THE FUTURE OF SHORELINE MANAGEMENT CONFERENCE PAPERS

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ALCROW

NRA

National Rivers Authority

SHORELINE MANAGEMENT : THE ANGLIAN PERSPECTIVE

FIRST EDITION 1991

FOREWORD

This study has provided new insight into the future development of Shoreline Management in this country.

It is pioneering, it is innovative, it is exciting. It breaks away from the traditional piecemeal approaches of the past and presents a vision of the future of coastal management which will put the UK in the forefront of this vitally important subject within Europe.

These are strong statements but they reflect the scale of this undertaking, its importance and the commitment which has gone into the project from a number of directions. Commitment from all those who were involved in the study in hundreds of different ways - providing information, analysing data, researching trends, developing computer programs - supported throughout by NRA managers and staff, with financial and professional support from the Ministry of Agriculture Fisheries & Food.

The end result of all this activity has been to produce the most powerful coastal database system in the UK - a medium for developing a radical new approach to the management of sea defences and the coastal zone by taking a regional overview. Its contribution is already being felt in the planning process, investment plans and project design.

The study has coincided with unprecedented interest in the coastal environment, the issue of global climate change and sea level rise. Much has been said about resolving conflicts in the coastal zone, improving understanding, disseminating knowledge and developing a coastal management approach. Equally there has been dialogue about the coastal environment and in particular the need to move away from hard defences towards soft engineering solutions. This study will have a profound influence in the decades ahead on both coastal management and the move towards more environmentally sensitive engineering solutions.

The Anglian Region of NRA has always regarded itself as innovative and progressive. Its strong record on sea defence and land drainage speaks for itself. Much has been achieved in this study and we hope that others will come to share this enthusiasm. The study has integrity and value and both of these attributes are important in the development of the system for the benefit of those whose lives and property are at risk in the region.

Kevin Bond
Director of Operations
National Rivers Authority

SHORELINE MANAGEMENT : THE ANGLIAN PERSPECTIVE

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PART I - OVERVIEW

1 INCEPTION AND DEVELOPMENT

It was against a background of,

- a real risk of flooding
- a justified need for major flood defence investment
- a geomorphologically and geologically complex and diverse coastline
- the possibility of sea level rise from global warming

that the Sea Defence Management Study (SDMS) was conceived in 1987.

After completion of a preliminary study the SDMS was commenced in 1988. By the spring of 1991 after an investment of £1.65m and three years of effort, the SDMS was completed. This however is only the beginning. The study has introduced new concepts and a new approach to the planning and provision of sea defences. Although this approach to Shoreline Management is in its infancy, the benefits derived are already significant. With continued development and positive application the approach will be of increasing benefit for effective flood protection of the Anglian Region.

The Anglian Region

Much of the Region is flat, low lying and below maximum recorded sea level. The Region covers one of the most vulnerable and variable coastlines in Britain stretching from the Humber in the north to the Thames in the south. With over one fifth of the Region below flood risk level a major investment programme is planned. To ensure the continuing protection of three quarters of a million people and the billions of pounds of investment in infrastructure and land, a ten year programme amounting to a total expenditure of £430m on coastal and tidal defences is being implemented.

The Region is protected from tidal flooding by about 1,500km of defences. The wide range of coastal geomorphology, the underlying geology and the exposure to wind and waves require a variety of defence solutions for this sensitive coastline. Coastal towns and land are protected by natural systems such as sand dunes and beaches, and engineered defence structures such as groynes, embankments and sea walls. Estuary towns and land are protected by saltings, embankments, flood walls and surge barriers. There is evidence that flood defence was carried out as early as the Roman times, but the major reinforcement and extension of the defences took place after the disastrous 1953 east coast flood in which over 200 people drowned. Limited refurbishment also took place in those places affected by the 1978 flood, which caused major damage to Wisbech, King's Lynn and parts of the Norfolk coast; fortunately this time with no loss of life. On both occasions the North Sea surge was the major factor contributing to the damage.

North Sea Surges

Surges occur frequently in the North Sea. They are created by low atmospheric pressure and the funnelling effect of the North Sea coastline. Surges of 1m occur four or five times a year but often not coincidental with spring tides, onshore winds or high tide. During a surge the sea level rises dramatically and in the case of 1953 the sea rose over 2m higher than predicted and in 1978 the still water levels recorded were higher than the 1953 level.

The Need to Understand Processes

Protection against surges dictates the level, the location and often the type of defence. However, it is the ongoing day in day out rise and fall of the tide, the tidal currents and the action of wind and waves on the coast that can undermine defences, cause accretion and erosion and change the shape of the foreshore. Effective flood defence in Anglian Region therefore requires knowledge of processes and changes along the coastline as a whole on an integrated basis irrespective of responsibility. Such an approach has been adopted in the SDMS. It is an approach that is not only very relevant today but even more relevant tomorrow with the possibility of global warming and sea level rise.

Given that the objective of the Study was to establish a management strategy based on a sound regional understanding it was felt necessary to extend the northern boundary of the study to incorporate the Holderness coast. This thereby includes a potentially important sediment source for the East coast. In contrast the Kent coast, on the south side of the Thames Estuary, was not considered to interact significantly with the regime along the Essex coast and was not therefore included. The extent of the study area is shown in Figure 1.1.

The Preliminary Study (1987 to 1988)

In 1987 the Anglian Regional Flood Defence Committee took a major initiative. This initiative was to move away from the piecemeal approach of the past towards an integrated look at the whole coastline. An early task was to examine the feasibility of this approach, and to identify, topics for investigation and to consider the cost implications. In late 1987 Halcrow was appointed for the preliminary study:

- to examine and collate references and data sources for the coast
- to identify dominant coastal processes and responses
- to develop a short term management strategy.

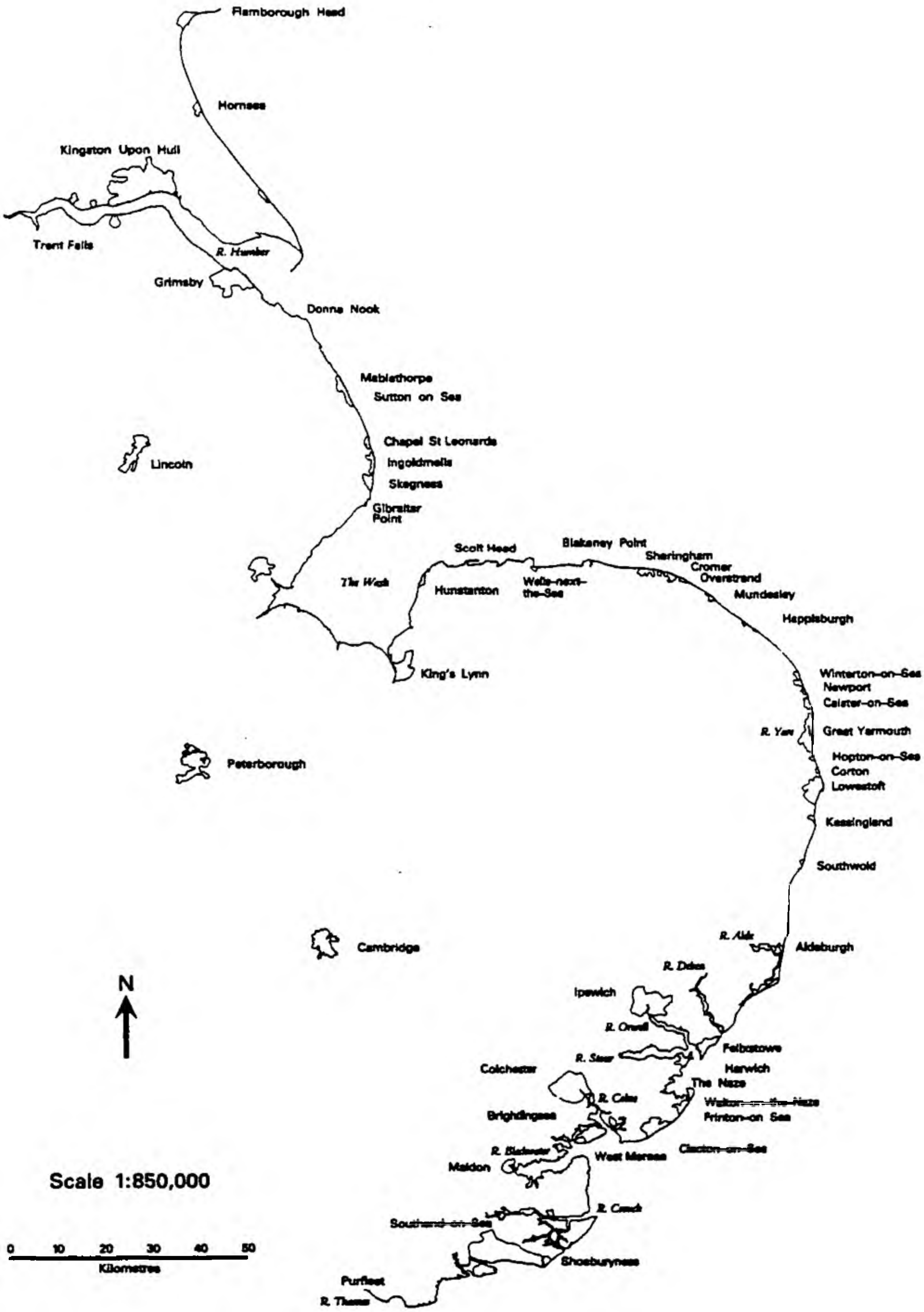


Figure 1.1 - The Study Area

This stage of the study was completed in 1988 at a cost of £0.25m. The output of the study included,

- a coastal atlas showing coastal data and information pictorially
- a database of references and sources of information
- a Geographical Information System (GIS) of the main variables
- a study report
- a short term management strategy.

Benefits from the preliminary study were:

- a better understanding of the coastal processes (eg offshore bank formation)
- a better understanding of responses (eg steepening occurring over 70% of the coastline)
- a database of references and facts invaluable for strategic management and scheme development.

The Completion of SDMS (1988 to 1991)

During 1988 Halcrow was appointed with the following tasks:

- filling in data gaps of the preliminary study
- continuing the further development and understanding of the coastal processes and mechanisms
- refining and developing the Geographical Information System into a fully operational tool
- defining a monitoring programme
- developing a management strategy

The overall objective being to develop a management strategy on a sound basis for investment plans for flood defence.

Approach

As already noted, the need to obtain some basic understanding of coastal mechanisms along the Anglian coast was seen as the foundation on which to build the management strategy. In order to achieve this it was considered necessary to:

(a) define the management framework;

(b) undertake studies to provide an understanding of the coastal processes involved;

(c) initiate a programme of field work, required to further this understanding;

(d) establish a system by which information can be extracted, manipulated and updated by those implementing the management strategy.

The rationale of the approach adopted was to construct a coherent picture of the dominant processes from the wide range of information that was already available. This philosophy was adopted because it was felt that over such a large and diverse area, any attempt to apply numerical models to examine processes and coastal development would inevitably be constrained by limited knowledge of the governing mechanisms. The prime objective was therefore to structure the data in such a way that it could be rapidly manipulated. A thorough analysis of existing sources of information was then made, to gain both insights and to focus subsequent field work and numerical model studies. In this way both the information base and the interpretive capability were progressively improved.

Study Components

In order to achieve this the project was divided up into a number of task areas as follows:

Data Collection	-	initially this focused on extracting information from existing archives. Once the most significant gaps had been identified, a major field survey programme completed the required data coverage.
Supporting Studies	-	these ranged from studies to exploit existing data sources (eg wave hindcast, analysis of extreme sea levels, etc), through the development of models to investigate specific phenomena (eg a beach response model to investigate beach steepening), to impact studies (eg sea level rise and climatic change) and reviews (eg literature, changes in the North Sea basin and Essex Saltings Programme).
Monitoring Programme	-	a number of studies investigated various aspects of monitoring to provide the basis for defining a comprehensive regional monitoring programme. In addition a software package was developed to support the collection and subsequent analysis of the data.

Management System	-	this entailed the development of a geographic information system (GIS) to meet the needs of the approach as outlined above.
Management Strategy	-	based on an analysis of the governing coastal processes in conjunction with the Authority's management objectives, the basis for response options can be evaluated. More importantly, the strategy forms one part of the management framework which comprises data collection, information management, and strategic planning.

Whilst the database includes sea defence, this does not include historical developments, nor any detailed investigations into structural integrity. Furthermore the development of the management strategy is based on a technical evaluation of the available data and does not include any benefit-cost considerations. Both of these aspects were outside the scope of this project.

The various components and findings of the study were documented in a series of 25 reports. This volume seeks to draw together the different aspects of the study to provide an overall appreciation of the project.

2 COSTS AND BENEFITS

Introduction

The decision in 1987 to embark on an integrated coastal study was farsighted. The SDMS has now come to a very successful fruition with many benefits. The timing has coincided with unprecedented interest in the coastal environment, the issue of global warming, climate change and sea level rise. It provides a sound basis for discussion and informing the public and all those in the coastal zone on these issues.

The Cost

The total cost of the SDMS is £1.6m which has been grant aided by MAFF. The breakdown of the total cost is approximately:

	£m
Preliminary Study (87 to 88)	0.25
<u>Field Measurements</u>	
Bathymetric Survey	0.40
Nearshore Geological Survey	0.15
Estuary Sediment Trends	0.18
Nearshore Currents	0.16
Sediment Modelling	0.10
Offshore Banks	0.02
Impact of Climate Change	0.03
impact of Sea Level Rise	0.02
Estuary Studies	0.03
<u>Monitoring</u>	
Beach Survey Methods) Satellite Data) Monitoring Programme)	0.17
GIS and Management Strategy	0.24
TOTAL	1.65

(NB This cost excludes the purchase of GIS hardware at approx £40,000).

Benefits of Study

The prime purpose of the SDMS is to provide a sound basis for investment plans. However, to achieve this objective and to ensure that the management strategy is both technically sound and regionally coherent, a diverse and wide range of topics have been investigated. The study is in essence a large Research and Development project with many of the initiatives being exploratory in nature. As in the case of Research and Development projects, some parts of the study have been more fruitful whilst others have been less fruitful than expected. Perhaps not fully appreciated at the time of commencement of the study, was the total range of benefits that would ensue from the study.

The benefits of the study can be broadly split as outlined in Figure 2.1.

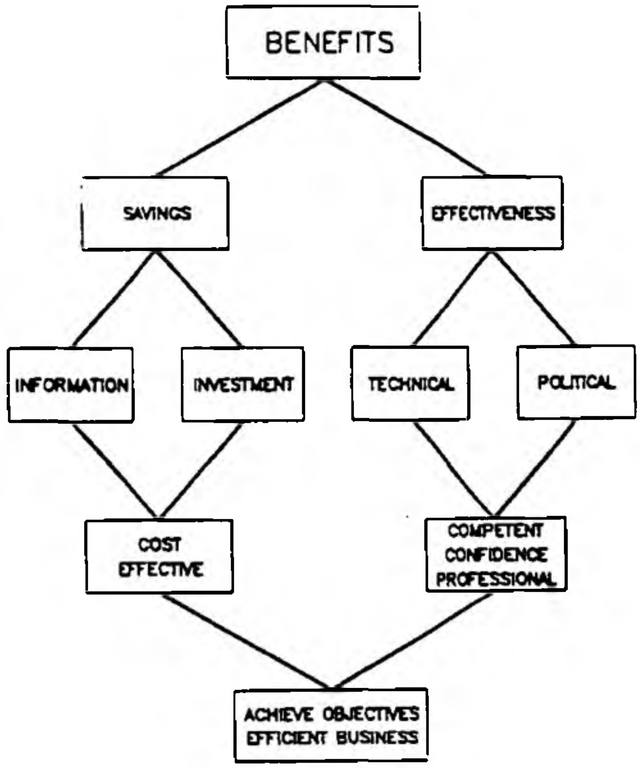


Figure 2.1 - Study Benefits

SAVINGS which will arise from project development

SAVINGS

Direct cost savings
or costs that would
have been incurred
(Tangible benefits)

SAVINGS will arise from two areas of project development:

INFORMATION

Improved quality and availability of data. Economy of scale in collation and collection

INVESTMENT

Investment options more robust and wide ranging

The EFFECTIVENESS of Flood Defences will be improved

EFFECTIVENESS

Improvements to effectiveness of the flood defences (Intangible benefits)

EFFECTIVENESS will be improved in two areas:

TECHNICAL	POLITICAL
Improved knowledge and understanding to develop standards, asset plans and levels of service	To move towards a coastal management approach. To develop corporate and management plans. To improve image, public relations and education

These benefits produce a cost effective, competent, confident and professional service ensuring the achievement of objectives and an efficient business. (See Fig 2.1).

Benefits and Savings Achieved

The ready availability of information on sea defences and the coastline as a whole has already proved invaluable in dealing with the media and public interest groups. The NRA is an environmentally aware and open organisation and the study has done much to maintain and improve this image.

Data was provided for the National Sea Defence Survey in 1990 for the whole of the Anglian coastline. This was computer generated from the SDMS database. Without the SDMS a cost of at least £0.3m would have been incurred on this exercise alone.

During the last year a number of projects have used the SDMS data and information. Projects include the Heacham Hunstanton Beach Recharge (£4.2m), the Essex Rural Walls (£30m), Lincolnshire Coast Study (£30m), Happisburgh/Winterton groynes (£30m) and numerous smaller projects. It is estimated that without the SDMS at least £0.3m would have been incurred on data collection and retrieval. The study has ensured easy access to a comprehensive range of good quality data to support these important projects and a total of £0.6m saving has been achieved.

Benefits and Savings

The £0.6m saving already achieved is only the beginning. A total 10 year investment programme of £340m on sea and tidal defences will continue to demand extensive and quality data from the SDMS. A simple 10 year savings chart has been produced (Fig 2.2). This shows that over a ten year period the study will have cost £3.6m and savings on information alone are expected to exceed £2.1m. Savings on investment are difficult to predict but improved quality and more extensive data will improve the robustness of projects and allow options such as beach recharge to be developed. It is expected that investment savings alone could pay for the whole of the SDMS costs several times over. All of these savings ignore the improvements to the technical and political effectiveness of the Authority.

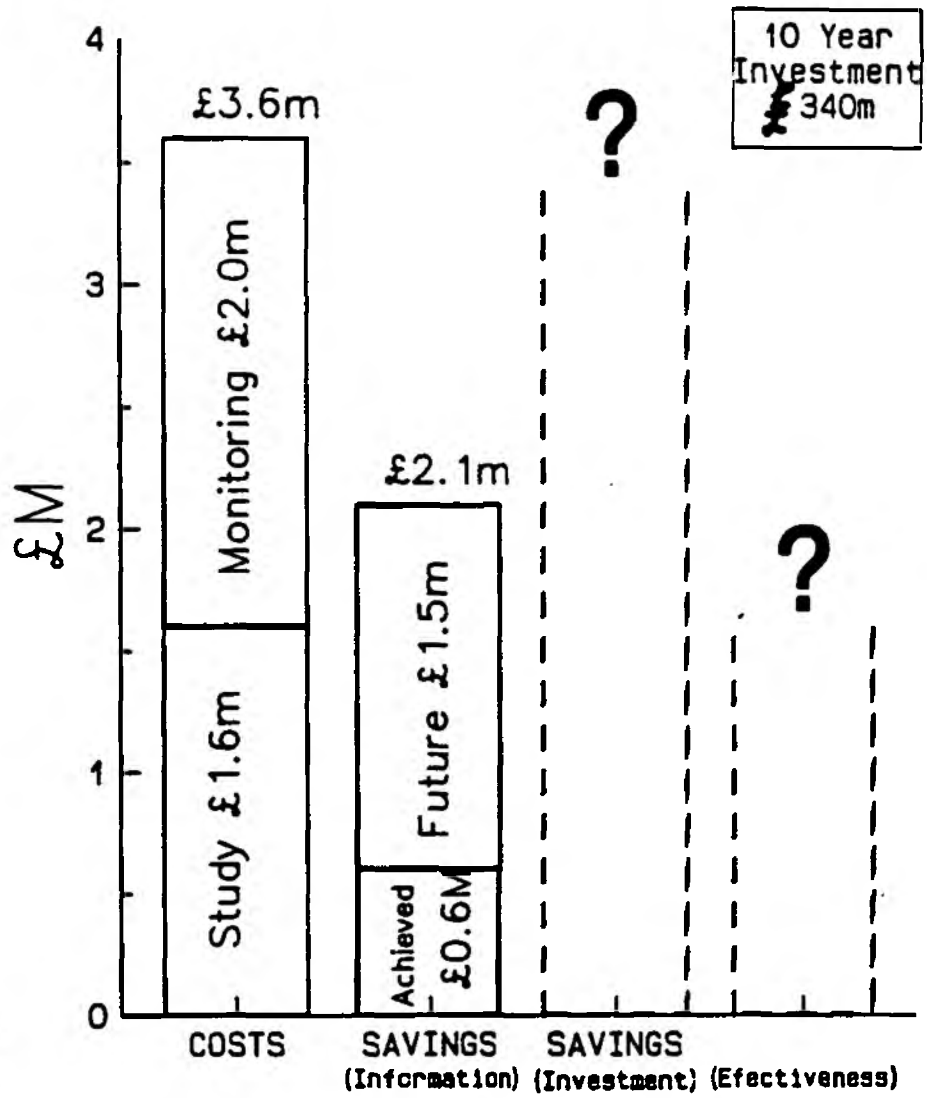


Figure 2.2 - Projected 10 Year Savings

Long Term Benefits

Monetary savings can justify the project in the short term but it is the longer term intangible benefits which are likely to have the greatest pay off. Some of these benefits are likely to be:

- early information on and perhaps early warning of problems associated with sea level rise

- moving towards "soft engineering" (working with nature rather than against)

- a basis for assessing changes in coastal processes and response.

3 THE WAY FORWARD

Introduction

The database developed as part of the project is only a snapshot in time. It needs to be kept alive to produce robust design and trend data. To achieve this an annual programme of monitoring has already commenced. The GIS System forms a basis for a management strategy of the coast. Such strategic management approach is fundamental to Shoreline Management and key to the wider aspects of Coastal Zone Management. Keeping the database up to date and developing management strategies are important. Of equal importance is the need to invest in Research and Development and to apply the knowledge gained particularly in the area of "soft engineering".

The future is therefore about making effective use of what has been achieved and to manage the application and development.

The Aim of the Monitoring Programme

The aim of the monitoring programme is to provide data in a structured, standardised and quality controlled manner. The data to be collected includes:

Forcing	Response
(Those components acting on the coastline to produce changes)	(The response to the forcing components in terms of shoreline changes)
Winds	Aerial Survey
Tidal Prism in estuaries	Hydrographic Survey
Water levels	Beach Survey
	Inspections

The data to be collected has been carefully reviewed and refined to ensure that all data will have a specific use. The timing and frequency of collection of the response data has been fixed such that trends can be identified. Full details of the monitoring programme are included later in this volume.

Monitoring Programme

A programme of monitoring representing an investment of £0.26m per year has commenced. Other North Sea countries have similar coastal processes and defence needs to the Region and a survey has been carried out of their annual monitoring programmes.

Denmark	A programme of annual surveying, aerial photography, water level and wave measurement for 500km of North Sea coast costing approx £0.33m pa.

Germany	Occasional surveys of the entire North Sea coast and more specific annual programme for the East Frisian Islands. The latter alone have a seaboard of some 200km and the expenditure is approx £0.32m per annum.
Netherlands	Comprehensive monitoring programme of entire 450km of coast which costs £1.60m per annum.
Belgium	Bathymetric and aerial surveys in the spring and autumn on 65km of coast at a cost of £1.16m per annum.

The annual costs per km compare as follows:

	Length of Open Coast (km)	Annual Expenditure £(m)	Annual Cost/km of Open Coast £
NRA Anglian Region	375*	0.25	670
Denmark	500	0.33	660
Germany	200	0.32	1,600
Netherlands	450	1.60	3,550
Belgium	65	1.16	17,860

* Open coast only. (1200km including estuary and sea defences).

If the estuarial length is included then the cost in the Anglian region falls to £210/km. These figures indicate that the investment in the monitoring activity proposed for Anglian Region is generally much lower per km than those for the rest of the Europe.

The Need for Monitoring

Monitoring is the lifeblood of the GIS system and ultimately the management strategy. The GIS system holds the available information and data and enables it to be displayed and analysed with reference to its spatial or geographic characteristics. The updating of information and data on the GIS is essential in order to carry out meaningful analysis, develop understanding of processes and monitor the performance of flood defences. This will be particularly important for soft engineering defences which require regular monitoring to establish recharge and recycling needs.

Monitoring will also allow patterns of change to be identified and therefore it is likely to provide an early indication of the impacts of sea level rise. As time goes on, a consistent and reliable data set will be available to provide sound long-term analysis and enable predictive models to be developed of how the coast will react to specific types or series of events. This will further enhance design capabilities and provide significant cost savings in avoiding both over and under design.

Monitoring enables the coast to be managed in sympathy with the natural coastal process and to develop effective flood protection to reduce flood risks. This is good for the environment, for those living in flood risk areas and for the taxpayer who has to foot the bill.

Implementation of Shoreline Management

The programme is managed from the Regional Office at Peterborough. However, an important concept of the management approach is the involvement of local operations personnel in the collection of data and understanding of the purpose for the data. Special software has been written to assist operations personnel in the collection and quality control of data and to provide useful data for day to day management of the coastline. Each District Office has been equipped with the necessary software and hardware to view the data and to provide digitised data for input into the central GIS systems. Since completion of the study earlier this year much work has been done on the monitoring programme and the letting of the necessary contracts.

District Councils with coast protection responsibilities, have also been actively involved in this monitoring programme and the collation of data. District Councils with major lengths of coast protection are equipping themselves with software and hardware similar to the NRA district offices. With monitoring now underway it is intended to move forward and develop the strategic part of the GIS and its broader role in Shoreline Management and coastal management.

Towards Coastal Zone Management

The GIS system provides us, for the first time, with a sound basis for the development of a management strategy and a Shoreline Management approach. The next major step is to integrate Shoreline Management with the wider needs of Coastal Zone Management. The management strategy developed and the information being collated will provide a vehicle for the wider discussions necessary on policy guidelines and management response. Development of this area will commence in 1992 and will involve wide dissemination and discussion with local authorities and all those involved in the coastal zone.

Application

Application of the information and knowledge into specific project and strategic plans is an ongoing process and will bring many benefits as already mentioned. Soft engineering depends entirely on understanding processes and monitoring performance. Without this knowledge such soft engineering or "working with nature" approaches will not be possible. The monitoring of performance of the soft engineering solutions developed will be integrated with the annual monitoring programme and fed into the central GIS.

Research and Development

The SDMS has already provided insight into several research needs. The NRA approach is to feed research requirements into a national procedure system and to develop research on a structural basis. The development of process knowledge and the shoreline management approach will provide key areas for structured research for the future.

PART II - STUDIES

4 DATA COLLECTION

The approach adopted placed a strong emphasis on data and its organisation for easy access. In this respect initial work concentrated on existing data archives. Subsequently, after the initial archive had been used in preliminary analysis work, some field surveys were undertaken to meet specific needs; most notably in the nearshore zone.

Referral Database

To begin with details of references and data sources were gathered. This entailed contacting a wide range of organisations who possibly held information relevant to the Anglian Coast. The response was very good and subsequent visits were used to identify additional sources and to extract specific items that were required for the study.

This information formed the basis of a referral database for references and data sources. It includes entries for reports, papers and relevant literature, as well as details of the type, extent and holder for the various sources of measured data that have been identified. The database was set-up using Ashton-Tate's 'dBASE III plus' software and can be searched on a number of fields, such as key word, data type, author, coastal region, location and so on. Searches can be constructed in several ways, to give either comprehensive listings (eg all references for the Lincoln region), or much more specific responses (eg the data on waves collected during 1982 off the Norfolk Region). This therefore provides a rapid means of identifying what information is available. If kept up-to-date it will provide a useful catalogue for future use within the Anglian Region.

Existing Data

The task of gathering data followed on from the preliminary work of identifying data sources. In order to define the scope of this task data collection concentrated on a number of key variables, as summarised in Table 4.1. These were selected on the basis that they provide information on the direct influences and responses of the coast (eg waves, tides, rate of retreat, flood areas, etc), on the character of the coast (eg morphology, ecology, etc), on human interests which may be affected (eg present coastal works, SSSIs, land use, etc). In all some 60 different agencies were approached and the response provided adequate coverage for most of the variables.

After being screened and compiled into the desired format, all the various data were entered into a database capable of storing the geographical location of the data. The system is based on a geographical information system (GIS) and has a database which is able to handle not only single attributes but also attributes which themselves have complex data structures. Configured for this particular application the system was used to meet the following objectives:

- to map relevant variables for the Anglian coastal region

- to use the graphical output of the system to present each variable or combination of variables as a series of maps

- to assess the inter-relationships between variables and their contribution to coastal erosion

- to produce interpretive maps which form the basis of a coastal management policy.

The design of the data model to handle the data and the customisation of the GIS to meet the project needs are considered further in Chapter 9.

In the course of preliminary analysis work, it became clear that there were some gaps which would have to be filled before an adequate regional assessment could be completed. This requirement could in part be met using numerical modelling as described in the next chapter. There was however a marked lack of information relating to the nearshore zone, and this led to the field survey programme carried out during the summer of 1989.

MAIN VARIABLE	SIGNIFICANCE
CURRENTS	- controls sediment movement in offshore zone - links nearshore processes with far field effects in the North Sea
COASTAL MOVEMENT	- indicates areas of high/low activity - necessary to be able to make forecasts - relates to sediment budget
COASTAL WORKS	- required to establish any interaction with coastal processes
ECOLOGY	- a measure of shoreline (cliff, dune, saltmarsh) stability, shelter, relationship to rivers and estuaries - required to assess environmental impact
FISHERIES	- changes to habitat
INFRASTRUCTURE	- constrains the coastline - can alter the inshore wave energy regime
INDUSTRY	- coastal impact (eg outfalls) - threat to habitats - modify sediment paths - alter local currents, wave conditions - lead to changes in the sediment budget
JURISDICTION	- important for the development of management strategy
AGRICULTURE	- changes to habitat - drainage patterns and run-off
SEDIMENTS	- determines mobility of material - can help to establish source(s) - basis of sediment budget
MORPHOLOGY	- provides basic description of coastline - features can have a physical significance (eg offshore banks dissipate wave energy, cliffs can provide a sediment supply, etc) - widths of the foreshore provide an indication of plan effects - slopes control the form of incoming waves - indicate nature of sediment transport - represent sediment sources and sinks - intertidal features indicate beach cycles and on-offshore movement
BIRDS	- required to assess environmental impact
CONSERVATION SITES	- special consideration to prevent undesirable changes
WATER QUALITY	- influences vegetation and hence shoreline stability - can effect marine life and alter habitats - density affects influence and transport regimes
RAINFALL	- influenced ground water levels and river discharges - relates to the sediment load in rivers - can affect cliff stability
TEMPERATURE	- seasonal variations may contribute to erosion
WIND	- generates waves and surges - governs sub-aerial erosion and deposition
WATER LEVELS	- major effect on coastal processes - controls extent of wave influence on shoreline - relates to potential for land flooding
WAVES	- determines potential for shoreline erosion and accretion - influences movement and height of offshore banks

TABLE 4.1 - SIGNIFICANCE OF MAIN VARIABLES

Nearshore Bathymetry Survey

A survey of the exposed open sections of Anglian coastline from Shoeburyness in Essex to Grimsby in Humberside was undertaken by BMT Ceemaid Ltd. The only exclusion was the area between Lowestoft and Great Yarmouth because data was available in an appropriate form from Waveney District Council.

The survey was carried out along section lines normal to the shore, at approximately 1km intervals along the coast. The lines were surveyed through traditional levelling across the beaches and by hydrographic techniques across the nearshore. Wherever feasible, the beach levelling and hydrographic data were quality checked by overlapping data over part of the intertidal zone. The offshore extent of each line was determined by target depth considerations. Offshore target depths of between 3m and 10m below OD had been defined for each section line in advance of the survey work. In general this aimed to keep the survey within 2-4km of the coast, whilst extending out beyond the nearshore closure depth (see below).

Summary of Findings

The data has been used extensively during the interpretive phase of the project in order to define the morphological characteristics of the nearshore zone. In particular cross-sections were used to establish the seaward limit and representative slope for the nearshore zone. The former was based on the limit of significant profile change as a consequence of storm action, although this should not be thought of as the limit of cross-shore sediment movement. For the majority of profiles this was characterised by a break in slope and the depth at this point was found to be in reasonable agreement with predictions used to specify the survey, based on the analytical work of Hellemeier (1981), Table 2.1. Certain sections do not follow the general profile trend and were more difficult to interpret. This was the case in the vicinity of the offshore banks on the Norfolk coast and on those profiles which extended into estuaries (showing channelled morphology).

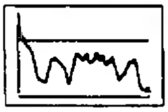
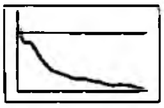
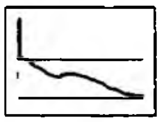
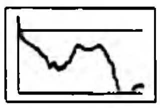
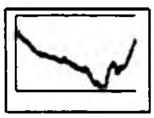
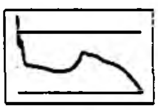
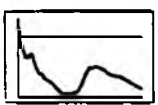
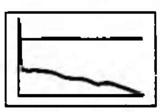
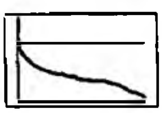
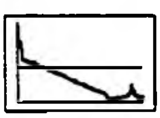
	Donna Nook	Intermediate Longshore Bar/Trough Domain
	Sutton (Lincs)	Intermediate Rhythmic Bar & Beach Domain
	Seathorne (Lincs)	Reflective Domain
	Gibraltar Point	Complex Sand Ridge System
	Happisburgh	Reflective Domain
	Sea Palling	Intermediate Longshore Bar/Trough Domain
	Great Yarmouth	Offshore Bank System
	Corton	Offshore Trough /Ridge System
	Pakefield	Intermediate Rhythmic Bar & Beach Domain
	Southwold.	Reflective Domain
	Dunwich	Offshore Ridge System
	Aldeburgh	Intermediate Longshore Bar/Trough Domain
	Orford Ness	Reflective Domain
	Clacton	Intermediate Transverse Bar & Rip Domain
	Dengie	Dissipative Domain

Figure 4.1 - Selected Nearshore Profiles

Location	Profiles	Closure Depth (m)			Hallemeiers close out depth (m)
		Min	Max	Mean	
Humber-Gibraltar	L101-L2A8	5.1	10.3	7.7	8.9
Wash-Weybourne	L2A8-N2B1	Interpreted between 9 and 12			8.7
Weybourne-Caister	N2B1-N4B3	6.4	12.0	9.2	10.4
Caister-Yarmouth	N4B4-N4A7	6.0	8.2	7.1	5.4
Yarmouth-Aldeburgh	N4A7-S1A4	5.3	9.0	7.1	6.3
Aldeburgh-Orford	S1A4-S1B14	5.8	10.0	7.9	6.5
Orford-Bawdsey	S2C4-S2B7	6.1	8.4	7.2	-
Felixstowe-Mersea	E1D2-E2A4	2.2	7.0	4.6	-
Mersea-Dengie	E2A4-E3D5	2.0	5.3	3.7	-

Table 4.2 - Nearshore Closure Depths

Figure 4.1 shows a selection of profiles together with an indicative "state" based on the classification system proposed by Wright and Short (1983). It should be noted the vertical scale varies from section to section. The majority of the sections have been classified as intermediate (ie incorporating elements of both reflective and dissipative demains). However those areas which exhibit reflective domains, such as Lincolnshire and Happisburgh coincide with regions of highest wave activity. By contrast, the sections classified as dissipative correspond to regions with relatively low wave activity.

Nearshore Geological Survey

British Geological Survey were appointed to undertake a detailed offshore survey of 12 corridors evenly distributed geographically around the coastline from Spurn Head in the north to Brightlingsea in the south. The corridors surveyed were rectangular in plan and were generally aligned normal to the coastline. They extended 5km offshore over a width of approximately 2km. They extended onshore to cover the hinterland (for some 200m from the high water mark).

The integrated programme included geological field mapping and surveying (onshore), with echo sounding, sidescan sonar, shallow penetration seismic and grab sampling (offshore). From the resulting data the graphical presentation was prepared for each corridor comprising a bathymetry map, mobile sediment map, geology excluding mobile sediments map and a profile. Four additional sites were mapped from published and archive material covering Maplin, Great Yarmouth, The Wash and Holderness.

A continuous definition of the geology along the coastal strip was derived by BGS using the results of the survey, existing maps and unpublished data to produce a much more detailed definition of the "coastal" geology. The results are presented in two parts:

(a) the hinterland, being the cliff or a strip of land some 500m wide.

(b) the backshore/foreshore zone.

For each strip, the presence of up to three geological classes are recorded. For the cliffs this defines the geological succession from oldest to youngest, whereas elsewhere it details the surficial or mobile classes and underlying non-mobile classes (where known).

Summary of Findings

The following general observations on the geology of the area are to be noted:

(a) From Holderness southward to Lowestoft (with the exception of the Wash) the predominant mobile sediment types are sands and gravels with some limited areas of muddy sediments. In the north of the Holderness area, and on the Binks, Great Yarmouth and Lowestoft corridors, these sandy sediments form coast parallel banks or ridges up to 20m thick.

(b) Southward from Sizewell there are greater proportions of muddy sediments, although sands are still present. Sediment thicknesses are thin and in some areas, notably The Naze, bedrock is exposed at the seabed.

(c) The Wash forms a coastal embayment and in this context is a microenvironment, isolated from the general trends seen in the open coastal areas. Sediment patterns here are mainly influenced from the sea and this has led to a fining of sediment type from gravels in the outer parts of the Wash, through sands in the central and deeper water areas, to muds on the coastal margins.

(d) The rock units beneath the mobile sediment layer, may be geographically subdivided:

(i) from Holderness to the northern margin of Scolt Head they consist of Pleistocene tills of the Bolders Bank Formation. An upper sand unit is present in the Binks, Donna Nook and Mablethorpe corridors.

(ii) in the Cromer and Scolt Head corridors they consist of Upper Cretaceous Chalk.

(iii) from Waxham to the Naze they consist of Pleistocene sands and silty clays.

(iv) from Bawdsey to Maplin they consist of the early Tertiary London Clay Formation.

(e) In many places the coast is a geological boundary with a distinct break in the onshore and offshore continuity of the preserved sequences. This is most notable in the Cromer, Waxham and Lowestoft corridors where there is an abrupt change in the onshore to offshore Pleistocene sequence.

Estuary Sediment Trends

A study of sediments within and immediately adjacent to the north of the Humber Estuary was undertaken by GeoSea Consulting Ltd. By collecting samples over a regular grid spaced at 0.9km intervals and analysing the samples for their grain size distribution, GeoSea sought to: establish patterns of sediment transport; identify specific transport environments and the probability that each size of material is eroded, transported and deposited in each; and to correlate patterns of transport with known processes. This information was to be used to improve understanding of the mechanisms of erosion and deposition within and adjacent to the Humber Estuary.

Collection of the sediment samples was by grab deployed from a boat or a small hovercraft in intertidal areas. A total of 886 stations were visited. Grab samples were attempted at each and samples suitable for grain size distribution analysis were obtained at most locations. Grain size distributions were divided into four facies, sand (<20% mud), bimodal (sand/mud mixture), mud (<20% sand) and multimodal facies.

Summary of Findings

There was good correlation between the sediment paths indicated by means of the GeoSea analysis technique and several authoritative observations on transport paths.

The trends indicate a counter clockwise circulatory regime around Foul Holme Spit (opposite Immingham), a clockwise regime around Middle Ground (opposite Grimsby) and seaward transport in the intertidal sediments on both sides of the estuary (Figure 4.2). Spurn Head is dominated by transport in the expected direction down the spit but appears to be related to sediments in a counter clockwise circulation in the area of the Binks. The Binks itself appears to be a consequence of the dominant ebb regime passing to the south of Spurn Head interacting with the seaward-to-landward regime associated with New Sand Hole. Sediments lost from the Binks appear to be transported to the north east. The Lincolnshire shoreline south east of Grimsby is dominated by sand derived from the offshore region south of New Sand Hole. Interestingly these paths are wholly consistent with the tidal residuals for the Humber Estuary as derived by Falconer and Owens (1990), Figure 4.3.

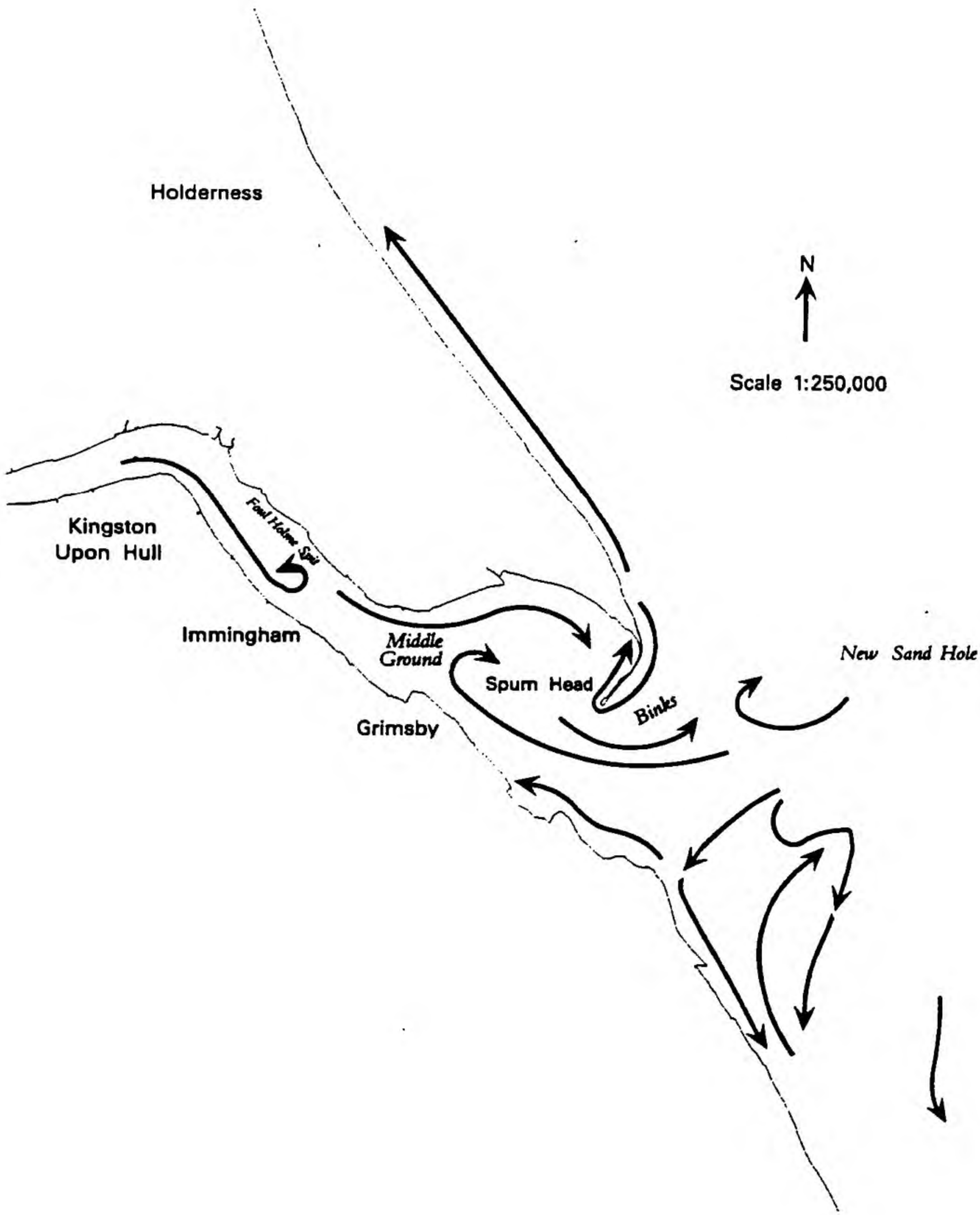


Figure 4.2 - Sediment Transport in the Humber Estuary

The study has shown that if Holderness sediments do reach the Lincolnshire coast, transport must be to the offshore before returning to the coast in order to clear the barrier created by the Binks and New Sand Hole. More conclusive evidence on the original source of Lincolnshire sediments was not possible principally because of the lack of success in assessing transport in the multimodal facies.

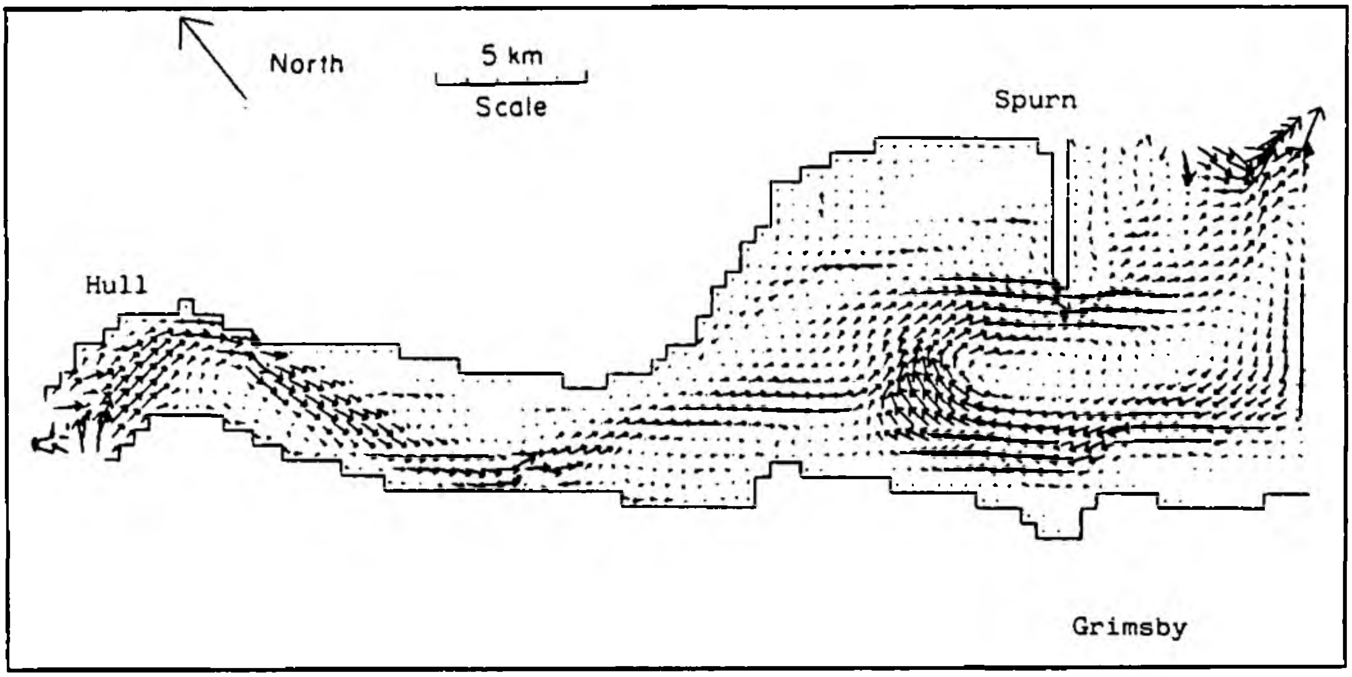


Figure 4.3 : Numerically predicted residual velocity field in the Humber Estuary for a mid-tidal range (from Falconer and Owens, 1990)

5 SUPPORTING STUDIES

The programme of further studies was structured to develop a better understanding of certin phenomena (such as beach steepening) and to extend the database (eg for waves and tides). These studies included:

- a definition of the wave climate for the region
- an analysis of extreme sea levels around the coast
- the study and subsequent modelling of the tides and residual flow regime for the southern North Sea
- an examination of the long term shoreline movement using as map data
- the development of a beach response model
- a numerical analysis of spatial changes in the bank system off Great Yarmouth
- a quantification of sea level change tectonic movement and subsidence in a geological setting
- a pilot study to develop a methodology for investigating the potential impacts due to future sea level rise
- an assessment of historical changes in storminess and how storm patterns may be influenced as a conseuqence of global warming projections
- a review of the Essex saltings research programme
- a summary of recent literature on coastal processes relevant to the Anglian coast.

A number of these studies are closely linked and most made extensive use of data collected for the project as already described. Space does no permit a full account and the following serves to provide a brief summary of this work.

Wave Climate

The exposure to wave attack varies substantially along the coast of the Anglian region, which extends from the Humber to the Thames. The coast was divided into six smaller areas, centred approximately on Skegness, Cromer, Yarmouth, Dunwich, Felixstowe and Clacton. The offshore wave climate is expected to be approximately the same throughout each of these chosen areas.

All sources of wind and wave data were examined in order to select those best able to meet the requirements of the project. The various data sets were reviewed and compared in detail for the northern-most area. This resulted in the choice of a wave hindcasting model as the preferred method, suitable for use in all the remaining areas.

An offshore wave climate was derived for each of the areas, in the form of hourly averaged hindcasts of wave heights, periods and directions. This format is suitable for use in subsequent refraction modelling. The results for each area were plotted as time series and as probability distributions for validation against other sets of wave data within the same area.

A series of wave refraction models were used to develop the nearshore wave climate at 38 points along the coast, spaced at approximately 10km intervals. Each model covered an area similar to that used to develop the offshore climate, but also took account of variations in tidal range.

Time series of offshore waves and tidal water levels were used with the results from the refraction models to compute an inshore time series at each point. A comparison with measured data showed good agreement when the shallow water limits to the energy spectrum were incorporated. The statistical output provides a range of useful values for assessing the influence of waves on the coast. In general there appears to be good qualitative agreement between known shoreline processes and the prevailing wave conditions predicted by the model.

Summary of Findings

When developing the time series of wave conditions for the most recent ten years, an attempt was made to put this into a longer term perspective. However, the lack of consistency through time of wind and wave measurements meant that a major effort would have been required to synthesise a long term record for direct comparison. Nevertheless, given the inter-annual variability and the recent trend towards more severe sea-states noted by a number of workers, Lamb and Weiss (1979), Rye (1976), Neu (1984), there is some merit in examining the variations within the available time series.

The wave time series for Dowsing was used to assess the "storminess" over the period 1978 to 1986. Figure 5.1 shows the percentage of time that the significant wave height exceeds the 2 metre threshold. The plot shows significant inter-annual variability for all directions, north-east and north-west sectors. Variations for the south-east and south-west sectors are less marked.

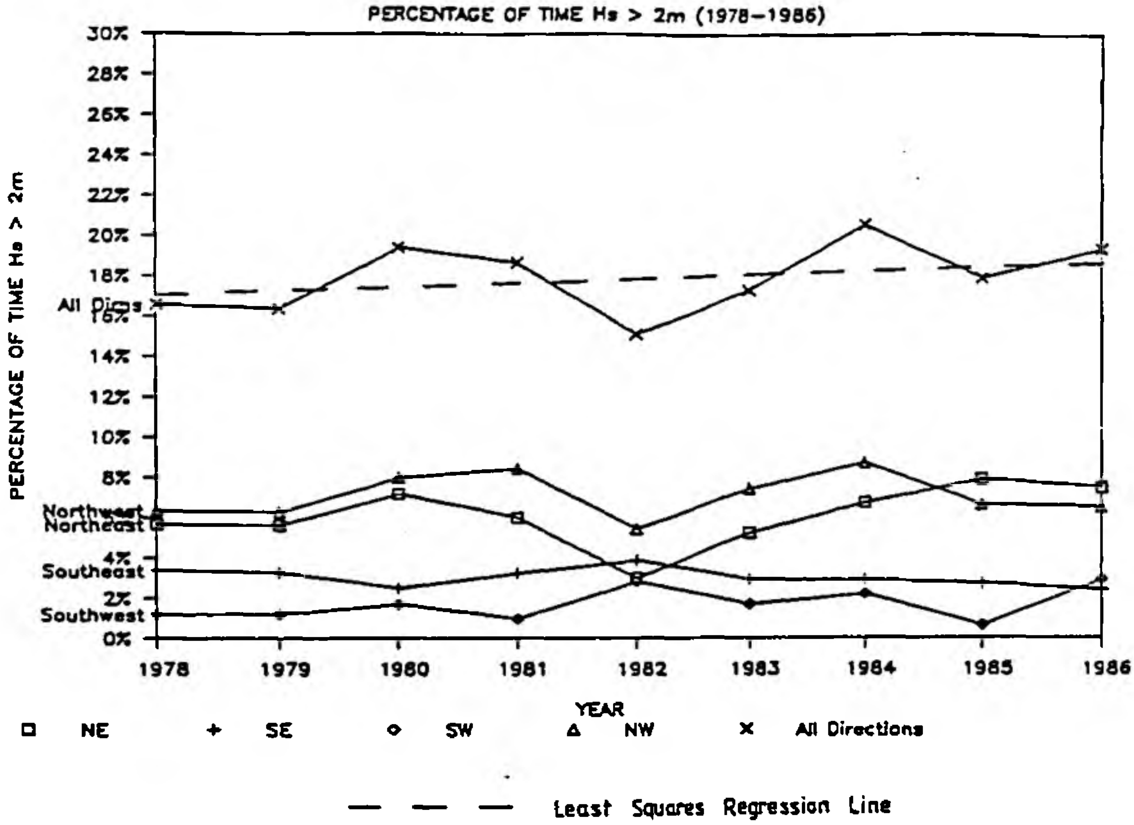


Figure 5.1 - Mean Annual Wave Statistics for Dowsing

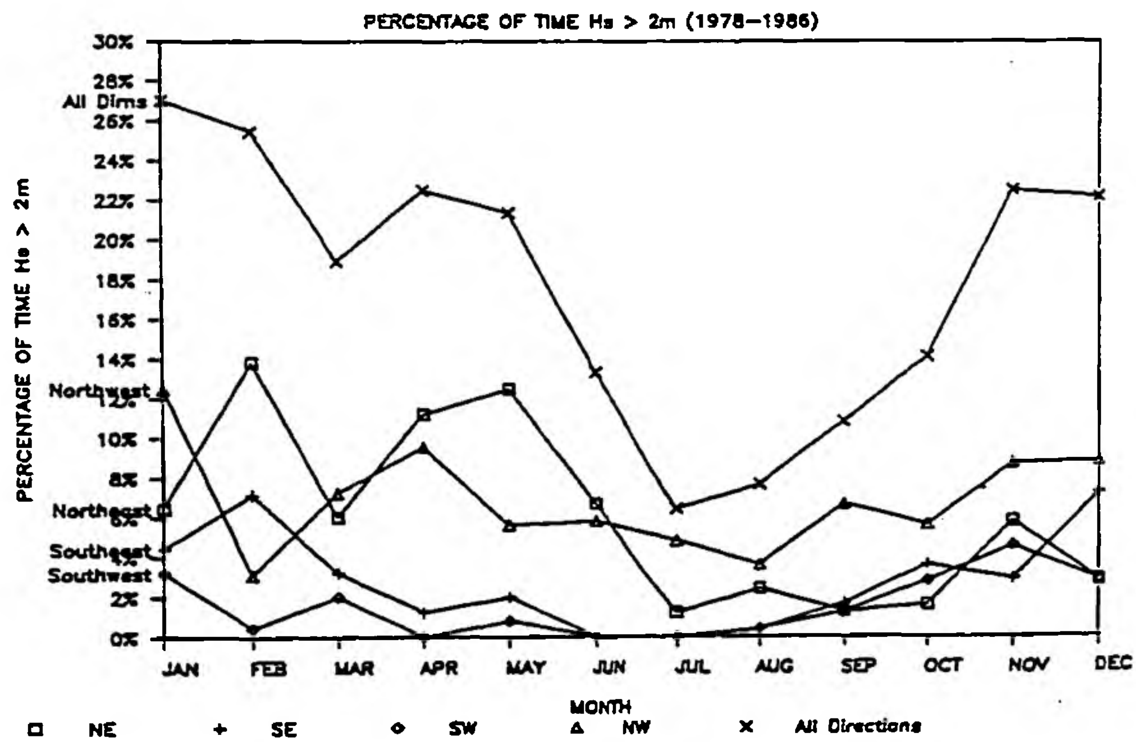


Figure 5.2 - Mean Seasonal Wave Statistics for Dowsing

Considering all directions, there appears to be a slight increase in the percentage of time above a threshold from just over 16% to about 18%. A least squares regression line to the data for percentage time does show a small, increasing trend. This trend is broadly in agreement with the findings of others but cannot be taken as evidence of any long term trend or cycle. To assess long term changes in the wave climate, a more extensive record would need to be examined, in conjunction with the prevailing meteorology for the period (see discussion on climate change later in this chapter).

The ten year time series at Dowsing was also used to examine the seasonal variability of the wave climate, and this is shown in Figure 5.2. This confirms the stormy nature of the winter period from November through to May and the relatively quiet nature of the months June, July and August. An interesting feature is the marked drop in all direction values during February/March, followed by an increase for the months April/May. Taking account of the variations in the directional values, there are a greater number of storms from the north-west, whilst the storms from the north-east are more persistent. In addition there is a tendency for the number of north-westerly storms to fall off in February and the number of north-easterly storms to fall off in March.

Extreme Water Levels

Extreme still water level estimates for twenty locations from the Thames Estuary to the Humber have been catalogued. These estimates are all based on a Generalised Extreme Value analysis of recorded annual maximum levels. There is therefore a consistency of approach, though the data sets used are of varying length.

Results are presented for data sets both adjusted and unadjusted for secular trend, but, in view of inconsistent results concerning secular trends, it is recommended that the unadjusted values should be used.

The various methods available to estimate extreme levels were reviewed. A comparison of the results for Lowestoft using a number of these methods, demonstrates that the recommended result is in good agreement with the other estimates, but lies towards the upper end of the range.

Tidal Circulation

The importance of tides along the East Anglian coast was clearly identified in the role of residual currents. Early studies and particularly this programme of modelling work was therefore carefully designed to not only provide tidal currents, but also, to map the nearshore tidal residuals.

The study entailed all stages of the development, calibration and validation of a tidal model of the southern North Sea. The primary aim of developing such a model was to obtain a reliable picture of the tidally forced current residuals in the region of the East Anglian Coast. From a knowledge of these it is possible to infer large scale tidally induced sediment transport trends, and to predict the likely impact of proposed coastal works on the nearshore sediment movement.

Model boundaries were taken across the channel between Dover and Cap Gris Nez and between Flamborough and Texel, Figure 5.3. Wetting and drying processes play an important role in influencing the tidal residual currents in the nearshore region, and a sophisticated wetting/drying algorithm was developed for the model. The numerical model was based on UKAEA Harwell's FLOW3D code and used a distorted grid mesh to solve the depth integrated equations of motion. A distorted grid allowed relatively

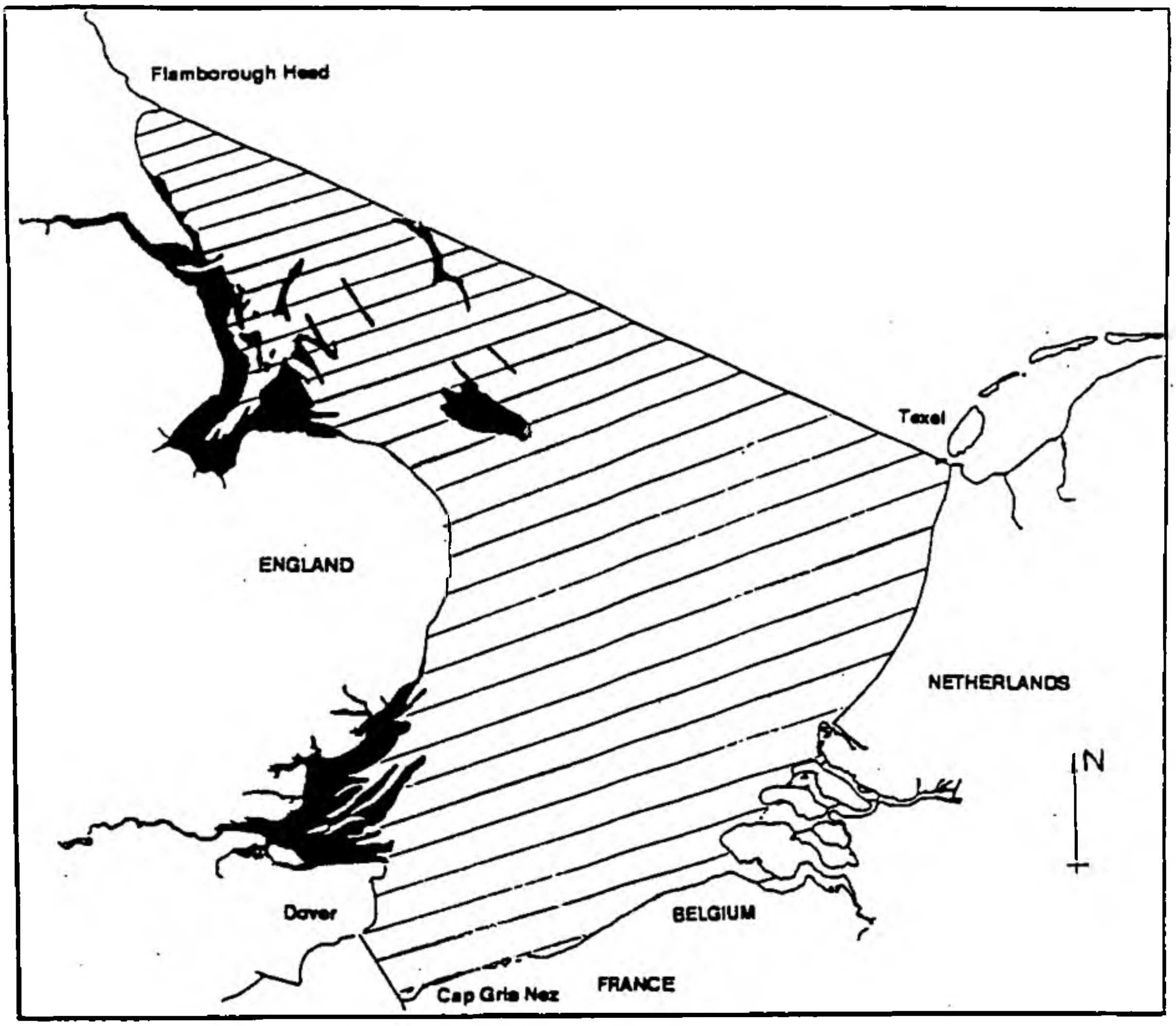


Figure 5.3 - North Sea Model Area

good resolution along and adjacent to the Anglian coast without requiring an excessive amount of computer time.

The model has been calibrated and validated using detailed spatial descriptions of each constituent and also point specific measurements of water levels and currents. Using the 32 day time series generated by the model, tidal constituents, summary tidal parameters and tidal residuals were computed at each node in the model.

Summary of Findings

Data published by the Proudman Oceanographic Laboratory (POL1990) was used for the calibration of the model. Very good agreement was obtained for tidal elevations. Velocities were calibrated using tidal ellipse parameters, a stringent test, which showed good levels of conformity against observational data. Model verification was performed by comparing results obtained using the calibrated model with observations obtained independently from the POL data. Given that the data had not originally been gathered specifically for the verification of a depth-averaged model, reasonable agreement was obtained with model results. The largest variability was noted for tidal currents and current residuals. The magnitude and direction of current residuals in the Southern Bight were in general agreement with previous numerical studies.

Further analysis of the model output into the time averaged (residual) flow and oscillatory eddy circulations provided a useful insight into the dynamic processes affecting sediment transport near the Anglian coast. The residual currents are in part driven by the tidal eddies. The form of these eddies, and in particular the eccentricity of the current ellipse, is shown to be linked to the forcing of residual currents. The anisotropy of the eddies also shows an interesting spatial correlation with known regions of significant sediment transport (Figure 5.4). The eddy properties examined appear to have a definite relationship with the type of bed forms present. There are a number of areas where the eddies have a high kinetic energy and high anisotropy, located in regions where the momentum flux shows a very rapid gradient.

The last of these properties seems to be associated with major changes in coastal orientation such as at the mouths of the main estuaries and in the vicinity of Gt Yarmouth/Lowestoft. The net result is regions of high vorticity capable of supporting linear bank systems, as outlined by Zimmermann (1981) and Huthnance (1982), and found at the Binks, Gibraltar Point and off Great Yarmouth. By way of contrast the areas of low anisotropy and kinetic energy where there is little or no momentum flux are found to coincide with the major flats in the region, notably Donna Nook, The Wash, Burnham Flats off Norfolk, Dengie, Maplin, and Margate Sand off the north Kent coast.

There are several factors which act to obscure any clear trend. Firstly, the sediment is not of uniform grain size, varying from clay to coarse shingle. The relationship between grain size and transport rate is by no means conclusively established. Secondly, sediment transport, particularly in the shore region, is a function not only of currents but also of wave action. Wave conditions and currents will in turn depend on the prevailing meterological conditions. Thirdly, the presence of sand banks up to 3km offshore along parts of the East Anglian Coast clearly influences the local currents and the incoming wave climate. Whilst the sand banks are included

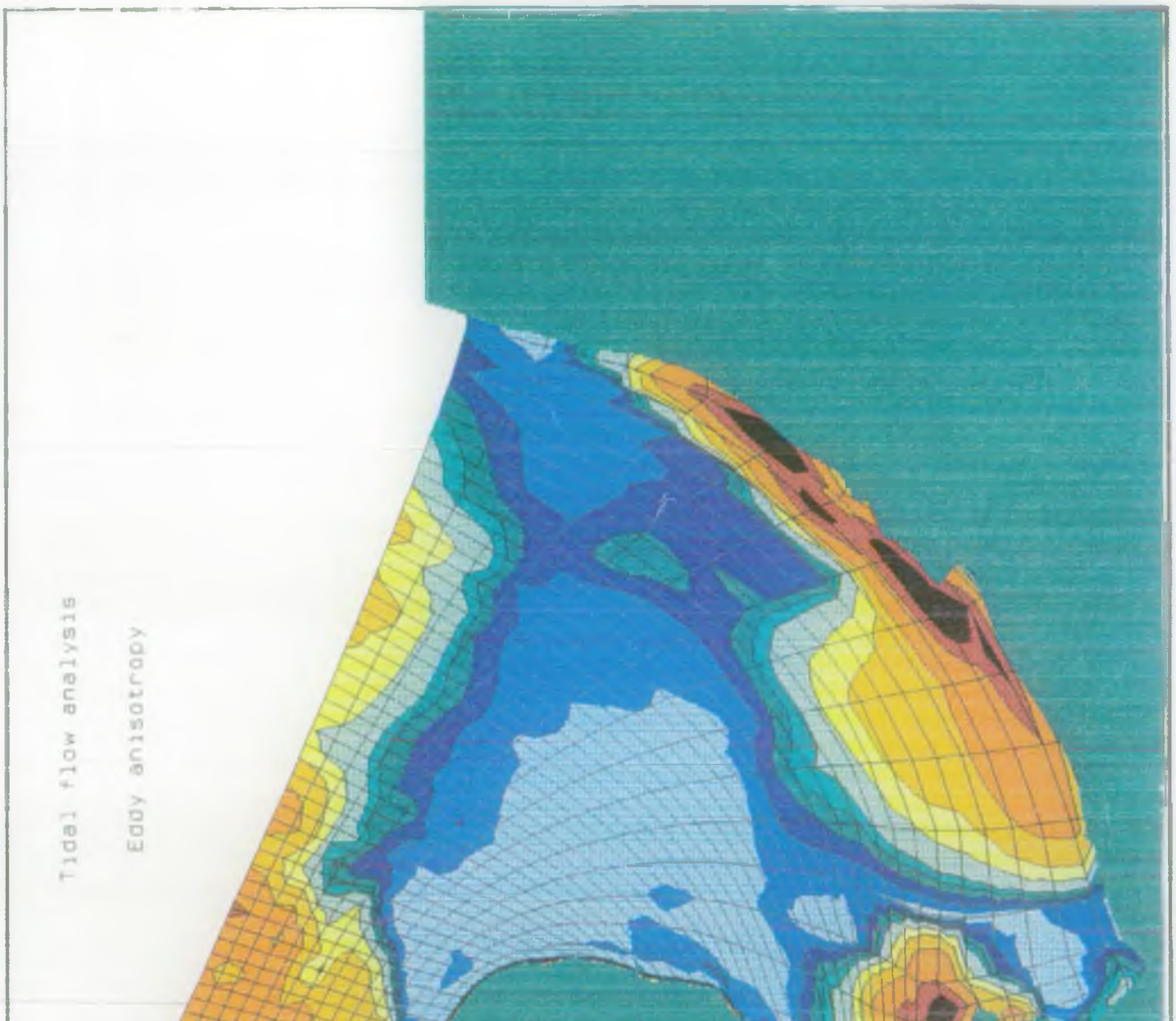


Figure 5.4 - Plot of Eddy Anisotropy Factor

in the tidal model, the resolution of the grid is limited. Further the bank itself is a store of potentially mobile sediment which may move onshore, offshore, long-shore or remain stationary. Finally, the underlying difference in scale of wave induced and current induced transport must be emphasised. Waves, by their nature, are relatively localised in space and are of short duration. As they are primarily wind driven their time-scale is comparable to the time-scale of wind variations, say of the order of 1 or 2 days. Also, their effects are noticed almost exclusively in shallow waters and beach regions. On the other hand residual currents represent a mechanism of transport over a much longer time-scale - months to years. Indeed it may be that under appropriate circumstances waves and residual currents will act to move coarse and fine scale material in opposite directions.

However, in coming to these conclusions it must be kept in mind that the present study has only dealt with tidally induced currents and current residuals. It is known that significant local changes in the tidally induced currents can be caused by surface wind stress particularly under storm conditions. To obtain a more complete picture of sediment transport trends along the Anglian coast will require an assessment of the influence of wave action and storm induced circulations on current residuals, as well as a better understanding of the relationship between sediment grain size and transport rate.

Shoreline Movement

The data used to calculate the rate of movement of the shoreline was abstracted from Ordnance Survey map sheets by researchers at the University of East Anglia. It consists of measurements relating to the cross-sectional profile at 250m intervals along the coast. Each measurement set contained the distance to each of three map lines; Mean High Water (MHW), Mean Low Water (MLW), and the coastline. These data were available for five map editions as follows:

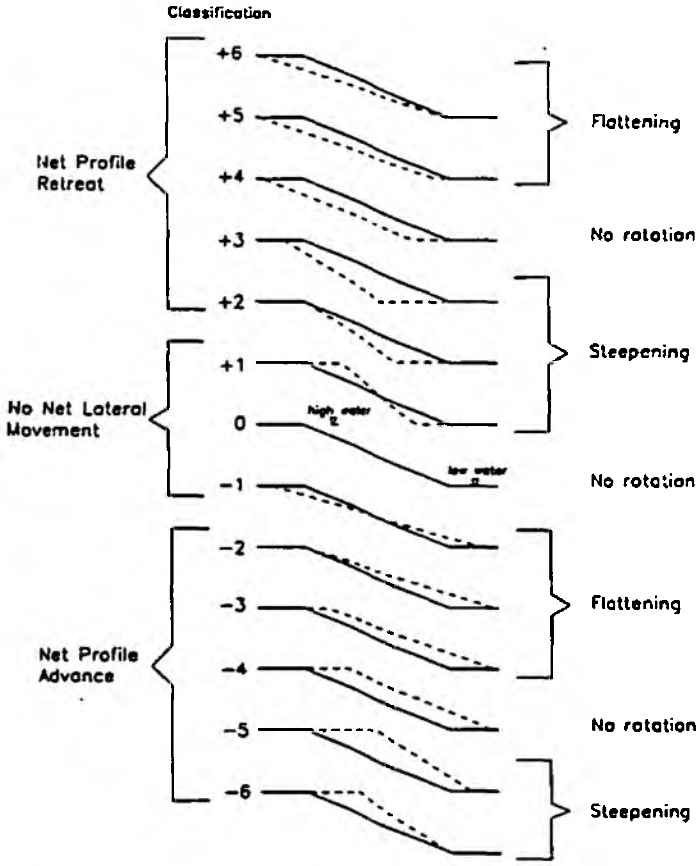
Map edition	Publishing Year (approx)		
1	1880	)	
2	1900	)	
3	1920	)	imperial maps
4	1950	)	
5	1970	metric map	

Although the map editions were published around the years indicated above, the survey dates for MHW, MLW and coastline are often quite different. Particular care had to be taken to ensure that as far as possible survey dates were used, so that errors were kept to a minimum (a fuller discussion of the data preparation is given in the Shoreline Management Data Model).

The definition of the coastline is somewhat variable both in terms of how and when in time it is mapped (source OS). Thus whilst an interesting comparison of this data could be made with historic records of individual defences on the coast, the data were considered too unreliable for an analysis of retreat in space and time and so were not used. The analysis therefore concentrated on the movement of MHW and MLW, together with two derived parameters

(a) steepening - the difference between MLW and MHW retreat rates.

(b) retreat - advance classification - describes the mode of retreat or advance (Figure 5.5).



Note: Dashed line indicates mode of change to profile.

Figure 5.5 - Retreat/Advance Classification

The following intervals were used to establish retreat rates at high and low water:

Interval No	Period (approx)
1	1880 - 1900
2	1900 - 1950
3	1880 - 1950
4	1950 - 1970
5	1880 - 1970

For the majority of the analyses the coast was divided into five segments covering Holderness, Lincoln, Norfolk (Wash to Winterton), Suffolk and Essex.

Summary of Findings

Preliminary analysis made use of the data set in its fullest form, that is, in two segments due to the natural break in records across the Wash. Results from this analysis provided the motivation to split the analysis region into five coastal segments, guided by the underlying geomorphological characteristics of the region. Subsequent analyses were performed on both raw and smoothed data, although only the results for the smoothed case have been presented.

Significant regional variations in retreat/advance characteristics have been found. Strongly periodic behaviour in both high and low water retreat rates have been identified. The wavelength of oscillation varies from one length of coast to another and between high and low water. Both the Holderness and Suffolk coasts display the same wavelength oscillations at low and high water, indicating that a highly coherent mechanism underlies the prevailing shoreline movement on these coasts.

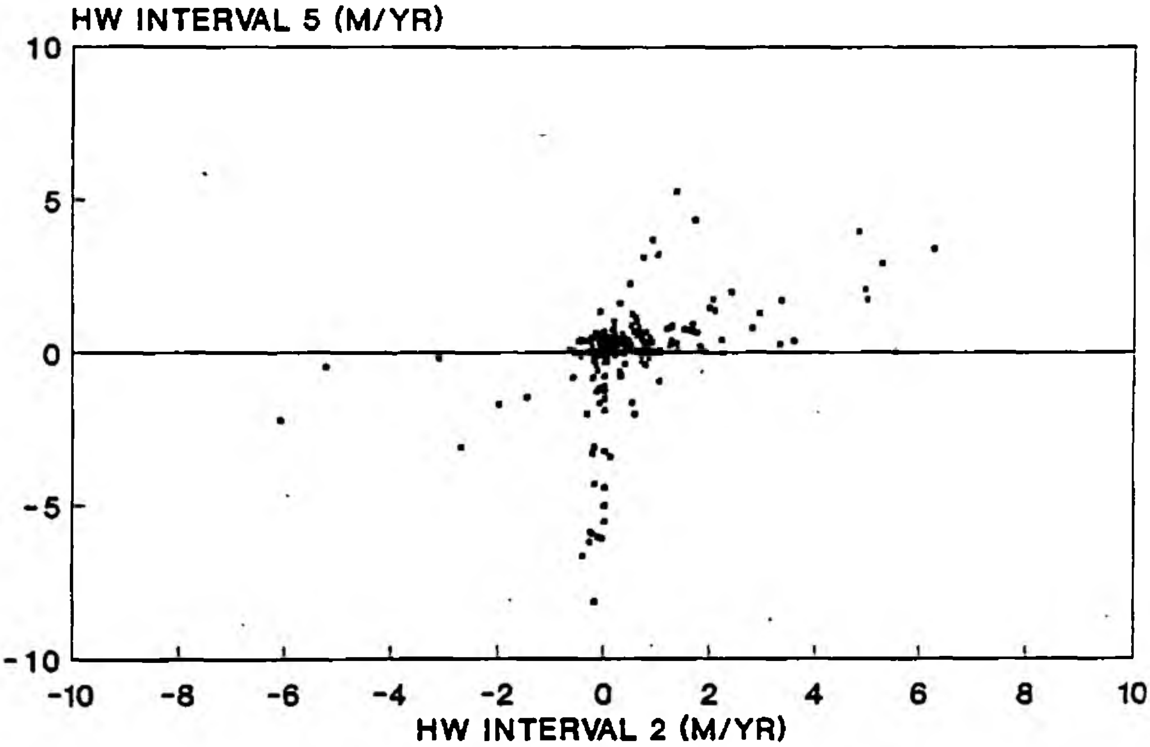


Figure 5.6 - Essex : HW Retreat Rates for Intervals 5 and 2 (Unsmoothed Data)

Analysis of the retreat rates for changes in time provided a poor definition of temporal variation. Linear regression analysis proved to be inappropriate in this case. The scatter plot of retreat rates calculated for intervals 5 and 2 for Essex (Figure 5.6) illustrates this well. There is a large scatter with clumps and alignments of points suggesting several different gradients to the eye. A detailed analysis of the retreat rates over each interval for every profile along the coast revealed a complex picture of retreat rate changes in time. Only exceptionally did any coastal segment show any preferred mode of behaviour. The analysis of the temporal variations in retreat rate indicates significant statistical uncertainty in computed quantities due to the small number of samples in time. It may be however that a more localised analysis of the retreat data, related to natural features and structures on the coast, would provide greater insight into the temporal variations.

Despite these qualifications, a definite large scale change in temporal behaviour has been identified. The region to the south of Cromer shows retreat rates with a tendency to accelerate over the first half of the record to subsequently decelerate (that is the rate from 1880-1900 was slower than the rate for 1900-1950 which in turn was faster than the rate for 1950-1970). By contrast, the region to the north of Cromer has an overall trend of deceleration followed by acceleration (ie the inverse of the region to the south).

The approach to the analysis has been a statistical one. This has identified certain properties but has also revealed the complexity of this data set. The main conclusions are:

- Whilst there has been long term erosion along extensive lengths of the high water line, the average for the whole coast is close to zero. This reflects the strong counter influence of accretion at nesses and spits, most notably Donna Nook and Gibraltar Point.

- In stark contrast, the long term retreat of low water line has an average for the whole coast of 1 metre/year. This is indicative of the fact that accretion is not nearly as extensive at low water and on retreating shores the foreshore is also steepening.

- There is a well defined spatial structure to the data, with length scales which range from 2.5km to 16km. Whilst this structure is to be found in all data sets (ie at each interval in time) there is no evidence for any consistency in time. Consequently this spatial structure does not appear to be stationary with respect to its position on the coast.

- A reasonable correlation between retreat rates and the rate of change of coastal orientation could only be identified on the Lincoln coast. Interestingly this is also the only coast with multiple harmonics to the length scale. This seems to indicate some form of natural perturbation.

- The changes in time are extremely complex and would merit more detailed site specific analysis. On a regional scale the coast to the south of Cromer had a faster rate of retreat between 1900 and 1950. To the north the retreat was faster from 1880 to 1900 and 1950 to 1970 and slowed during the intervening years. It should be stressed however that there is considerable localised variability within these overall trends.

Sediment Model

One of the phenomena identified during the initial study of existing data was that of beach steepening. This was generally found to be associated with the sand veneer beach, characteristic of much of the Anglian coast, tidal range, and to some extent the type of defence. In order to gain a better understanding of the processes involved, it was felt that a carefully focused model development provided the best way forward.

The aim of the study was to develop a sediment model which would be sufficiently comprehensive to enable the investigation of the following:

- The influence and importance of tidal currents and tidal range on beach processes and profile evolution;
- Cross-shore distribution of sediment transport (both long-shore and cross-shore);
- Response of sand and sand veneer beaches to wave action;
- Downcutting of clay layer of sand veneer beaches;
- Variation of gross and net sediment transports along the coast;
- Relative importance of frequent moderate wave events when compared to less frequent extreme events.

Apart from providing a basic appreciation of coastal processes in the Anglian region these would also contribute to greater understanding of the causes of beach steepening.

In order to incorporate these aspects it was necessary to develop a 3D model in advance of anything then available. The methodology adopted was to undertake the development in two stages. Stage A produced a 2DV (two-dimensional in the vertical and cross-shore horizontal dimensions) profile model by combining the existing models of Hydraulics Research Ltd (for wave transformation, tidal and wave-induced currents) and Imperial College (for undertow, cross-shore and long-shore sediment transport). The 2DV model is applicable to coastlines which can be idealised as being straight, with parallel depth contours and no long-shore variation in wave conditions. This model has the following capabilities:

- Wave transformation by refraction (due to depth variation and currents), shoaling, Doppler shifting, bottom friction and wave breaking;

- Interacted long-shore tidal and wave-induced currents;

- Cross-shore undertow velocities;

- Cross-shore and long-shore sediment transport rates, and downcutting of the cohesive profile;

- Depth profile changes due to sediment transport, downcutting and dune avalanching.

The model was extensively tested and validated against a wide range of laboratory and field data. A detailed description of Stage A is given in Hydraulics Research Report EX2010.

In Stage B of the study the 2DV model was extended by Halcrow to deal with weakly three-dimensional coastlines ie a coastline with slowly varying orientation and without major coast structures such as harbour breakwaters. The 3D model generates beach elevation changes due to both long-shore and cross-shore transport gradients arising from long-shore variation of wave height, period and direction and coastal orientation.

The model consists of a series of cross-shore profiles. Sediment is transported in the cross-shore direction within a profile and in the long-shore direction from one profile to another. The profiles are thus linked by sediment transport rather than hydrodynamically, except that the relative position of adjacent profiles is used to determine the orientation of the coastline for wave angle computation.

Following completion of the development stages the 3D model was extensively validated against field data from Holderness (measured by the University of Hull) and then a series of sensitivity tests undertaken to investigate clay downcutting.

<u>Summary of Findings</u>

(a) The principal features of the surveyed profiles at Holderness were reproduced under the appropriate wave and water level conditions. Generally northerly waves led to oblique bar formation due to separation of sediment transport from the shore parallel direction at a headland. In contrast, southerly or shore-normal waves tended to return the beach to a featureless equilibrium shape, again as indicated by the field data. Finally, severe wave and water level conditions produced pronounced bar-trough features due to large cross-shore transport gradients.

(b) The model illustrated the importance of tidal currents in modifying sediment transport patterns and hence profile development.

(c) The model demonstrated the importance of long-shore transport (and hence coastline orientation) in controlling beach development and thus the necessity of using a 3-D model for studying the Anglian coastline.

(d) It was found that tidal range was an important factor in beach development, a smaller range leading to greater changes in level due to concentration of wave breaking within a limited band.

(e) Exposure of the underlying clay was strongly influenced by sediment size, the coarser materials at the head of the beach being less easily removed.

(f) Downcutting tests indicated that increasing the volume of sand on the beach (by recharge for example) could reduce total volume of clay erosion but that the peak rate of erosion at a given location could be increased. Generally beach volatility had to be reduced in order to maintain sand cover and hence reduce downcutting.

(g) The model results indicated that beach steepening may be due to the relatively large tidal range of the Anglian coast (compared to other cohesive or veneer shores such as the Canadian Great Lakes) which concentrates erosion at the lower levels where the beach is subject to wave action for a greater part of the tidal cycle and where sand cover is finer and hence more mobile.

Additional Studies

As part of the Happisburgh-Winterton Sea Defences project (for NRA Anglian Region) the model has been extensively applied and tested as follows:

(a) The 3-D model was used to investigate the causes of beach volatility at Happisburgh-Winterton through a series of sensitivity tests. The results indicated that high oblique wave conditions in conjunction with storm surge are the driving forces causing volatility (a finding in agreement with work undertaken as part of the model validation for Holderness). These conclusions were confirmed soon afterwards by the storm of 6 October 1990. This produced volatility (ie beach levels raised by up to 2m at one location and lowered similarly elsewhere) and was found to have occurred at a time of particularly oblique waves in conjunction with storm surge.

(b) The model was then used to simulate the October event along the Happisburgh-Winterton frontage. The predictions of the model were compared to beach profiles taken after the storm. Generally agreement was very good, and the prominent sand bank which forms at Sea Palling during storm events was predicted quite accurately. This is illustrated by Figure 5.7.

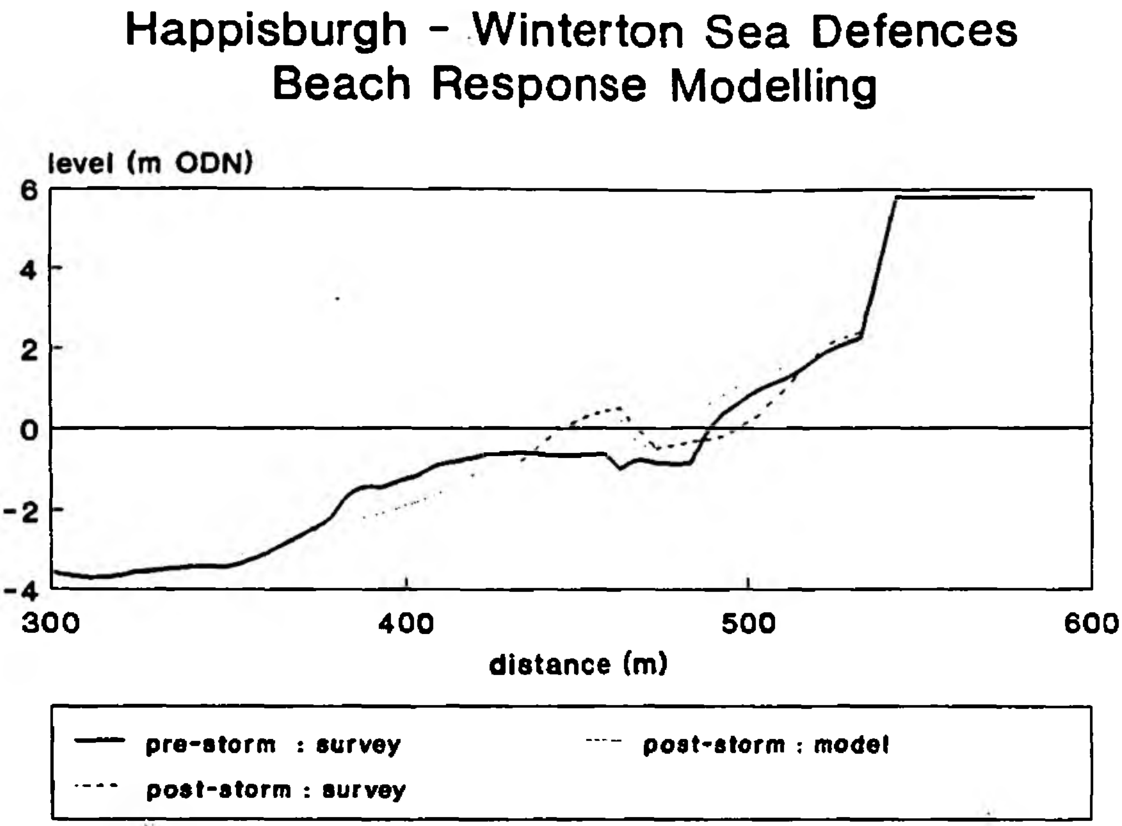


Figure 5.7 - Modelled profile of October Storm for Happisburgh to Winterton Beach

(c) Development of the model has continued, and the model now has the capability of simulating the effects of groynes and offshore breakwaters. Work undertaken to simulate the effect of a beach recharge has shown such a scheme could influence a much longer stretch of coastline than the area of the recharge itself, and that there might be beach lowering downdrift in some locations as a result. This result is not yet understood and investigations are continuing.

Offshore Banks

Using information gathered from the literature and a number of previous studies in the region a conceptual model for the evolution of the North Norfolk bank system was proposed. This comprises a nearshore circulation cell within the Yarmouth banks, with material arriving from the north at Winterton Ness and from the south of Benacre Ness (Figure 5.8). The volume of new material is however relatively small when compared to the volume in circulation (estimated at less than ½ percent). Material is however periodically lost from the cell in a northerly direction to form "embryonic" linear banks (where Winterton Overfalls and North Cross Sands are currently situated). This material is then worked by the tidal currents to promulgate linear banks which migrate offshore in a north-easterly direction (Figure 5.9).

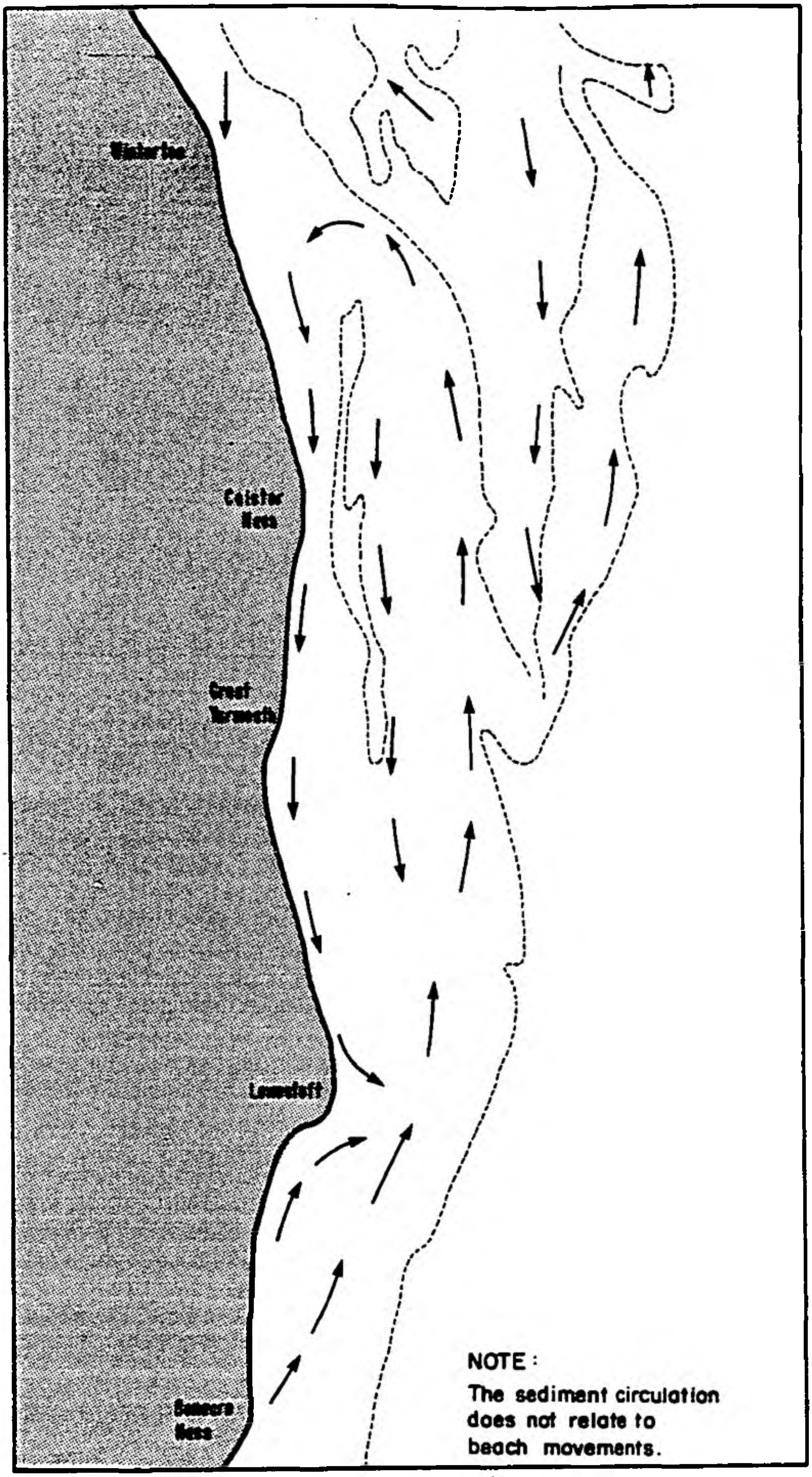


Figure 5.8 - Postulated Sediment Circulation for Nearshore Bank System

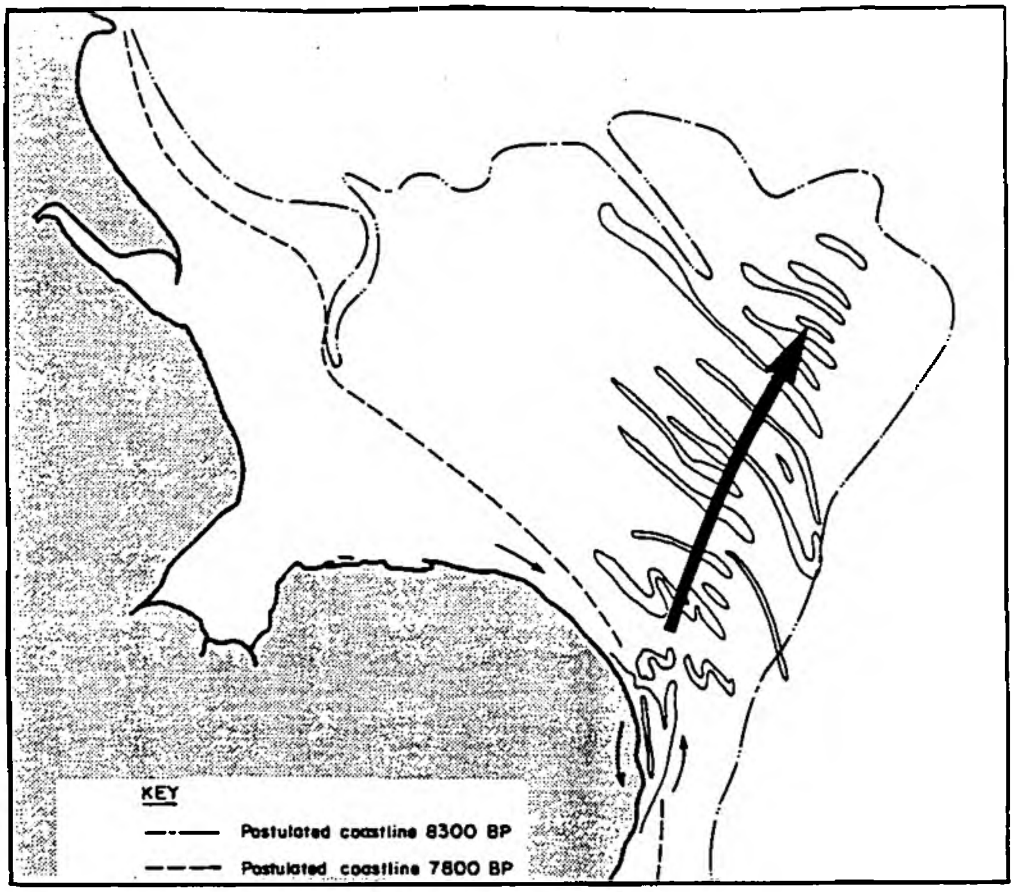


Figure 5.9 - Postulated Model for the Formation of the North Norfolk Linear Bank System

To try and explore this further, an analysis of historic charts for any trends or cycles was seen as a useful first step towards a better understanding of the processes involved.

The object of the study was to further substantiate or refute, the proposed model by analysing the recorded sandbank positions, between 1846 and 1987, in the Winterton/Benacre region. Sand bank data, in the form of bathymetry maps, were available at irregularly spaced intervals in both space and time. Fifteen Admiralty Charts were digitised with the bathymetry being defined by contours and spot heights. The data were mapped to National Grid coordinates and adjustments made to the bathymetry to give values relative to Ordnance Datum.

Two methods of analysing the sand bank movements were used, one adopted Fourier Transform techniques and the other empirical eigenvalue functions. Both methods are capable of detecting periodic or cyclical trends contained in the data, although the empirical orthogonal function analysis was generally more flexible. Also included was a set of animated sequences of the sand bank data, showing interpolated and filtered versions of the raw data.

Summary of Findings

The sampling rate of the bathymetry is adequate to resolve changes in the sand banks which occur over periods greater than about 30 years. This was acceptable for the type of sediment movements of interest. However from the analyses it is clear that there is significant movement on timescales shorter than 30 years which acts to confuse any long term periodic signals.

Various periodic changes in the sand bank configuration were found. In particular there was a cyclic phase variation found in the Fourier analysis of about 120 years associated with the double bank feature off Winterton. This was confirmed in the one dimensional eigenfunction analysis at this location. The eigenfunction analysis at Gt Yarmouth shows a quasi-periodic variation with a period between 40-50 years. This 40-50 year cycle reappears in the $1^1/_2$ dimensional eigenfunction analyses, as well as a possible 70 year cycle in the Scroby and Cross Sands bank system. Despite the modest strength of these cycles, a northward transport of materials has been identified, in accord with the initial hypothesis.

The two dimensional analysis has highlighted the importance of very short time-scale changes (almost instantaneous on the scale of 150 years). These abrupt changes in sand bank structure are most likely to have been caused by external agents such as violent storms.

The animated sequence showing the evolution of the sand bank data over the period of analysis provides a more tangible way of viewing the movement of sediment. Various apparent movements and circulations have been identified, which largely concur with the conclusions of the Stage II Study Report. Comparison of the raw data with reconstructions using a subset of eigenfunctions which capture more than 90% of the total variance shows that most of the large scale movement of the banks can be represented by a few eigenfunctions.

Also apparent in the animated sequence is a strong wavelike structure in the Scroby and Cross Sands bank systems (with a wavelength of about 6 kilometres). Furthermore the regions of wave activity coincide with areas which have the largest range of depths during the analysis period. From the form of these features it can be inferred that the residual flow will also exhibit a similar wavelike structure. The cause of such wave behaviour in the residual flow is uncertain. On the basis of existing data, a possible mechanism for such wave activity is the lateral shear of the residual currents, coupled with fluctuations in the flow around the headland promontory at Lowestoft. Both of these features are visible in the results obtained from the tidal circulation model, although the resolution of the bank system is rather limited. In order to develop this hypothesis further, a much better description of both the residual current structure and sediment movement is now needed.

Sea Level Change

The study reviewed a wide range of material to place changes in sea level in a geological context within the North Sea basin. The various aspects which contribute to a relative change in water levels against the land have been examined both in terms of the geological records and shorter term (c100 years) measured data sets.

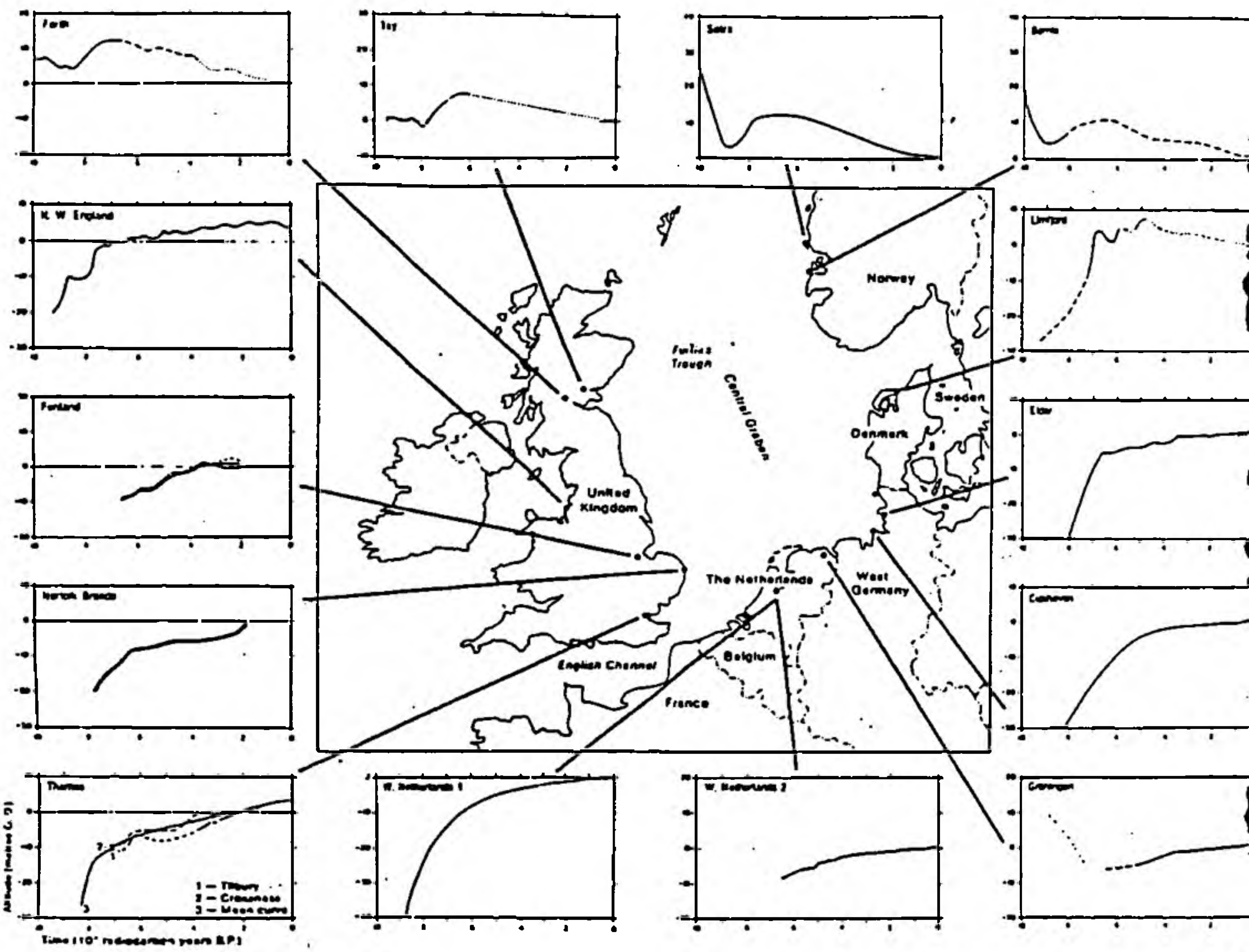


Figure 5.10 - Fourteen relative sea-level curves from around the North Sea and one from Northwest England drawn on a uniform scale. The original source for each area is noted by the original author. The dotted section of the Forth curve indicates even lower reliability noted by the author, the dotted section for the Tay and Limfjord curves are extrapolations by this author (Shennan, 1987).

Summarv of Findinas

Although it has not been possible to quantitatively differentiate between changes in regional eustatic sea-level and tectonic movements, a description of relative sea-level trends has been given on a regional basis. The evidence of contemporary trends indicates that along the coast of East Anglia sea-level is rising at about 2mm/year, although this increases to around 4mm/year for the area to the south of the River Blackwater. These changes have been related to historical changes in climate and sea-levels around the North Sea over the past 10,000 years (Figure 5.10). In addition, the various aspects of future change in global sea-levels have been briefly summarised.

Impact of Sea Level Rise

This study was instigated to develop a methodology for assessing the impact of sea level rise. The proposed method was explored in detail by way of a pilot study covering the Fenland area surrounding the Wash. The work, undertaken by the University of Durham, considers the inter-relationship of processes and their individual response to sea level rise, as a means of establishing the relative significance of changes within the system. This is in contrast to the common approach of trying to establish the specific impacts of a given sea level rise scenario, without due regard to the way processes interact.

The study established data requirements by determining which processes form an essential part of the system. A range of data was then collected to make an initial assessment and identify where future data collection efforts should be focused. The analysis sought to identify the key characteristics of the region and also define thresholds, where applicable, for key variables and their dependent variables.

Summarv of Findinas

The latest research in respect of future rises as a consequence of global warming suggests that, taking due account of local land subsidence, the rate of relative sea-level rise will be in the following range (rates in mm/year):

	1990-2030	2030-2070	2070-2100
High estimate	8.2	11.5	14.0
'Best guess' average	5.5	7.5	8.3
Low estimate	3.2	4.0	4.3

Particular emphasis is placed on the potential for a change in the rate of sea level rise and its likely impact on both the morphology and ecology of the area. This is likely to be most critical for saltmarshes and will determine whether they adapt, or are progressively eroded.

The standard of protection provided by existing defences is reduced if the allowance for sea-level rise is increased in line with the best guess estimate given above. This implies that as safety margins are lowered, the potential frequency of flooding is increased, although this will also be influenced by any changes in storminess as a consequence of climatic changes. In this area, this does not however imply any increase in the extent of potential flooding, the flood risk zone is already below high water level and is banded by rising land.

The low lying nature of the land surrounding many estuaries presents an interesting problem when considering setting back the defence line as a response option. Although second and third line defences may exist and could be upgraded for use as a front line, the problem is that much of the land is at a lower level than the fronting saltmarshes. This means than any set-back would have to be carefully designed to ensure that either land levels within the set back zone are raised or that the existing saltmarsh was capable of rolling back across this zone. With present knowledge, any such scheme would have to be considered highly experimental.

The recommendations include the need for a greater allowance for sea-level rise over the anticipated life of new structures. The latest estimates suggest a value of 5.5mm/year to 2030 and a value of 8mm/year thereafter to 2100. Most of the remaining recommendations relate to data collection and/or detailed studies of processes (eg socio-economic data; monitoring of sedimentary and vegetational change; and system response to a changing rate of sea level rise). Further research work on this topic is now ongoing as part of the NRA's national programme and includes work on changes in beach response and extreme water levels as a consequence of global warming.

Impact of Climatic Change

A part of the recent debate on global warming concerns the extent to which various aspects of our climate may change over the coming century. In respect of sea defences, one of the most significant aspects of climate is storminess and whether it is likely to vary in either intensity or frequency. Some recent work on measured data suggested that, over a relatively short time-scale (order of 25 years), there was some evidence for wave climate becoming more severe (Lamb + Weiss 1979, Rye 1976, Neu 1984). This study, undertaken by the University of East Anglia, was initiated to try and put this work into a longer term context and to examine what the future may hold.

The work divided into three parts. The first part addressed the storm climate of the last century. The second part related this to wave and surge conditions, whilst the final part examined global circulation models for any evidence of a change in circulation, as a consequence of CO_2 increases, which might influence storminess.

Storminess
To examine the storm climate over the last century daily pressure fields for the North Sea have been used to create what is known as a gale index. This provides a measure of the storm severity, and by ranking the storm into classes of gale, severe gale and very severe gale, a detailed analysis of storm structure over the period 1881-1989 has been performed. A variety of statistical techniques have been used and these are detailed in the Study Task Report.

Waves and Surges
Relating the gale index to more direct parameters, such as wave height and surge level, provides a means of judging the relevance of this parameter. In this study the scope of the evaluation was limited to using just a few data sets; this being sufficient to establish that a link can be made. A more extensive study would undoubtedly extend the correlation to a more formal regression model between gale index, wave height and surge level (particularly in the light of the results obtained).

Global Circulation Models
In the final part of the study, a comparison is made of the mean seasonal circulation based on observations and the predictions of four global circulation models (GCMs). This includes predictions for the present and for a world with double the present level of CO_2 (the dominant greenhouse gas). The detailed output from yet another GCM is then used to generate a gale index data set. This is for a relatively short period of 10 years between 2045 and 2054 but it allows a comparison to be made with historic records in order to assess potential change.

Summary of Findings

The results indicate no long-term periodicity in North Sea gales but suggest that, following a 60 year period of very gradual decline in the number of gales per year, the past 20 years has seen a steady increase in the number and intensity of gales (Figure 5.11). There is also evidence of some form of negative feedback process affecting the incidence and intensity of gales, with a stormy year most probably being followed by a relatively calm year.

Using data from stations in the North Sea, the second part of the analysis examines the relationship between the gale index, maximum significant wave height and storm surges. A regression equation, formulated with surge height at Immingham as the dependent variable, and wind speed (from the gale index) and wave height at Dowsing as the independent variables, indicates that nearly 40% of the variance in surge height can be attributed to the two predictor variables. This indicates that increased storminess is associated with increased surge levels, but requires further refinement with more data to account for the residual variance in surge height. Some suggestions are given on the minimum requirements for the development of a successful statistical storm surge model.

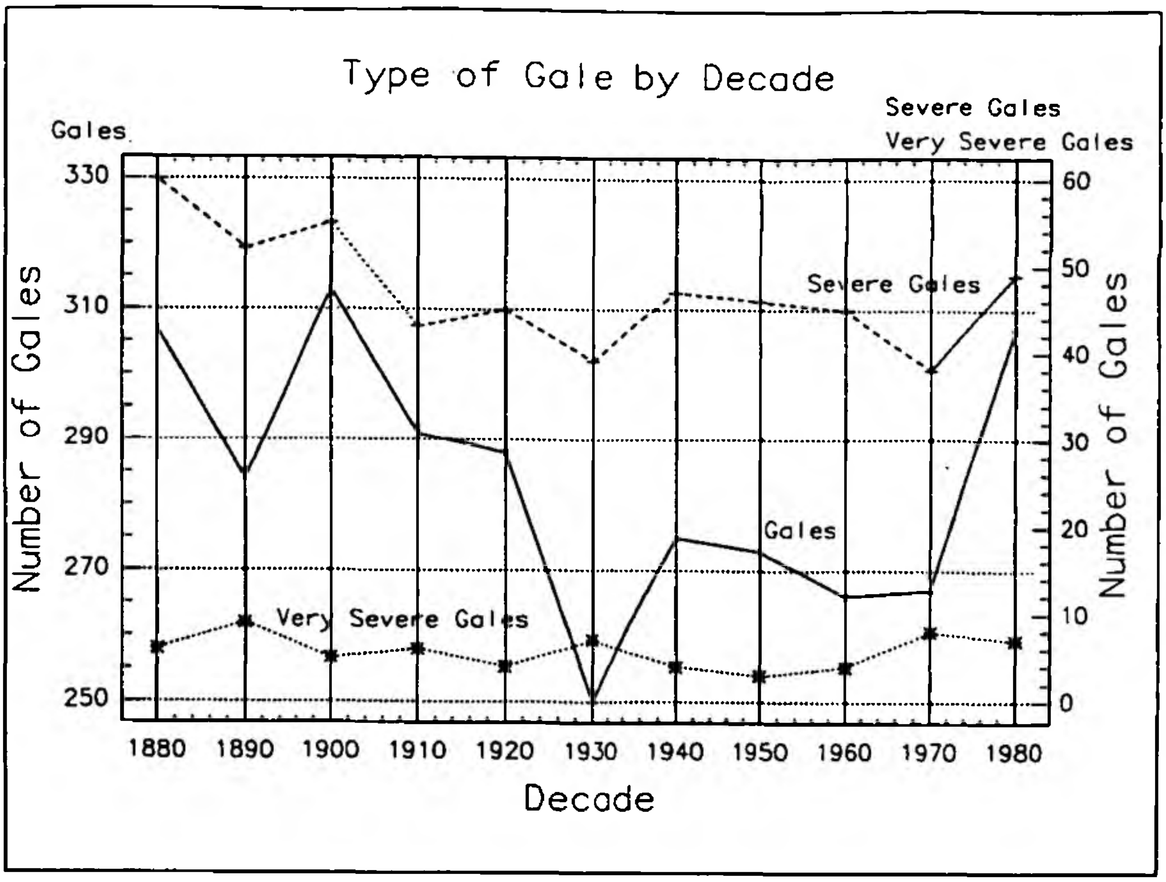


Figure 5.11 - Type of Gale by Decade

The third section uses data from computer models of the general circulation of the atmosphere to assess the nature of storminess over the North Sea in the next century. Based on the assumption that the most important influence on climate in this period will be the greenhouse effects, the models describe conditions for a 1 and 2 times CO_2 world. That is, a base case, using pre-industrial levels of atmospheric carbon dioxide, is compared with a world with double this level. The scope of the analysis is broadened by the introduction of new data, in the form of time series, covering a rangeof greenhouse scenarios. These are used to construct a gale index for the 21st century which can be directly compared with the properties of the gale index derived from historical data in the first part of this study.

The results, consistent for all models, indicate a slight increase in storminess during the next century, but that this is within the range of natural variability. That is, any change in storminess characteristics due to the greenhouse effect will be subordinate to the kinds of fluctuations observed over the last one hundred years. This leads to the conclusion that provided background changes in sea level are taken into account, the forcing conditions for waves and surges over the next one hundred years will not exceed past experience.

Estuary Studies

Within this study a mapping system for the estuaries was developed to try to assess the possible causes of saltmarsh deterioration and an historical review of the research related to the Essex saltings was undertaken.

Review of Essex Saltings Programme

The saltmarshes of Essex constitute a major feature of the coast and are of significant environmental and ecological importance. Of the 440km of seawall and revetments in Essex, the integrity of some 370km depends upon fronting saltings and high level foreshores.

Concern was expressed in 1976 over the observed erosion of the saltmarsh and the consequence of this on the seawalls. Experiments were subsequently initiated on the restoration and regeneration of the saltings and to this end the Essex Saltings Restoration Project (ESRP) was created. The ESRP has had a pioneering role in the application of restoration techniques to the problems at hand. A summary of the work carried out at each site and its effectiveness is given in the Study Task Report.

In addition to the restoration schemes there have also been a number of research projects undertaken into various aspects relevant to the Essex saltings. A review was made of the main organisations involved in this research, namely Hull University, NCC, Institute of Terrestrial Ecology, University of East Anglia and Hydraulics Research Ltd, and the research activities they engaged in.

From a regional perspective it was found that the majority of the saltmarshes outside Essex are located within the Wash, the Humber estuary and along the North Norfolk coast. In order to evaluate the relevance of the work in Essex to other areas of saltmarsh within the region, an assessment of the current status of these saltmarshes is required to determine whether they are eroding or accreting and the health of the vegetation. An initial assessment is provided by the estuary classification exercise.

In addition to the above review of the Essex saltings an assessment was made of future research needs for developing an understanding of the saltings and how best to incorporate them into the overall Management Strategy. The aims of such a research programme should be to extend knowledge of the role of saltings in coastal defence and provide support for the development of a management strategy.

Estuary Mapping Variables

A mapping system of the backshore morphology was developed by GeoSea with the aim of deriving estuary classifications. To facilitate the assessment of relationships between variables and to determine similarities or differences between estuaries, they were initially assigned to a level where Level I opens to the sea, Level II opens into Level I and so on. Subsequent analysis showed that this was not the most appropriate way to classify the estuaries and a revised approach was developed for incorporation in the Management Strategy (see Chapter 10).

Whilst this work includes some subjective evaluations, such as the General Health Index (Figure 5.12), a more quantitative evaluation has been performed at a total of 8 representative sites from around the region. This has entailed the use of photogrammetric techniques at the University of Hull, to map changes in the marsh and mud flats from a time sequence of aerial photographs.

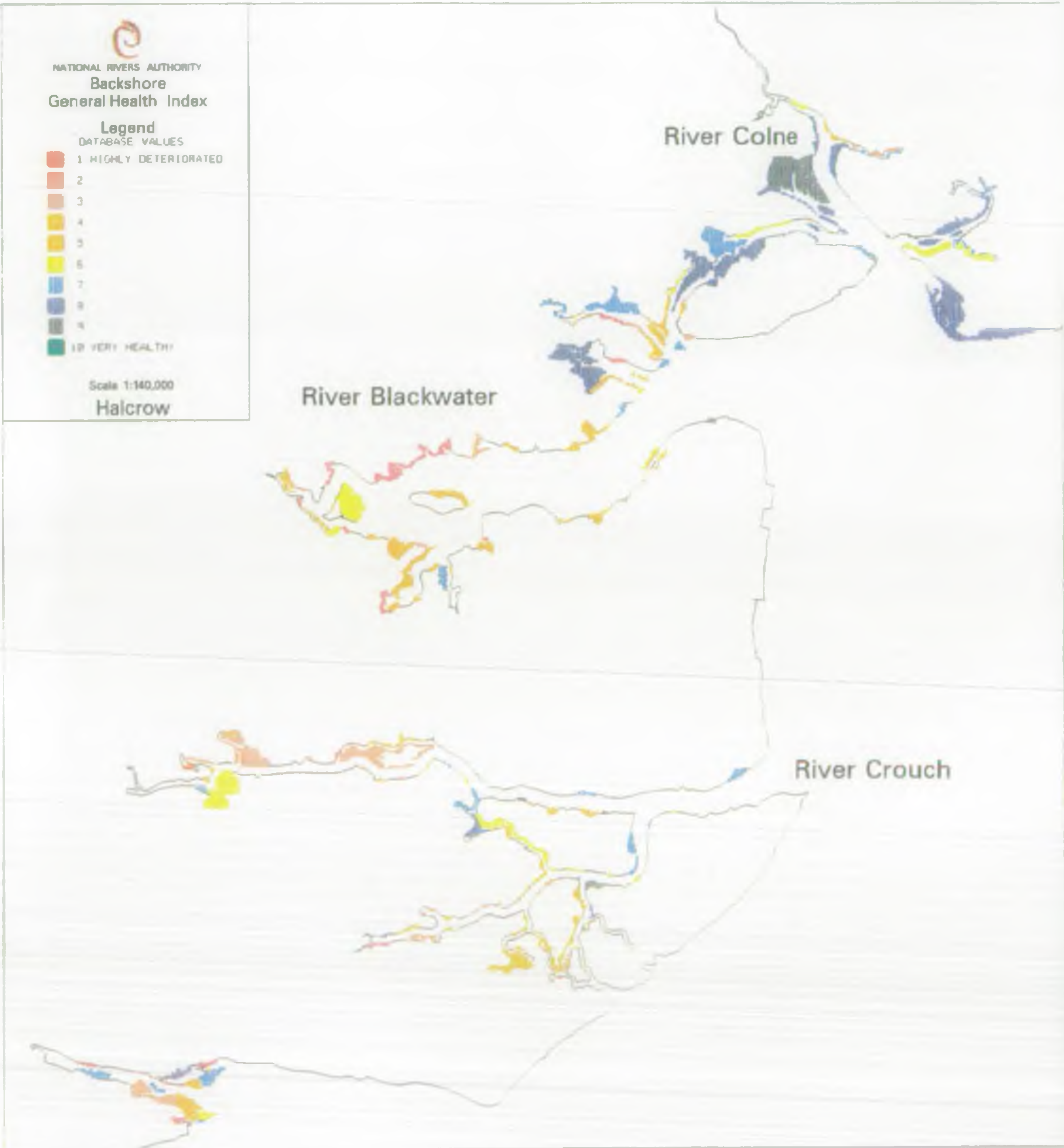


Figure 5.12 - Backshore General Health Index

Summary of Findings

The estuary studies have provided a comprehensive review of the saltmarshes in Essex, a critique of the experimental restoration schemes that were installed, a mapping system of the backshore morphology for deriving estuary classifications and an outline saltings research programme.

The saltings on the open coast have been extensively researched and documented. However, the situation in the estuaries and creeks is less clear with the relationship of marsh morphology and processes being less well understood. From the assessment of the experimental restoration schemes it was concluded that the success or otherwise of those schemes adopted in the estuarial locations was found to be dependent not only on localised processes but also on processes operating on the overall estuary system.

The benefits of utilising various photographic techniques has been demonstrated by the estuary mapping exercise. The definition of the morphology and related parameters that this provided has formed part of a detailed analysis, which is discussed in Chapter 6. One direct recommendation arising from this study is that such techniques can be used to monitor the general condition of the marshes and determine those areas that are actively eroding or accreting.

From the review of the main areas requiring further research, an outline research programme was suggested which would extend the knowledge of the role of saltings in coastal defence and provide support for the development of a management strategy. It is recommended that any research programme should be coordinated by a management group, comprising key personnel from the various organisations involved. This steering group will be instrumental in finalising the short and long term objectives and ascribing priorities to the various research activities. It is important also to ensure that output from individual projects provides a positive contribution to overall objectives and that the results are properly integrated into the Management Strategy.

Literature Review

The review concentrated on recent literature relating to the coastal processes present on the Anglian coast. A very substantial body of information was examined and abstracts have been prepared for about 100 of the most relevant papers and reports. These Abstracts are available for future reference in the Referral Database.

To provide a format for the review and the abstracts, the coastal domain was sub-divided into four sections:

- Fully Developed Sand Beaches
- Cohesive Shores
- Saltmarshes and Dunes
- Offshore Features

It was also evident that in the first three of these the processes could be divided according to time-scales, namely:

- Tidal Scale
- Event Scale (Storms)
- Seasonal/Annual
- Geologic

The literature search was based on this 4 x 4 matrix but in two groups:

- Natural Coastal Processes
- Man's Influence on Coastal Processes

Figures 5.13 and 5.14 identify the processes involved in each element of the matrix, excluding offshore features which form a distinctly separate section. However, it must be recognised that the boundaries between the sub-sections adopted are not precise.

The review does not discuss each matrix element individually; it brings together processes related to different types of coast to provide an integrated summary of the major developments in knowledge of those processes and their implications for shoreline management.

Shoreline Type / Process Time Scale	COHESIVE SHORES Dominantly influenced by a stiff cohesive or till sub-stratum		FULLY DEVELOPED SAND BEACHES Consisting of fully mobile cohesionless sediment	
	SUBAQUEOUS	SUBAERIAL	CROSS SHORE	ALONGSHORE
TIDAL SCALE (diurnal, semi-diurnal)	Structures effectively 'sealing' the intertidal platform		Sedimentation and Erosion caused by changes to tidal regimes.	
EVENT SCALE (2-7 days, meteorological systems)	Backshore seawall protecting the cliff toe from direct wave attack. The use of groynes on cohesive shores.	Cliff stabilization by drainage, grading and vegetation.	Seawalls protecting the backshore, effectiveness. Adjacent shoreline effects, profile effects, restriction of sediment supply all due to seawalls. Offshore breakwaters and perched beaches.	Groynes, jetties, headlands interrupting alongshore littoral drift. Offshore breakwaters, changes to bathymetry through dredging resulting in alteration of the nearshore wave climate and alongshore transport. Offshore deflection of littoral drift at structure.
SEASONAL/ANNUAL (short-term, cyclic)		Urbanisation effects on the stability of cliffs	Offshore breakwaters, submerged breakwaters, perched beaches effects in quiescent periods. Post-storm profile recovery and seawalls. Dune build-up through aeolian transport. Dune vegetation.	Effects of structures on annual net longshore transport. Offshore dredge holes and wave climate effects.
GEOLOGIC SCALE (long-term, sediment budget scale)	Protection of the nearshore profile from downcutting. Landfill artificial beaches and offshore breakwaters.		Beach or profile nourishment, design methods with respect to coastal processes. Longevity of beachfill. Use of structures to extend life of beachfill, economic feasibility. Sea level rise implications. Bypassing of littoral drift interruptions. Sediment budget management.	

Figure 5.13 Natural Coastal Processes

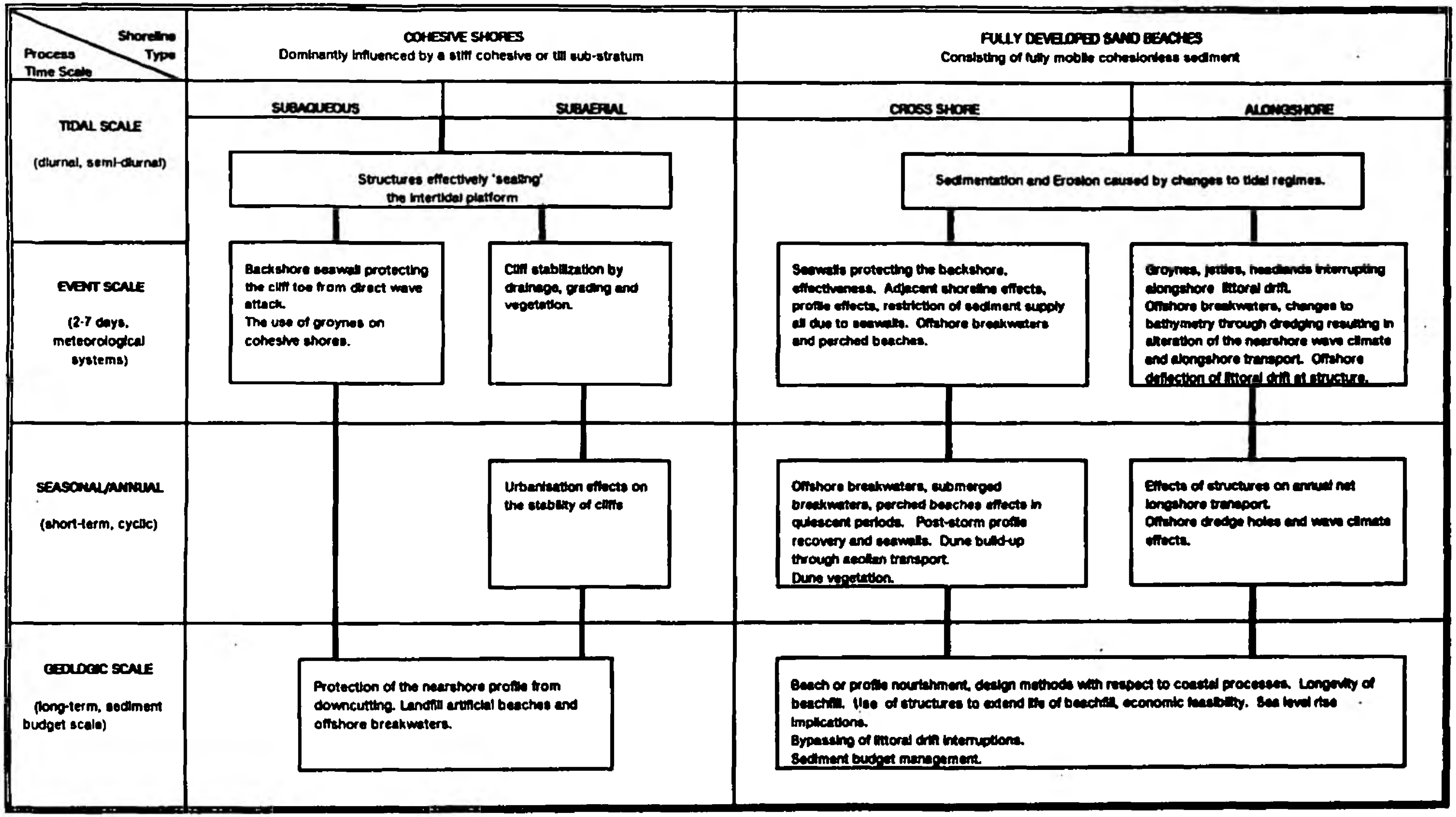


Figure 5.14 - Man's Influence on Coastal Processes

6 ANALYSIS AND INTERPRETATION

The types of data available vary substantially and need to be analysed in a number of different ways. Given that the principal key between the various data sets is a geographical one, it follows that much of the analysis task has made use of various forms of map. In essence there are four map types, namely:

(a) descriptive - to present measurable or observable features;

(b) interpretive - to present new information derived from the base data;

(c) evaluation - to illustrate impacts;

and (d) prescriptive - to present management options, zoning, etc.

Of these the most commonly used is the descriptive map which simply summarises a number of themes. In essence this is a presentation of the raw data for a particular feature or variable as it exists in the GIS. A series of descriptive maps for the estuaries (see for example Figure 5.12) have been used, in conjunction with the facility to report area and perimeter values associated with other database attributes, to examine the morphological properties of the estuaries and establish a classification.

Interpretive and evaluation maps form an essential part of the analysis process. They illustrate more complex relationships between variables which can be used to establish where interactions are occurring or test known associations and derived functions. A wide range of such maps have been used to first examine key characteristics of the coast and then develop prescriptive maps which define the dominant process units.

Estuary Classification

The objectives of this analysis were two-fold: first, to determine whether a relatively simple analysis of each estuary's shoreline morphology could result in a meaningful estuarine classification; and second, given the present concern over the "health" of the associated wetlands, to determine if such an analysis can provide insights to possible causes of marsh deterioration. In all, seven categories of map variables were selected (Table 6.1), each one chosen to provide information on the "morphological status" of the estuarine backshore.

Data Base

A total of 28 estuaries were identified and mapped. For each of the map variables listed in Table 6.1, the GIS provided an areal measurement. In addition to these data, the GIS also produced a variety of estuarine statistics which included length, width, area measures, perimeters and various "roughness factors", all of which are described in Table 6.1. For those estuaries with an appreciable river input, the mean annual discharge was also included in the analysis. To assess the characteristics, differences and similarities among the estuaries these data were "normalized" by dividing all areal units by the area of the estuary or marsh as appropriate.

Estuarine Classification

The estuaries were initially ranked into four levels according to their relative position in the drainage network. This classification was based on the classic geomorphic approach used in the ordering of streams within a drainage basin. However, subsequent examination of the map data failed to confirm that such a classification was useful in assessing similarities or differences among the estuaries. This was therefore abandoned and following considerable "trial and error", it was found that the greatest variability among the data was explained by grouping the estuaries into three categories, as follows:

(a) River estuaries: These make up 10 of the 28 estuaries and, according to strict definition, are the only true estuaries of the three classifications. Each contains a significant freshwater input from its associated river, the largest being the Humber with a mean annual discharge of 226 m^3s-1. Apart from the Wash which has multiple river sources, the remaining river estuaries have relatively small flows ranging from 0.33 m^3s-1 (Orwell) to 3.05 m^3s-1 (Blackwater).

(b) Blind rivers: This classification is comprised of channels that closely follow the general morphology of the river estuaries, but have no significant river input (eg. the River Roach). A few of the blind rivers are the result of human intervention as in The Strood and Pyefleet Channels which are truncated by a causeway crossing to Mersea Island. They are nearly all contained within a larger river estuary basin. Fourteen of the estuaries fall into this category.

(c) Low marsh: Only 4 of the estuaries are defined as low marsh. They consist almost entirely of marshland and are distinguished by having no association with a single dominant channel. Hamford Water is the largest and best example of this type.

It should, perhaps, be emphasized that the blind river and low marsh categories are not, by themselves, true estuaries, although they are often associated with river estuaries. However, the categories appear to provide the best assessment of the marshes which is the principal concern of the study.

Inter-category Comparison

The above classification was "discovered" by a thorough examination of the available data. The selection of the three categories was based on assessing the largest number of statistically acceptable differences among the map variables (at least at the 0.05 significance level). The following

A MAP VARIABLES (measured by the GIS in km^2)	B. VARIABLES OBTAINED FROM THE GIS
(1) Backshore Type 0 - unmapped; insufficient photo coverage 1 - backshore absent 2 - marsh 3 - beach 4 - incipient marsh development	(1) Width (km) - measured across the mouth of the estuary
(2) Vegetation Cover 1 - 0-20% 2 - 20-40% 3 - 40-60% 4 - 60-80% 5 - 80-100%	(2) Length (km)
(3) Drainage Characteristics 1 - not evident 2 - anthropogenic 3 - tidal creeks 4 - interconnected pans 5 - separate pans	(3) Areas (km^2) 1 - total estuarine area contained within the backshore/hinterland interface 2 - marsh area (data obtained from 1:10,000 OS maps) 3 - intertidal area
(4) Backshore/foreshore interface 1 - gentle gradient 2 - abrupt gradient 3 - eroding scarp	(4) Perimeters (km) 1 - perimeter of total area 2 - high water perimeter 3 - low water perimeter
(5) Marsh Detachment 1 - no evidence 2 - drainage channel paralleling sea wall or embankment 3 - slight marsh deterioration along sea wall 4 - detachment along sea wall with vegetation mud mounds 5 - wide, bare, unvegetated detachment	(5) Mean Annual Discharge (m^{3}s^{-1})
(6) General Health Index (GHI) Scale of 1 to 10 with 1 indicating a highly deteriorated marsh and 10 indicating a very healthy marsh	(6) Roughness factor - this is a measure of the degree of "meandering" of the perimeter relative to the area contained in a circle $\text{Roughness} = \dfrac{\text{perimeter}^2}{4\text{x}\text{pi}\text{x}\text{area}}$ 1 - total area roughness 2 - high water roughness 3 - low water roughness
(7) Special Features 1 - sand or shingle beach ridge advancing over marsh 2 - oyster beds 3 - "borrow pits" at back of marsh 4 - groynes 5 - polders 6 - barrier spit	

Table 6.1 - Legend of Map Variables and GIS data used in the Estuarine Classification

examination of each of the variables excludes the Wash and the Humber which are two estuaries that are so radically different from the others, that their inclusion in the statistics is not valid. Table 6.2 is a summary of the statistically acceptable variables which define the differences among the estuary categories.

VARIABLE	RIVER ESTUARIES		BLIND RIVERS		LOW MARSH	
N	8		14		4	
	MEAN	SD	MEAN	STD	MEAN	STD
LENGTH (km)	16.61	765	4.78	2.07	6.53	3.14
% WETLAND (FROM OS MAP)	17.06	1358	46.56	13.77	40.62	14.51
% MARSH + INTERTIDAL	57.35	1658	90.41	10.73	90.48	7.93
ROUGHNESS (TOTAL)	13.8	962	6.17	2.86	6.01	1.61
ROUGHNESS (LOW WATER)	33.89	1927	16.44	20.74	28.85	13.93
% MARSH (AS MAPPED)	16.8	1361	45.86	20.27	49.75	14.45
% BEACH	1.03	106	0.32	0.64	0.02	0.04
INTERCONNECTED PANS	18.14	1423	47.43	39.97	32.06	35.1
MARSH DETACH. (MEAN)	2.19	C4	1.05	0.49	1.3	0.33
GHI (MEAN)	5.29	086	6.36	1.25	7.4	1.29

Table 6.2 : Summary of Statistically Significant Differences Among the Map Variables

Relative Proportion of Wetland and Intertidal

The relative proportion of wetland in the river estuaries is nearly 3 times less than the other two categories. Paradoxically, the areal extent of the intertidal remains constant. This finding appears to be important as it suggests that the presence of freshwater inflow is greatly influencing marsh development.

Vegetation Cover

No significant differences were found among the five categories of vegetation cover. This is attributed to the qualitative assessment of this variable which was particularly difficult to judge consistently. The data, suggest that marsh cover increases from river estuaries to low marsh. This is seen in the mean values of vegetation cover which represent the weighting of the five categories. Using a scale of 1 to 5, river estuaries have a mean of 3.5, blind rivers 3.6, and low marsh 3.9. Given that river estuaries have considerably smaller areas of wetlands, these values suggest that the marshes that are present, are also the most poorly covered with vegetation.

Marsh Detachment
The marsh detachment variables were considered to be an important assessment of the state of marsh deterioration. The data show an excellent progression from the worst amount of detachment occurring in the river estuaries and the least in the low marsh. Table 6.2 provides the values for a "mean marsh detachment value" which range from 1 to 5 corresponding to the 5 map variables (where 1 is no evidence for detachment and 5 is the maximum observed detachment). River estuaries receive a value of 2.19, blind rivers 1.85, and low marsh 1.30; all values being significantly different from one another.

General Health Index (GHI)
The most common GHI value assigned to the river estuaries was 7. In blind rivers the value increased to 8, and for the low marsh the proportion of the 8 and 9 categories are greatly increased. The increasing health of the three environments is clearly apparent in the mean GHI which is 5.29 for the river estuaries, 6.36 for the blind rivers and 7.40 for the low marsh. The fact that this variable represents the most subjective of all the variables, and yet it defines the three environments with reasonable precision, reinforces the concept that the river estuaries are associated with marshes in the poorest state of development.

<u>Inter-variable comparison</u>

Of the 51 original variables, 17 were chosen for simple regression analyses. The selection was based on the adequacy of the data (eg. special features were omitted), and several categories were condensed to a single mean (ie. vegetation cover, backshore/foreshore interface, GHI etc.). As in the selection of the estuary classification, the Wash and the Humber are not included. The following discusses the implications of the significant correlations within each of the classification categories, as well as the differences between them.

Discharge/Area
This variable is confined to the river estuaries. Discharge is inversely correlated with length, although the regression is not quite significant at the 0.05 level (Figure 6.1). However, an excellent inverse relationship is also found with the total and high water roughness values (Figure 6.2) suggesting that smaller discharges are associated with more indented or meandering estuary margins. It follows that the estuary length will be increased with an increasing sinuosity and, therefore, it is clear that the three variables are closely related.

A possibly interesting relationship is found between discharge and the area of wetland (or marsh) (Figure 6.3). The regression (-0.37) is greatly improved (to -0.75) by omitting the Orwell which appears to have an anomalously small proportion of wetlands (Figure 6.3). If correct, this correlation suggests that wetlands decrease with increasing discharge, a finding that reinforces the apparent importance of freshwater inflow in the control of marsh development. There is also some suggestion that discharge is affecting the actual health of marshes (Figure 6.4).

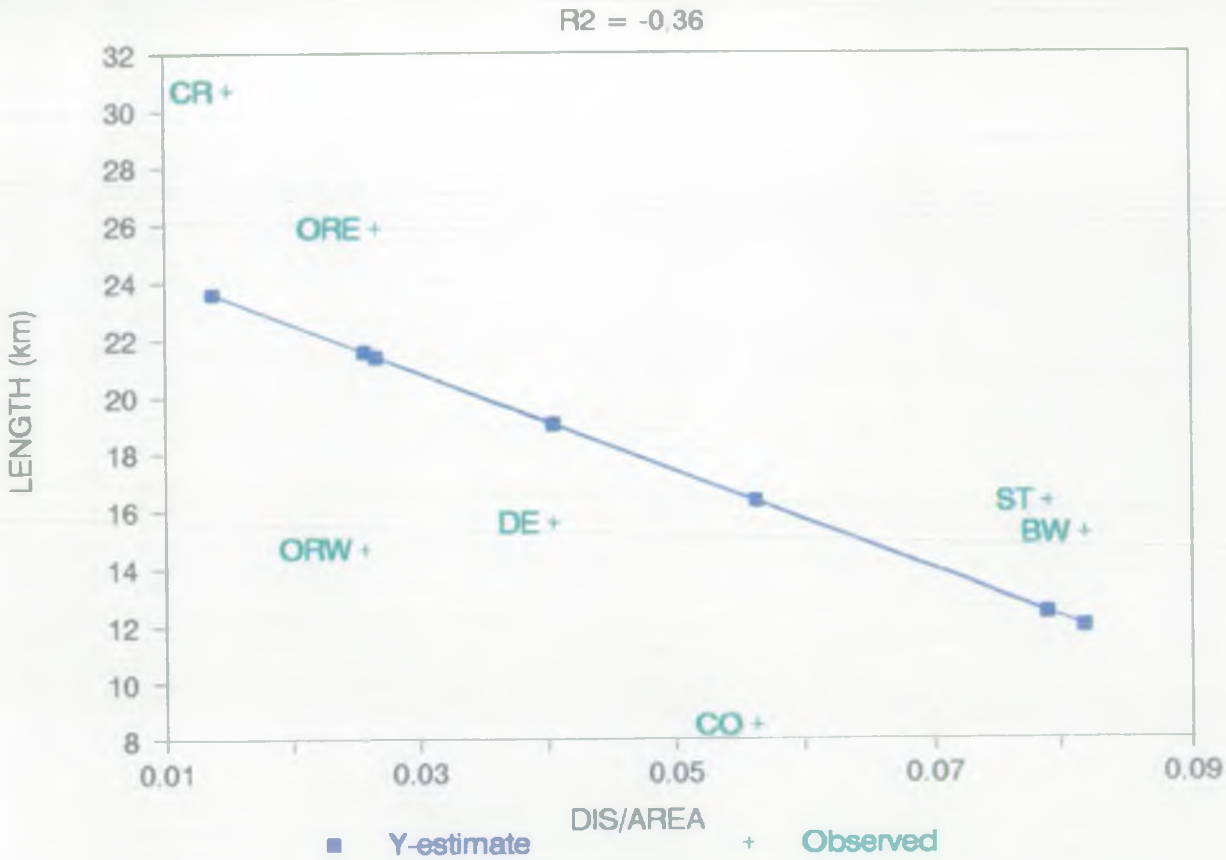


Figure 6.1 - Normalised Discharge v's Estuary Length

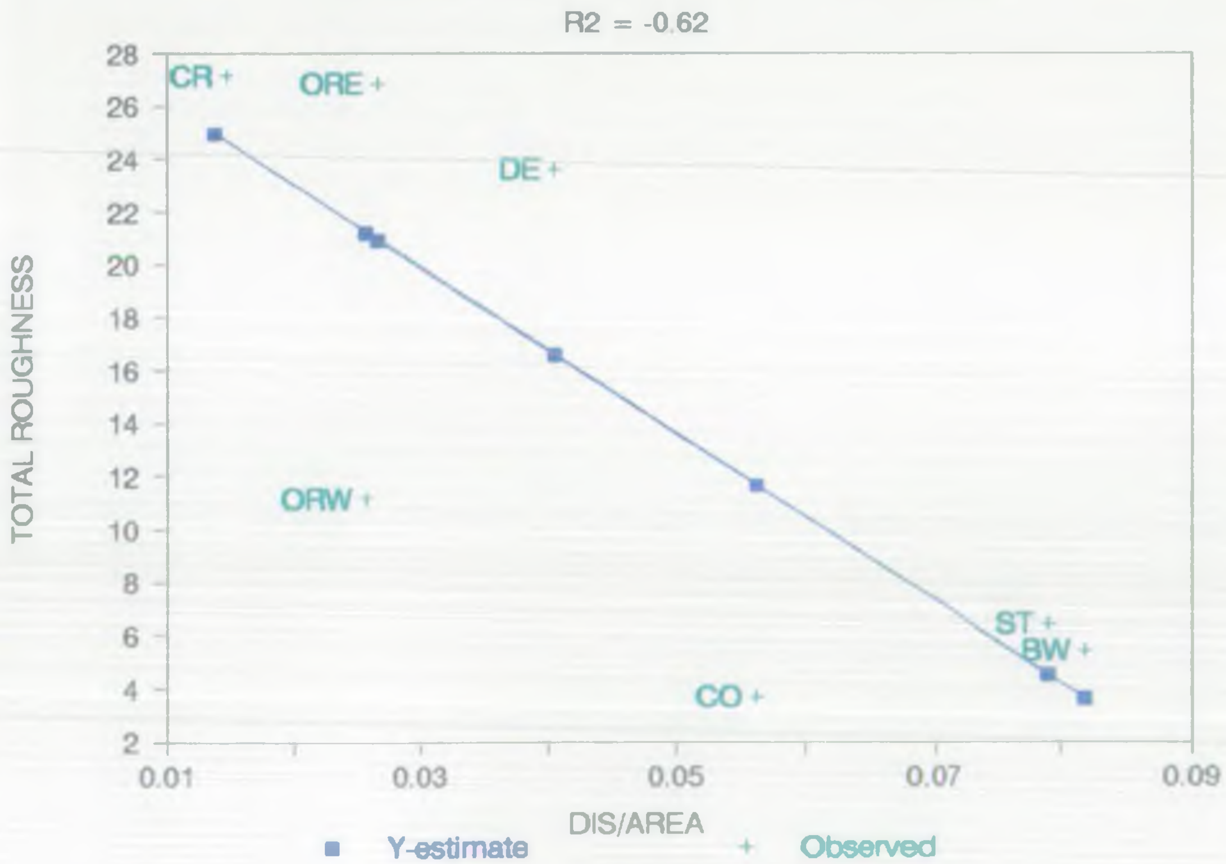


Figure 6.2 - Normalised Discharge vs Total Estuary Roughness

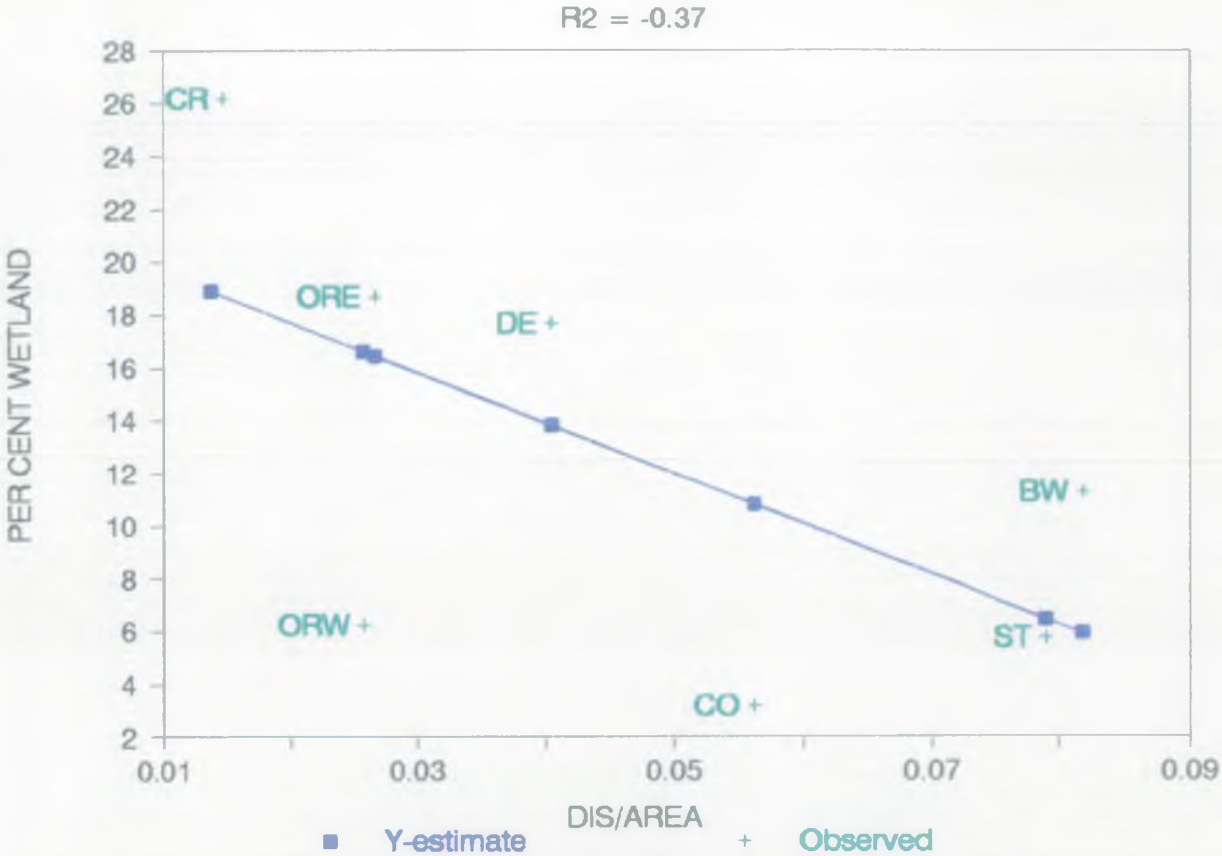


Figure 6.3 - Normalised Discharge v's % Estuary Wetland

Figure 6.4 - Normalised Discharge v's Mean General Health Index

Wetland
For the river estuaries, this variable correlates only with the total amount of marsh and intertidal areas. Of perhaps greater significance, is the lack of any relationship with the per cent intertidal when the correlation between these two variables is strong in the blind rivers and low marsh. This suggests that in the latter two categories, the marsh and intertidal areas are dynamically related to each other (ie. the amount of marsh increases at the expense of the intertidal flat and vice versa). For the river estuaries, however, this does not seem to be the case.

In the earlier discussion of the estuary classification, it was observed that the amount of intertidal area in the three categories was proportionately the same, but marshes were considerably less in the river estuaries. The consistent intertidal area in the three categories suggests that marine processes dominate, and that for the river estuaries, the freshwater influence as a controlling morphological factor must be small compared to the tidal prism. If such reasoning is correct, it appears that the amount of marsh in the river estuaries has a different control than in the blind river or low marsh environments, which may be related to the river flow.

Conclusions

Based on the relationships discussed the following conclusions were drawn:

- The spatial variability of the morphological data provided the basis for classifying the estuaries into three categories; namely, river estuaries, blind rivers and low marsh.

- Blind rivers and low marsh environments contain about three times more wetland than the river estuaries; however, the proportion of intertidal area remains the same for all three categories. These facts suggest that the marine-dominated processes are similar throughout the environments, but the presence of a river input (which is small compared to the tidal prism) is having an effect on the present marsh development.

- In the blind river and low marsh environments, the proportion of wetlands and intertidal areas appear to be dynamically related. Marsh develops or deteriorates with a consequent decrease or increase in the intertidal area. There is no such relationship in the river estuaries indicating that there must be a further control that influences marsh development. This observation, combined with other independent relationships, suggest that the control is related to river discharge.

- Collaborative evidence on the effects of fresh water discharge are emphasized by the inverse relationships between discharge with the amount of wetlands and the mean general health index.

Open Coast Classification

As part of the Stage II studies, the coast was classified into a series of coastal units. With the availability within Stage III of both new and more coherent data sets, the analysis has been re-worked in a more structured way. The first stage entailed examining variables combined in a number of ways to provide interpretive and evaluation maps. After some trial and error, variables were combined to give meaningful sub-divisions of the coast, which could be used to formulate coastal units.

Interpretive Maps

To begin with, each of the raw data sets to be used in the analysis were classified. This is an iterative process whereby queries are prepared which divide the data set up into a series of classes. The aim is to obtain a reasonably even sub-division of the data range and to have somewhere between 3 and 6 classes. In all eighteen data sets were prepared in this way, as summarised in Table 6.3. Having determined the appropriate classification scheme for a data set, the classes are mapped onto a 'standard' set of linework based on a line 500m landward of the coastline and the seaward edge of the nearshore zone. This means the polygons formed for each variable can be overlayed to derive combinations. (The linework used was chosen because this represents the zone being managed and provides a good graphical indication of the physical extent of the coastal strip).

Category	Feature
Coastal Character	backshore width foreshore width nearshore width mobile geology solid geology hinterland geomorphology landscape character flood protection zones surface water catchment estuary/coast divisions conservation areas
Coastal Forcing	1:100 year extreme wave height alongshore wave energy spring tidal range tidal velocity square residual
Coastal Response	HW retreat rates foreshore steepening rates retreat - advance classification

Table 6.3 - Data sets used in the Classification Process

The following describes a selection of the maps developed to illustrate certain aspects of the processes on the Anglian Coast.

Wave Action (Figure 6.5)
This map combines the 1 in 100 year significant wave height with the mean annual alongshore wave energy, to provide a measure of variations in wave activity at the shore. Three areas fall into the most active class, these being Lincoln, Gore Point to Blakeney and Sheringham to Winterton. By contrast the Wash has relatively low wave activity, as has the majority of the coast south of Benacre, although there are some localised increases.

Tidal Action (Figure 6.6)
A measure of tidal activity has been derived by combining the spring tidal range and the second moment of the tidal current residual. The large tidal range leads to the Wash, Lincoln and the southern part of Holderness being the tidally most active regions. Interestingly the influence of tidal residuals causes the lengths from Caister to Sea Palling and Overstrand to Sheringham to also appear in the highly active class. It is also apparent that whilst the tidal range has fallen to 2 metres at Lowestoft, the coast north of Lowestoft is at least intermediately active due to high tidal current residuals. To the south of Lowestoft there is a region of low activity, before increasing again in the Thames estuary.

(Note: It is considered likely that model predictions for both waves and tides within the Thames estuary are low due limitations in model resolution and the forcing mechanisms included in the various models).

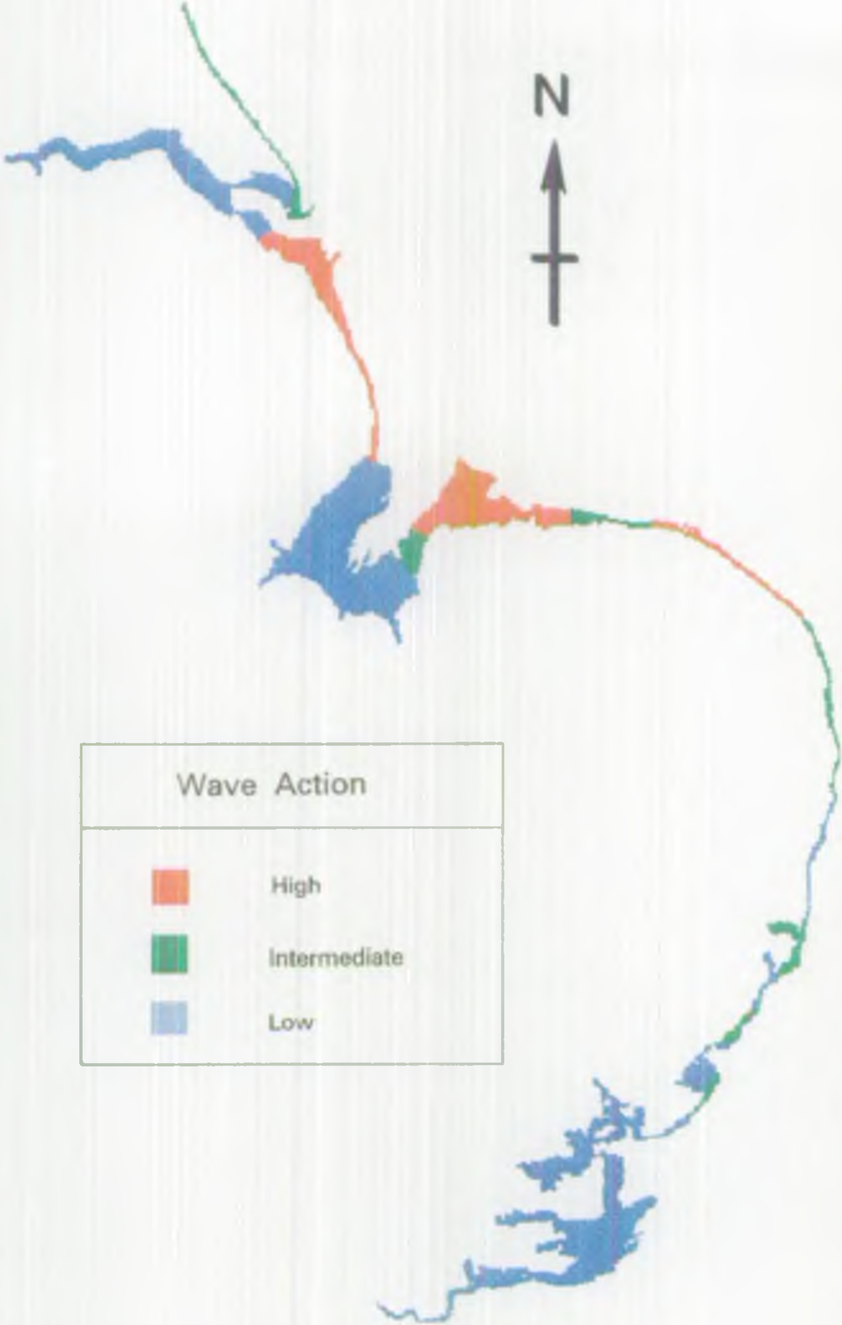


Figure 6.5 - Wave Action

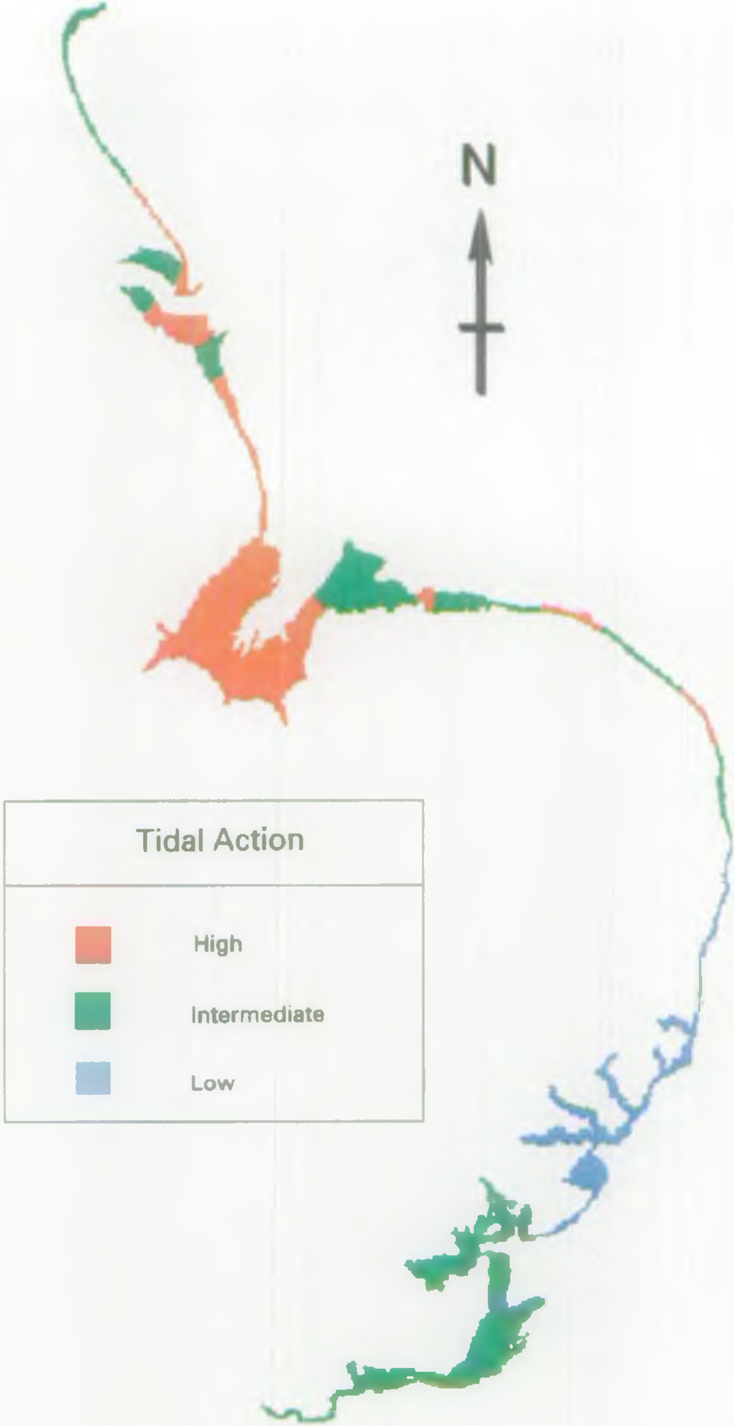


Figure 6.6 - Tidal Action

Wave Action/Tidal Action (Figure 6.7)

This map is derived from the above two maps to show the relative importance of waves and tides. The resultant map does not provide an absolute measure of the physical processes but rather a relative measure, given the extent of regional variations. The figure clearly suggests that only limited lengths of the coast are wave dominated; notably Overstrand to Mundesley and intermittently on the Suffolk coast. Much of the rest of the coast is being dominated by tidal action, although it is interesting to note that Brancaster Bay and much of Lincoln exhibit a rough equality of wave and tide action.

Coastal Forcing (Figure 6.8)

This map seeks to show how waves and tides combine indicating which parts of the coast are the most "dynamic". The most active lengths of coast are south Holderness, Lincoln, Brancaster Bay, Sheringham to Bacton and Sea Palling. What is most interesting on this map is the extent of low and very low classes. Indeed within the classification scheme adopted, there is almost no separation between these two classes, such that from Lowestoft south could be considered a single class of low. This would appear to reflect an elegant balance between decreasing wave action as one progresses into the Thames estuary, countered by increasing tidal action. The result is a relatively constant but low level of "forcing" when compared to the much more dynamic region to the north of Lowestoft.

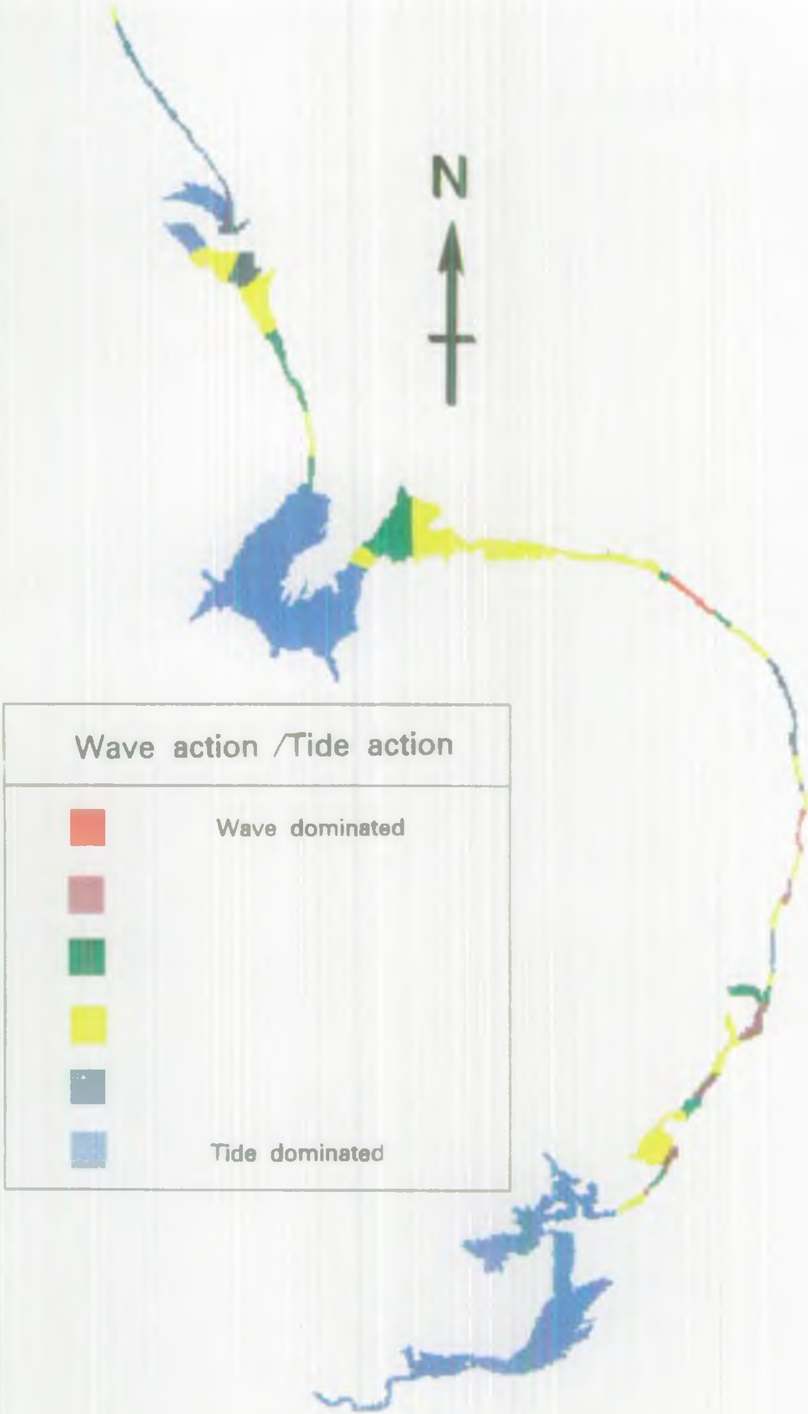
Sediment Potential (Figure 6.9)

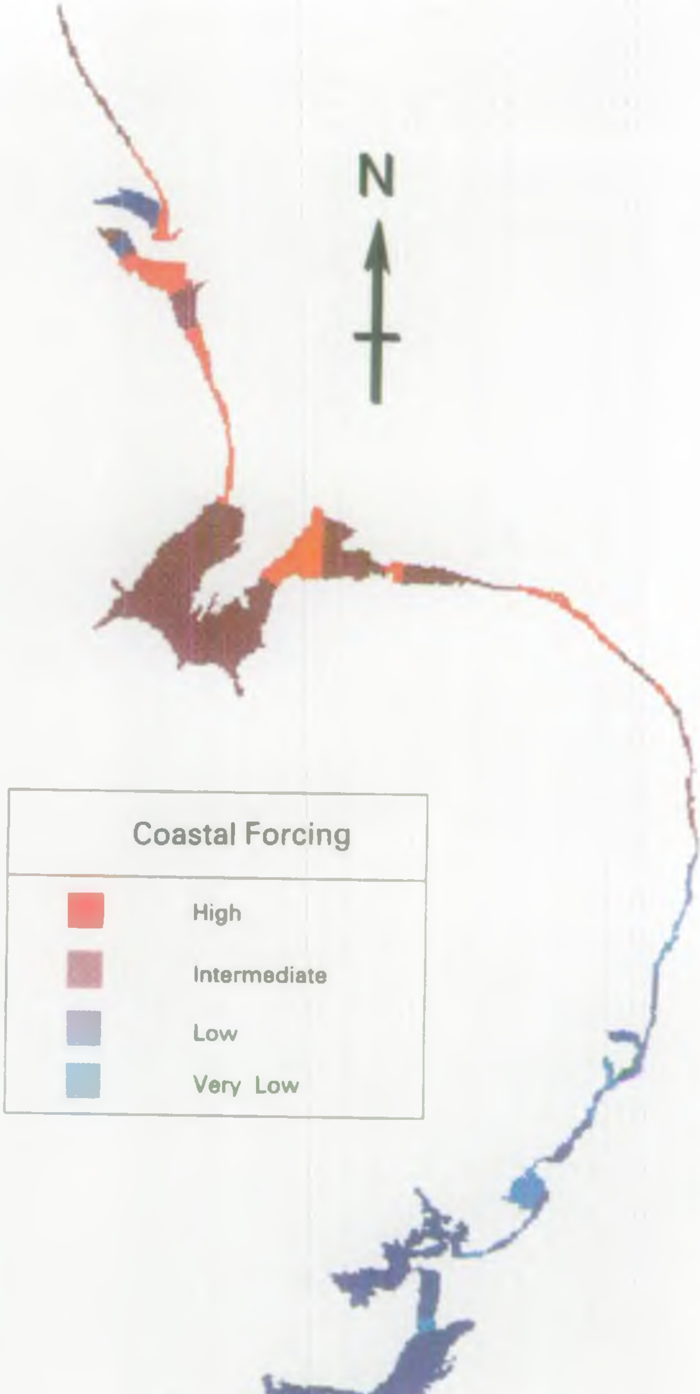
Having considered measures of "forcing", this map begins to address the question of what these forces act upon. The map shows how surficial sediments and the non-mobile sediments within the backshore/foreshore (ie on the beach) combine. Whilst this is not a measure of sediment supply, the varying character (ie sand on cohesive, sand on non-cohesive, etc) provides a measure of the type and adequacy of beach forming material. From Sea Palling to Bawdsey there is predominantly non-cohesive material to depth. Elsewhere the open coast is dominated by sands overlying cohesive beds (generally referred to as cohesive shores in this report). Within the estuaries silts and clays predominate.

Beach Steepening and the Underlying Geology (Figure 6.10)

This figure maps the association of beach steeping with beach geology in well defined classes. The underlying geology is taken to be the material below the surface or mobile sediment but within the potential depth of wave activity (5-10 metres on this coast). Perhaps the most notable feature is the marked division between bright and pale colours, north and south of Eccles and Bawdsey. This reflects the distribution of non-cohesive and cohesive non-mobile geology.

Holderness, Lincolnshire, Cley to Bacton and south of Harwich are all very similar in having intermediate to high steepening with a cohesive sub-layer. Within these lengths there is also some distinctive zones of rapid steepening in non-cohesive material but these are associated with spit and ness type features as at Spurn, Donna Nook and Blakeney in particular.


N
Wave action /Tide action
Wave dominated
Tide dominated


N
Coastal Forcing
High
Intermediate
Low
Very Low

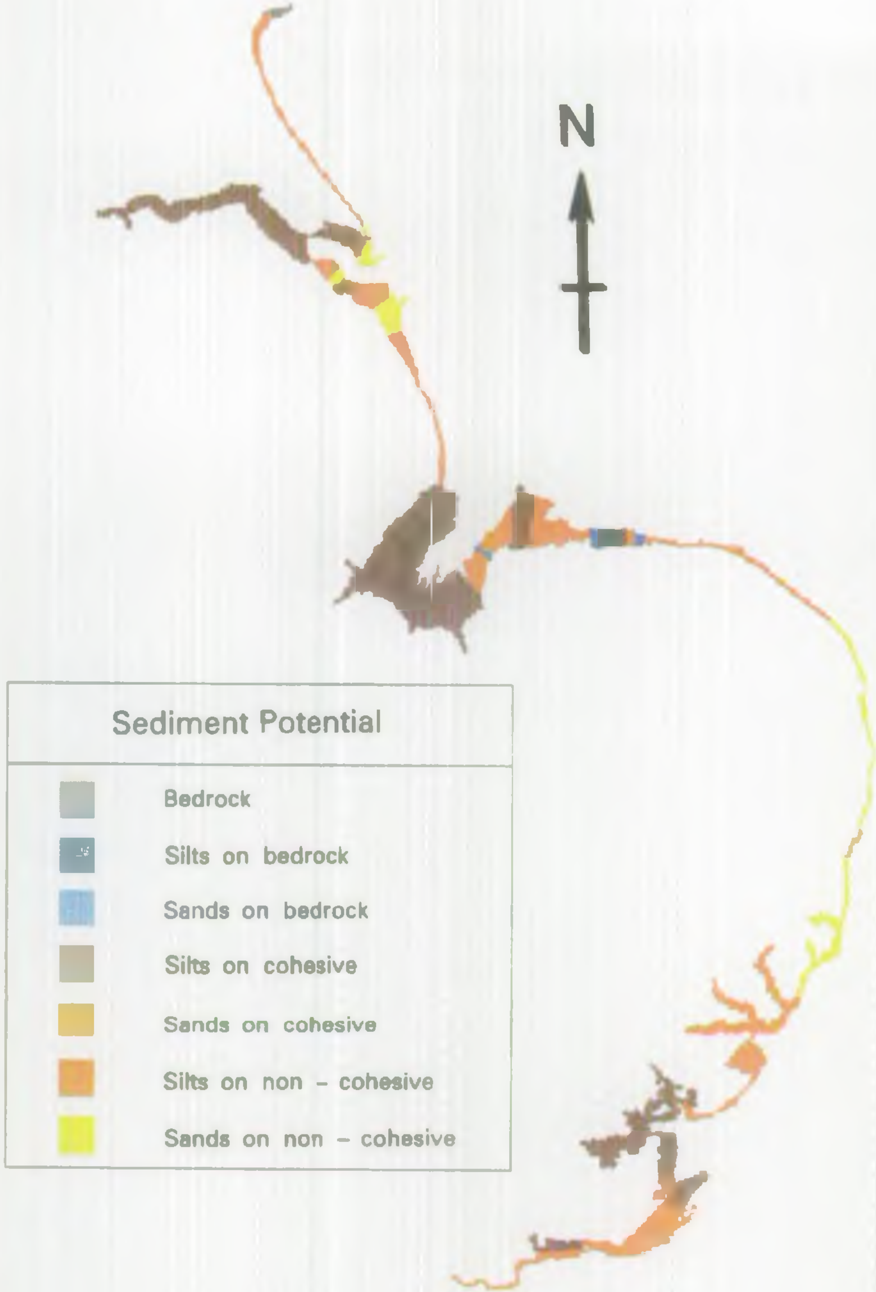


Figure 6.9 - Sediment Potential

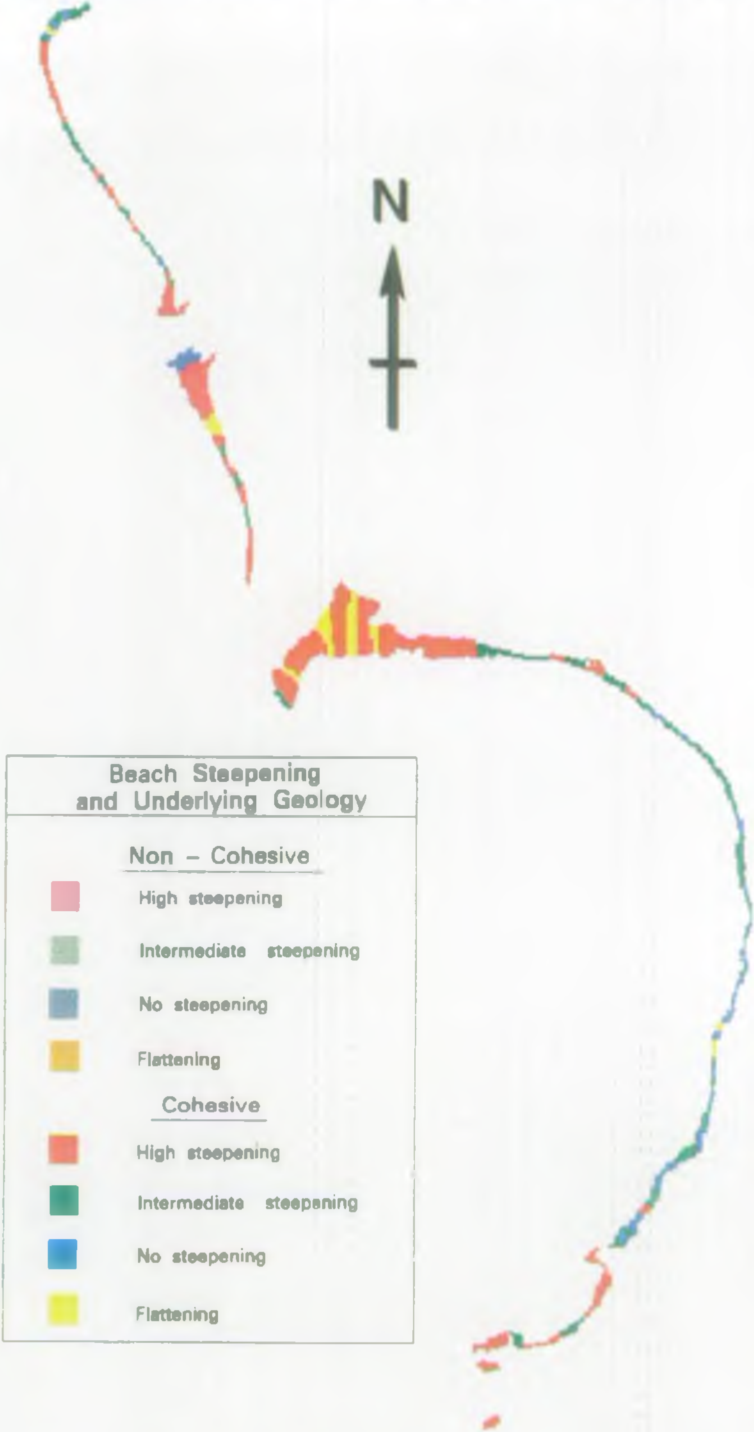


Figure 6.10 Beach Steepening and Underlying Geology

These regions are contrasted by the length from Eccles to Bawdsey which comprises no steepening or low steepening in non-cohesive sediments. Westwood Marsh features as an outcrop in this length, where landward migration is leading to some flattening.

Attempts were made to derive a similar association between the geology and the retreat rates themselves. No clear relationship was apparent, with a full range of retreat/advance classes found within each class of geology. A series of maps for wave action against steepening and retreat similarly showed no consistent trends, nor did the map of tidal action and retreat. By contrast the maps of tide and steepening were more successful. When considering just the spring tidal range and steepening there was a rough agreement but some notable inconsistencies, such as at Cromer and Tendring. However when the residual currents were added in to give 'tidal action', as discussed above, the agreement was greatly improved. This would seem to suggest the importance of both tidal range and current action in the steepening process, a finding wholly consistent with the 3-D modelling results (see Chapter 5).

Evaluation Maps

Developed using the same technique as for the interpretive maps, certain key aspects of the hazard potential and impact have been mapped.

Shoreline Erosion Potential (Figure 6.11)
One set of maps examined during the analysis showed the variations of backshore, foreshore and nearshore widths around the coast. This showed a wide variability both around the coast and between each other. Thus the significance of any retreat will vary depending on the "room" available. Combining the backshore width and the retreat rates for high water provides a measure of the potential risk due to continuing erosion, assuming the rates remain reasonably constant. The map highlights the vulnerability of Holderness, Mablethorpe to Sutton, Overstrand, Mundesley to Bacton, much of the coast south of Lowestoft to Orford Ness and the Tendring Peninsula.

Beach Face Erosion Potential (Figure 6.12)
Extending the concept of the previous map, this figure shows the significance of beach steepening. Given the physical setting as defined by the foreshore and nearshore widths combined, where either or both of these widths are narrow and there has historically been a high rate of steepening, it indicates the most vulnerable lengths of coast. The disposition of the most critical areas is somewhat different from those vulnerable to shoreline erosion (Figure 6.11). Areas which are highlighted as high risk are Holderness, Lincoln, much of Norfolk (notably Cromer to Bacton and then intermittently to Winterton) from Gorleston to Lowestoft and the whole of the Tendring Peninsula. The southern portion of Orford Ness is also shown as high risk, but this is a consequence of the southerly migration of the ness.

Natural Flood Vulnerability (Figure 6.13)
To provide an indication of the relative vulnerability to flooding of the natural coast (ie with no regard to the presence of sea defences) the data sets for hinterland geomorphology, landscape character and the flood protection zones were combined. The resultant map clearly identifies Lincoln, the Wash and Essex as the most flood prone areas. Interestingly, Orford Ness, Westwood Marshes and Happisburgh to Winterton are also highlighted. The latter is of particular importance because of the extensive low lying Broadlands, which are effectively protected by this length of coast from the open sea.

Conservation Sites (Figure 6.14)
The range of data currently available is not sufficient for a detailed analysis of environmental sensitivity. A comprehensive approach should seek to assign such measures as vulnerability and recoverability to different habitats but a suitable methodology has yet to be widely agreed. This is however an important aspect of any evaluation and so an initial assessment has been made using what data is available.

This makes the assumption that all estuaries are environmentally important and sensitive (estuarine environments are highly productive with organic production between 5 and 10 tons/acre/year compared with 1.5 to 5 tons/acre/year for good agricultural land - Walker, 1985). The designated conservation sites, be they of local, national or international status, are then taken as encapsulating the majority of important and/or sensitive sites on the coast. As can be seen, the lengths of coast which fall outside any designation are relatively short. This is of course to be expected on a coast that has a rich diversity of morphology and habitat because of the wide variations in regime to be found around the region.

Open Coast Process Units

Whilst the evaluation maps summarise the nature of the problem to be managed, the interpretive maps provide a guide to the regional influence of key processes. Making use of the latter, a set of process units has been formulated. The most basic regional classification is defined using a simplified lithology comprising bedrock, non-cohesive and cohesive formations, where this relates to the non-mobile rather than surface component. To this is added the coastal forcing, so that for each lithological type there are four classes of "activity", (Figure 6.15). Already this simple summary of geological setting and coastal forcing is beginning to delineate units. What is missing is the recognition of any coastal "features" which themselves comprise particular aspects of a unit. These are added in using the hinterland geomorphology and by specifically defining the estuaries as separate from the open coast.

The resultant map divides the coast up into a highly complex set of units (some 50 combinations in all). Fortunately these occur in well defined patterns on the coast, allowing them to be grouped to form coherent process units. The resultant open coast units are summarised in Figure 6.24 as the units coloured alternately red and green.

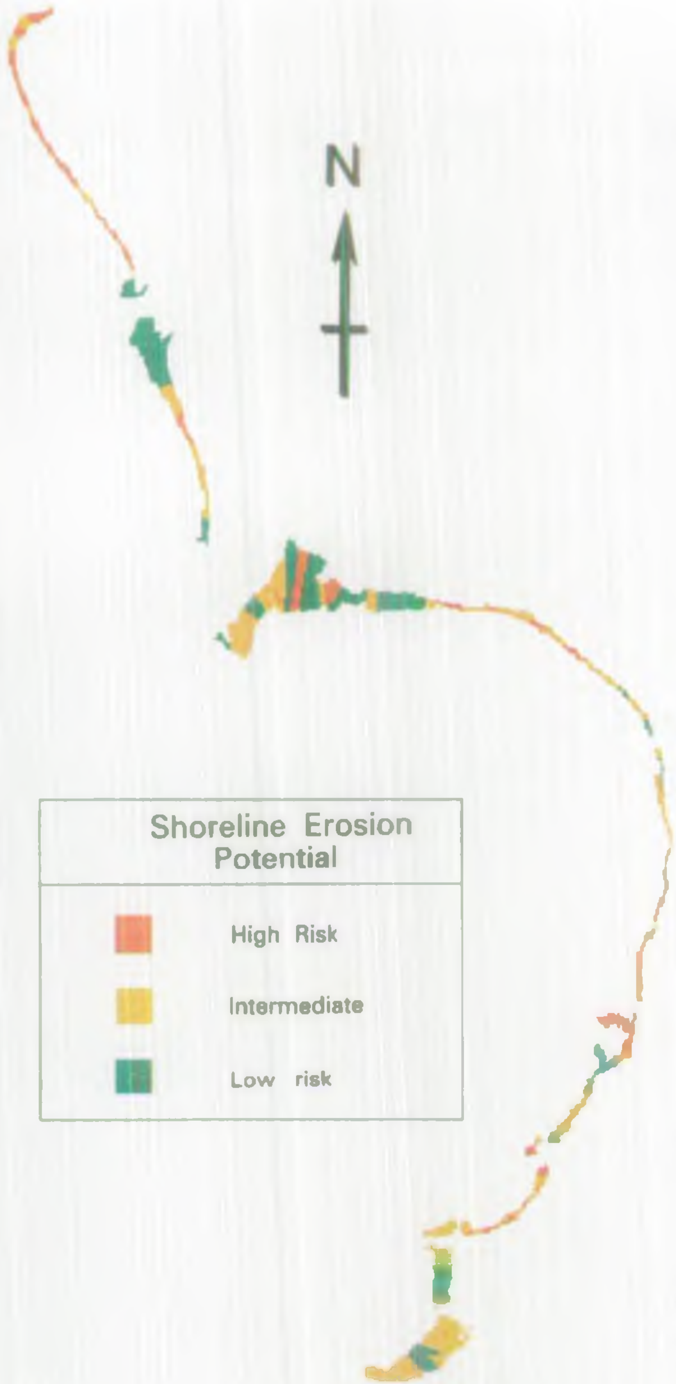


Figure 6.11 - Shoreline Erosion Potential

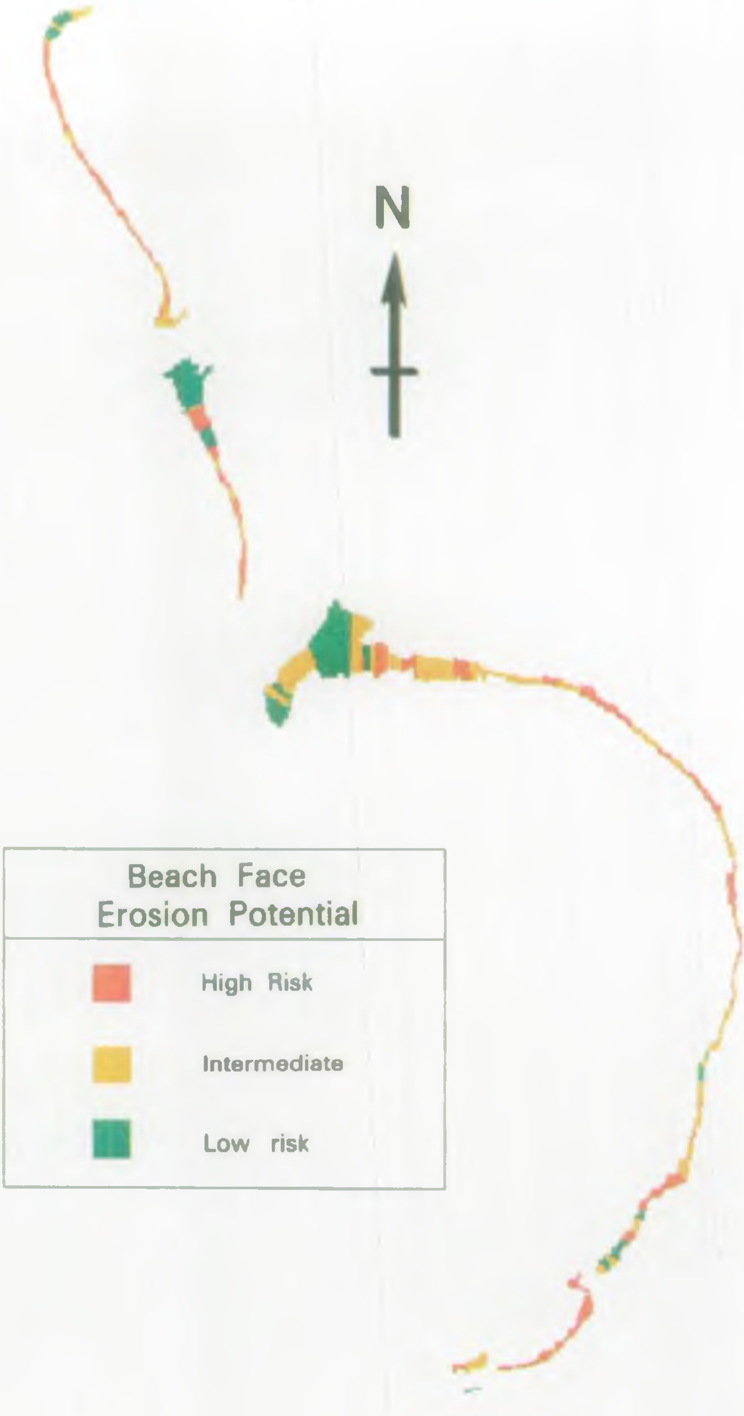


Figure 6.12 - Beach Face Erosion Potential

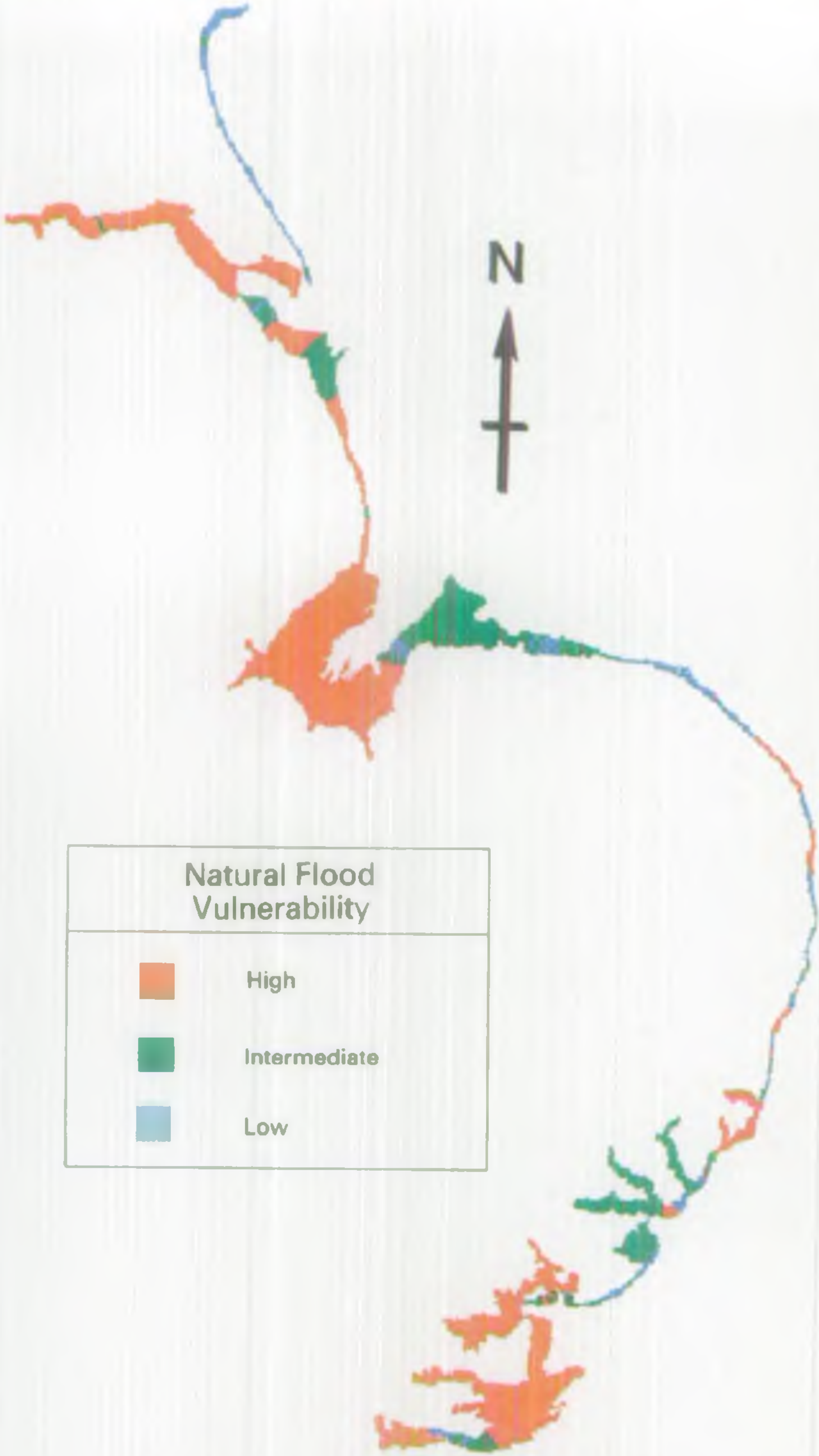


Figure 6.13 - Natural Flood Vulnerability

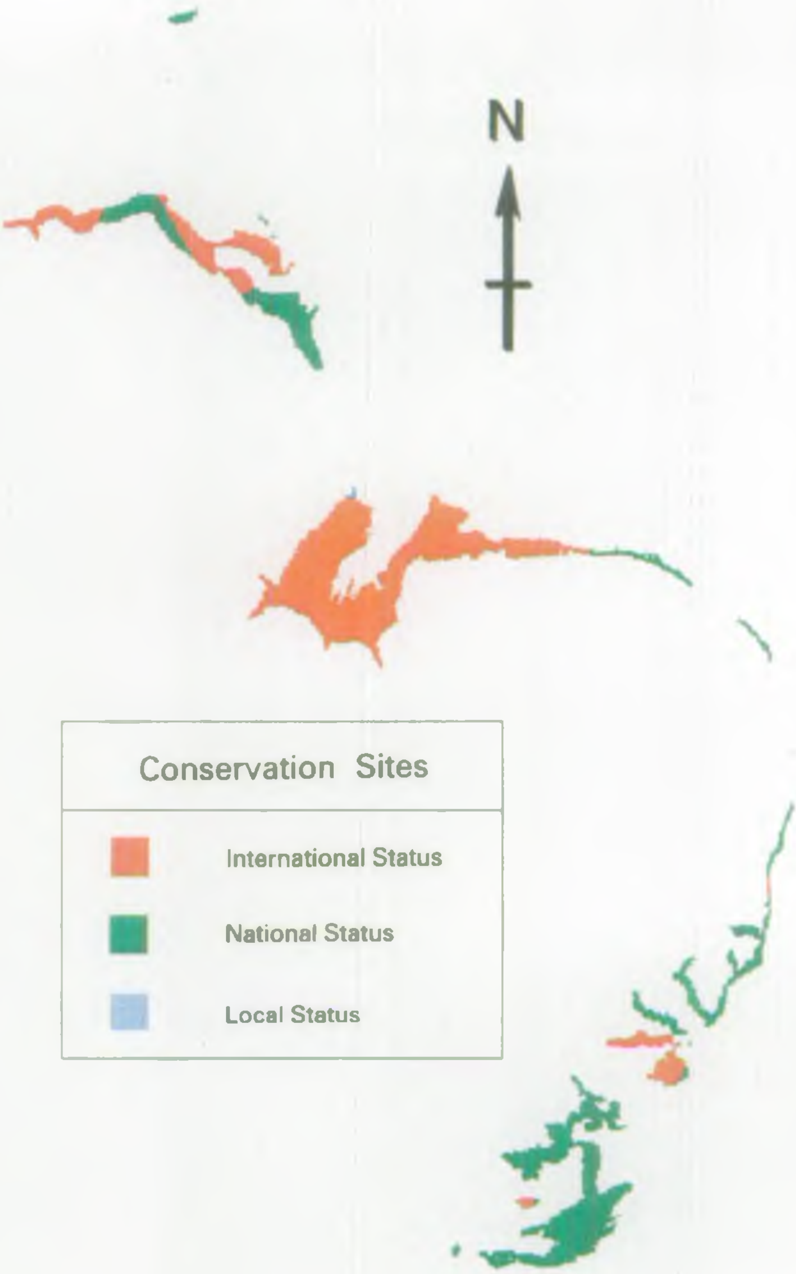


Figure 6.14 - Conservation Sites

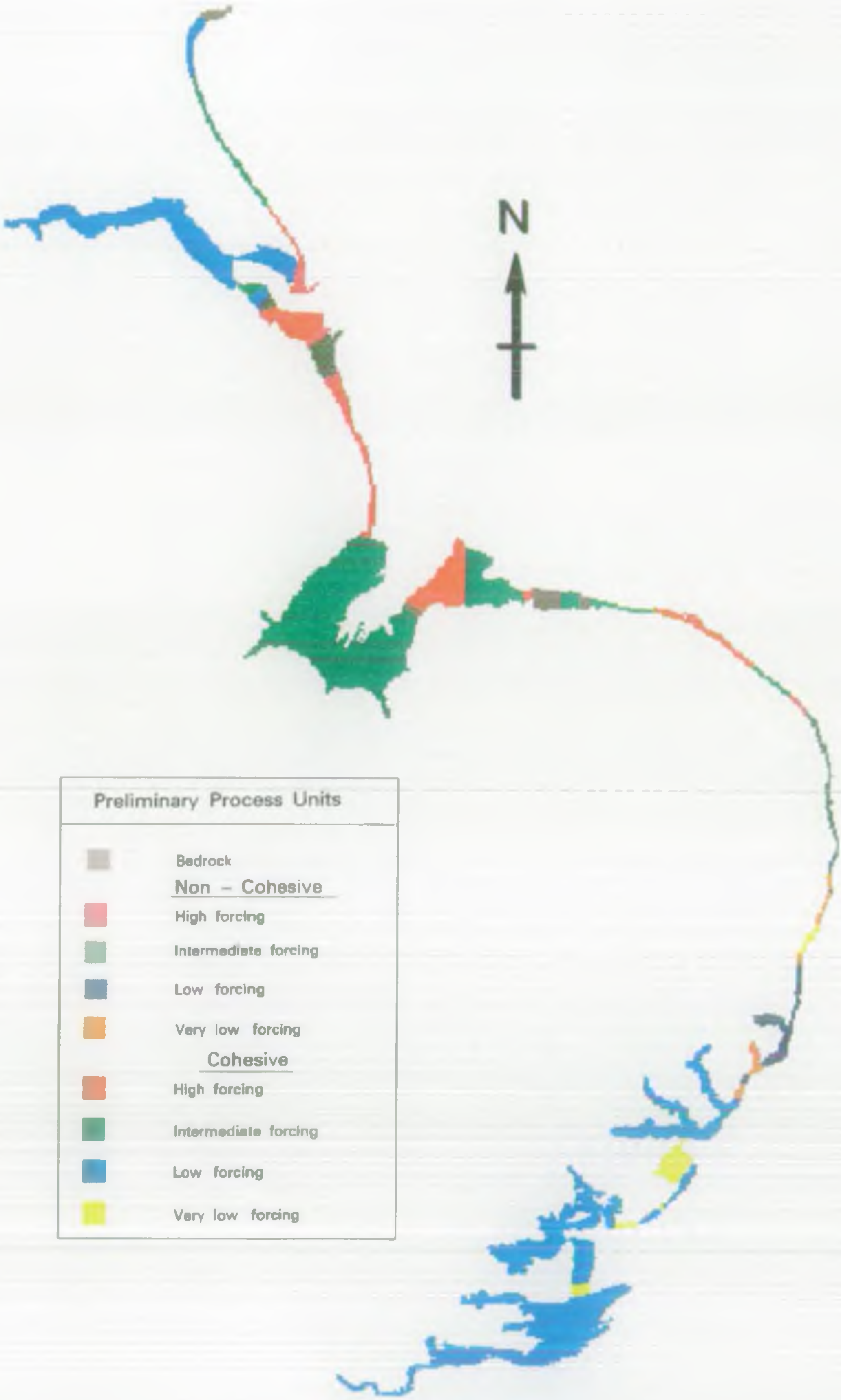


Figure 6.15 - Preliminary Process Units

Coastal Units

The previous two Sections have considered the estuaries and the open coast independently. Combining the results we can establish a completed definition of the coastal units. These are shown as numbered units in Figure 6.16 and summarised in Table 6.4. The Table also gives a name to the unit, an indicative length and type, and illustrates more regional grouping of the units; first at a process level and then in terms of regional lithology.

Significance for Sea Defences

The definition of coastal units provides a consistent regional framework, which acknowledges the key processes, for use in the development of the Management Strategy. There are however a number of more direct implications to be drawn from the wide range of studies undertaken, as summarised below.

Foreshore Steepening

The steepening process is widespread and shows a strong association with the geology and level of tidal action. This finding is borne out by the 3-D model of beach behaviour developed to study this phenomenon. In particular this work shows the high volatility of the veneer type beaches and the need to control this volatility in order reduce downcutting of the cohesive sub-base. It is also clear that along lengths of coast where there is a need to maintain the existing line of defences, it will be necessary to take positive measures on the foreshore/nearshore to try and slow or halt the beach steepening process.

Structure to Retreat

The retreat rates data shows a consistent spatial structure around the coast with length scales varying between 2.5 and 16km. Furthermore there is a strong correlation between high and low retreat rates on the Holderness, Lincoln and Suffolk coasts. This suggests that the underlying mechanism is highly coherent in space and inducing some form of natural resonance. Whilst no direct link to physical processes has been established, this finding supports the conclusions on 'tides and waves' and 'profile evolution' given below.

Tides and Waves

The analysis has once again shown the need to consider both waves and tides acting in concert for much of the Anglian coast. Indeed, the concept of waves being responsible for local, short term movement of sediment and tides for the long term more regional movements has been reinforced by the results of the tidal modelling work. Furthermore, the analysis of tidal residuals has linked the type of eddy circulation that results from the tidal motion to the different forms of bank and sand flat in the region. Whilst this helps to better appreciate regional sediment movement, the main engineering significance is that designs should not assume that waves alone control beach stability, nor that wave driven sediment movement is solely or in some cases even partially alongshore (ie onshore-offshore movement

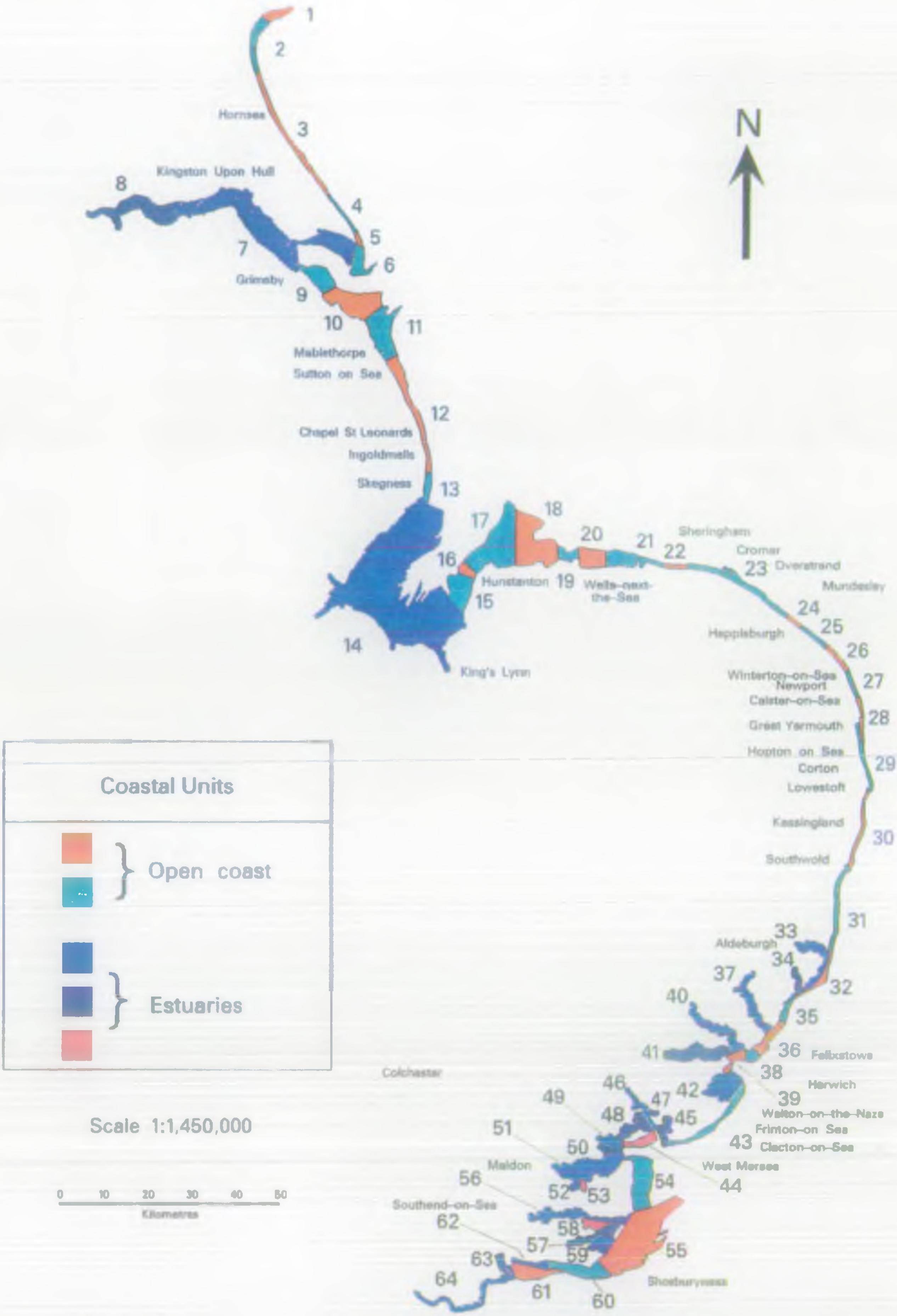


Figure 6.16 - Coastal Units

Unit	Location	Length (km)	Type	Unit Groupings
1	Flamborough Head	7	Rock headland	
2	Bridlington	13	Low cliff transition	
3	Holderness (north)	32	Cohesive cliffs	Holderness
4	Holderness (south)	11	Cohesive cliffs	
5	Easington	3	Cohesive cliffs	
6	Spurn	6	Sand spit	
7	Outer Humber	48	Young river estuary	Humber
8	Inner Humber	21	Old river estuary	
9	Grimsby/Cleethorpes	8	Dune beach	
10	Grainthorpe Haven	12	Marsh	
11	Saltfleet	11	Dune beach	Lincoln
12	Mablethorpe-Skegness	27	Beach ridge	Cohesive
13	Skegness/Gibraltar Point	6	Sand spit	
14	Wash	82	River estuary	Wash
15	Snettisham Scalp - Hunstanton	8	Beach ridge/marsh	
16	Hunstanton Cliffs	2	Bedrock cliffs	
17	Brancaster Bay	11	Beach ridge/marsh	
18	Scolt Head	10	Barrier beach/spit	N Norfolk
19	Holkham Bay	5	Beach ridge/marsh	
20	Wells-next-the-Sea	8	Barrier beach/marsh	
21	Blakeney	13	Barrier beach/spit/low marsh	
22	Weybourne	6	Shingle beach ridge	
23	Sheringham - Mundesley	25	Cohesive cliffs	
24	Bacton	4	Cohesive cliff transition	
25	Walcott-Horsey	7	Dune beach on till	E Norfolk
26	Winterton Ness	7	Dune beach	
27	Newport/California	7	Cliffs/beach ridge	
28	Caister Ness	10	Dune beach/spit	
29	Gorleston-Lowestoft	16	Cliff/beach ridge	S Norfolk
30	Benacre Ness	18	Low cliffs/beach ridge/marsh	
31	Thorpe Ness	20	Low cliffs/beach ridge/marsh	

Table 6.4 - Summary of Coastal Units

Unit	Location	Length (km)	Type	Unit Groupings	
32	Orford Ness	16	Shingle spit		Non-cohesive
33	Alde/Ore	23	River estuary	Suffolk	
34	Butley	5	River estuary		
35	Shingle Street	5	Gravel-sand beach		
36	Bawdsey-Felixstowe	9	Low Cliff		
37	Deben	17	River estuary		
38	Landguard Point	2	Sand spit		
39	Harwich	7	Cohesive cliff/marsh	Harwich	
40	Orwell	17	River estuary		
41	Stour	17	River estuary		
42	Hamford Water	6	Low marsh		
43	The Naze-Colne Point	22	Cohesive cliff/marsh		
44	Mersea Island	7	Cohesive cliff/barrier beach		
45	Ray/Flag/St Osyth Creeks	5	Blind river/low marsh		
46	Colne	11	River estuary		
47	Alresford Creek	2	Blind river		
48	Pyefleet/Geedon/Strood Creeks	10	Blind river	Tendring	
49	Salcott Channel	5	Blind river		
50	Tollesbury Fleet	5	Low marsh		Cohesive
51	Blackwater	15	River estuary		
52	Lawling Creek	2	Blind river		
53	Mayland Creek	2	Blind river		
54	Dengie Flat	14	Low marsh		
55	Maplin Sands	17	Low marsh		
56	Crouch	24	River estuary		
57	Roach	13	Blind river		
58	Paglesham Pool	4	Blind river		
59	Middleway/Potton/Shelford Creeks	5	Blind river	Thames	
60	Southend-on-Sea	12	Sand flats		
61	Canvey Island	11	Low estuary island		
62	Hadleigh Ray/Benfleet Creek	8	Blind river		
63	Holehaven/Vange Creeks	6	Blind river		
64	Thames	29	River estuary		

Table 6.4 (Continued) - Summary of Coastal Units

can be very significant leading to an exchange with sediment in transport in the nearshore zone).

Sea Level Rise

The recent publications of the Intergovernmental Panel on Climate Change (IPCC) have been reviewed and as a consequence the recommended allowance for future sea level rise has been increased. This will however need to be kept under review as new work is published. It is also important that the significance of sea level rise is related to the sensitivity of particular design options, which will vary from one location to another. In particular renewable or short term solutions (design life less than 20-30 years) can use significantly lower values for the annual increase than long term or more permanent solutions. This is likely to be of particular benefit when considering beach nourishment or recycling schemes which can be more responsive to changes as they (progressively) occur.

The other aspect of global warming of concern for the design of engineering works is climate change, and in particular possible increases in storminess. Although short term measurements suggest an increase, this is not supported as a consistent trend over the last century. Indeed the level of storminess appears now to be comparable with the level at the end of the last century. Perhaps the key point is that designs should take account of the longer term variability in climate. Rather fortuitously, data sets covering the last 20-25 years do capture a significant proportion of this variability. The *quid pro quo* is that analysis of these for extremes, etc, must recognise the underlying trend of the data.

Profile Evolution

The earlier discussion on beach steepening and the above comments on sea level rise both combine in a longer term perspective of the problem, which is illustrated by the nearshore profiles (see discussion in Chapter 2). This relates to the development of the North Sea basin. Some 8,300 years ago the basin was divided by a ridge of land which ran from North Norfolk to Texel on the Dutch coast. To the south was the Thames-Rhine estuary and to the north was a sea basin. As sea levels rose this ridge was overwashed and the two basins coalesced. The more or less continuous rise of sea level to the present day means that the basin is still adjusting to the changing regime. Thus whilst originally much of the coast, and in particular the cohesive shore, must have been highly dissipative, this is now becoming increasingly reflective in character as a consequence of the steepening process. From a practical point of view we must acknowledge the major scale of the changes taking place and seek to accommodate these changes in long term strategic planning (time scale of 50-100 years). This must recognise that as long as sea levels continue to rise, so erosion will continue and that as far as possible we should not build-in undue future liability by allowing development which over-constrains the coast.

Offshore Banks

The banks off Great Yarmouth are clearly an important component of the coastal evolution in this area. A model for their evolution has been postulated, whereby the banks form a circulating cell which serves to gather sediment moving along the shore and initialise the formation of new banks which then evolve as linear banks moving offshore to the north-east. Whilst the results of the present study were consistent with this model, they also showed movements on a much shorter (order of weeks) time-scale. This will need to be better understood if the model is to be confirmed. The significance of this process is that, if material is in circulation, then dredging from within the cell could be particularly harmful in the longer term.

Estuary Type

The estuaries have been examined in terms of some key morphological descriptions. This has allowed them to be classified into three types; river estuaries, blind rivers and low marsh. Of these the river estuaries have saltmarsh in a significantly poorer state than the other types of estuary. Within the river estuaries there then appears to be a link with river drainage and hence the level of pollution on sediment load. Clearly the validity and significance of this link needs to be explored in more detail.

PART III - MANAGEMENT FRAMEWORK

7 OUTLINE OF FRAMEWORK

It is now widely recognised that the coast is a sensitive interface between land and sea, the behaviour of which is governed by distant as well as local conditions. Changes on a coastline result from the interaction of sea level fluctuations, uplift/subsidence of the land mass and variation in the sediment supply. These all tend to be episodic in nature with differing rates and timescales. Consequently, changes take place over periods which vary from daily to several decades, with relevant geological changes occurring over even longer periods.

Over recent years there have been some fundamental changes in approach to the provision of flood protection and measures to limit erosion. In practical terms this has resulted in new types of structures and in particular a "soft" approach, based on techniques of beach nourishment and subsequent management, as an alternative to the more traditional "hard" approach, using sea walls and groyne systems. Implicit in the use of such alternatives is a greater understanding of coastal processes, which has come about as a consequence of international research efforts over the last few decades.

As such techniques are based on understanding the dominant coastal processes of an area, it has become important to study the whole coastal regime; rather than just the frontage of interest. It has become clear from these more regional studies that there are great benefits to be gained from adopting a strategic approach to the provision of coastal works. At the same time, there are increasing pressures from the diverse and often conflicting range of coastal interests, such as conservation, tourism and industry. This therefore requires a more complete assessment of the shoreline management options and has provided the incentive to develop suitable management techniques.

With the more traditional approach problems are identified and solved in an ad hoc manner. This makes it extremely difficult to ensure that schemes are developed to be efficient and cost effective for the nation as a whole. Furthermore, it is much more difficult to ensure natural processes are used to best effect. This therefore emphasises the need for a more strategic approach to shoreline management (Note: shoreline management is taken as all efforts to control the shoreline, with the emphasis on coastal hazards and the need to protect against either flooding, erosion, or both).

The 'Management Framework' Concept

In order to be able to contemplate a shoreline management approach it is necessary to obtain a proper understanding of the natural processes involved. For a given regime or region, studies will necessarily consider historical changes, the effects of the marine climate, the patterns of sediment movement and probably need to assess water quality and ecological sensitivity. This then allows the management issues such as conflicts of interest, level of protection and type of protection to be considered in the light of a proper understanding.

Nevertheless whether considering issues or processes, the fundamental requirement is information. The balance between the two will usually only alter the range and extent of data collected. Thus, the principal *Input* is information, whether existing, generated by routine monitoring, or the result of forecasts.

This type of approach based on extracting information from a wide range of archives, rapidly generates a large volume of material. To provide easy reference, this needs to be adequately catalogued if the process of interpretation is to remain manageable. For a relatively short length of coast it may be that much of the information can simply be documented, possibly in report or tabular format. As the study area becomes large or more complex, so the use of a suitable computer database can be beneficial for the control and manipulation of data. In either case this should provide details of the coastal characteristics (morphology, ecology, usage etc), the coastal forcing (waves, tides, etc) and coastal response (erosion, accretion), which are used to develop the coastal classification. This can be conceived as a system for managing the information, ie a *Management System*.

As already noted the information on processes and usage provide a fundamental input to the development of a management strategy. Such a strategy must obviously be formulated within the constraints of the legal and institutional frameworks which prevail. It will therefore comprise objectives based on the legal obligations and aims of the Authority. These will be taken forward by policy guidelines which identify both the imposed constraints and strategic decisions which endeavour to make best use of available resources. Whilst these guidelines should assist future planning, the management response options define how the various options can be implemented. Taken together the objectives, guidelines and response comprise the *Management Strategy*.

There are thus three components to the Management Framework namely the *Input*, the *System* and the *Strategy*; as summarised in Figure 7.1. This framework can be initiated and developed to varying levels, as discussed below. It is also important to recognise that it is applicable to the management of any process based system. The Management Framework concept can therefore readily be extended from shoreline management into the realms of coastal management and river basin or catchment management.

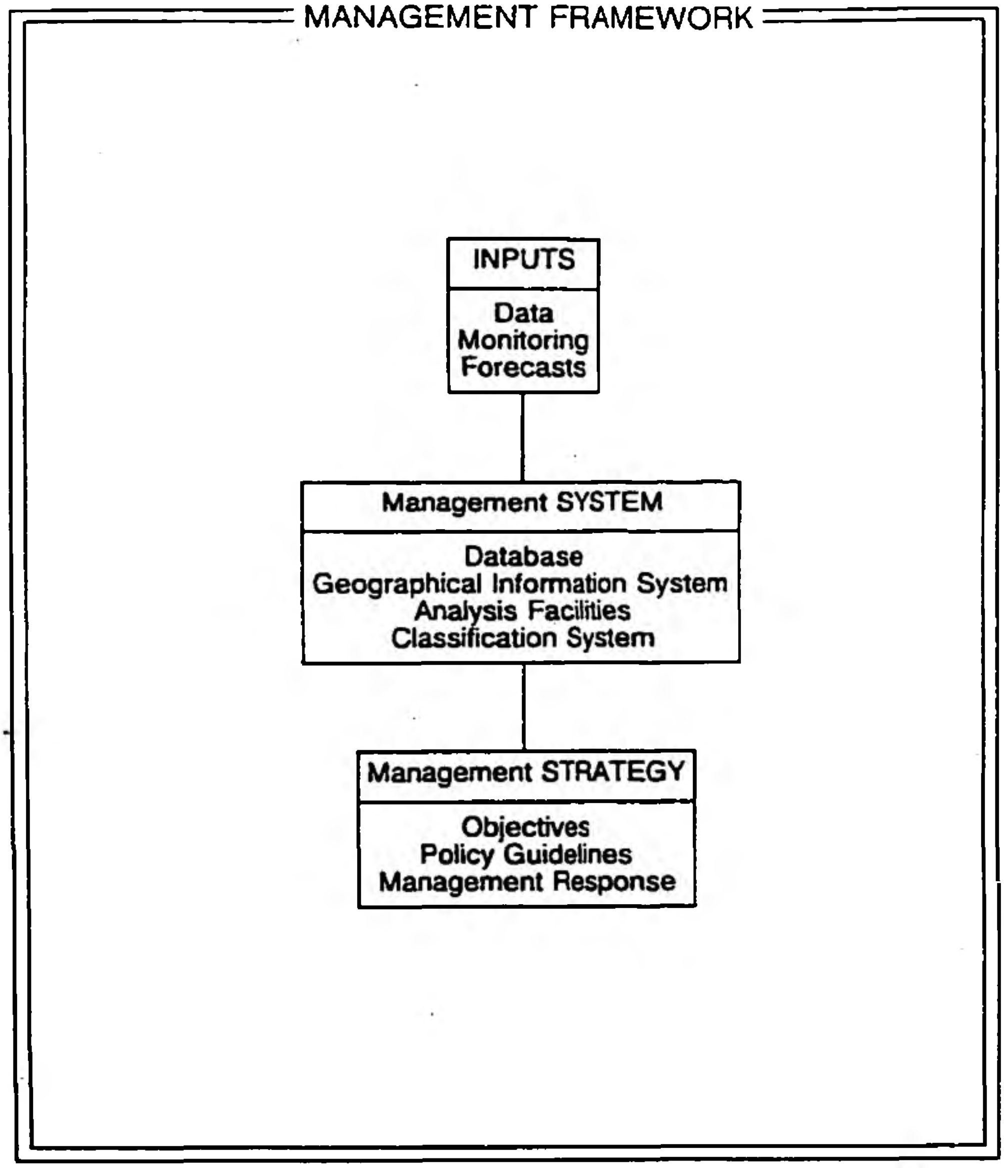


Figure 7.1 - Outline of Management Framework

Initial Management Framework

The underlying premise of the approach is that information can be used to develop an understanding of processes, as a basis for sound management action. A first step is therefore to establish a preliminary or initial view, based on existing data. This acts as a baseline for the future and was essentially the focus of the initial development during the Study. The input was predominantly existing data, a geographic information system was tested as the core of the system to manage information, and the short term management strategy evolved based on a set of objectives, guidelines and response options, Figure 7.2.

Whilst a great deal of benefit is gained from moving to a regional strategy formulated on an improved understanding of the processes, this still does not acknowledge the dynamic nature of the problem. As well as mans actions on the coast, the environment itself is constantly adapting. There is therefore a clear need for some form of feedback loop within the Management Framework.

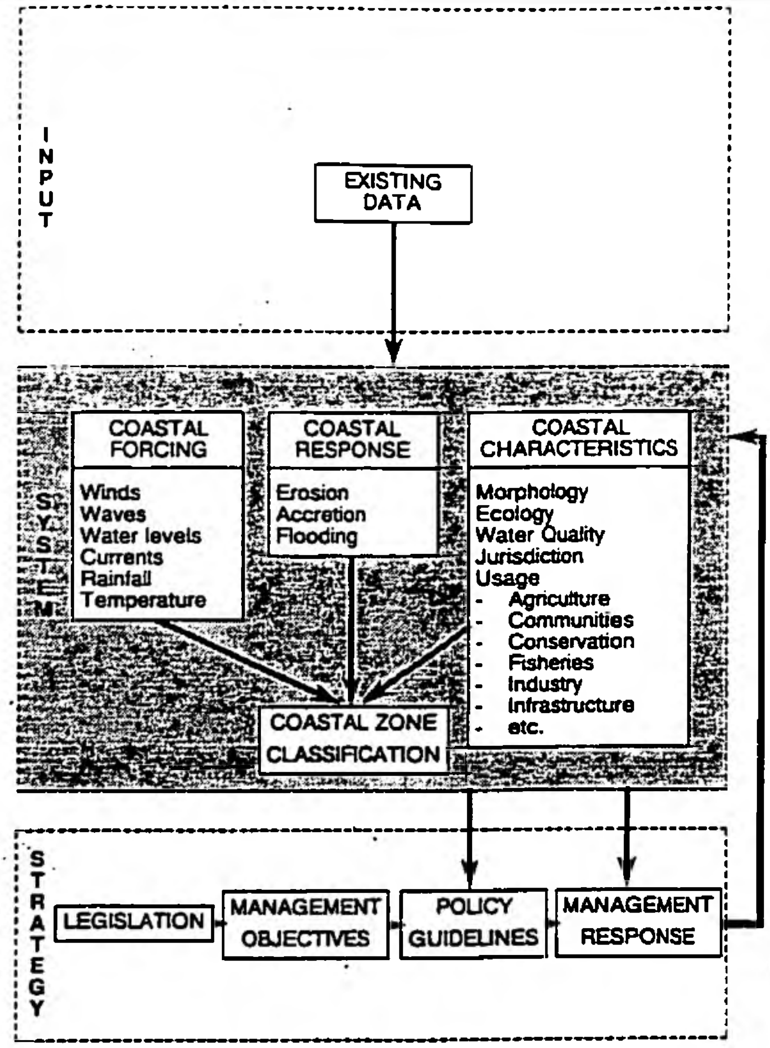


Figure 7.2 - Initial Management Framework

Responsive Management Framework

The next stage of development is to move from the static or single "snap-shot" view of the Initial Management Framework, to a dynamic system. This requires the coastal classification to be updated based on the results of routine monitoring and/or the output of forecasts. As the coastal classification changes, so the management response strategy may be updated and this in turn feeds back by influencing the coastal characteristics (eg a decision to build artificial headlands may alter the littoral movement of sediment and hence change the morphology).

A programme of routine monitoring will provide data on winds, water levels, beach profiles and coastal habitats, which can be processed and reduced to a form that can be added to the *Management System*. The sea defence manager can then use the system to re-evaluate the coastal classification by re-working the interpretive analysis.

In a similar way studies of change can be initiated, such as a change of use, or changes due to forecast sea level rise. These can be carried out as independent exercises and the results compiled in terms of a new definition of coastal characteristics, forcing and response. This is equivalent to the data reduction procedure for monitoring. Thus a new set of parameters can be introduced into the *Management System* and the coastal classification can be re-examined.

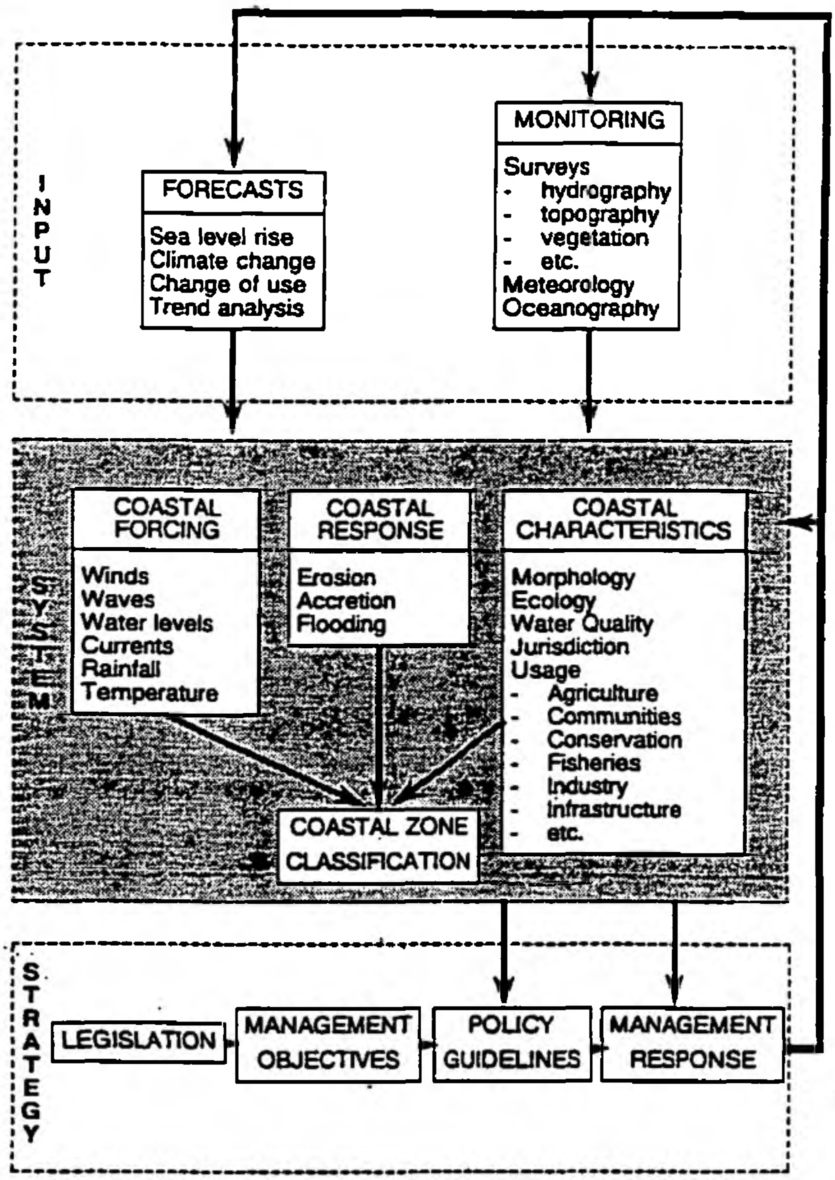


Figure 7.3 - Responsive Management Framework

Both monitoring and forecast facilities are independent of the *Management System* and require changes to components such as coastal response or coastal forcing to be specifically defined. Given a new definition of variables, the *Management System* can then be used to update the coastal classification. Hence this framework provides a means of responding to changes, once these changes have been defined (Figure 7.3). The Responsive Management Framework is proposed as the basis for the future management of the Anglian coast.

8 MONITORING

The effectiveness of any management process is determined by the accuracy of the information upon which decisions are to be based. The management framework being developed under the Study, with the Shoreline Management System at its heart, relies upon a wide ranging and accurate database being established. The information gathered in the Management Study has provided much new understanding of coastal processes. This has already led to a more regional approach to solving the flood defence problems of particular lengths of coast. Unfortunately, these very developments and the changing nature of coastal processes themselves, mean that the database will soon lose its value unless the information is kept current. This means that data on the most essential variables must be updated on a routine basis.

The studies outlined below review the effectiveness of existing monitoring procedures which generate such data, consider alternative monitoring methods which might be adopted and define the form of monitoring programme to be adopted.

Outline of Studies

Beach Profiles
The Authority has over many years monitored beach levels on the Lincolnshire coast, at Humberston, Heacham, Aldeburgh and Tendring. District Councils (Waveney, Suffolk Coastal and Tendring) and Universities (principally UEA) have also collected and maintained records of beach levels over an extended period for sections of the Norfolk, Suffolk and Essex coastlines. This extensive database was brought together by Hydraulics Research Ltd extended to include most recent data records and further analysed. In reviewing the data, profiles for Lincolnshire were corrected to take into account inconsistencies in the zero chainage points from which recorded levels had been measured.

The results of the statistical analysis are somewhat erratic and prompted the examination on the extent and frequency of future survey work (see below). Where the results of the analysis can be considered to be reliable, some clear trends are discernible. When compared with the shoreline retreat data (based on historical Ordnance Survey maps) some anomalies are revealed but in general the results show a consistent indication of beach movement.

Aerial Survey
Aerial photographs provide the coastal engineer with useful permanent records on how shorelines change with time. As properly referenced stereoscopic pairs, they also provide a means of obtaining beach level data. Consequently the technique has the potential to generate level data for the entire length of the coast (ie not in any way restricted to a particular profile line). To evaluate the adequacy of such profiles a comparison between conventional land survey and aerial survey techniques was undertaken. The conclusion reached was that photographically generated level data for

upper beach areas was at least as reliable as data obtained by traditional techniques. Lower down the beach, the lack of any relief was likely to be the reason for inaccuracies identified. Aerial surveys in themselves do not supersede conventional land survey profiling but do serve to complement and extend the range of information available.

Survey Frequency and Accuracy
In addition to the appraisal of beach measurement techniques, Hydraulics Research Ltd used the beach survey database to examine the effectiveness of existing survey practices. Survey accuracy, extent and frequency were all reviewed to determine the most appropriate periods for measurement. This led to the conclusion that there was little to be gained by surveying quarterly rather than half yearly and that the timing of surveys should be mid-summer and mid-winter. On the question of accuracy, the sensitivity tests suggested that great accuracy was not required but that errors should be kept to within ±10cm. The importance of good quality control was stressed and in particular the benefits of prompt analysis of survey data.

Satellite Data
The importance of saltmarshes is recognised both for the protection they afford to sea defences and for their ecological role. Satellite image analysis techniques have been used previously to distinguish between different vegetation types and one of the research studies undertaken under Stage III was to appraise its potential for distinguishing between different saltmarsh species. Comparison of images classified by Durham University with field data obtained from NCC, confirmed the accuracy of the classification for the Wash and Essex marshes. Using a sequence of images, a consistent method of analysis, and the manipulative capacity of GIS, spatial and temporal changes in the distribution of saltmarsh vegetation and intertidal sediments can be both recorded and quantified.

Monitoring Programme
An evaluation of what data should be collected and the drafting of guidelines on what, where and how future monitoring should be undertaken was carried out by Shoreline Management Partnership. Their task was completed in three stages. The first stage took the form of a review of data requirements. Following discussion with the Authority these concepts were developed under a second stage into draft monitoring guidelines. A final stage incorporated further comment from the Authority and the findings of both Hydraulics Research Ltd's and Durham University's studies, establishing the guidelines in their finished form.

Supporting Software
The final area of monitoring development relates to the provision of the software through which District offices are to capture, analyse and present data, in a form that is compatible with the Management System. To satisfy this need and allow certain levels of interaction with the management system, the SANDS Monitoring Software has been developed. The role of this system is described in more detail in overleaf.

Recommendations for Future Monitoring

The focus of the monitoring programme is to capture information on both the forcing and the response. Forcing comprises data on winds, waves and water levels, whereas the response component will include beach change, spit development, cliff losses, vegetation change and, over the long term, changes in the nearshore bed. These data do of course need to be supplemented by a good record of the defences and of the shoreline condition. Consequently, structure and beach inspections are also included within the monitoring programme.

Data Acquisition

As already mentioned, the means by which data should be collected was addressed in a staged review, which included extensive discussion on requirements with Regional and District officers from the Authority. This led to proposals for a programme comprising a range of data acquisition activities, as outlined in Tables 8.1a and b. An important aspect of the programme is that certain data sets, such as winds, will be obtained centrally, processed and then distributed to the Districts. At the same time, other data sets, such as beach profiles, will be gathered on a local basis in each District, processed and stored for local use, whilst also being sent to the centre to ensure that a formal archive is maintained.

Data Processing and Interpretation

Simply collecting this data and archiving it would have little value. One of the main objectives of the programme is to get some fairly immediate feedback on shoreline behaviour and the structural integrity of the defences. This is to be aided by using a piece of software designed to capture, analyse and present the data in an appropriate format. Called SANDS (Shoreline And Nearshore Data System) it has been developed to provide the functions outlined in Figure 8.1. The software is PC based, sitting on an Informix database, and is fully menu driven with extensive help facilities.

The system configuration is summarised in Figure 8.2 and explained in detail in the SANDS User Manual. The principal *core function* of the system is the Diary. This allows beach inspections, structure inspections, beach profiles and miscellaneous events to be recorded in a consistent manner and against a time reference. Supporting *functions* include a map to locate measurement sites and structures and a graphing facility to extract time series data such as winds, waves and tides as well as beach profiles. In addition there are various service utilities to deal with importing data, processing, reporting and archiving.

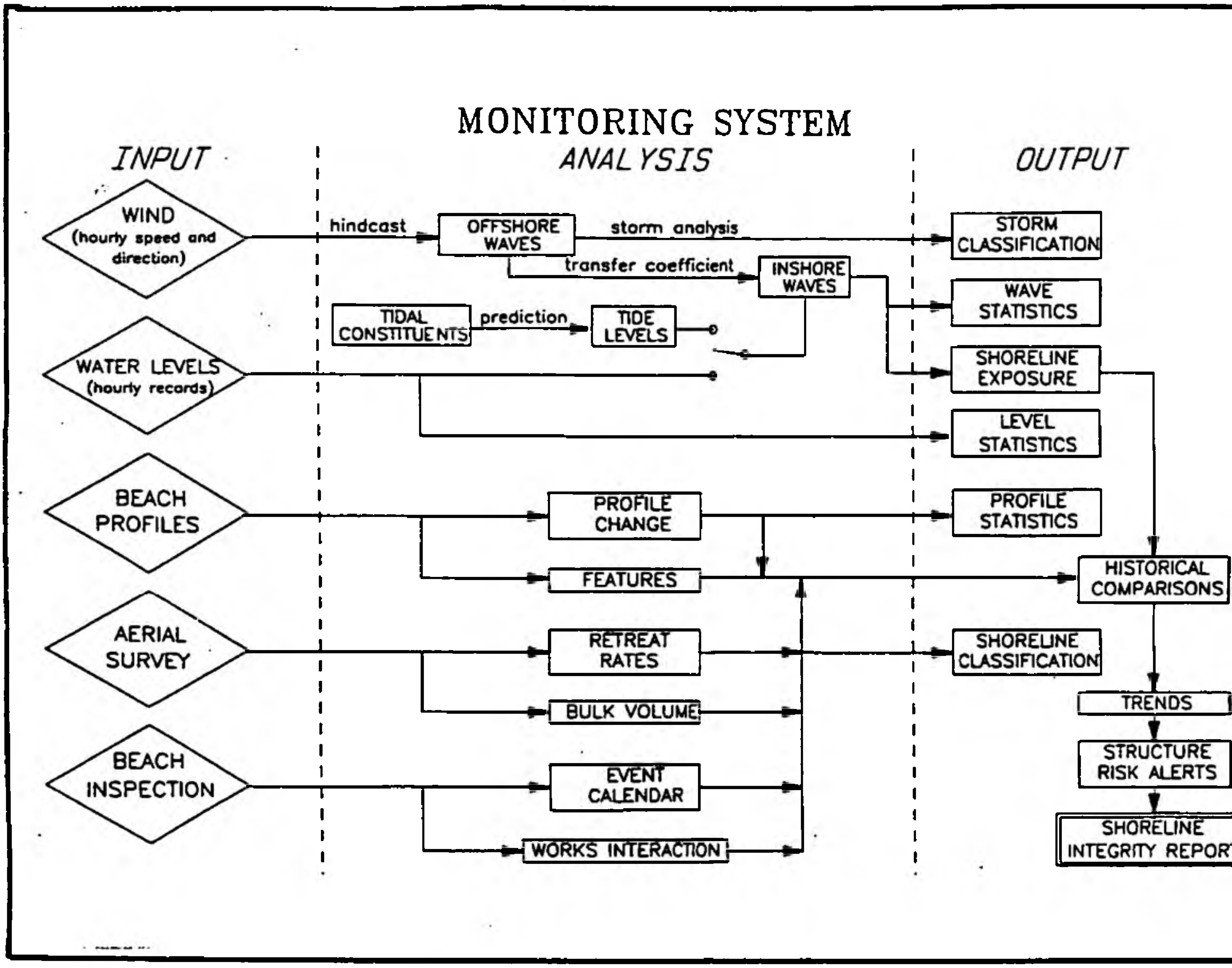


Figure 8.1 - Functions of Monitoring System

Description	Format	Frequency	Analysis	Storage	Use
Wind	Velocity and Direction	Hourly	Inshore wave climate Offshore storm climate	Head Office (analysis summaries to Districts)	To assess beach exposure by considering incident energy over both the upper and lower portions of the beach and to compare this with the long term "typical" values.
Still water level	Height ref. to datum	Quarter-hourly	Harmonic analysis Integration with inshore wave climate calculation	Head Office (analysis summaries to Districts)	Can be used to estimate extreme water levels and provides an input to inshore wave computations. This in turn enables the significance of storm surge to be assessed (particularly in respect of how this may influence beach exposure).
Tidal Prism Assessment	Still water levels and currents (strength and direction)	Annual (with five to ten year cycle times for specific estuaries)	Tidal prism computation	Head Office and Districts	Initially this will enable some basic analysis of estuary dynamics to be carried out. In the longer term it will provide a clear indication of changes in the hydraulic regime.

Table 8.1a - Data Acquisition for Forcing Component

Description	Format	Frequency	Analysis	Storage	Use
Aerial Survey	Photographs (stereoscopic pairs)	Annual (extended to survey saltmarsh every five years possibly supplemented with satellite imagery)	Foreshore/ Backshore levels	Head Office (level data in hardcopy to Districts)	This will help to identify key features in the coastal zone. Quantitatively it will enable the plan form of high and low water to be mapped and provide beach profiles. It will also be valuable in monitoring cliff top retreat and changes (both physical and ecological) within the salt marshes.
Hydrographic Survey	Co-ordinated depths as spot heights and contours	Quinquennial	Time series changes (correlation with exposure conditions and their typicality)	Head Office (hard copies of data to Districts)	This will help to establish the extent of cross-shore movement of sediment and movement within the nearshore. It will also enable the inshore wave and current climates to be refined as and when necessary.
Land Survey	Chainage and depth (on surveyed lines with consistent start co-ordinates and bearing)	Biannual	Time series changes (correlation with incident energy over discrete level ranges)	District and Head Office	Many of the existing profile sections are longstanding and should be continued in order to assess trends and volatility. At the same time this should serve as ground truth for the aerial survey.
Inspections	Manual records	Biannual	Times series changes from fixed-aspect photographs; dip records etc.	Head Office and Districts	The observation of general beach features can be related to processes and events as recorded from the above. The record of the defences allows performance to be monitored against shoreline behaviour.

Table 8.1b - Data Acquisition for Response Component

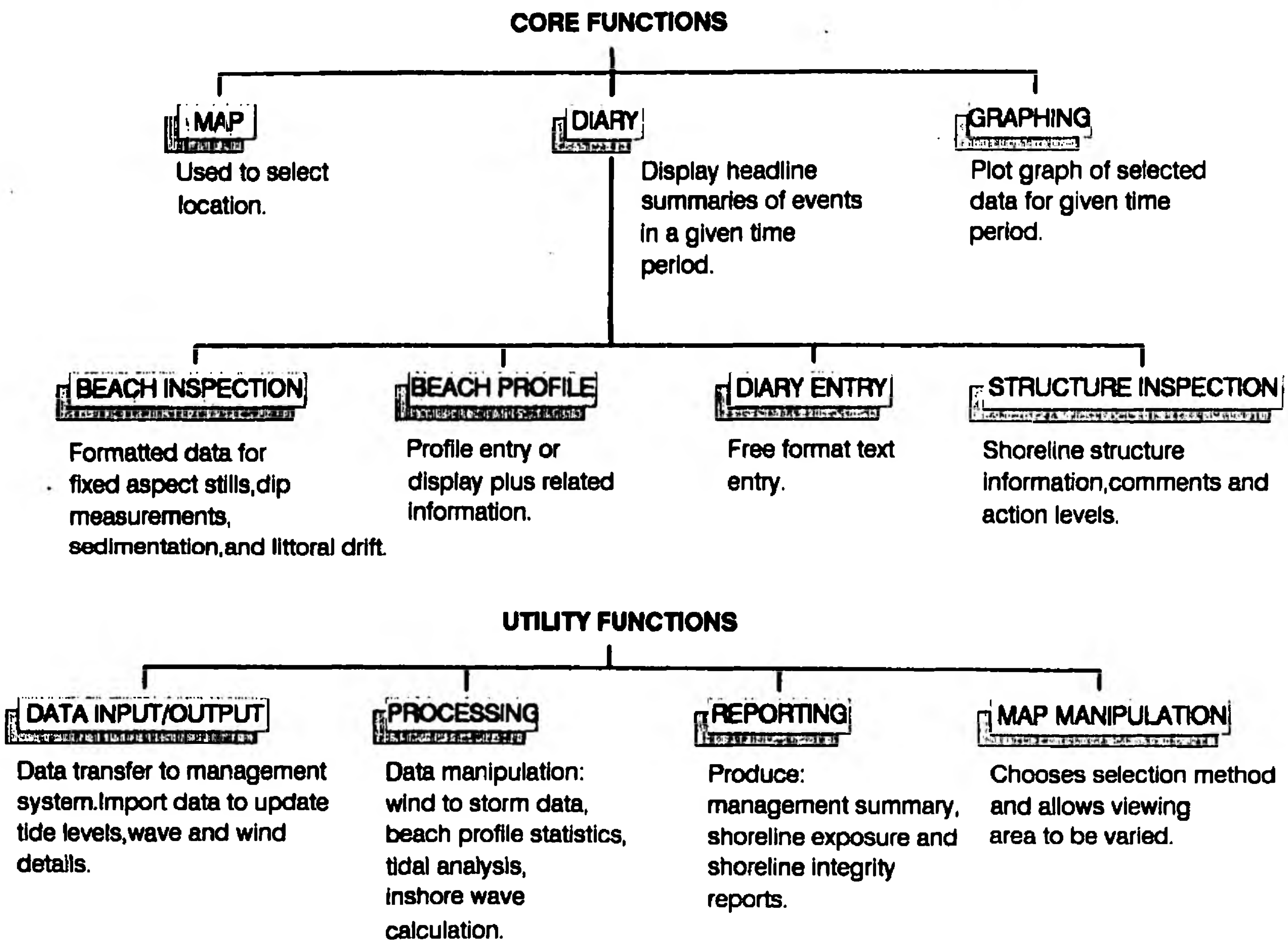


Figure 8.2 - Functions of SANDS

Monitoring Programme Implementation

The data collection and analysis programme described above will require suitable management and organisation to proceed smoothly and successfully. The programme requires regional coordination, district management and specialist input. As a consequence the Coastal Information Officer will provide overall coordination from Head Office, with an officer nominated in each District for local management of the programme.

After the initial set-up there is only a small specialist input associated with shoreline inspections, system review and update. This arrangement should provide a sensible balance for the Authority between predominantly 'in-house' resources and more limited outside specialist inputs.

The implementation of the programme is staged over a two year period, which is outlined in some detail in the Monitoring Guidelines Report. Once established, the programme reduces to a routine annual cycle of work, as summarised in Figure 8.3. Thus whether data is sampled bi-annually, annually or on a five year cycle, the programme has been designed to require a reasonably consistent level of input from year-to-year. The main exception to this will be the five yearly extension of the aerial survey operation to include the estuary saltings.

Benefits of Monitoring

The benefits to be derived from a comprehensive monitoring programme are:

(a) it forms an essential link within the overall Shoreline Management Framework, which ensures that due account is taken of the dynamic nature of the coast in formulating the management strategy;

(b) the move towards "soft" engineering in the form of beach recharge, etc, requires a greater commitment to regular monitoring;

(c) monitoring on a regional basis will enable patterns of change to be identified and is therefore likely to provide an early indication of the direct impacts of sea level rise;

(d) the long term collection of data will provide a sound basis for defining design parameters, as well as the variability of individual parameters. The latter will be needed for any form of risk analysis, required to establish the standard of defence being provided.

As can be seen, much of the data would be needed anyway to meet many of the existing needs of the Authority. The monitoring programme places the activity of data collection on a formal and rational footing, which should ensure that it gives best value for money in terms of data availability to meet the Authority's needs.

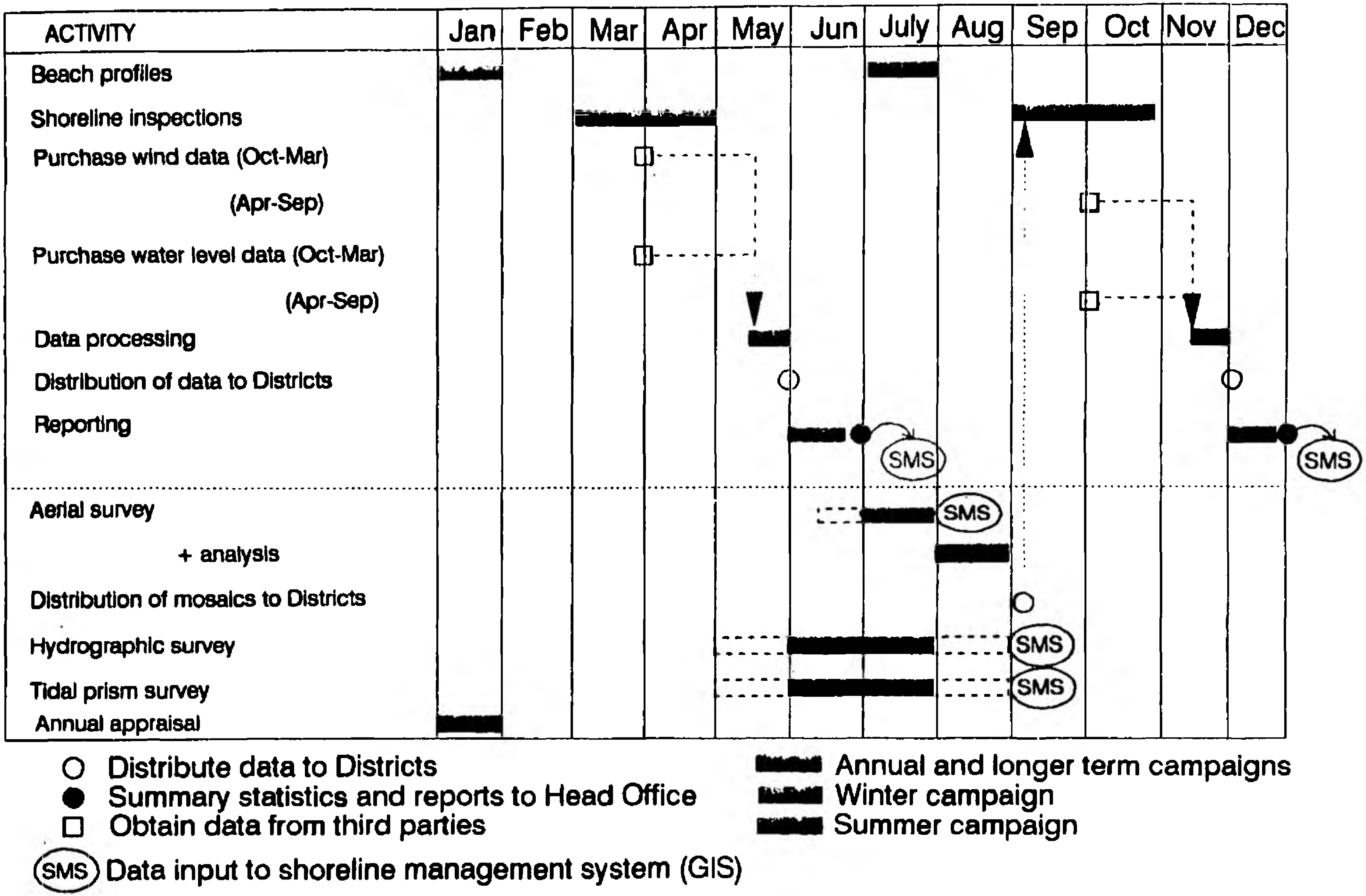


Table 8.3 - Monitoring Cycle

9 MANAGEMENT SYSTEM

The initial pilot study aimed to evaluate the use of a geographic information system (GIS) as a means of controlling and manipulating information. The GIS used for this was PC based and found to have a number of limitations in respect of the overall aims of the project. Nonetheless it established both the analysis potential of the approach, as well as the benefits of rapid access to data that had hitherto been disparate and scattered in a range of organisations and offices throughout the region.

There then followed a review of the Authority's needs and the available systems prior to the formal adoption of a particular system. Work then proceeded to the formal development of both the data model and the system configuration. In parallel with this, much effort has gone into data capture and some very extensive data sets are now available.

The following sections provide a summary of the system development.

GIS Review

Using this approach a number of insights into coastal behaviour were obtained. By looking at the coast as a whole and then moving in to particular localities, the various qualitative descriptions led to many conclusions with respect to local processes. In contrast the quantitative data were best examined as x-y plots, so that the peaks and troughs in different data sets could be compared and related to coastal chainage. Such comparisons led to a number of conclusions about the governing processes on a regional scale.

Based on the experiences gained from the pilot study, the following enhancements were found to greatly improve the value of the GIS for this application:

- access to time series data
- x-y plots of time series
- x-y plots of magnitude against chainage
- statistical analysis facilities
- capture of satellite imagery
- a surface modelling capability

Of these the first four were seen as the most important for the system to be used as an analytical tool. If coupled with an appropriate user interface this provides a system which could be used for routine analysis by those responsible for managing the coast.

In addition to the objectives listed above, the system was to be developed for use in a management role. A part of this was to be the formal integration of the monitoring programme, outlined in Chapter 8, as an essential part of the overall management framework. The focus here was the requirement for a system using existing and new data as an interpretive/management tool.

Application of the system as a management tool envisaged the following uses:

(a) retrieval of information for a specific site;
(b) provision of summary data for planning purposes (eg the regional extent of an attribute);
(c) preparation of graphical displays for educational and public relations exercises;
(d) classification of the coast into management zones;
(e) sensitivity testing of the classification system;
(f) predictive modelling

The uses envisaged are therefore a combination of management style summaries of information and more detailed analytic applications. Furthermore, the intended use of the system as a management tool led to significant emphasis being placed on the user interface and standard of presentation (on screen and as graphic output).

The review of GIS was undertaken in close collaboration with the Management Services Department of the Authority and considered:

- Software Functionality
- Hardware Platforms
- Company Profile
- Users Views
- Customisation, Training & Support
- Costs

A number of systems were examined and the detailed intercomparison led to the selection of Intergraphs MGE product. This system was then adopted in July 1989.

Outline of System

The potential benefits of GIS are becoming more widely recognised and because of this the Authority have themselves initiated pilot studies relating to other core functions. As a consequence shoreline management will, in the fullness of time, be one of a range of applications using the GIS. This has a number of implications for both data model design and system configuration. Most notably to avoid duplication of data, multi-application access has to be provided with suitable controls to ensure data security and integrity.

In accordance with these needs, a data model was prepared for the data sets which will be the responsibility of the Engineering Department. This includes most of the data sets relevant to shoreline management. Some information is however rightly maintained by other departments, notably

- conservation and ecology - Conservation Department
- water quality - Water Quality Department
- administration boundaries - Management Services Department

Whilst a limited model and some data has been prepared covering these aspects, it is envisaged that the responsibility for these data sets will transfer to the source departments.

The approach to system configuration has been similar. The set-up and supporting software has been developed to service applications for a number of departments and, is known as the 'Environment Management System'. The Shoreline Management application is now fully implemented, whilst a number of other applications exist as pilot demonstrations.

The following sections describe the three key aspects of the system development, namely:-

- data model
- data capture
- system configuration

The first of these deals with **what** data is to be included and **how** it is to be included. This is followed by a brief discussion on how the required data was obtained and incorporated into the GIS. The section on system configuration describes how the GIS software has been developed to include a range of additional tools required for this application. A final section outlines the potential for further development and the need for a well defined programme and associated procedures for system maintenance.

Data Model

Whilst the data to be included in a particular application reflects the project needs, **how** it is included needs to take account of some basic rules for the construction of data bases and, to a limited extent, the specific constraint imposed by the GIS being used. This process is formalised through the preparation of a **data model** which documents the format of each variable and how one data set relates to others within the system.

When bringing together large and varied data sets, it is important to ensure that consistent structures are used and that any unwarranted duplication is removed. In particular, if a relational database is to perform satisfactorily, the tables must be reduced to a form which removes unnecessary redundancy, duplication and loops. This is known as normalisation or canonical reduction and can be achieved using well established procedures. Fortunately, within a GIS this is not a particularly onerous task (although still requiring some care) because of the discipline imposed by relating data to specific real world features.

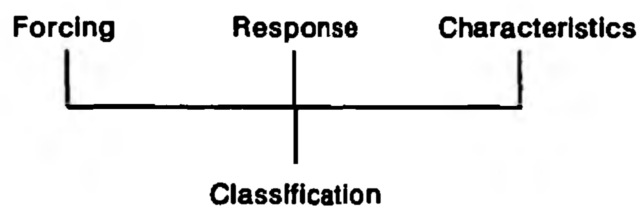
Each vendor has its own terminology for describing how the data is structured within the GIS. The terminology adopted here is that used for Intergraph's, Modular GIS Environment, MGE, the most important terms being defined as follows:

Index	-	a group of categories
Category	-	a group or class of features
Feature	-	a graphical representation of an item
Attributes	-	the data associated with a particular feature

To control the structure of the four groups defined above, involves the interaction of four types of table. The structure of the tables and the links between them are summarised in Figure 5.9. The *feature table* contains the map features and details of how they will be represented graphically, the *category table* defines how the map features are grouped and the *map table* defines the graphics, contained in map files, associated with each category. There is only one of each of these three tables and they are of fixed format, although they can be added to if necessary. The fourth table is the *User Defined Attribute Table* which contains the information to be linked with a particular feature. There are many of these, each uniquely named, and the format of this table varies from one feature to another.

Within this framework the task of data model design therefore reduces to defining the indexes, categories, features and the information to be contained within the attribute tables. As presented above, the model assumes that each feature simply has a single table attached to it. This is not always very convenient and it is often better to introduce other tables which are linked by an attribute common to both tables. Where this is the case some data reduction may again be necessary.

As a stand alone model for shoreline management, the various categories needed to develop the coastal classification can be grouped into three, viz:



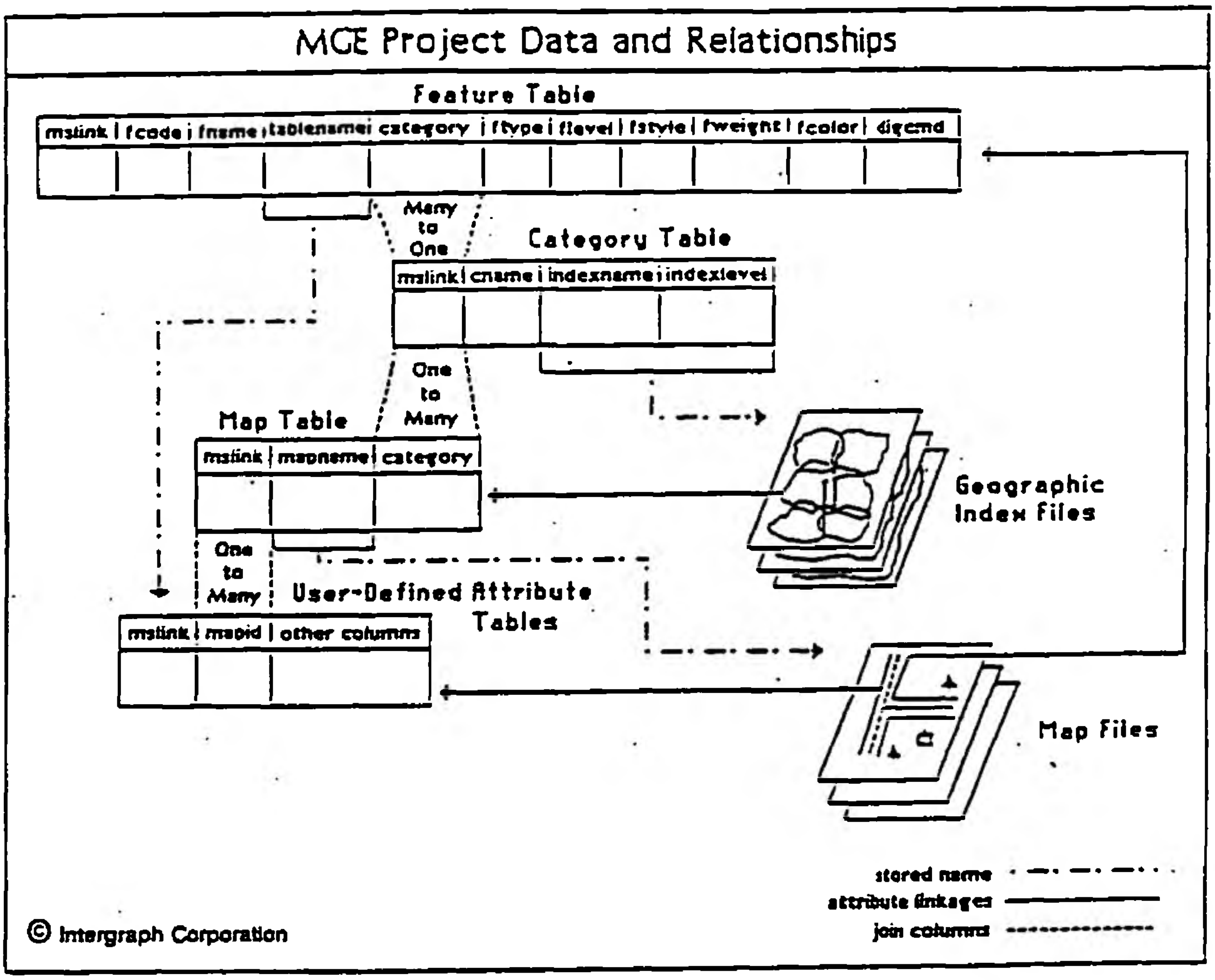
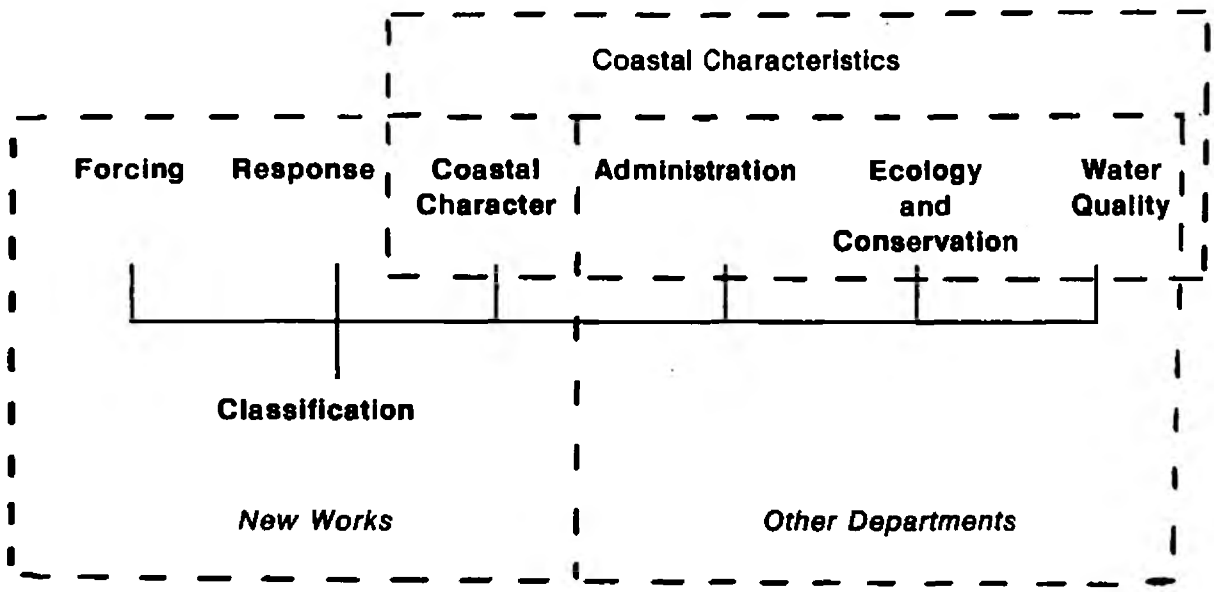


Figure 9.1 - Principal GIS Tables

Whilst information covering these three groups is the overriding requirement, there is also a need for the model to be consistent with the control of data sources within the Authority. As a consequence there is a need for some sub-division, particularly in respect of coastal characteristics. The resulting grouping of categories produces the following Indexes:



The distribution of data is more explicitly defined by considering the categories within each index, as summarised in Table 9.1. Most of the information required falls under the control of New Works but access to the other data sets will need to be established via the relevant departments. Furthermore some of the data sets under the Character Index are there because this was the most expedient way to establish the model. As the use of GIS develops within the Authority, it may be that responsibility for certain data sets can be transferred. For instance hydrogeology has been included to give a basic definition of surface and ground water catchments (based on BGS maps). A much more detailed description is available within the Water Resources department and this would be a better source as and when it has been captured.

Within each category there is a set of one or more features. Where appropriate a feature is associated with an attribute table. This part of the model tends to vary widely depending on the nature of a particular category of information. Two examples are shown in Figures 9.2 and 9.3. The first shows the coastal works categories where there are many features and some interconnection between them. By way of contrast, Figure 9.3 shows the water levels category with only two features but each with a hierarchy of attribute tables.

Engineering Department				Other Departments		
Forcing	Response	Character	Classification	Admin	Ecology	Water Quality
currents rainfall river discharge temperature water levels waves winds	beach profiles land subsidence sea bed movement shoreline movement	agriculture amenity coastal works estuaries geology hydrogeology industry infrastructure military morphology photographs sedimentology shore ownership topography	coastal strips process units policy guidelines	24/5 Survey admin boundaries OS-10,000 OS-50,000 raster maps	bird counts bird feeding areas coastal flora conservation sites fisheries sea banks	sampling points

Table 9.1 - Summary of Categories in the Shoreline Management Data Model

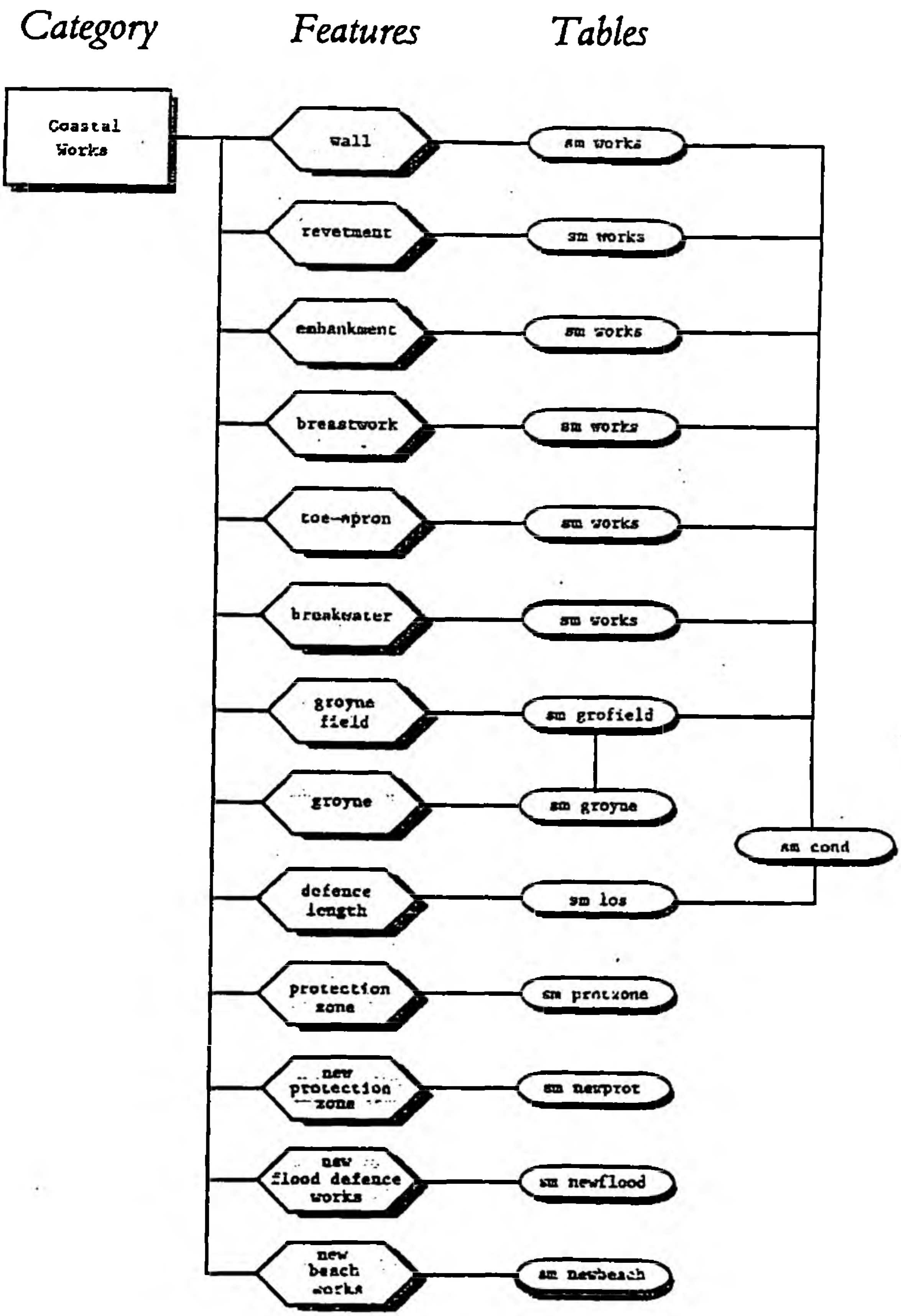


Figure 9.2 : Model for Coastal Works

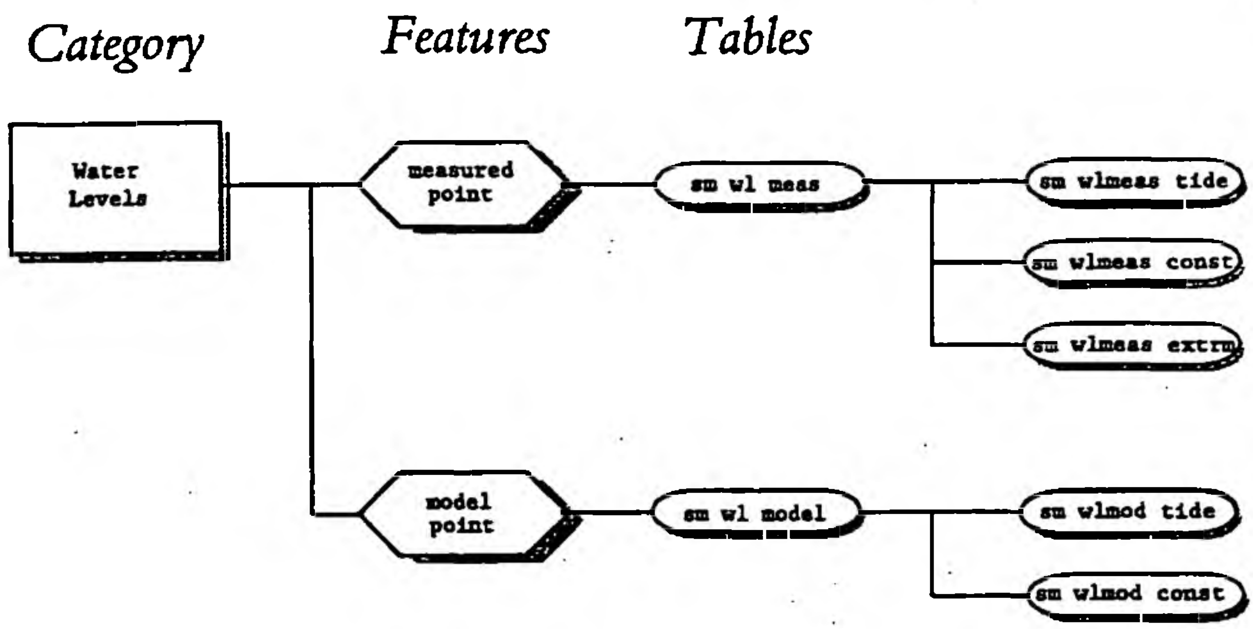


Figure 9.3 : Model for Water Levels

In designing the data model, particular attention has been given to the time domain and the coastal location. A number of techniques have been used, to take account of attributes and graphics which can change with time. Coastal location requires features to be related to their location on the coast in an alongshore sense. This allows different features and attributes to be related to one another based on their "position" on the coast. Again this is achieved using appropriate constructs within the data model.

Clearly a detailed explanation of all the above aspects is required for each category. As a first stage a draft model was documented and submitted to the Authority for approval. This was then used as a basis for implementation, although some revisions were necessary as the model evolved. The resultant data model has now been comprehensively documented in the Shoreline Management Data Model. This includes an outline of each category, details of data sources, update requirements and type of update, and definition of the contents of each table.

Data Capture

The map data has been captured using a digitising table, whereas much of the digital data was ported directly using load routines written specifically for each data set. Much care has been exercised in checking each data set for graphical and attribute completeness, as well as the integrity of the links between the two. This has been aided by the use of certain MGE utilities for checking features and database links. Extensive checks have also been carried out on the attributes themselves, most particularly for the coastal works data set which was passed through several independent screenings.

In certain cases some interpretation has been required either during the data gathering exercise (eg flood protection zones) or in translating the data into representative graphics in thͻ GIS (eg coastal geology). To ensure that these considerations are not lost, relevant notes have been included in the Shoreline Management Data Model.

Finally there are a number of constraints imposed by the conventions within MGE. Most notably polygons and line work cannot overlap on a single layer if they are to be used for spatial analysis, and it is better to keep feature types (points, lines, polygons) on separate layers. These and other detailed requirements for implementation are also documented in the Shoreline Management Data Model.

System Configuration

As already mentioned, the core system has been designed to deal with a range of applications in a single environment. The shoreline management application sits within this, and has been customised to provide some utilities which are specific to the data sets available.

(a) Environment Management System - EMS

The EMS product comprises a standard set of utilities, together with utilities designed to meet the needs of each individual application. By entering MGE via EMS all the appropriate environment variables are automatically set so that the user has access to the relevant utilities for the application selected. If MGE is entered directly then the user only has access to the EMS utilities and not any application specific tools. By running 'ems' the following screen appears:

The user selects the application he requires as the *Active Project* from the list of options. Initially all the files required will be resident on the user's workstation and only the database will be remote. In future it is planned that project files (design files, etc) will either be distributed around the network, or on a central server.

After an application has been selected, the standard MGE Project Manager form appears. A map or area is selected using one of the options available to enter the graphics environment. Once loaded, the user has the full range of available utilities. In addition there are application buttons (top right of screen) for EMS and the *Active Project*. Under the EMS menu button are the following utilities:

views - customised views of the study region which allow the user to rapidly move to a particular area

ref file	-	similar to the Microstation menu for manipulating reference files except the 'attach' option brings-up a form from which the user can select a design file
database	-	some standard database query utilities, plus a geodatabase locate function which handles look-up tables and join tables
fence	-	a selection of ways to place a fence round an area
x-y graph	-	allows various forms of graph to be generated displayed and manipulated
chainage	-	assigns a coastal chainage for a selected feature to the associated attribute table
photos	-	enables raster scanned photographs to be displayed
graphical attributes	-	picks-up and manipulates, sketches, annotated cross-sections and the like
statistics	-	allows basic statistics to be computed for the results of a user defined database query
data model	-	tools to generate data model flow diagrams
plots	-	access to standard plot utilities.

(b) Shoreline Management System (SMS)

The application developed for the Sea Defence Management Study has been called the Shoreline Management System, with the acronym SMS. All tables, feature codes and design files which relate to this application have been prefixed by 'sm_'.

Many aspects of the shoreline management model design make use of standard features within EMS. For instance the coastal works have a label wherever a cross-section has been prepared for a particular defence. This can be retrieved using the 'graphical attribute' facility. There are however certain requirements which are specific to the application. For SMS the following menu buttons have been developed:

display	-	this allows the user to explore the different data sets by simply switching them on and off using a set of buttons denoting each data type

graphs - allows graphical displays to be produced based on information held in the database. Each option is specific to a particular type of data and produces a customised form of graphical display

reports - enables the user to fence an area and produce a report. With the present configuration the reports are written using Informix and are specific to a particular query

models - these manipulate attributes in the database according to some pre-defined algorithm. A utility to manipulate the coastal zone classification data has been incorporated. Future models might include mapping of a hazard zone based on the linear projection of retreat rates, overtopping for a given storm condition, and estimates of levels of service.

Future Development and Maintenance

The model that has been established is very extensive, containing a wide range of data. It has been developed, via a pilot system, to a full implementation. During the analysis phase of Stage III the ability to manipulate data has been thoroughly tested. What is now required is an extensive evaluation in a management role. This will undoubtedly highlight aspects which could be improved, either in terms of work flow or in the way specific information is handled. Generally these problems can be overcome by designing suitable utilities or refining the data model.

The capabilities of GIS software continue to advance rapidly. Even during the course of the project there have been some significant enhancements. Over the coming year new additions are likely to include improved file management and security, a new customisation language and the ability to write database reports using the relational interface server (RIS) rather than the underlying database. Each of these will need to be accommodated if the system is to develop and make maximum use of the tools available to improve efficiency.

The other aspect of using the system is maintenance. On a routine basis this will require procedures for checking out, modifying and checking-in files, as well as taking a back-up copy of the system on a regular basis (at least once a week). Updates will also need to be carried out according to defined procedures. The frequency of updates and type of update is recorded in the data model. An annual programme will be developed to schedule this work. This schedule will also need to take account of the requirements of the annual monitoring cycle, which will run in parallel with specific inputs to SMS as identified in Table 8.3.

It should be stressed that a GIS is not like a spreadsheet or simple PC database. The software is substantial and with the wide range of data that has been captured, this is now a large system. A significant investment of time and effort will therefore be required if its scope is to be realised and subsequently maintained. For the concept of a Management System to work as the central component of the Management Framework, its use and application to specific problems must become an integral part of the Authority's routine operations. Only then will the benefits of this development be fully realised.

10 MANAGEMENT STRATEGY

The final component of the Management Framework is the Strategy itself. This must be formulated to function within the prevailing legal and institutional frameworks. Starting with clearly stated aims and objectives, the strategy establishes guidelines on policy issues and then sets out appropriate response options; acknowledging both the natural processes and the constraints imposed by the guidelines.

Aims and Objectives

The legal powers for the flood defence function are provided by the Land Drainage Act, 1976 as amended by the Water Act, 1989 (The Act). The overall duty of the Authority is one of general supervision over all matters relating to flood defence, including

(i) surveys of defences
(ii) maintain existing works
(iii) improve any existing works
and (iv) construct new works.

Under the Act, the Authority arranges for all flood defence functions to be carried out by a Regional Flood Defence Committee (RFDC). Within the Anglian Region, Local Flood Defence Committees (LFDC's) have been set up under the Land Drainage Act, 1976, Section 4. The necessary powers are delegated to the LFDC's and the role of the RFDC is to secure a degree of regional consistency.

The role of the LFDC's include a requirement to identify what works are to be done, prepare a programme and approve the monies, which must be raised locally, to fund the programme. Money raised by an LFDC must be spent on flood defence functions in or for the benefit of the District.

The powers to undertake work are permissive and the LFDC's must decide what should be done. In general this is governed by whether it is reasonable to maintain, improve or create works and this is adjudged on whether a proposal is economically worthwhile. This is of course subject to the necessary resources being available. As a consequence proposals are ranked based on need and urgency so that works can be carried out in an appropriate order of priority.

This therefore is the legal and institutional framework which governs the provision and maintenance of flood defence. Within this framework the prime aim of the Authority is to provide effective defence for people and property against flooding from rivers and the sea. In order to achieve this somewhat open ended goal it is appropriate to define what is to be achieved in terms of more measurable shorter term objectives.

The objectives which have been agreed with the Authority for the Shoreline Management Strategy are set out in Table 10.1 These seek to achieve the aim by way of appropriate use of technology to provide defences, making best use of available resources and taking due account of other interests within the coastal zone. Any guidance on the range of policies which could be adopted and the appropriate management response must be consistent with these objectives.

AIM
To provide effective defence for people and property against flooding from rivers and the sea.
OBJECTIVES
(i) To implement a sea defence management strategy that ensures the integrity of sea and tidal flood defences
(ii) To ensure that such plans are based on sound economic and technical principles and in turn provide the best investment of public money
(iii) To promote and make use of research and development into future flood defence needs arising from climate change, or improved practices and encourage the development of Information Technology as appropriate.
(iv) To protect and where works are intended identify opportunities for enhancement of landscape, amenity and conservation.
(v) To liaise with and develop close working relationships with other responsible coastal authorities and organisations, to understand each others objectives and responsibilities, to resolve conflicts, to promote public awareness and understanding, all as necessary to work towards an integrated coastal management approach.

Table 10.1 Management Aims and Objectives

In developing a strategy within the existing legal framework it is necessary to consider how this might be limited or constrained as a consequence. One obvious dichotomy results from processes acting on a regional scale, whilst coastal works are provided on a local basis, either in the form of sea defences as proposed by LFDC's, or coast protection works which are the responsibility of the Maritime Councils. Within the Anglian Region this is mitigated by the relatively large proportion of coast which falls under NRA control and the liaison now taking place between responsible authorities. There is therefore reasonable scope for a strategic view. Furthermore, providing a broad view is taken by LFDC's with respect to the need for funds to be spent for the benefit of the District, the division of the region into Districts (which are not necessarily compatible with the processes) is unlikely to result in undesirable fragmentation. This control on the spending of funds also influences the implementation of regional standards and guidelines which may be proposed by the RFDC.

Even though much of the Anglian coast is low lying and as a consequence within the Authority's jurisdiction, there is a need to interface closely with local planning. The two most significant influences in this context are developments within zones which are or may need to be protected by sea defences and the construction of coast protection works to reduce cliff erosion. The former can result in a rearguard demand for defences which may be inappropriate in the context of regional processes. By contrast, the latter may limit the supply of sediment to the nearshore system and so deprive downdrift beaches of natural replenishment. At present the Authority is a Statutory Consultee under DoE Circular 17/82 for applications affecting flood defences. The Authority also endeavours to influence local planning issues, but the Planning Authority, or DoE, makes the final decision on such matters.

Finally with the desire to consider a flexible approach to the provision of sea defences, rather than simply maintaining a fixed line, there is a need to consider the Authority's scope with respect to existing defences. The main concern is whether having provided a defence, this can be moved or allowed to decline in standard. The legal position seems reasonably clear in that the powers are permissive and there is no duty imposed on the NRA to construct, or to improve, or even to maintain. Whilst this may need to be qualified as a consequence of other interests such as nature conservation, recreational use, navigation, fisheries and the works of statutory undertakers, there is clear scope for the Authority to make best use of available resources without being obliged to provide defences in any particular location or to any given standard.

Policy Guidelines

Whilst sea defences are only ever provided to meet a human need, it is essential that the planning of defences takes due account of other coastal interests. Having determined a need for defences at a particular location, it is necessary to establish the extent and standard to be adopted as a precursor to deciding the type and form of the defence. Equally, the factors which influence the extent and standard need to be considered on a regional basis if defences are to be provided on a consistent basis and limited resources are to be used to best effect. As noted in the previous Section, however, any policy which may be developed on this basis cannot be imposed within the present institutional framework and will require consultation and liaison.

This therefore leads to the concept of Policy Guidelines. These seek to provide guidance on what policy options should be considered at a particular location and are developed using a set of rules applied on a regional basis. As such the Policy Guidelines aim to provide a framework for reviewing the levels of service provided by the defences and balancing these with protection requirements.

In doing this there are two principal considerations; the *location* of the defence and the *standard* of the defence. The first defines where, relative to the "shoreline" and the potential flood zone, the defences could be provided, together with the extent of defence required. The second defines the level of protection to be provided. They are not independent and on a regional basis it is only possible to define the range of options to be considered. More detailed, site specific studies are needed to establish the optimum combination of *location* and *standard*. For instance there may be a choice between maintaining the existing line of defence to a standard below the target, or moving inland and providing a defence which meets the target standard. The final choice will depend on the cost and benefits associated with each option, coupled with local preference and the ability to obtain funding.

The Policy Guidelines have been developed as a data set which provides a regional summary of the range of options to aid further discussions. Eventually this will provide a basis for decision making and the setting of policy. In order to formulate the policy guidelines the two primary considerations of *location* and *standard* have been sub-divided as follows:

Location - stand ground
- move

Standard - maintain
- regrade

As already noted the various options can be implemented in different ways, and *location* and *standard* options can interact. These are summarised in Figure 10.1, for the full range of options that have been considered. Wherever the *location* options to standground (1.1) or move seaward (1.2(i)) are adopted, it is assumed that the *standard* option should be maintain (2.1). Where there is scope to optimise the defence (1.2(ii)), usually by straightening out the line of the defence to reduce its overall length, then when making the change *the standard* of defence would generally be maintained. There may however be an option to leave the defences on the present line and regrade the *standard*. When moving landward there are options to move inland (1.2(iii)) and move to high ground (1.2(iv)). The first of these provides for a new line to be adopted which is within the flood zone. This may be appropriate to cope with an eroding shore or to avoid having to provide defences which would be subjected to high wave and/or tide conditions. The second option is a move to the back of the flood protection zone so that sea defences, in their legal sense, are no longer required. For both of these options, the alternative is to regrade the defences on the existing line and this would usually be a regrade downwards (2.2(ii)).

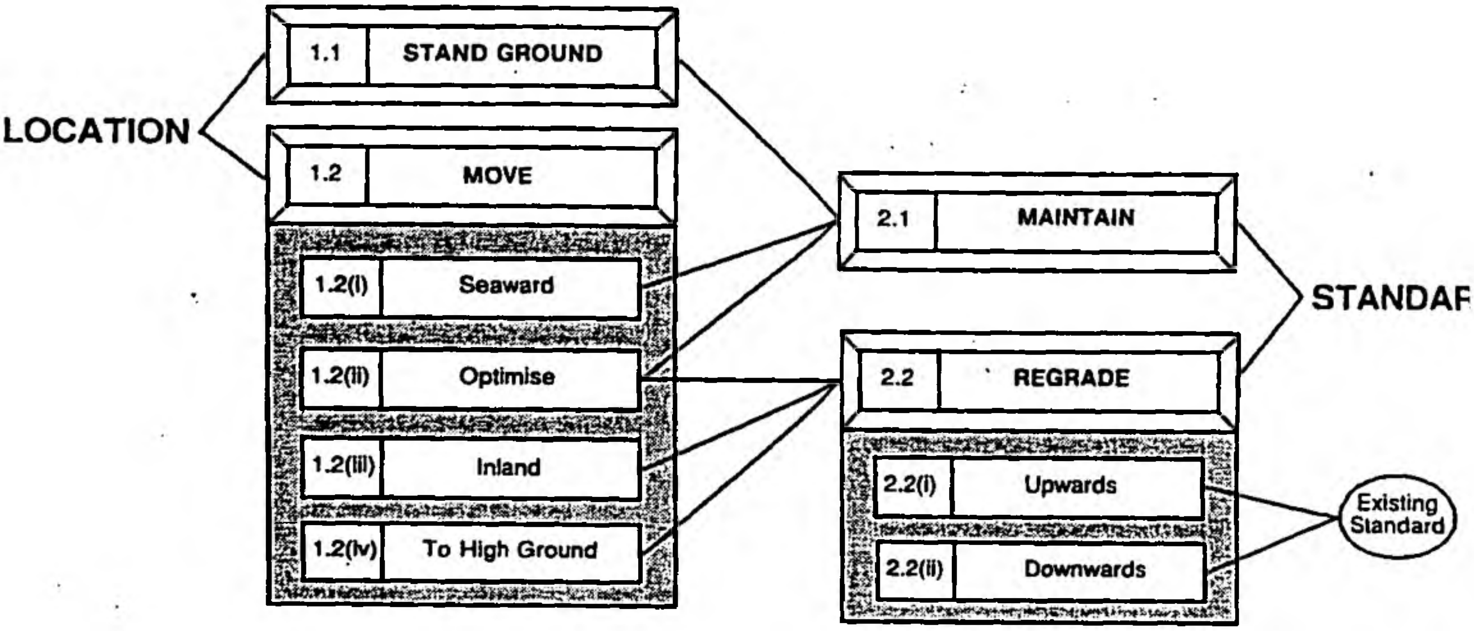


Figure 10.1 - Policy Guideline Linkages

The database contains details of the infrastructure and other interests used to formulate the Policy Guidelines. This enables rapid manipulation of the option so that changes in conditions or local requirements can be accommodated. The interactive nature of the Policy Guidelines thereby provides a flexible framework to guide future planning and the development of new schemes.

The various options are illustrated in Figures 10.2 and 10.3, using a hypothetical stretch of coast. In Figure 10.2, the *location* options which fall within the maintain *standard* option are shown. This is complemented by Figure 10.3, which shows the *location* options for which there is an alternative of regrading the *standard*, rather than moving the defence.

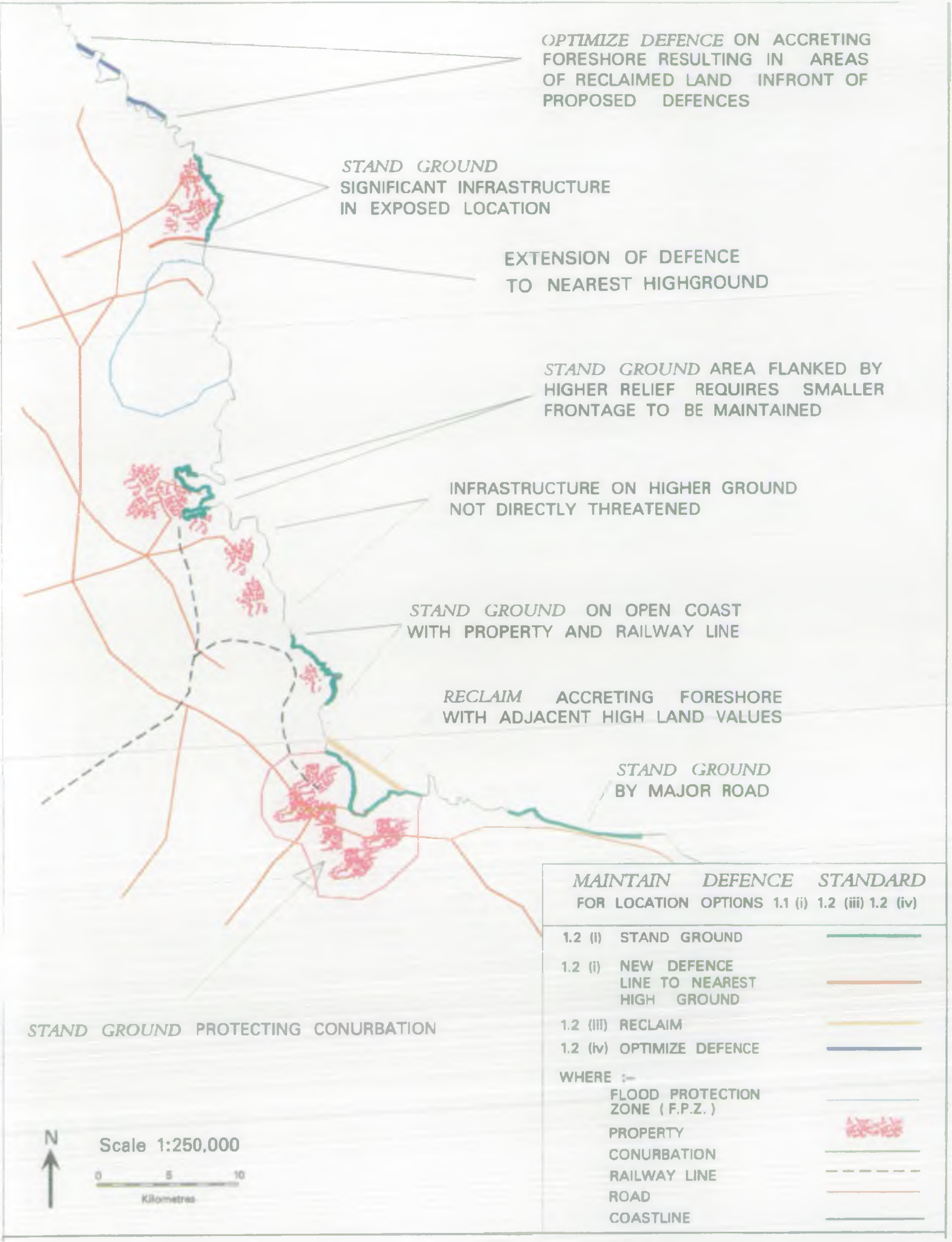


Figure 10.2 - Maintain Defence Standard

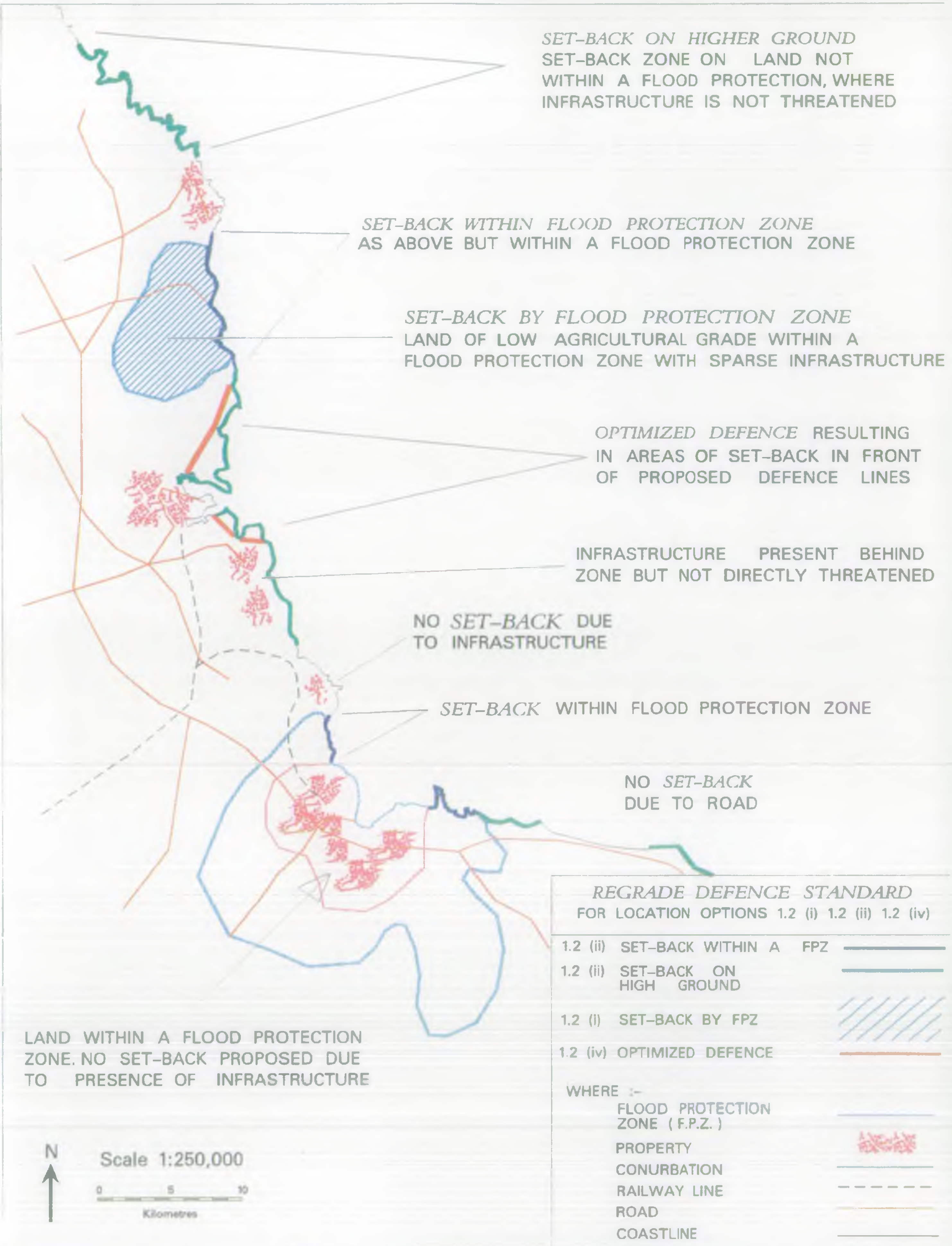


Figure 10.3 - Regrade Defence Standard

Finally, there is a need to recognise the limits of the issues considered in developing the Policy Guidelines. Whilst these have embraced most human interest on the coast, conservation needs and in particular the constraints imposed by the presence of sensitive ecological communities or habitats have not been considered in detail. This is because designated sites cover a large proportion of the Anglian Coast and almost all of the NRA's frontage (the only exceptions being the central portion of the Lincoln and Clacton frontages). Beyond the fundamental requirement to take full account of designated sites, the conservation needs often require extensive study and consultation. In part this reflects conflicts that exist within the natural environment, such as between morphological and ecological change. This necessitates a choice between allowing natural change, and so risk losing a particular habitat or coastal form, or trying to preserve the status quo by imposing artificial conditions. The problem is exacerbated by our limited knowledge of how ecosystems work, so making it difficult to establish sound management guidance. One approach for management purposes is to define various forms of suitability and vulnerability indices, but this practice is currently much disputed by conservation bodies. Thus, whilst the requirement to enhance conservation is identified as one of the Management Objectives, only the strategic level of designation can be taken account of within the Policy Guidelines.

Response Options

Considering the problem of shoreline management without reference to the legislative and institutional framework, the range of response options could include

- **regulation** - to control certain coastal activities (eg removal of beach material or dredging in particular locations);
- **planning** - to limit development in areas that are vulnerable to flooding or erosion;
- **education** - to make the public more aware of the sensitive and vulnerable nature of the coast and hence more receptive to appropriate management methods;
- **engineering** - to monitor, modify and develop new means of shoreline protection as appropriate;
- **system management** - to protect and rejuvenate natural habitats and landforms which provide a valuable natural resource and are often a responsive form of stabilisation on otherwise vulnerable shores.

This range of options would provide for a highly flexible approach to Shoreline Management, although it does require extensive consultation procedures to ensure that the needs of the many interests on the coast are properly accounted for. With the legislative and institutional constraints already outlined such a range of options could not be adopted by the Authority of its own accord. As a consequence Management Response options are essentially limited to engineering and system management.

Considering the engineering and system-management options in more detail, the possibilities include:

- **Monitor** - where no intervention is planned there will always be a need to monitor coastal response
- **Reinstate** - where the existing form of defence is appropriate and should be maintained. This comprises:

  Option (a) beach renourishment/recycling
  Option (b) saltings regeneration
  Option (c) structural reconstruction

- Modify - make some adjustment to the existing form of defence either to improve performance or reduce any negative effect. This comprises:

Option (d)	removal of natural features or structures
Option (e)	structural alterations
Option (f)	stabilisation (cliffs/dunes/saltings)
Option (g)	nearshore intervention (dredging at inlets and banks/sand bypassing
Option (h)	remove or control cause of degradation (reduce pollution/limit access eg using dune fences)

- Create - install new structures which can work within the prevailing regime to improve the overall defence system. This comprises:

Option (i)	embayments (offshore breakwaters/headlands/groynes)
Option (j)	linear protection (revetments/embankments/seawalls)

The option to *monitor* applies to the whole coast and so has not been mapped. This option can be considered a minimum level of shoreline management.

The active processes have been mapped into coastal units which provide an appropriate sub-division for a process based management strategy. On to this is superimposed the constraints due to existing usage, as defined by the Policy Guidelines. Together, these guide the selection of a suitable range of Management Response options for each coastal unit. The final choice will depend on the outcome of a more detailed study at a particular site, together with the appropriate environmental appraisal and benefit - cost justification.

Implementation

The Management Strategy outlined is based on a combination of objectives, policy guidelines and management response options. These are not seen as defining immediate requirements for the capital programme; although the definition of existing defence standards may help to prioritise the need for new schemes. The Strategy essentially provides an initial point of reference when considering a new scheme.

There are clearly some constraints on the scope for implementation. The strategy has been prepared for the whole coast without regard for jurisdiction. Thus, there are units which are not subject to flooding and do not fall within the Authority's remit. The most notable of these are the lengths of cliffed coast, particularly in Norfolk and Suffolk. For the present these provide an important supply of material to the beach. Quite often this supply is transitory and quickly moves downdrift or offshore. Even as new schemes are adopted which reduce the volatility and long term migration of material, it will be necessary that supply from the cliffs is maintained. This will only be possible by negotiation and agreement with Local Authorities.

As discussed in the previous Section, the issue of conservation requirements will also have a significant impact on future schemes. Here again the constraints imposed by the various site designations will need to be evaluated during the design stage in conjunction with the now well established consultation procedures.

Whilst the strategy takes a regional view and seeks to rationalise the approach to providing sea defences, this may not match local needs. As identified at the beginning of this chapter it is the prerogative of the Local Flood Defence Committee's to determine what works should be undertaken. They may well choose to take a longer term view and promote schemes to protect land which under current assessment rules (based on benefit-costs) could not be justified.

Finally, the problems within the estuaries do not appear to be entirely coastal related. The significant correlation between river discharge and health of the marshes stresses the need for a holistic view to management. This will therefore require close co-operation with the relevant departments within the Authority, both to pursue the question of cause and effect, and in order to determine the appropriate ameliorative action.

CONCLUSION

The problem of managing such an extensive and varied coast in a consistent manner has prompted a unique regional study. From the outset it was recognised that any strategic approach to shoreline management required a fuller understanding of the coastal processes and in particular the causes of foreshore recession and lowering. The Study was completed in April 1991 at a cost of £1.65m.

The components of the Study have been diverse and wide ranging. In the early stages of the Study many of the initiatives were exploratory in nature, seeking to evaluate various techniques. Having established a valid methodology, this has subsequently been developed in some detail through extensive field work, some sophisticated and highly advanced modelling work, and the configuration of a GIS to control and manipulate the data. These various elements are all essential components in preparing a Management Strategy. In order to advance and evolve this strategy the data base must now be kept up-to-date and for this reason a regional monitoring programme has been adopted.

The information now available provides a comprehensive platform upon which to develop a regional strategy. This will steadily improve as the monitoring programme proceeds and supplies a continuing feed back on coastal change. Now that this information is being stored in a rational and coherent basis via the Management System, it is available for future analysis and is already meeting day-to-day design needs. As such the components of the Management Framework are becoming an integral part of routine operations within the Authority. This change in philosophy from site specific to a more regional approach, supported by the Framework now in place, means that Shoreline Management is becoming a practical reality.

Further work is planned within the Research and Development programme of the NRA, covering a range of subjects including saltings, wave forms tidal prisms and extreme water levels. In addition the liaison with Planning Authorities, the Maritime Councils, Conservation Bodies and other interest groups will play an essential part in formulating future policy.

All these activities combine to make the Authority more effective and efficient in its role of projecting people and property against flooding from rivers and the sea. Additionally the Authority is now well equipped to make a positive contribution to the wider needs of coastal zone management.

GLOSSARY

Coastal characteristic - a distinguishing feature of the coast, either natural or human (eg morphology, ecology, usage, etc)

Coastal forcing - the natural processes acting on the coast (eg winds, waves, tides, etc)

Coastal processes - the interaction of coastal forcing with coastal characteristics (eg sediment transport, pollutant dispersion, etc)

Coastal response - change resulting from coastal processes (eg erosion, flooding, etc)

Coastal resources - the coastal characteristics which can be used for human benefit (life support, economic gain, recreation, etc)

Coastal elements - any physical or human component on the coast, this being the aggregate of characteristics, forcing and response

Shoreline - one characteristic of the coast. Poorly defined but essentially the interface between land and sea

Shoreline management - relates to efforts to control the shoreline interface. As such, this usually focuses on coastal hazards and the need to provide protection against either flooding or erosion

Coastal zone - some combination of land and sea area, delimited by taking account of one or more elements

Coastal zone management - the planning and allocation of resources within a given area

Management framework - the complete structure, which includes all aspects of the management process (ie data inputs, analysis and understandings, strategic planning)

Management system - the tools used to develop and implement a management strategy. These can range from paper based archives to a computer database with facilities to present information spatially and undertake various forms of analysis

Management strategy - sets out the requirements for a management plan. The aims and objectives set out what is to be achieved and will be judged against defined criteria. Implementation will make use of guidelines and an appropriate range of response options.

Management plan - defines how the strategy will actually be implemented

Aims or goals - focus on long term aims and may be somewhat open ended

Objectives - shorter term aims which are measurable and provide a means of fulfilling the goals

Assessment criteria - the measures or standards used to develop the management plan and subsequently assess progress towards implementation

Policy Guidelines - define preferred resource use and external constraints

Response options - means by which the Guidelines can be implemented taking due account of dominant coastal processes

Legal framework - defined by Government policy and ensuing statutes

Institutional/Organisational framework - devolves from the legal framework as the basis for implementing the statutes

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Shoreline Management Partnership
University of Durham
University of East Anglia
University of Hull

under the direction and management of Sir William Halcrow & Partners Ltd.

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Essex Saltings Restoration Project
Great Grimsby Borough Council
Great Yarmouth Borough Council
Harwich Port Authority
Holderness Borough Council
Hull University
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Suffolk Coastal District Council
Suffolk County Council
Tendring District Council
University of East Anglia
Waveney District Council

APPENDIX A

SUMMARY LIST OF REPORTS AND MANUALS

APPENDIX A - SUMMARY LIST OF REPORTS AND MANUALS

1 REPORTS

(All reports by Sir William Halcrow & Partners Ltd unless otherwise indicated)

Preliminary Study

Inception Report, September 1987

Supplementary Studies Report, November 1988, including:

- Wave Climate, (Hydraulics Research Ltd, Halcrow)
- Residual Currents (BMT, Ceemaid Ltd)
- Beach profile Analysis (Hydraulics Research Ltd)
- Extreme Sea-Levels (BMT, Ceemaid Ltd)
- Sea-Level Change (University of East Anglia)
- Literature Review (Imperial College)

Stage II Study Report, November 1988

Stage II Strategy Report, November 1988

Anglian Coastal Management Atlas, 1988

Sea Defence Management Study

GIS Review, July 1989

Field Survey Report:

- Volume 1 - Bathymetric Survey, September 1990 (BMT, Ceemaid Ltd)
- Volume 2 - Geological Survey, August 1990 (British Geological Survey)
- Volume 3 - Estuary Sediment Trends, May 1990 (GeoSea)

Data Collection and Analysis Programme for the Anglian Shoreline, May 1990 (Shoreline Management Partnership)

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2 MANUALS

Shoreline Management Data Model

EMS User Manual

SANDS User Manual