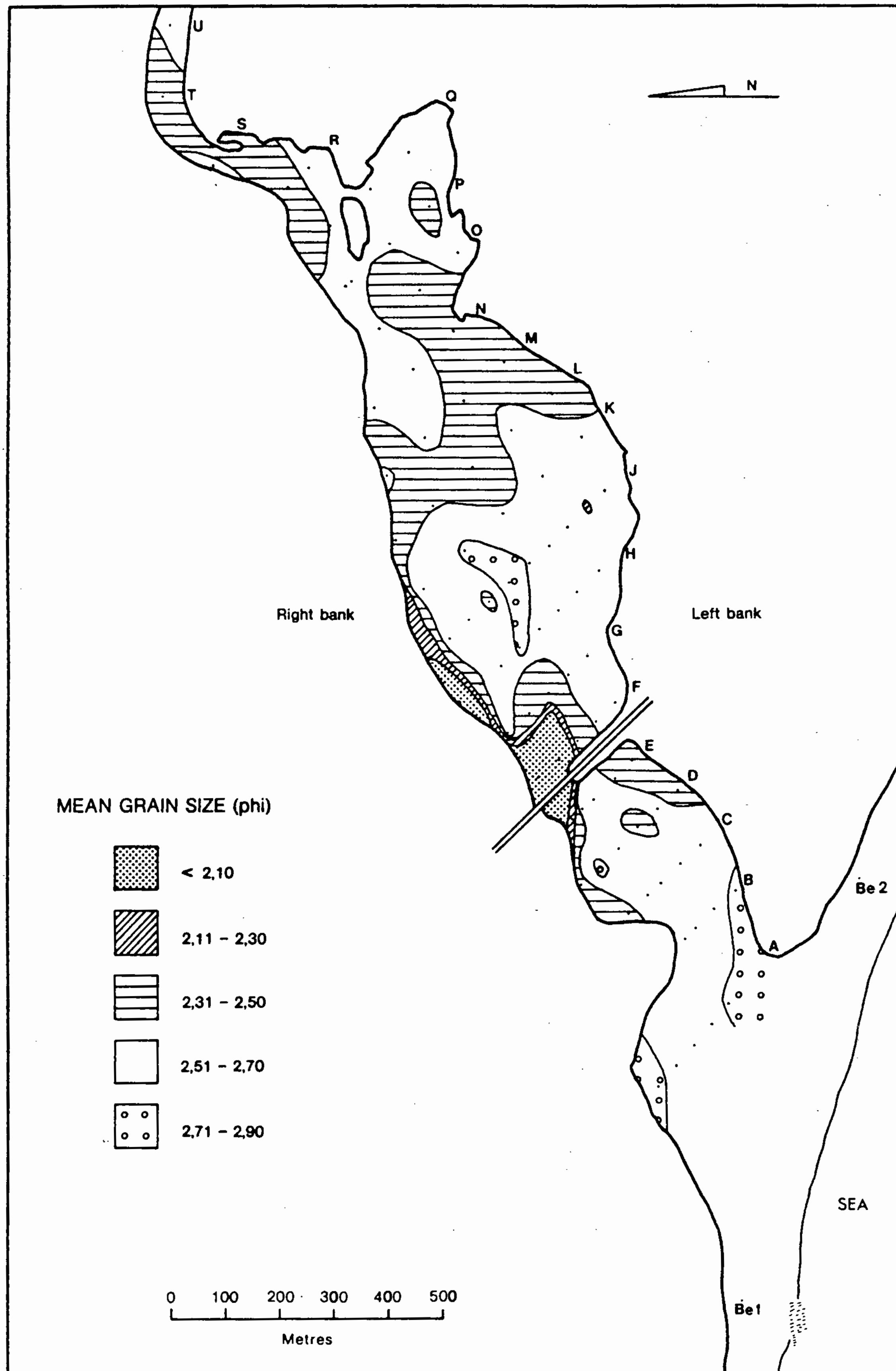


FIG 5.19 MEAN GRAIN SIZE DISTRIBUTION OF SURFACE SEDIMENTS.

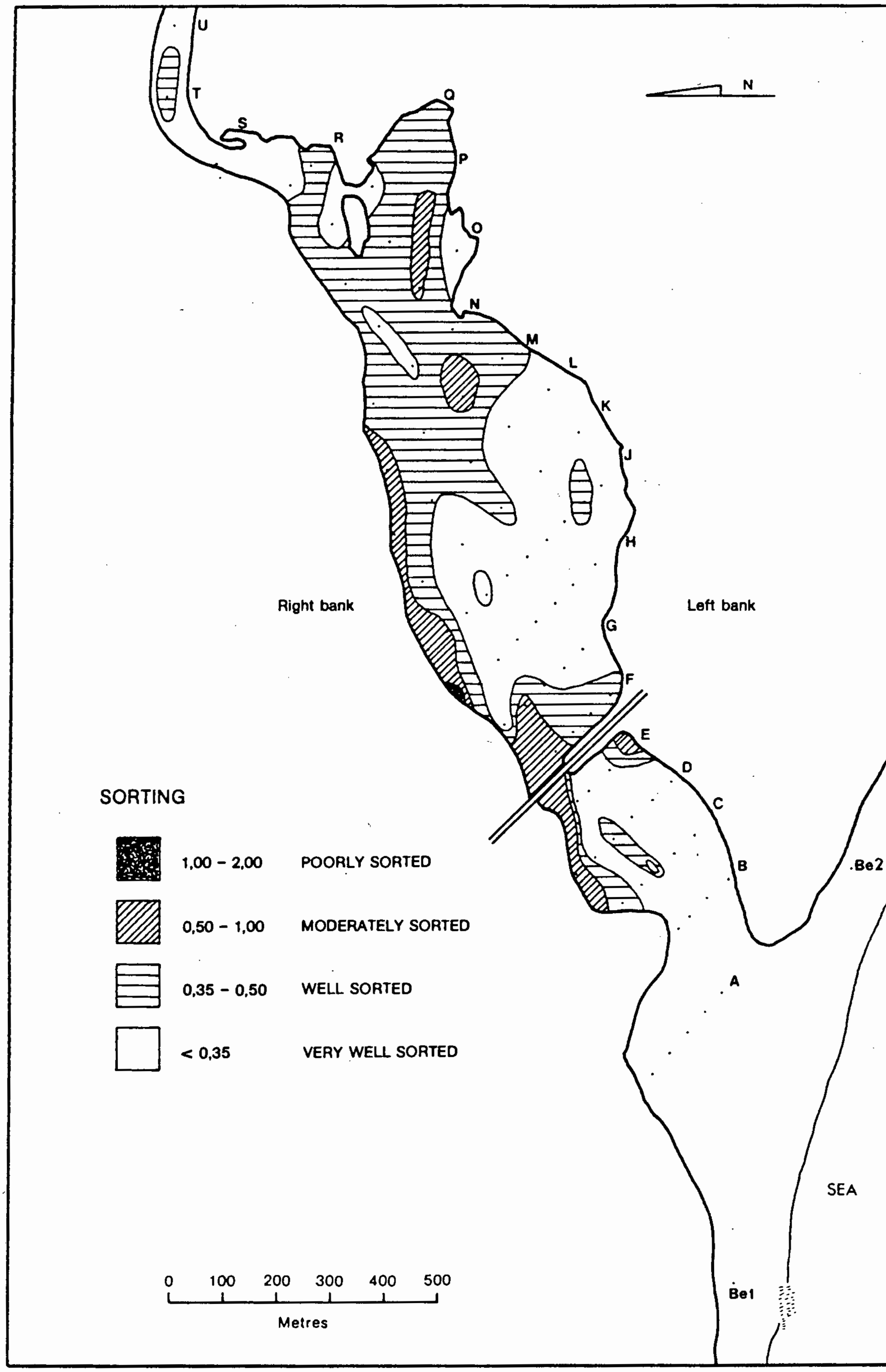


FIG 5.20 SORTING CHARACTERISTICS OF SURFACE SEDIMENTS.

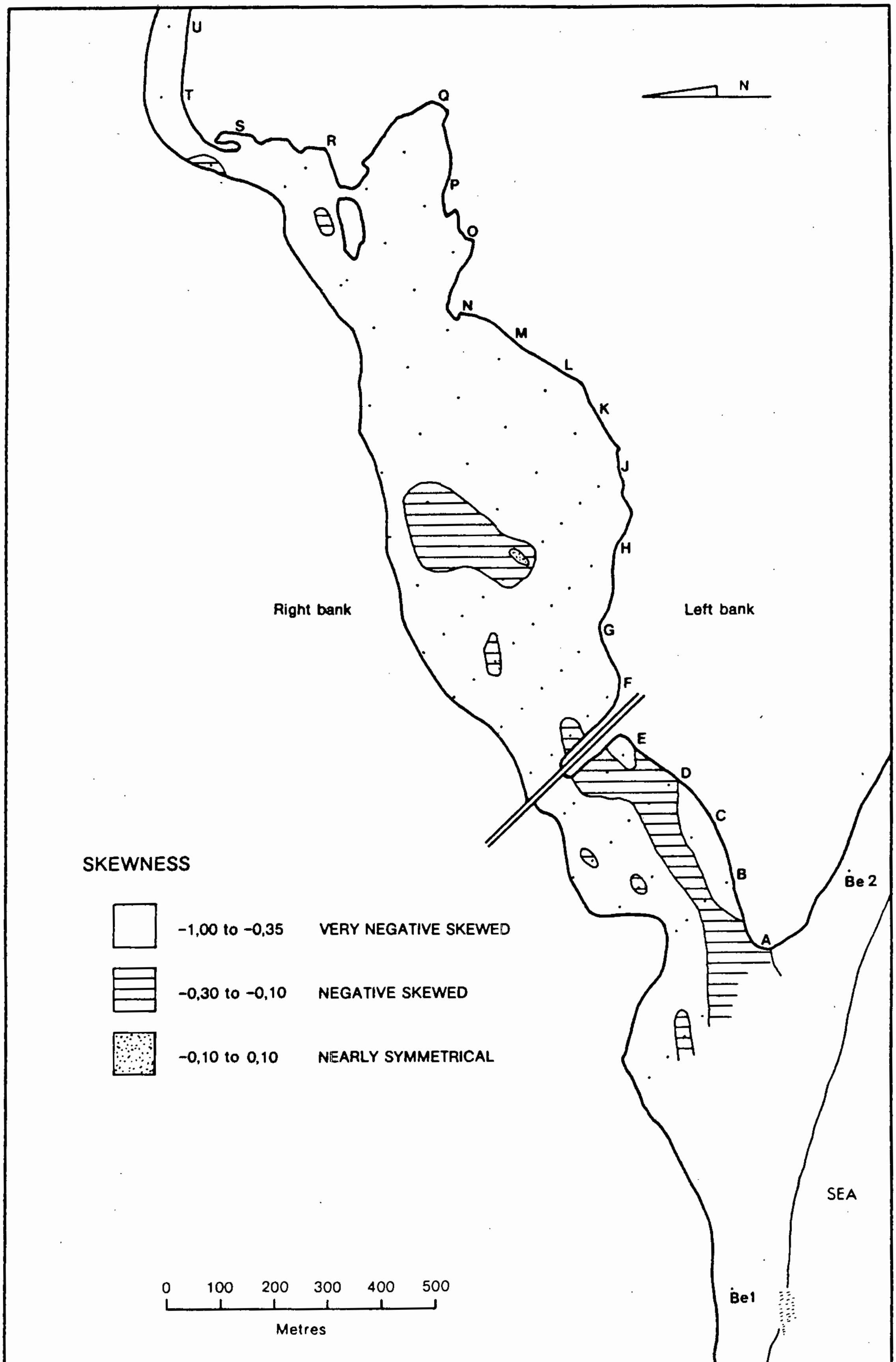


FIG 5.21 SKEWNESS VARIATIONS OF SURFACE SEDIMENTS.

fine sand size, further subdivisions have been made and indicate that the major portion of the estuary consists of fine sand smaller than 2,3 phi (203 microns). The increase in grain size towards the right bank and towards the bridge is clearly visible, while a small increase in size also occurs in the upper part of the study area. Around the bridge, coarse gravel and shell lag deposits are encountered (sample positions F4, F5 and E5), indicating that there is no sand deposition occurring here.

Sorting (Fig 5.20) reveals that approximately half of the samples are very well sorted with the remaining samples being well to moderately sorted with one poorly sorted sample. The very well sorted samples are found towards the left bank mainly on the open sand area above the bridge, and on the new stabilised area (Fig 5.8) and beach, below the bridge. Samples become less well sorted towards the right bank and upstream, with the majority of the moderately sorted sediments occurring against the right bank. One poorly sorted sample was recorded at H8. Visual observation reveals that the unsampled pebble/shell positions (F4,F5 and E5) are also poorly sorted. The similarity in patterns of the mean grain size and sorting plots (Figs 5.19 and 5.20) are clearly visible.

All the samples have a negative skewness (Fig 5.21), with the very negatively skewed samples dominating. Negatively skewed samples occur in a narrow band below the bridge and in a small inlier on the open sand layer above the bridge. Sample J5 has a nearly symmetrical skewness.

Bivariate scatterplots of the surface sample analyses are depicted in Fig 5.22. In each of the three scatterplots, analyses from below the bridge have been plotted against those from above the bridge. The mean versus sorting plot (Fig 5.22a) shows values for above and below the bridge all plotting in a field in the right bottom corner. The values

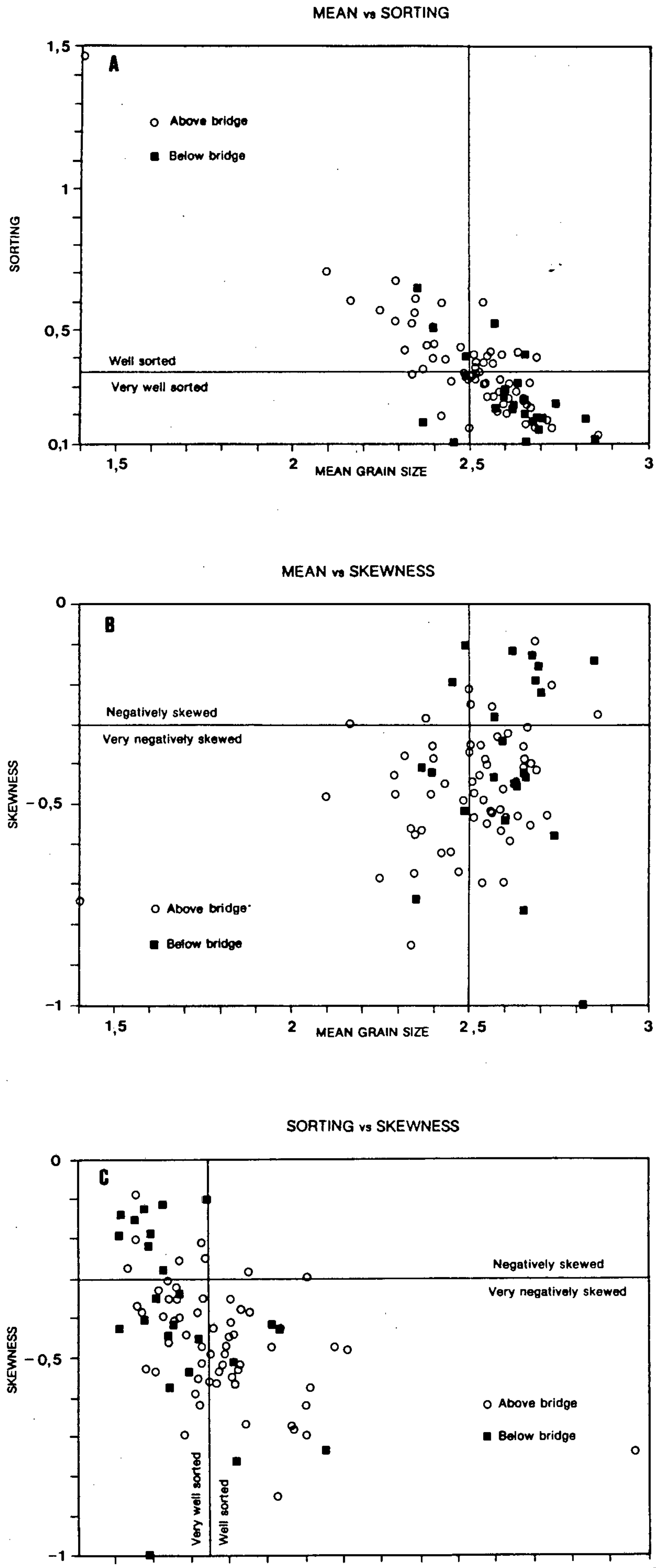


FIG 5.22 BIVARIATE SCATTERGRAMS OF THE SURFACE SAMPLES. A. MEAN GRAIN SIZE VERSUS SORTING. B. MEAN GRAIN SIZE VERSUS SKEWNESS. C. SORTING VERSUS SKEWNESS.

for below the bridge tend however to be restricted more to the bottom right than for the above bridge samples. Samples from below the bridge are smaller than 2,5 phi and are very well sorted. The positive relationship between decreasing grain size and increasing sorting is clearly visible in the figure. In Fig 5.22b mean versus skewness plots show a widely dispersed pattern and reveal very little distinction between values for above and below the bridge. The figure does show however that for below the bridge an equal number of samples are negatively and very negatively skewed. By comparison, above the bridge the majority of samples are very negatively skewed. The sorting versus skewness plot (Fig 5.22c) shows a small difference in the fields for above and below the bridge. Plots for below the bridge are generally very well sorted while above the bridge about half are well sorted. A small group of very well sorted samples from below the bridge plot apart from the bulk of the samples.

Having presented the results of the three approaches to the study, the following chapter discusses these results in the context of the impact of bridge and embankment construction in the Uilkraals estuary.

CHAPTER SIX

DISCUSSION

Page

CHAPTER SIX

DISCUSSION

Continuing with the format of the previous chapters the discussion looks firstly at aerial photography, secondly at the ground survey and thirdly at the core and surface sampling in the context of the original aims. In the final section, secondary impacts which have arisen as a result of the embankments and the sediment redistribution are documented and discussed.

6.1 AERIAL PHOTOGRAPHY

Comparison of measurements in the natural state, that is, before major human intervention on the estuary, with those taken after the bridge construction and with the temporary embankments present, permits the possible impacts of these obstructions on the sediment distribution in the Uilkraals estuary to be determined.

River characteristics

Measurements of thalweg and aerial length for the period of study (Fig 5.1) clearly indicate the effects of the temporary embankments on channel length. Changes in the mouth positions which result, are illustrated in Fig 6.1. Thalweg lengths for the first three photographs are very similar followed by a marked drop in April 1980, a marked increase in July 1980, a small increase in December 1980 and a drop in 1987. The sudden drop in April 1980 can be attributed to the construction of the first temporary rubble embankment in 1979 (Fig 5.5). Having forced the river towards the left bank, a large portion of the channel which flowed where the stagnant pool then existed was cut off from the major channel, hence reducing the thalweg length by approximately 300 m. The western beach was enlarged substantially with the river in this position. The increase in length (over 400 m) in July 1980 resulted from the construction of the second temporary embankment (built just prior to the date of photography) which forced the channel back towards the right bank and near its old river course (Fig 5.6 and 6.1). The further increase in length in

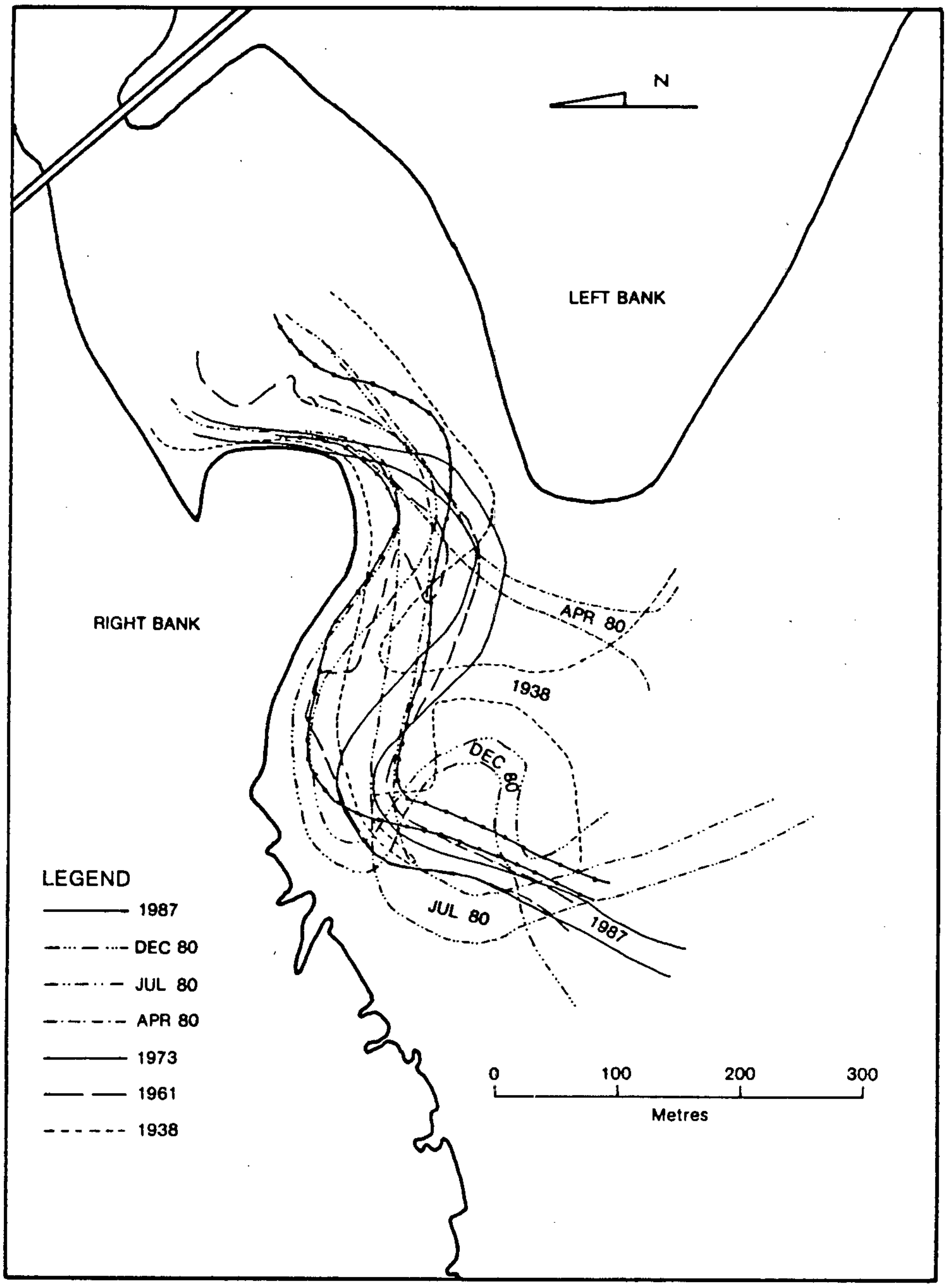


FIG 6.1 ESTUARY MOUTH POSITIONS FOR THE STUDY PERIOD.

December 1980 can be accounted for by the large bend that the river makes before it enters the sea. This may have resulted from the readjustment of the channel after the removal of the second temporary embankment or may simply reflect environmental conditions (e.g. run-off and longshore drift) at the time. Alexander (1979) notes that the local sea currents, wind blown sand and river morphological processes may affect the position of estuary mouths. The large bend in the estuary in December 1980 probably results from low flow conditions during this period. The highest average monthly catchment rainfall for this period was 87 mm in November. The equilibrium condition for lower flow will be a flatter gradient and therefore a longer route which is accommodated by having the mouth away from the direct line of exit from the valley (Alexander, 1979). The longer thalwegs in July and December 1980 suggest that the second embankment pushed the channel further west than has been recorded in the natural state. The drop in thalweg in 1987 probably resulted from the channel returning to a more natural position which it occupied before the temporary embankments were built. In Fig 6.1 the extreme mouth positions in April and July 1980 are clearly visible. For the other years the mouth positions were between these extremes, but tended to favour the western side of the beach.

The aerial distances are similarly affected by the temporary embankments. The low value in April 1980 results from the channel being forced towards the left bank by the first temporary embankment with the high value in July 1980 resulting from the second temporary embankment forcing the channel towards the right bank. The low value for 1938 can be attributed to the mouth entering the sea towards the left bank (Fig 5.2 and 6.1). Before the stabilization of the dunes on the left bank (Walsh, 1968 ; Heydorn & Bickerton, 1982), the river was able to enter the sea over a much larger area than at present, enabling the mouth to move much further east.

The sinuosity (as already noted) reflects the trend of the thalweg measurements because of the small changes in aerial length. As described above, the low value in April 1980 and the high value in December 1980 result from the presence of the first and second temporary embankments, respectively.

Increased sinuosity is often as a result of the deposition of sediment. NRIO (1986) has reported that sedimentation upstream of the Mdloti estuary bridge has resulted in increased thalweg and sinuosity. By looking at the converse relationship, that is sinuosity as an indicator of sedimentation, it is possible that sinuosity could reflect sedimentation in the Uilkraals estuary. To distinguish between the influence of the temporary embankments and the permanent road embankment, thalweg lengths have been measured upstream of the line separating the marine and floodplain area. As the aerial distance is fixed, changes in thalweg will directly affect sinuosity. The data presented in Table 5.2 indicate that, above the separating line, thalweg changes much less than below the line. With the small change in thalweg length between the separating line and the bridge (due to the rather fixed position of the channel between these points) changes in thalweg would reflect changes in sedimentation upstream of the bridge. The small increase points, however, to there being very little sedimentation upstream of the bridge. Alternatively, if there has been sedimentation it is not reflected in the thalweg values. These data also show that the major changes in thalweg length can be accounted for by changes in the mouth area as a result of the temporary embankment construction and not as a result of the bridge embankment.

Floodplain measurements

Measurements of the floodplain indicate that very little areal change has occurred in the different divisions over the study period. Some of the smaller changes can be attributed to erosion and growth of floodplain plant communities. Tidal levels at the time of photography, and the inaccuracy in the measurement techniques, could have been further responsible for some of these small changes. However, the increase in the herbland sand area between 1938 and 1961 is a natural change that can be accounted for by the increased size of the protruding area on the left bank. The other notable change was also to the herbland sand which, between 1980 and 1987, increased by 4,2 ha or 4,6 %. Over the same period the open sand area decreased by 3,4 ha or 4,8 %. This change is largely as a result of the vegetation of the sand bank on the seaward side of the bridge embankment (new vegetated area in Fig 5.8). The presence of vegetation here indicates that the sand has built up above the normal high tide level and has become stabilised since 1980 (Plates 5 and 6). The road embankment is probably directly responsible for this build-up. This will be discussed in a later section.

Dry sand areas vary little; the only substantial increase occurs between 1938 and 1961. This could be because the stabilization of the eastern spit has restricted the area through which the river can enter the sea and has thus limited the river to specific channels. With the restriction of the river to specific channels, a build-up of sediment could easily occur. The similarity in the size of the dry sand areas for the remaining period indicates that there has been no major build-up of either marine or terrestrial sediment in the estuary.

Of further interest to this discussion is the position of the dry sand area over the study period. In 1938 and 1961 (Figs 5.2 and 5.3) the larger channel is against the right bank with the major sand bodies towards the left bank. In both photographs a smaller channel flows against or near the left bank. The seaward sand bodies thus sit between two channels. In 1973 that situation is exaggerated by the construction works for the bridge (Fig 5.4). At this time, a large sand area was situated in the centre of the floodplain with the channel on the left being bigger than before. Upstream of the construction works there are now two dry sand areas. From April 1980 onwards the photographs show a definite change in the channel positions. Each shows the channel against the right bank, a position into which it has been forced by the construction of the bridge and embankment (Figs 5.5 to 5.8). Downstream of the bridge the dry area on the left bank is bigger and becomes progressively more stabilized until eventually vegetated (Fig 5.8 and Plate 5). A channel against the left bank thus no longer remains. Upstream of the bridge a large sand area is situated in the middle of the floodplain with a smaller sand area towards the left bank. The major channel flows between these two sand banks, while a slightly smaller channel flows against the right bank after meandering freely across the wide floodplain upstream.

The similarity of the three photographs for 1980 indicates that throughout the year the positions of the sand banks and channels were little affected by changes in run-off in the different seasons. A high run-off event, as evidenced by the flooding of the caravan park in June 1980, had very little impact on the channel and sand bank positions.

Marine area

The major changes to the marine area have taken place during vegetation of the left bank between 1938 and 1973, as a result of stabilization of the dunes by the Department of Forestry over the preceding few years. The small decrease in vegetation in December 1980 and 1987 probably resulted from the erosion of the primary dunes by wave action. The close proximity of the high-tide line to the dune vegetation suggests that dune erosion is occurring (Plate 7). Ground observations made in 1987 indicate that this is indeed happening. Similarly, the large decrease in the open sand area over the same period could be due to beach erosion. The removal of sand will enable the sea to reach further up the beach which, when viewed from above, reduces the beach or open sand area. This change could also be an artefact of differences in tidal level at the time of photography, although such a large change would be hard to explain by this factor alone.

River widths

River width data (Table 5.3) indicate that the river is narrow near the mouth and upper part of the study area, and wider over the shallow open sand areas upstream of the bridge. Mean widths for each year give very little idea of the impact that the embankments may have had and rather reflect changes that have occurred in the channel width over the shallow open sand areas.

To determine the influence of the road embankment on the mean river widths, widths before and after bridge construction have been calculated (Table 5.4). The results show that near the bridge the river has widened and, further away, has decreased in width (Fig 5.10). The concentration of river flow underneath the bridge will have increased the flow velocities, resulting in erosion and a deepening of the channel with a concurrent widening as the channel becomes deeper. The drop in width further away is probably a natural readjustment to the widening around the bridge. In Figs 5.5 to 5.8 the widening of the river on either side of the bridge is clearly visible when compared to the earlier photographs.

Lateral stability

The lateral stability results (Table 5.5) indicate the influence of the temporary embankments on the channel positions. At station 1 the high lateral displacement (235 m) has arisen from the extreme mouth positions in April and July 1980 which, as already noted, have resulted directly from the influence of the temporary embankments. The high displacement at station 5 reflects the high value in 1938 which has arisen because the major channel was against the right bank. For all the other periods the main channel at station 5 was closer to the left bank, resulting in lower displacement values.

The influence of the road embankment on lateral displacement has been determined by calculating displacement before and after bridge construction (Table 5.6). At station 1 a change reflects the influence of the temporary embankments and reveals little about the impact of the bridge. The small displacements at stations 3 and 4 however, indicate that since bridge construction, the river has become more stable in this area. The drop in displacement at stations 2 and 5 also reflects the stabilising influence of the road embankment. Over the open sand area upstream of the bridge, lateral displacement has increased since bridge construction. Whether this is as a result of bridge construction is, however, very difficult to determine as the river can flow in any of a number of channels over this shallow open sand area and other factors, such as run-off (Alexander, 1979), may be involved. The presence or absence of a smaller channel, which feeds into the main channel from the left bank, is largely responsible for the changes at station 8. In the upper study area the similarity in displacement before and after bridge construction indicates that this area is very stable and is essentially unaffected by changes lower in the estuary.

Prior to bridge construction, the river was not restricted in its lateral movement and had an average lateral shift of 61,5 m. After bridge construction, the average post-bridge lateral shift dropped by only a small amount to 56,1 m. However, recalculations of the average shift without the strong influence of the high values at station 1 show a pre-bridge average of 58,7 m and a post-bridge average of 36,2 m. This indicates a 38 % increase in the stability of the estuary channel, excluding the mouth (station 1), since bridge construction.

The average lateral shift of 87,4 m with a coefficient of variation of 25,2 % indicates slightly to moderately unstable conditions. This is based on work by J. Perry (pers. comm.) on Natal estuaries and similar work on Cape estuaries. In Table 6.1 average lateral displacement data for the Uilkraals estuary can be compared with those of selected Cape estuaries. The values above compare closely to those of the Kromme, which has been defined as slightly unstable. Lateral shift as a percentage of river width is, however, much higher in the Uilkraals than in the Kromme;

Estuary	*Lateral shift*		*Coef.var.*	[4] *Verbal*
	[1] metres	[2] % $\bar{R}$.width	[3] $\bar{v}$ %	
Heuningnes	54,3	113,1	43,5	unstable
Hartenbos	33,7	62,3	37,2	m.unstable
Kromme	67,9	54,9	24,3	s.unstable
Seekoei	52,4	60,0	36,9	m.unstable
Kabeljous	181,5	176,2	37,7	unstable
Sondags	29,3	46,6	24,9	s.unstable
Uilkraals				
[1]*total	87,4	136,0	25,2	s/m.unstable
[5]*pre-bridge	58,7	91,8	24,6	s/m.unstable
[5]*post-bridge	36,2	56,5	19,3	s.unstable

1 Average lateral shift (metres)
2 Lateral stability as a percentage of average river width
3 Average coefficient of variation (percent)
4 Verbal description of stability (after J.Perry,pers.comm.)
5 Excluding values at station 1

TABLE 6.1 LATERAL STABILITY DATA FOR A NUMBER OF CAPE ESTUARIES AND THE UILKRAALS ESTUARY.

comparing more closely with that of the Heuningnes and Kabeljous, both of which are defined as unstable. Values for lateral displacement before and after bridge construction are both lower than those calculated without the bridge being taken into consideration (total value). Pre-bridge values compare closely to those of the Kromme, while after bridge construction values are similar to those of the Sondags estuary, both of which are termed slightly unstable. The values for the Sondags are, however, much lower than those of the Kromme, indicating more stable conditions.

The mean channel positions presented in Table 5.7 and Fig 5.12 reveal that in the area of the bridge (stations 3 and 4), the channel is positioned 54 m closer to the right bank after bridge construction than before. Upstream of the bridge (stations 5 and 6) the mean position is closer to the left bank. The effect of the bridge has been to restrict the channel to the area under the bridge as is obviously expected. The changes upstream reflect the fact that the major channel now flows near the left bank and not towards the right bank as in 1938.

Measurements of the river, floodplain and marine characteristics indicate that in most cases the natural changes are small, and that the biggest changes have been in response to human intervention. River characteristics, which under normal conditions are very similar, changed substantially in the Uilkraals under the influence of the temporary embankments. Of the floodplain measurements the most noticeable change has been the increase in herbland sand due to the stabilisation and vegetation of the open sand area downstream of the bridge embankment. Large vegetation changes in the marine area have resulted directly from dune stabilisation over a number of years. Similarly, river width and lateral stability data illustrate how the natural state and behaviour of the channels have been affected by the permanent and temporary embankments.

6.2 GROUND SURVEY

Many writers, e.g. Esterhuysen & Rust (1987) and Farquharson (1970), have reported increased flow velocities under bridges due to the reduction of channel cross-sectional areas by embankment construction on floodplains. The increased flow velocities often result in scouring around the bridge. In fluvially dominated rivers, scour occurs downstream of the bridge e.g. Kromme estuary (pers. obs.), and in flood-tide dominated rivers, scour is prevalent upstream of the bridge. Further, the restriction of flow as it moves under the bridge causes a damming effect which reduces current speed and initiates sediment deposition (Alexander, 1978). Sediment build-up in this way occurs either upstream or downstream of the embankment depending on the dominant flow direction. In fluvially dominated rivers such as the Kariega and Boesmans, sedimentation and consolidation of the sandbanks has occurred downstream owing to the hydraulic sheltering effect of the causeways (Fromme, 1986).

The ground survey results of the Uilkraals estuary shown on the contour map and cross-sections (Figs 5.13 and 5.14) show that there has been a build-up of sediment on the downstream side of the road embankment. Further, increased flow velocities in the vicinity of the bridge have resulted in scouring which has been greater upstream than downstream of the bridge. The greater scouring upstream suggests that at the time of the survey the flow under the bridge was flood-tide dominated. During the incoming tide, sand of marine origin is dammed up against the embankment, while increased velocities under the bridge have caused scouring upstream. During terrestrial floods the embankment probably acts as a " hydraulic shelter " (Fromme, 1986) by stopping the removal of sand that has built-up downstream of the embankment.

Comparisons of the cross-sections under the bridge (Fig 5.15) show that there has been a net loss of material since bridge construction. This gives supporting evidence that scouring has occurred under the bridge.

6.3 SEDIMENT SAMPLING

6.3.1 Core stratigraphy and analysis

Core stratigraphy is relatively simple, enabling correlations to be made between the cores. Cores C2 to C5 all have fine sands overlying a lag deposit consisting of fine to granule-sized pebble and shell material. The lag deposit, probably representing an old erosion surface or flood deposit, has formed a layer upon which the younger sediments have been deposited. The differences in the depth of the lag deposits in the cores can probably be attributed to the unevenness of the original surface. Core C1, the deepest obtained, lacks this pebble/shell layer, enabling a longer core to be obtained than at the other core sample positions.

In core C1 a mud ball layer is encountered at about 1,4 m depth and is thought to represent the break-off of blocks from a laminated mud layer (Dardis & Plumstead, 1988) which have been picked up during a high flow event, rolled and deposited as ball-like features at a later stage during the same event. Karcz (1969) has shown that this process occurs in the Wadi deposits of the southern coastal plain of Israel, where ill-formed angular mud balls, formed during flash floods, are found embedded in redeposited coarse sediments. In core 1 of the Uilkraals sediments at about 2 m, a laminated carbonaceous-rich mud layer (very similar in appearance to that of the mud ball layer) bounded by a laminated mud/sand layer, reflects slow sediment accumulation in an environment of very low current velocity. Either this layer, or the herbland mud areas bordering the open sand area, could be the source material for the mud balls. In core C2, a thin mud ball layer bounded by shells can be correlated with the mud ball layer in core C1. Cores C3, C4 and C5 have varying amounts of shell material and pebbles between the upper fine sand and coarser bottom lag deposit.

The core stratigraphy examined above suggests that recent sedimentation has been restricted to deposition above the course lag deposit encountered in cores C2 to C5. At C1, however, the absence of this layer probably represents an old channel course which has been scoured to a depth below that of the lag deposit.

It is evident from the results of the statistical analyses that there are only small differences between the sample analyses of each core. Broadly, all the cores show a decreasing trend in mean grain size from the coarse pebble/shell lag deposit at the bottom to the finer sand at the top of the cores. C1 is the exception with very fine material below the clay layer. Within the fine sand fraction in the upper metre of the cores C1, C2 and C3, samples show a slight decrease in mean grain size, while in cores C4 and C5 mean sample size increase slightly. Samples are mainly well to very well sorted but are moderately sorted in the coarser lag deposits. Sorting increase upwards, especially in the upper metre of the cores. Skewness shows no consistent trend, remaining largely very negatively skewed throughout the length of the cores. In the upper metre or so, all the cores show remarkably similar values, namely, fine sand size samples (mostly less than 2,5 phi) and well- but mainly very well sorted samples which are largely very negatively skewed.

Mean grain size suggests the deposition of the lag deposits under medium energy conditions and the fine sands under low energy conditions (Solohub & Klovan, 1970). The similarity in the mean grain size of the fine upper sands indicates that the mode of deposition has changed very little over the period of sand deposition. The very good sorting of the sands reflects deposition in which the sorting process is very efficient - as in, for instance, beach or wind blown sands (Briggs, 1977). The good sorting may also reflect very similar characteristics of sediments in the source area. The strong skewness probably results from the removal of fines in the source area of the sediments by wave or wind action (Buller & McManus, 1979), or even by strong current action (Blatt *et al.*, 1980). The grain analysis statistics suggest therefore that deposition of the fine sand took place under low energy conditions by either wind or current action of material with a marine origin. The fine carbonaceous shell material within the sediments is further evidence of their marine origin.

During normal flow conditions marine sediment moves up the estuary under the influence of the flood-dominated tidal current and with the addition of wind-blown sands from the south and south-east (see wind roses in Figs 3.5 and 3.6). During terrestrial floods, this material is picked up by the higher velocity flood waters, carried downstream and deposited when flow velocities decrease. Evidence of a probable flood event is given by the mud balls which clearly indicate higher flow conditions. By producing an obstruction to flow, the embankment probably initiates much deposition in the near vicinity.

The lack of a marked increase in mean grain size on either side of the the mud ball layer can be accounted for by the fact that during the flood events, sand of similar size and characteristics higher up in the estuary, is picked up and redeposited. The grain size and other sand characteristics thus remain much the same.

The statistical analyses of the core samples, especially in the upper sections, are very similar and as such are unable to reveal any difference in the modes of deposition above and below the bridge. However it is most likely that the embankment has affected deposition in two ways. Firstly, it may act as an obstruction to flood water movement and initiate deposition upstream. The absence of mud balls in the cores below the bridge may have resulted from these sediments being unable to reach downstream due to the embankment obstruction. Secondly, the "hydraulic sheltering" effect of the embankment may have protected sediment downstream from being removed, thus allowing the gradual build-up of marine sand against the embankment.

6.3.2 Surface sample analysis

Surface sediment in the estuary consists mainly of fine sand with a very narrow size range; the fine sand suggesting deposition under low energy conditions. Subdivisions of the sand fraction indicate that the sand size increases towards the right bank. Coarser sands and the pebble/shell lag deposit are limited to a small area on the right bank, mostly around the bridge. The increase in mean grain size towards the right bank and the coarser material found here suggest relatively high energy conditions towards the right bank and in the vicinity of the bridge. The higher energy conditions around the bridge result from the increased flow velocities caused by the constricting effect of the embankment. Studies of the Bushmans estuary (Weaver, 1977) showed similar patterns with low energy conditions behind the embankment and medium energy conditions under the spanned bridge sections on either side. Upstream of the Uilkraals bridge, the coarser mean sediment size on the right bank may have arisen during higher flow events when water impinging on the bank scoured away finer material.

Sorting (Fig 5.20) reflects the pattern of the mean grain size distribution, with very well sorted areas corresponding to the areas of finest sand and moderately sorted areas corresponding to the larger mean sizes associated with the channels in the vicinity of the bridge. Buller & McManus (1979) note a similar relationship between median and sorting for sediments of the Upper Tay estuary. In the Bushmans estuary (Weaver, 1977), however, the relationship between sorting and mean grain size is somewhat different from that of the Uilkraals estuary. The poorly sorted sediments of the Bushmans estuary correspond to the areas of low energy conditions and the well to very well sorted sediment to higher energy channel conditions. These differences probably arise from the following: in the Bushmans, the poor sorting of the fine sands results from the mixing with finer silt and clay particles; while in the Uilkraals, there is very little finer material for such mixing. The good sorting in the Bushmans channel results from consistent flow conditions (Weaver, 1977) in a deep channel (4,8 m) while in the Uilkraals, poor flow conditions occur in the channel under the bridge due to the shallow nature of the channel and restriction to flow by lag deposits and building rubble. In the Uilkraals estuary, the well- and very well sorted sands are probably deposits of marine or wind blown material (Briggs, 1977), under low energy conditions. The very good sorting of the beach sediments Be1 and Be2 and in the samples of line 1, support a marine origin for the estuarine sediments. The moderate to poorly sorted samples probably represent deposition of coarser sediment of varying sizes by stronger current action and inconsistent current conditions (Stephenson, 1970). The small decrease in sorting upstream of the open sand area may represent the influence of some terrestrially derived material.

In Fig 5.21 skewness plots illustrate that the majority of the samples are very negatively skewed, with a few negatively skewed samples occurring in a narrow band below the bridge and as an inlier above the bridge. The very negative skewness of the sands, as discussed under the core analysis (section 5.3.1), results from the winnowing of the fine material in the sediment source area by wave or wind action; the source area in this case being the beach. The narrow band of negatively skewed samples probably results from the combined deposition of tidally deposited marine sands and finer wind blown sand. As wind action is generally insufficiently competent to move coarse grains, aeolian sands tend to be more positively skewed (Blatt *et al.*, 1980). Thus a combination of very negatively skewed marine sands with the more positively skewed wind blown sands will result in less negatively skewed sand deposition in the estuary. The samples remain negatively skewed because the very fine material is removed by tidal currents soon after deposition. The origin of the inlier of negatively skewed samples is uncertain.

Aside from its constricting effects, the embankment may have further influenced the system by reducing the amount of wind blown sand that can reach the upper part of the estuary.

The bivariate scatterplots (Fig 5.22) reveal rather little about the possible differences in the modes of deposition above and below the bridge. The fields of each overlap to such a great extent that little distinction can be made between them. In the sorting versus skewness scatterplot (Fig 5.22c) a small group of samples from below the bridge plot separately to the main field. These samples, which are correlated with the narrow negatively skewed area below the bridge have a negative skewness and are very well sorted. This separation suggests that their mode of deposition is different from the bulk of the sediments. The possible mode of deposition of these sediments has been considered in the discussion of the surface skewness plots above.

Surface sample analysis has helped to understand the processes operating and describe the present sediment distribution in the estuary. As reflected in the analyses, the bridge has affected the sediments by increasing grain size and decreasing sorting in the near vicinity. The only noticeable difference in the sediment distribution above and below the bridge is that the coarser and poorer sorted sediments extend further upstream from the bridge than they do below the bridge, and that a band of negatively skewed samples occurs downstream and stops at the bridge. The scatterplots reveal that in general the modes of deposition above and below the bridge are similar.

6.4 SECONDARY IMPACTS

The construction of the bridge and embankment, the presence of the temporary embankments, and changes in sediment distribution are primary impacts which have occurred to the Uilkraals estuarine system. Secondary impacts result from the changes brought about by these factors. The impacts, which are both of short and long term, illustrate how engineering projects may result in adverse effects in estuarine environments.

6.4.1 Temporary embankments - short term impacts

Secondary impacts which have resulted from the temporary embankments are mainly of a short duration. Construction of the first temporary embankment in 1978 resulted in the formation of a stagnant pool and a series of small dunes in front of the holiday bungalows. Gaigher (1978), after visiting the estuary, reported that the stagnant pool was littered with rotting redbait (*Pyra*) pods and sea-bamboo, and that it was likely to become a health hazard in the area most frequented by the public. Later the pool became covered in a thick algal growth (Plate 3). The embankment itself was aesthetically unpleasing and erosion of the embankment by wave and tidal action produced rubble that was dangerous to recreation and bathing.

The second embankment, constructed to rectify the problem of the stagnant pool and sand dunes, was also aesthetically unpleasing and detracted from recreation. The major impact of this embankment was, however, the increased possibility of flooding of the caravan park. As a result, the embankment was soon removed. The channel subsequently moved back to a more natural position and aesthetically the estuary became more attractive. Only the rubble remains are proof of the existence of either of the embankments.

6.4.2 Bridge and embankment - long term impacts

The secondary impacts that have occurred as a result of the presence of the permanent bridge and embankment are the disappearance of the bloodworm *Arenicola loveni* from the estuary (Gaigher, 1984) and the vegetation of the open sand area below the bridge. Possible future impacts are problems relating to the flooding of the caravan park and erosion of the sand promontory on which the holiday bungalows are situated.

In 1955 Mr G. F. van Wyk found a substantial population of the bloodworm *Arenicola loveni* both upstream and downstream of the foot bridge close to the present road bridge (Heydorn & Bickerton, 1982). Gaigher (1984), when he visited the estuary in 1973, found a strong viable bloodworm population. Three years later he could find no trace of bloodworm above the bridge, and only two surface signs were observed on the seaward side. In 1979 a survey by the Estuarine and Coastal Research Unit (ECRU) also revealed no bloodworm in the estuary. Gaigher (1984), having dispelled of other possible reasons for the extinction of the bloodworm, suggests that the embankment would have affected the *Arenicola* colony by way of its influence on the hydrology of the estuary (pg. 7). The embankment most likely retards the drainage of freshwater floods, and prolongs the retention time of freshwater over tidal sandbanks. In this way *Arenicola*, which are more intolerant to low salinities than other organisms in the same category, have become extinct.

Vegetation of the sand bank below the bridge is illustrated in Plate 5 and 6. The presence of vegetation suggests that the sand surface has built up above normal high water levels and indicates that this area has become more stable since 1980, when there was no vegetation here. Pioneer dune species of marram grass (*Ammophila arenaria)* and sea wheat (*Agropyron distichum)* found on top of small hummock dunes suggest the build up of sand above the estuary spring-tide level. The small dunes further indicate that wind processes are operative over the now partly vegetated open sand area. A small hummock dune colonised by pioneer species is illustrated in Plate 6.

Flooding of the caravan park remains a continual threat. Constriction of floodwaters by the embankment will increase the level of water passing under the bridge. At the same time the well defined channel below the bridge, and the alignment of the bridge supports towards the caravan park, concentrates river flow towards the caravan park and sand promontory. Flooding of the caravan park has been reported by a former supervisor of the park Mr Terblanche. A continual build up in the level of the new vegetated sand area could further restrict flow to the channel, thus increasing the threat of flooding.

The possible future erosion of the sand promontory has been noted by Heydorn & Bickerton (1982) and suggested by Dr Alan Heydorn in personal communication. It is feared that the conditions causing flooding will also erode the sand promontory. Data presented in this study however suggest that no serious erosion of the promontory will occur. This is based on the following evidence:

* the vegetation of the marine right bank area has increased since 1938, the big increase between 1938 and 1961 probably resulting from the stabilising effect of encroaching *Acacias*. Since 1973 the marine right bank vegetation has increased or remained the same - showing no evidence of erosion.

* on the bridge side of the promontory, comparison of the estuary edge before and after bridge construction shows that there has been no change in the edge position since bridge construction. Even on the July 1980 photograph,

taken five days after the June 1980 flood (2/7/80), there is no evidence of erosion of the promontory.

There may be seasonal and annual changes to the edge of the promontory which relate to changes in run-off. A high flow event may remove sand while during lower flow conditions sand may build up again. The changes are, however, expected to be relatively minor.

A number of secondary impacts have been examined which result from both the construction of the temporary embankments, and the permanent road bridge and embankment. The impacts of the temporary embankments were short lived and no longer have any effect on the system. Impacts resulting from the road bridge and embankment are, however, long termed and have a much greater effect on the estuarine system. The potential impacts - the erosion of the sand promontory and the flooding of the caravan park, are major problems in the future management of the Uilkraals estuary.

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

The first objective of this study, which was to describe the temporal changes in the sediment distribution and channel characteristics, has been met by quantitatively measuring various selected parameters from aerial photographs. The quantitative measurements presented in the results of this study reveal that in most cases the natural changes in the river, floodplain and marine parameters are small, and that the biggest changes have been in response to human intervention. These changes result from dune stabilization adjacent to the estuary, construction of the two temporary embankments and the presence of the road bridge and embankment. River width and lateral stability data reveal changes in the natural state and behaviour of the channel since bridge construction, and while the temporary embankments were present.

Data obtained from ground survey, aerial photographs and sediment sampling have been used to meet the second objective, which was to describe the present sediment distribution and dynamics of the lower Uilkraals estuary. The present sediment distribution is controlled very much by the increased flow velocities under the bridge and by the damming effect of the embankment. Flood-tidal currents and wind from the south are responsible for bringing sand into the estuary while river floods flush sand from the estuary. A major build up of sand has occurred on the open sand area downstream of the bridge, while in the main channel much sand has been eroded away.

To meet the third objective of this study, which was to determine the significance of the impacts of the bridge construction and the temporary embankments on the sediment morphology and dynamics of the Uilkraals estuary, data has been assimilated from each of the three techniques. The impacts resulting from the temporary embankments were:

* the extreme mouth positions, on either side of the beach, into which the mouth was forced by their construction

* the formation of a stagnant pool and a series of small dunes in front of the holiday bungalows.

Secondary impacts, which developed as a consequence of sediment redistribution, include the problems and cost of trying to remove the dunes and stagnant pool which had lowered the quality of recreation. The increased possibility of flooding of the caravan park resulted from the presence of the second temporary embankment. The impacts were, however, of a short duration lasting for approximately three years from 1978 up until the end of 1980 when the second temporary embankment was removed. Since the removal of the second temporary embankment the channel has returned to a more natural position at the mouth and most of the secondary impacts have ameliorated. These points suggest that the embankments have been of little significance in terms of the long term functioning of the Uilkraals estuarine system.

The impacts on the sediment morphology and dynamics resulting from the road bridge and embankment are:

* the restriction of flow to the area under the spanned bridge section

* the build up of sand on the open sand area downstream of the bridge

* that the embankment stops wind blown sand from the beach moving further into the estuary and

* that the embankment acts as a "hydraulic shelter" during high river flow, thus allowing the build up of sand on the downstream side.

The vegetation of the sand area downstream of the bridge resulted from the build up of sand in this area which occurred because the embankment both stops wind blown sand from moving further into estuary and acts as a "hydraulic shelter" during floods. In the long term, this build up could be significant as the area may eventually become isolated and no longer a functional part of the estuary. Secondary impacts resulting from the change in estuarine dynamics are the disappearance of the bloodworm *Arenicola loveni* and the threat to the caravan park of flooding. Both of these impacts are significant in considering the future management of the estuary.

The final objective of the study was to provide recommendations for future management. These are as follows:

* no further embankments should be constructed in the estuary. If there is still a need to increase space adjacent to the caravan park and holiday bungalows for bathing and recreation, the best possible means would be to stop vehicular access to the beach area.

* the construction of a culvert or culverts under the bridge embankment would alleviate a number of problems in the estuary by increasing the cross-sectional channel area. Firstly, during high run-off events there would be a lower concentration of flow under the bridge, thus reducing the likelihood of flooding of the caravan park and erosion of the promontory on which the holiday bungalows stand. Secondly, the retention of freshwater in the estuary after high flow events would be less, thus rendering the estuary more acceptable for repopulation by the bloodworm *Arenicola loveni*. Finally, with water passing through the culverts, the new vegetated area may

be subjected to flooding and erosion. The change in dynamics will probably result in the redistribution of the sediment, with this area again becoming a functional part of the estuary. If the culvert recommendation is considered, it is suggested that experts should be consulted in the early stages of planning to give advice on design criteria for, and location of the culverts.

This study has shown that the sediment distribution and dynamics of the Uilkraals estuary have been affected by human disturbance . The impacts of the temporary embankments were of a short duration and had no effect on the long term functioning of the estuary. The road bridge and embankment have, on the other hand, had a significant impact on the long term functioning of the estuary. By taking cognizance of the recommendations however, many of the long term problems may be ameliorated.

To avoid the type of impacts illustrated in this study, it is vital that, in the future planning and design of engineering projects within estuarine systems there is an understanding of the processes operating therein. In so doing many of the ecological and physical problems, which result from the unnatural redistribution of sediments, may be avoided in other estuaries along the southern African coast.

* * * * *

REFERENCES

Alexander, W.J.R. 1978 The effect of river management practices on the sedimentation of estuaries in Natal. Department of Water Affairs, Technical Note No.87. 23pp.

Alexander, W.J.R. 1979 Sedimentation in estuaries; causes, effects and remedies. 4th National Oceanograhpic Symposium, Cape Town. 8pp.

Acocks, J.P.H. 1975 Veld types of South Africa. Memoirs of the Botanical Survey of South Africa, **40**. 128pp.

Bayne, S. 1984 Aerial Photography and Environmental Impact Analysis. Unpublished M.Sc. Thesis, University of Cape Town. 133pp.

Beaumont, R.D. and Heydenrych, P.J. 1980 The effects of development on the Diep River Estuarine system near Cape Town. South African Water Bulletin, April, p. 10-18.

Begg, G.W. 1978 The Estuaries of Natal. Natal Town and Regional Planning Commission, Report Vol.**41**, Backhouse, Pietermaritzburg. 657pp.

Begg, G.W. 1984 On progress and problems in the rehabilitation of Natal's Estuaries. Coastal Zone Management Seminar, Pietermaritsburg 1984. Natal Town and Regional Planning Supplementary Report, Vol.**14**, p.35-49.

Blatt, H., Middleton, G. & Murray, R. 1980 Origin of Sedimentary Rocks. Prentice-Hall, New Jersey. 782pp.

Briggs, D.J. 1977 Sources and Methods in Geography: Sediments. Butterworths & Co, London. 190pp.

British Standard, 1975 Methods of the Test for Soils for Civil Engineering Purposes. **BS-1377** : 1975. British Standards Institute, London.

Bruton, M.N., & Appleton, C.C. 1975 Survey of Mgobezeleni lake-system in Zululand, with a note of the effect of a bridge on the Mangrove Swamp. Transactions of the Royal Society of South Africa, **41**(3), p. 283-294.

Buller, A.T. & McManus, J. 1979 Sediment sampling and analysis. In. K.R. Dyer (Ed) Estuarine Hydrography and Sedimentation. Cambridge University Press, Cambridge, p. 87-130.

Cape Provincial Administration 1968 Proposed bridge over the Uilkraals River. Site Plan. Department of Roads, Caledon.

Dardis, G.F. & Plumstead, E. 1988 Mudball genesis in a sud-tropical estuarine environment, Mbashee River Mouth, Transkei, Southern Africa. In. G.F. Dardis & B.P. Moon (Eds) Geomorphological Studies in Southern Africa. Balkema, Rotterdam, p. 435-443.

Dart, M.C. & Sheldon, D. 1980 Management of the Thames Estuary. DSS Report No. PC1/80. Thames Water Directorate of Scientific Services. New Head Laboratories, London, p. 1-51 (unpublished report).

Day, J.H. 1980 What is an estuary? South African Journal of Science, **76**, p. 198.

Day, J.H. 1981 Estuarine sediments, turbidity and the penetration of light. In. J.H. Day (Ed) Estuarine Ecology, with Particular Reference to Southern Africa. Balkema, Cape Town, p. 45-56.

Day, J.H. & Grindley, J.R. 1981 The estuarine ecosystem and environmental constraints. In. J.H. Day (Ed) Estuarine Ecology, with Particular Reference to Southern Africa. Balkema, Cape Town, p. 345-397.

Dyer, K.R. 1979 Estuaries and estuarine sedimentation. In. K.R. Dyer (Ed) Estuarine Hydrography and Sedimentation. Cambridge University Press, Cambridge, p. 1-18.

El Ashry, M.R. and Wanless, H.R. 1967 Shoreline features and their change. Photogrammetric Engineering., **32**(2), p. 184-189.

Esterhuysen, K. & Rust, I.C. 1987 Channel Migration in the lower Swartkops estuary. South African Journal of Science, **83**, p. 521-525.

Farquharson, F.L. 1970 Roads versus estuaries. Limnological Society of South Africa Newsletter, **15**, p. 40-45.

Flemming, B.W. 1977 Distribution of recent sediments in Saldanha Bay and Langebaan Lagoon. Transactions of the Royal Society of South Africa, **42**, p. 317-340.

Folk, R.L. 1966 A review of the grain size parameters. Sedimentology., **6**, p. 103-109.

Folk, R.L. 1968 Petrology of Sedimentary Rocks. Hemphill, Austin Texas. 170pp.

Folk, R.L., and Ward, W.C. 1957 Brazos River Bar : a study of the significance of grain size parameters. Journal of Sedimentary Petrology., **32**, p. 602-606.

Friedman, G.M. 1961 Distinction between dune, beach and river sands from their textural characteristics. Journal of Sedimentary Petrology., **31**, p. 514-529.

Fromme, G.A.W. 1977 Establishment of a standard relationship between settling velocity and grain size of coastal sand. Physical Oceanography Division, NRIO, CSIR Research Report, **356**, Stellenbosch. 35pp.

Fromme, G.A.W. 1986 The dynamics of the Boknes, Boesmans, Kariega and Kasuga estuaries. Sediment Dynamics Division, NRIO, CSIR Report T/SEA 8616, Stellenbosch. 54pp.

Gaigher, C.M. 1978 CPA, Nature and Environmental Conservation Memorandum. 2pp.

Gaigher, C.M. 1984 The effects of bridge building on the bloodworm population in the Uilkraals River Estuary. The Naturalist, **28**(1), p. 16-18.

Griffiths, J.C. 1967 Scientific Method in Analysis of Sediments. McGraw-Hill, New York. 508pp.

Gutkind, E.A. 1956 Our world from the air : conflict and adaptation. In. W.L. Thomas (Ed) Mankind's Role in Changing the Face of the Earth. University of Chicago Press, Chicago, p. 1-44.

Grindley, J.R. & Heydorn, A.E.F. 1979 Man's impact on estuarine environments. South African Journal of Science, **75**, p. 554-560.

Heydorn, A.E.F. 1979 Overview of present knowledge of South African estuaries and requirements for their management. South African Journal of Science, **75**, p. 544-546.

Heydorn, A.E.F. & Tinley, K.L. 1980 Estuaries of the Cape, Part I. Synopses of the Cape Coast. Natural Features, Dynamics and Utilization. CSIR Research Report, **380**. Stellenbosch. 96pp.

Heydorn, A.E.F. & Bickerton, I.B. 1982 Estuaries of the Cape, Part II. Synopses of Available Information on Individual Systems. Report No. 9, Uilkraals. CSIR Research Report, **408**, Stellenbosch. 37pp.

Hjulstrom, F. 1935 Studies of the morphological activity of rivers as illustrated by the River Fyris. Bulletin of the Geological Institite of Uppsala, 25, p. 221-227.

Howard-Williams, W., Howard-Williams, C. & Longman, T. 1975 Preliminary Ecological Survey of the Lower Swartvlei Estuary with Special Reference to the Area Spanned by a Road Bridge. Report to the Department of Planning and the Environment. Institute of Freshwater Studies, Rhodes University, Grahamstown. 11pp.

Inman, D.L. 1952 Measures for describing the size distribution of sediments. Journal of Sedimentary Petrology., **22**(3), p. 125-145.

Karcz, I. 1969 Mud pebbles formed in a flash flood environment. Journal of Sedimentary Petrology, **39**, p. 333-337.

Kellerhals, R., Church, M. & Bray, D.I. 1976 Classification and analysis of river processes. Journal of the Hydraulics Division, American Society of Civil Engineers, p.813-827.

Kidson, C. & Manton, M.M.M. 1973 Assessment of coastal change with the aid of photogrammetric and computer-aided techniques. Estuarine and Coastal Marine Science., **1**(1), p. 271-281.

King, C.A.M. 1966 Techniques in Geomorphology. Edward Arnold, London. 342pp.

Klemas, V. 1976 Remote Sensing of Coastal Wetland Vegetation and Estuarine Water Properties. In. M.L. Wiley (Ed) Estuarine Processes. Volume II Circulation, Sediments and Transfer of Material in the Estuary. Academic Press, New York, p. 381-403.

Krumbein, W.C. 1934 Size frequency distributions of Sediments. Journal of Sedimentary Petrology., **4**, p. 65-77.

Malan, J.A. 1987 The Bredasdorp Group in the area between Gans Bay and Mossel Bay. South African Journal of Science, **83**, p. 506-507.

McCammon, R.B. 1962 Efficiencies of percentile measures for describing the mean size and sorting of sedimentary particles. Journal of Geology., **70**, p. 453-465.

McLusky, D.S. 1981 The Estuarine Ecosystem. Blackie, Glasgow. 150pp.

Meade, R.H. 1972 Transport and deposition of sediments in estuaries. The Geological Society of America, Memoir 133, p. 91-120.

Moll, E.J., Cambell, B.M., Cowling, R.M., Bossi, L., Jarman, M.L. & Boucher, C. 1984 A description of major vegetation categories in and adjacent to the Fynbos Biome. South African National Scientific Programmes Report No. 83. 29pp.

NRIO, 1983 Hydrological / hydraulic study of Cape estuaries. The Sondags Estuary. Sediment Dynamics Division, Coastal Engineering and Hydraulics, NRIO, CSIR, Memorandum 8303, Stellenbosch. 8pp.

NRIO, 1986 Hydrological / hydraulic study of Natal estuaries. Data Report No.9 (revised) Mdloti NN3. Sediment Dynamics Division, Coastal Engineering and Hydraulics, NRIO, CSIR, Data Report D8606, Stellenbosch. 9pp.

NRIO, 1987 Basic physical geography/hydro data for estuaries of the south-western Cape (CSW 1-26). Sediment Dynamics Division, Coastal Engineering and Hydraulics, NRIO, CSIR, Data Report D8705, Stellenbosch. 6pp.

O'Connor, B.A. 1983 Sediment transport in the estuarine and coastal environment. The Dock and Harbour Authority, **63**, No.747, p. 324-329.

Perry, J.E. 1985 An Overview of Hydrological Factors Affecting Siltation in the Lower Reaches of Natal's Rivers. Sediment Dynamics Division, Coastal Engineering and Hydraulics, NRIO, CSIR, Stellenbosch. 20pp.

Pettijohn, F.J. 1975 Sedimentary Rocks. Harper & Row, New York, 628pp.

Pitman, W.V., Potgieter, D.J., Middleton, B.J. & Midgley, D.C. 1981 Surface water resources of South-Africa. Volume IV, Drainage Regions EGHJKL, The Western Cape, Part 2, Report No. 13/81. Hydrological Research Unit, Univ. of the Witwatersrand, Johannesburg.

Postma, H. 1967 Sediment transport and sedimentation in the estuarine environment. In. G.H. Lauff (Ed) Estuaries. American Association for the Advancement of Science, Publication 83, Washington, p. 158-179.

Prichard, D.W. 1967 What is an estuary, physical viewpoint. In. G.H. Lauff (Ed) Estuaries. American Association for the Advancement of Science, Publication 83, Washington, p. 3-5.

Rooseboom, W.G. 1975 Sedimentproduksiekaart vir Suid-Africa, Technical Report No. 61, Department of Water Affairs, Pretoria.

Ryan, P.G., Underhill, L.G., Cooper, J. & Walther, M. (In press.) Waders (Charadrii) and other waterbirds on the coast, adjacent wetlands and offshore islands of the Southwestern Cape Province, South Africa, Summer 1980/81.

Saeijs, H.L.F. 1982 Estuaries and Man. In. H.L.F. Saeijs (Ed) Changing Estuaries : a Review and New Strategy for Management and Design in Coastal Engineering. Rijkwaterstaat Communications, 32, p. 25-108.

SANCOR, 1983 The SANCOR Estuaries Programme 1982-1986. Pretoria, CSIR. South African National Scientific Programmes Report, No. 67. 42pp.

SANCOR, 1986 SANCOR Newsletter March 1986, No 93.

Schanda, E. 1976 (Ed) Remote Sensing for Environmental Sciences. Springer-Verlag, Berlin. 367pp.

Schlee, J., Uchupi, E. & Trumbull, J.V.A. 1964 Statistical parameters of Cape Cod Beach and Eolian Sands. United States Geological Survey Professional Paper, 501-D, p. 118-122.

Siegfried, W.R. 1981 The estuarine avifauna of South Africa. In. J.H. Day (Ed) Estuarine Ecology with Particular Referernce to Southern Africa. Balkema, Cape Town, p. 223-250.

Siesser, W.G. 1972 Petrology of the Cainozoic coastal limestones of the Cape Province, South Africa. Transactions of the Geological Society South Africa, 75(3), p. 117-185.

Solohub, J.J., & Klovan, J.E. 1970 Evaluation of grain size parameters in lacustrine environments. Journal of Sedimentary Petrology, 40, p. 81-101.

Spies, J.J., Engelbrecht, L.N.J., Malherbe, S.J. & Viljoen, J. 1963 Die geologie van die gebied tussen Bredasdorp en Gansbaai. Expl.Sheets 3419C and 3419D (Gansbaai) and 3420C (Bredasdorp) Geol. Surv. S. Afr., 39pp.

Stafford, D.B. 1968 Development and Evaluation of a Procedure for Using Aerial Photographs to Conduct a Survey of Coastal Erosion. A Report Prepared for the State of North Carolina. Department of Civil Engineering, North Carolina State University. 64pp.

Stafford, D.B. & Langfelder, J. 1971 Air photo survey of coastal erosion. Photogrammetric Engineering, 37(6), p. 565-576.

Stephenson, R.A. 1970 On the use of grain size analysis in geomorphological studies. Professional Geographer, 22, p. 274-285.

Strahler, A.N. 1975 Physical Geography. John Wiley & Sons, New York. 643pp.

Swart, D.H. & Serdyn de V., J. 1984 Statistical analysis of visually observed wave data from voluntary observing ships (VOS) for South-African east coast. CSIR, Stellenbosch.

Summers, R.W., Pringle, J.S. & Cooper, J. 1976 The Status of Coastal Waders in the South-Western Cape, South Africa. Western Cape Wader Study Group, Cape Town. 162pp.

Walsh, B.N. 1968 Some notes on the incidence and control of driftsands along the Caledon, Bredasdorp and Riversdale coastline of South Africa. Department of Forestry, Bulletin No. 44, Pretoria. 79pp.

Ward, C.J. 1971 The Plant Ecology of the Isipingo Beach Area, Natal, S. Africa. M.Sc. Thesis. Dept. of Botany, University of Natal. 342pp.

Weaver, A.v.B. 1977 An Examination of the Effects of Flow Restriction Upon the Hydraulic Regime of a Section of the Bushman's River. Unpublished Honours Thesis, Rhodes University, Grahamstown. 34pp.

Weisser, P.J. 1979 Suitabitity of air-photo interpretation for monitoring coastal dune vegetation on the Zululand dunes, South Africa. In. The Use of Ecological Variables in Environmental Monitoring. The National Swedish Environment Protection Board, Report PM 1151.

Weisser, P.J. & Marques, F. 1979 Gross vegetation changes in the dune area between Richards Bay and the Mfolozi River, 1937-1974. Bothalia, **12**(4), p. 711-721.

Weisser, P.J. & Parsons, R.J. 1981 Monitoring *Phragmites australis* increases from 1937 to 1976 in the Siyai Lagoon (Natal, South Africa) by means of air photo interpretation. Bothalia, **13**(3 & 4), p. 553-556.

Weisser, P.J. & Ward, C.J. 1982 Destruction of the *Phoenix/Hibiscus* and *Barrintonia racemosa* communities at Richards Bay, Natal, South Africa. Bothalia, **14**(1), p. 123-125.

Weisser, P.J., Garland, I.F. & Drews, B.K. 1982 Dune advancement 1937-1977 at the Mlalazi Nature Reserve, Mtunzini, Natal, South Africa, and a preliminary vegetation-succession chronology. Bothalia, **14**(1), p. 127-130.

APPENDIX I

NATIONAL PROGRAMME

The SANCOR Estuaries Programme established in 1982 served as a focus for estuarine research in South Africa for the five years from 1982-1986. The objective of the programme (SANCOR, 1983, p.3) "...is to provide a scientific understanding of estuaries - in particular of the interactive physical, chemical and biological processes within them, of their inter-action with the fringe areas and with their adjacent marine and terrestrial environments and finally of human impacts upon them - thereby contributing information required for their wise management".

At a meeting in September 1985 the SANCOR Estuaries Programme appointed a working group under the chairmanship of Dr. D.H. Swart, of the NRIO, to investigate the objectives of the Estuarine Programme for the following five years (Phase 2 : 1987-1992) in the light of the existing programme document (SANCOR newsletter, 1986). The working group found that the broad terms of reference and objectives of the estuaries programme as formulated in the South African National Programme Report No. 67 are still valid today and can form the framework for the next five years. Listed in the objectives (SANCOR. 1983, p.10) are natural processes and human manipulations which need attention. Of the natural processes "...interactions between estuarine, terrestrial and marine environments via run-off from the land and tidal interchange..." are pertinent to the study. Of the latter "...artificial manipulations of estuary mouths and stabilization of the surrounding dune fields..." and "... bridges and road construction including their effect on hydraulics and aesthetics..." are both important. In reviewing the objectives of 1983, the working group (SANCOR Newsletter, 1986. p.2) highlighted among other points, that "human influences in and manipulation of estuarine systems are of the utmost importance and should receive sufficient attention in the planning of research".

APPENDIX II

SPECIES COMPOSITION AND PHYSICAL FEATURES OF THREE VEGETATION MAPPING UNITS IN THE UILKRAALS ESTUARY
(after Heydorn and Bickerton, 1982)

Sporobolus virginicus / Juncus actus / Salicornia meyerana Floodplain Herbland

Total cover (%)	55-85
Height (m)	0-0,75
No. of species	11

Chenolea diffusa, Falkia repens, Juncus actus, Limonium linifolium var. *maritimum, Plantago carnosa, Pteronia uncinata, Salicornia meyerana, Samolus porosus, Scirpus littoralis, Sporobolus virginicus, Thesium frisea.*

Restioeleocharis / Metalasia sp. (Parsons 123) Low Shrubland

Total cover (%)	45
Height (m)	0-0,5
No. of species	14

Acacia cyclops, Chironia baccifera, Limonium sp., *Metalasia muricata, Metalasia* sp., *Muraltia satureioides, Nylandtia spinosa, Passerina glomerata, Psoralea fruticans, Pterocelastrus tricuspidatus, Pteronia uncinata, Phylica ericoides, Restio eleocharis, Selago* sp.

Chrysanthemoides monolifera Low Dune Shrubland

Total cover (%)	45
Height (m)	0-1,0
No. of species	10

Agropyron distichum, Arctotheca populifolia, Chrysanthemoides monolifera, Chrysocoma coma aurea, Ehrharta villosa, Helichrysum crispum, Senecio elegans, Senecio maritimus, Tetragonia decumbens, Thesidium fragile.

APPENDIX III

CORE SEDIMENT SAMPLE ANALYSES

Depth	Mean (phi)	Sorting	Skewness
Hole C2			
0.0	2.73	0.25	-0.37
0.1	2.56	0.37	-0.38
0.2	2.71	0.30	-0.59
0.3	2.58	0.38	-0.45
0.4	2.59	0.36	-0.47
0.5	2.56	0.41	-0.53
0.6	2.54	0.44	-0.54
0.7	2.53	0.44	-0.49
0.8	2.53	0.45	-0.50
0.9	2.40	0.48	-0.47
1.0	2.24	0.74	-0.62
1.1	2.42	0.51	-0.53
1.2	2.15	0.90	-0.72
1.3	2.50	0.49	-0.58
1.4	2.55	0.37	-0.64
1.6	2.42	0.43	-0.42
1.7	2.34	0.57	-0.55
1.8	2.32	0.45	-0.34
1.9	2.35	0.59	-0.57
2.0	2.41	0.50	-0.56
2.1	2.42	0.70	-0.70
2.2	2.65	0.34	-0.70
2.3	2.40	0.52	-0.49
2.4	2.15	0.83	-0.68
2.5	2.47	0.48	-0.44
2.6	2.25	0.49	-0.43
2.7	2.08	0.64	-0.53
Hole C3			
0.0	2.60	0.30	-0.38
0.1	2.61	0.31	-0.39
0.2	2.64	0.27	-0.38
0.3	2.63	0.30	-0.37
0.4	2.62	0.26	-0.37
0.5	2.66	0.26	-0.42
0.6	2.59	0.28	-0.27
0.7	2.65	0.28	-0.44
0.8	2.60	0.29	-0.34
0.9	2.59	0.33	-0.46
1.0	2.61	0.28	-0.40
1.1	2.58	0.32	-0.36
1.2	2.59	0.30	-0.41
1.3	2.55	0.35	-0.41
1.4	2.53	0.40	-0.54
1.5	2.46	0.55	-0.56
1.6	2.52	0.44	-0.54
1.7	2.38	0.63	-0.56
1.8	2.44	0.53	-0.57
1.9	2.29	0.71	-0.62
2.0	2.63	0.35	-0.40
2.1	2.60	0.36	-0.58
2.2	2.48	0.45	-0.52
2.3	2.39	0.68	-0.68
2.4	2.39	0.71	-0.72

CORE SEDIMENT SAMPLE ANALYSES

Depth	Mean (phi)	Sorting	Skewness
Hole C4			
0.0	2.43	0.49	-0.63
0.1	2.56	0.38	-0.45
0.2	2.55	0.40	-0.50
0.3	2.61	0.32	-0.50
0.4	2.42	0.59	-0.58
0.5	2.56	0.36	-0.37
0.6	2.52	0.39	-0.42
0.7	2.56	0.39	-0.58
0.8	2.46	0.45	-0.38
0.9	2.61	0.35	-0.56
1.0	2.78	0.15	-0.20
1.1	2.56	0.39	-0.54
1.2	2.39	0.52	-0.48
1.3	2.44	0.53	-0.47
1.4	2.45	0.49	-0.58
1.5	2.42	0.56	-0.63
1.6	2.26	0.56	-0.49
1.7	1.65	1.10	-0.61
1.8	1.23	1.42	-0.49
Hole C5			
0.0	2.58	0.31	-0.22
0.1	2.64	0.26	-0.29
0.2	2.62	0.35	-0.47
0.3	2.66	0.23	-0.24
0.4	2.72	0.23	-0.39
0.5	2.70	0.25	-0.36
0.6	2.72	0.20	-0.30
0.7	2.66	0.33	-0.52
0.8	2.64	0.44	-0.46
0.9	2.67	0.27	-0.39
1.0	2.49	0.36	-0.34
1.1	2.49	0.39	-0.42
1.2	2.48	0.39	-0.41
1.3	2.63	0.32	-0.41
1.4	2.07	0.79	-0.49
1.5	2.42	0.44	-0.50
1.6	1.33	1.19	-0.58
1.7	2.61	0.28	-0.37
1.8	2.27	0.56	-0.53
1.9	2.00	0.89	-0.54
2.0	2.00	0.98	-0.67

APPENDIX IV

SURFACE SEDIMENT SAMPLE ANALYSES

Below bridge

Sample No's	Mean (phi)	Sorting	Skewness
A1	2.70	0.19	-0.22
A2	2.60	0.29	-0.54
A3	2.69	0.15	-0.15
A4	2.65	0.21	-0.35
A5	2.82	0.19	-1.00
B1	2.74	0.24	-0.58
B2	2.59	0.27	-0.34
B3	2.66	0.11	-0.43
B4	2.62	0.24	-0.45
C1	2.65	0.25	-0.42
C2	2.67	0.18	-0.13
C3	2.57	0.53	-0.43
C4	2.68	0.19	-0.19
C5	2.49	0.41	-0.51
D1	2.45	0.11	-0.20
D2	2.57	0.23	-0.28
D3	2.36	0.18	-0.41
D4	2.65	0.42	-0.76
D5	2.85	0.11	-0.14
D6	2.35	0.65	-0.74
E1	2.39	0.51	-0.42
E2	2.49	0.34	-0.10
E3	2.62	0.22	-0.12
E4	2.63	0.32	-0.45
E5	Pebble bottom		

Above bridge

Sample No's	Mean (phi)	Sorting	Skewness
F1	2.63	0.42	-0.53
F2	2.54	0.39	-0.49
F3	2.38	0.45	-0.28
F4	Pebble bottom		
F5	Pebble bottom		
G1	2.50	0.15	-0.37
G2	2.59	0.28	-0.69
G3	2.33	0.35	-0.56
G4	2.35	0.61	-0.57
G5	2.59	0.24	-0.46
H1	2.58	0.21	-0.33
H2	2.61	0.31	-0.59
H3	2.55	0.27	-0.40
H4	2.58	0.33	-0.51
H5	2.72	0.18	-0.53
H6	2.56	0.27	-0.25
H7	2.48	0.35	-0.49
H8	1.40	1.47	-0.74

Sample No's	Mean (phi)	Sorting	Skewness
J1	2.61	0.26	-0.32
J2	2.31	0.43	-0.38
J3	2.65	0.17	-0.38
J4	2.65	0.26	-0.35
J5	2.68	0.15	-0.09
J6	2.86	0.13	-0.27
J7	2.47	0.44	-0.67
J8	2.60	0.20	-0.53
J9	2.54	0.60	-0.69
J10	2.10	0.71	-0.48
K1	2.54	0.32	-0.39
K2	2.66	0.24	-0.30
K3	2.53	0.36	-0.42
K4	2.73	0.15	-0.20
K5	2.69	0.40	-0.41
L1	2.44	0.32	-0.62
L2	2.67	0.22	-0.40
L3	2.43	0.40	-0.45
L4	2.49	0.33	-0.21
L5	2.42	0.60	-0.62
M1	2.39	0.40	-0.35
M2	2.34	0.56	-0.67
M3	2.56	0.38	-0.52
M4	2.29	0.67	-0.47
N1	2.36	0.37	-0.56
N2	2.63	0.29	-0.44
N3	2.56	0.43	-0.52
O1	2.65	0.25	-0.40
O2	2.34	0.52	-0.85
O3	2.52	0.33	-0.47
P1	2.39	0.51	-0.47
P2	2.52	0.39	-0.47
P3	2.51	0.37	-0.53
P4	2.51	0.41	-0.44
Q1	2.55	0.41	-0.55
Q2	2.67	0.32	-0.55
Q3	2.50	0.34	-0.25
R1	2.59	0.41	-0.56
R2	2.25	0.57	-0.68
S1	2.16	0.60	-0.30
T1	2.40	0.45	-0.38
U1	2.29	0.53	-0.42
Be1	2.50	0.24	-0.35
Be2	2.53	0.33	-0.35

PLATE 1 OBLIQUE AERIAL VIEW OF THE UILKRAALS ESTUARY. THE BRIDGE AND EMBANKMENT (E) CAN BE SEEN IN THE MIDDLE DISTANCE. THE STAGNANT POOL (S) AND THE FIRST TEMPORARY EMBANKMENT (e) CAN BE SEEN IN FRONT OF THE HOLIDAY BUNGALOWS (ECRU, 15/8/1979).

PLATE 2 REMAINS OF THE FIRST TEMPORARY EMBANKMENT. THE PHOTOGRAPH WAS TAKEN IN FRONT OF THE HOLIDAY BUNGALOWS ON THE RIGHT BANK (ECRU, 7/12/1979).

PLATE 3 STAGNANT POOL WITH ALGAL GROWTH. THE PHOTOGRAPH IS TAKEN FROM THE HOLIDAY BUNGALOWS LOOKING TOWARDS FRANSKRAAL (ECRU, 7/12/1979).

PLATE 4 SECOND TEMPORARY EMBANKMENT. THE VIEW IS FROM THE LEFT BANK LOOKING TOWARDS THE HOLIDAY BUNGALOWS (ECRU, 16/7/1980).

PLATE 5 NEW VEGATATED SAND AREA WITH THE BRIDGE IN THE BACKGROUND. THE PHOTOGRAPH IS TAKEN LOOKING FROM THE LEFT BANK (17/9/1987).

PLATE 6 SMALL DUNE ON NEW VEGETATED AREA. THE DUNE IS APPROXIMATELY 0,7 M ABOVE THE SURROUNDING AREA (17/9/1987).

PLATE 7 FEBRUARY 1987 AERIAL PHOTOGRAPH. B - BRIDGE, E - EMBANKMENT, N - NEW VEGETATED AREA.


N
B
E