CHAPTER 197

A REGIONAL STUDY OF COASTAL MORPHOLOGY

I H Townend[1], C A Fleming[1], P McLaren[2] and A Hunter-Blair[3]

ABSTRACT

In 1987 Anglian Water (now the National Rivers Authority, Anglian Region) initiated a coastal management study covering 750 km of coastline, the largest and most comprehensive study of its kind in the UK. Stage I involved the selection of the best technical approach to the problem. In Stage II the successful consultants adopted a philosophy of maximising the use of existing data sources through a geographic information system (GIS) incorporating a database and powerful enquiry facilities. In all 19 main variables were included in the GIS database, each with complex data structures in order to provide a comprehensive description of any particular variable. The main variables were selected on the basis that they either provided information on the direct influences or responses of the coast or on their implications with respect to any protection strategy that may be implemented.

Analysis of the data through the GIS led to a number of significant findings with respect to dominant processes on the coast. This work also highlighted the areas in which further data collection and study would be beneficial to formulating the most appropriate long term management strategy. As a result Stage III of the study has been initiated in order to develop a better understanding of the physical processes responsible for the mechanisms identified.

INTRODUCTION

In 1953 a major storm surge in the southern part of the North Sea caused severe flooding in south east England, leading to the loss of some 200 lives, as well as domestic livestock, wildlife and devastating damage to property and agricultural land. As a result there was a major reconstruction of the sea defences along the east coast of England. These defences have been maintained, extended and rebuilt during the ensuing years, but the time has now come to

----

[1]Sir William Halcrow & Partners Ltd, Swindon, UK; [2]GeoSea Consulting Ltd, Gambridge, UK; [3]National Rivers Authority (Anglian Region), Peterborough, UK.

re-think the sea defence system as a whole and make some major reinvestments. Overall there are some 300 km of first line sea defences and it has been estimated that it will cost £130 m over the next 10 years to bring these defences up to standard.

Anglian Water, realising the problems that must be faced in the future, and being responsible for one the longest and most vulnerable coastlines in Britain stretching from the estuaries of the Humber to the Thames, commissioned a study of the foreshore, which would help them to establish a coastal management strategy based on sound scientific principles. Thus the Anglian Sea Defence Management Study emerged and is one of the most extensive studies of coastline properties and processes to have been carried out in the UK.

The general terms of reference for the investigations were to provide an understanding of the mechanisms causing changes in foreshore levels along the Anglian Coast and this is the focus of this paper. For completeness a brief outline is given of the study as a whole, together with some indication of the form of the management strategy.

THE STUDY

Study Area

Anglian Water's sea defences run from Canvey Island on the Thames to Trent Falls on the Humber Estuary. Given that the objective of the study was to establish management procedures based on a sound regional understanding, it was felt necessary to extend the northern boundary of the study area to incorporate the Holderness coast. This thereby includes an 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.

Stage I

The first stage was a form of competition, where three consultants were invited by the Authority to present their approach to the problem. In effect they were asked the question "If this was your problem, what would you do about it?" The winning proposal focused on making maximum use of existing data sources to develop an integrated management strategy for the whole coastline.

Stage II

The rationale of the approach adopted was to extract a coherent picture 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 genesis would inevitably be constrained by limited knowledge of the governing mechanisms. The

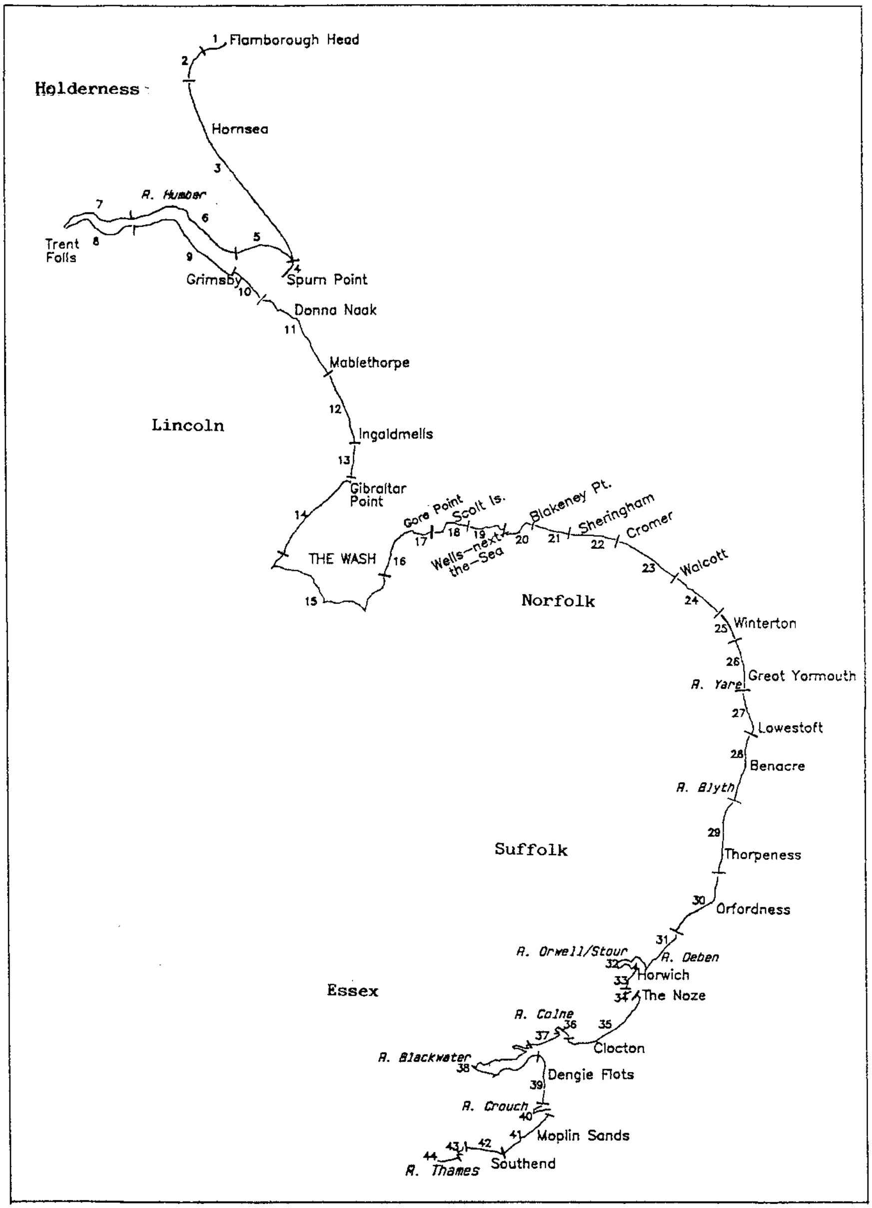

Figure 1: Study Area with Coastal Units

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 could then be made, to both gain insights and focus the objectives of future field work and numerical model studies.

As the first stage a referral database was established. This database essentially provides a listing of relevant 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 were identified. The database was set up using Ashton Tate's 'dBASE III' software using two separate record structures; one for references and the other for environmental data. 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 in the Norfolk region).

It was recognised from the outset that a number of important variables could not be adequately defined by simply using existing sources. As a consequence six supplementary studies were undertaken, with the objective of providing additional data and/or some further understanding. These studies provided:

- a definition of the wave climate offshore and at approximately 10 km intervals along the coast;
- an understanding of the coupling between the residual flow regime in the southern North Sea and local wind effects, in determining nearshore current residuals;
- detailed analysis results of beach profiles taken over the last 10 to 25 years;
- a description of extreme sea levels around the coast;
- a quantification of sea level rise, tectonic movement and subsidence in a geological setting;
- a summary of recent literature on the subject of coastal processes relevant to the Anglian coast.

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 is referred to as the 'Coastal Management Database' (CMD) and was used to meet the following objectives:

- to map relevant variables for the entire coastal region;
- to use the graphical output of the system to present each variable or combination of variables on a series of maps;
- to assess the inter-relationships among variables and their contribution to coastal erosion;

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

The variables included in the database, were selected on the basis that they either provide information on the direct influences and responses of the coast (eg waves, coastal morphology, rate of retreat, etc) or on their implications with respect to the impact of the erosion and any defence strategy that may be implemented (eg present coastal works, SSSIs, land use, etc).

The development and application of the GIS is described more fully by Fleming and Townend (1989) and Townend (1990).

DISCUSSION OF RESULTS

A detailed examination and intercomparison of data sets has led to a number of general conclusions with respect to governing processes. These were used with more localised interpretations to assess coastal regimes and to establish a series of coastal units (Townend and McLaren, 1989).

For the purposes of this study the coastal zone is defined as made up of five parts; hinterland, backshore, foreshore, nearshore and offshore (Figure 3). The hinterland is landward and includes any cliff or dune system, the backshore (if it is present) extends to high water, between high and low water is classed as the foreshore, from low water out to an approximate limit of storm erosion (d_L) is taken as the nearshore, and from there on out is the offshore.

Governing Processes

The data interpretation is wide ranging and a number of key insights have been found. In many cases these were established as a result of the contrasts existing along the coast. A necessary qualification is therefore that if there is no contrast in a particular variable on the coastline, then the associated understanding may not have been picked up. Sea level rise is one such possibility, where an appreciation was derived by testing the data against an accepted "rule", rather than a direct correlation of cause and effect. Furthermore associations were only sought as a first step in seeking to develop a better understanding of the underlying physical processes.

i) <u>Coastal Retreat/Advance Classification</u>

An examination of long term estimates of coastal retreat and advance (established using historic Ordnance Survey maps) reveals that a very large proportion of the Anglian coast is retreating. Recent beach profile data, although more variable, reveal consistent trends.

The long term retreat data were used to develop a retreat/advance classification system which characterises the different types of

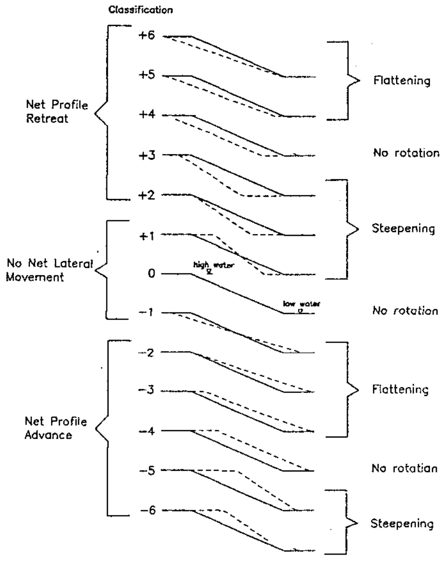

Figure 2: Retreat/Advance Classification

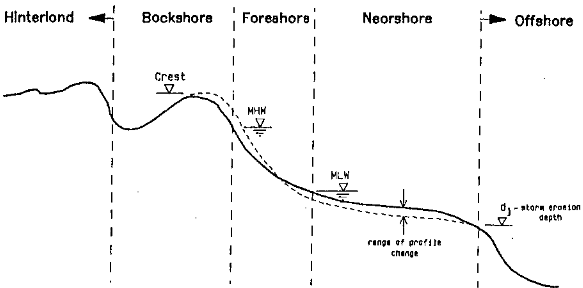

Figure 3: Coastal Zone Definition

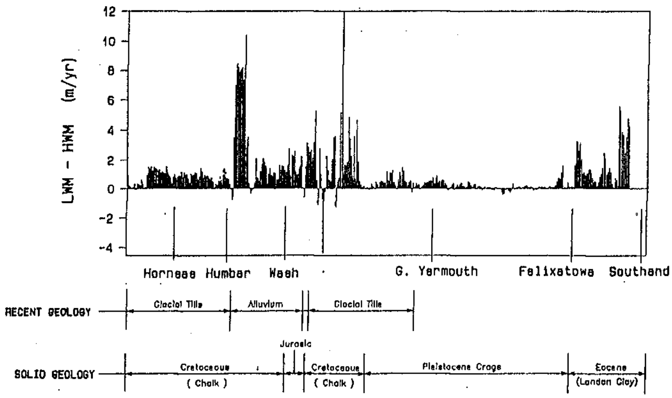

Figure 4: Differential Beach Retreat

beach movement. Rates of retreat at high and low water are combined to define horizontal and rotational movements of the foreshore. In all 13 combinations have been defined and these are illustrated in Figure 2. The results for the Anglian coast, excluding the Humber, the Wash and the Essex rivers, reveal that some 70% of the coast has been subject to retreat, with 15% advancing and 15% showing no horizontal movement (Table 1). The problem of erosion on the Anglian coast is therefore clearly a substantial one.

The coastal retreat/advance classification also highlights one other characteristic that has been found to be particularly significant on the Anglian coast. Classification types +1, +2 and +3, totalling 67%, represent types of retreat in which the beach is steepening and types -5 and -6, totalling 11%, describe types of advance, again where the beach is steepening. Thus beaches appear to be steepening (to a varying extent) for 78% of the total shoreline. This is therefore an ongoing mechanism, which is of prime importance where coastal works are sited at the top of the beach.

Table 1 : Summary of Retreat/Advance Classification Data

	Net Profile Retreat		No Net Movement		Net Profile Advance	
	Type	%	Type	%	Type	%
Steepening	+2	15.1			-6	1.9
	+3	41.4	+1	10.8	-5	9.1
No Rotation	+4	10.2	0	3.2	-4	2.4
Flattening	+5	3.8	-1	0.3	-3	1.3
	+6	0.0			-2	0.5

Note: results exclude the Humber, the Wash and the Essex Rivers

In addition to providing a broad overall summary of the retreat data, the retreat/advance classification also provided extremely useful information for the interpretation task. There is considerable variation of classification type along the coast and this variation is often quite rapid. In some cases the fact that the mode of retreat did not change helped to define the limits of a coastal unit. Elsewhere it was the consistent way in which classification type changed along the shore which helped to identify particular features.

ii) Geological Setting

The retreat/advance classification provides a clear indication of the extent of the beach steepening phenomenon. Beach steepening is not however, happening uniformly along the coast (Figure 4). Indeed on the coast between Great Yarmouth and Harwich it is hardly happening at all, despite the fact that the rate of retreat is comparable with other areas. What is striking is the marked change at either end of this particular length, which appears to correlate with the change in geology. To the north and south the coast comprises tills, alluvium and clays and is therefore essentially cohesive. In contrast the intermediate length is composed of Pleistocene Crags which makes it a predominantly non-cohesive shore.

Examining the geology set against the retreat rate, reveals that beach steepening is remarkably consistent along the till cliff frontages of Holderness, whereas the more complex stratigraphy of the North Norfolk cliffs results in more variable rates. This variability increases substantially in low-lying areas such as the barrier beach system from Weybourne to the Wash, where there are marked changes in the sediments which provide the geological setting. Interestingly, the Lincoln and Clacton coasts have very similar retreat characteristics and both comprise sand veneer beaches overlaying a clay bed, suggesting that there is much in common in the way these two areas behave. This all emphasises the importance of the nearshore geology.

One further association that has been noted is the increase in nearshore width in areas with the highest rate of beach steepening. Figure 5 shows the two data sets at approximately a 10 km resolution, and the correlation is clear. Examining the data at a finer resolution (eg 1 km) the correlation is less obvious because the beach steepening in areas with high nearshore widths is very erratic. Thus high values of beach steepening occur when the nearshore width is high, but the converse does not necessarily hold.

This is fortuitous because it provides a setting in which steepening can take place. The corollary must be that there is a threshold at which steepening no longer takes place (possibly because retreat increases to a point where the additional sediment supply becomes sufficient to protect the resultant, much narrower beach).

The geological setting has been found to induce beach steepening. The physical explanation is less clear. It has been postulated that this is a consequence of increased downcutting towards low water on cohesive shores, where the erosion process is irreversible (once a clay surface is eroded the fines are rapidly washed away). It may also reflect a changing tidal regime as a consequence of sea level rise.

iii) Coastal Orientation

A surprising feature of the coastal retreat data is an apparent rhythmic variation along the shore. Further analysis revealed that there is indeed a cyclic variation along the entire coast with a periodicity of between 3 and 6 kilometres.

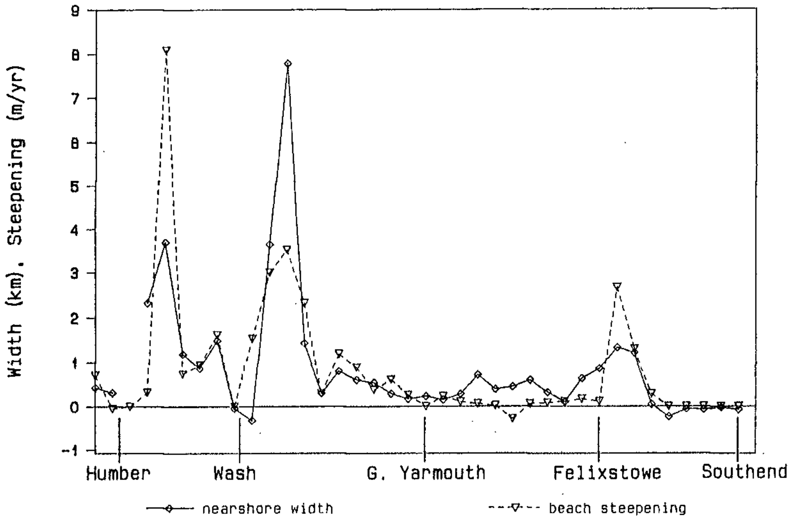

Figure 5: Comparison of Nearshore Width with Beach Steepening

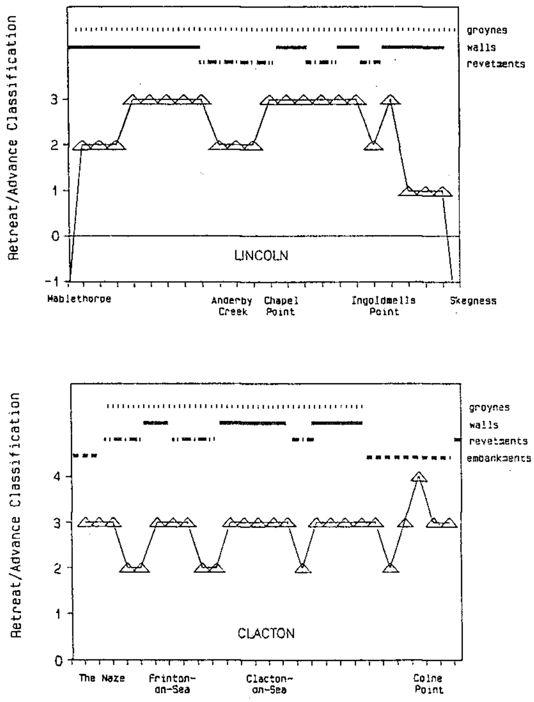

Figure 6: Influence of Coastal Structures on Mode of Retreat

In the search for an association with this rhythmic variation, coastal orientation was examined. The data was prepared by taking off the bearing of the normal to the coast at one kilometre intervals, using the latest edition of the 1:50,000 OS retreat revealed no obvious association. However by deriving the rate of change of orientation along the coast a good match was found. Maximum retreat occurs within embayments and minimum retreat or accretion takes place on bulging shores. This is indicative of a natural instability where erosion at one point produces an exaggerated response which is then countered by an under-response on the adjacent shoreline.

There are two types of feature which can cause a reversal of this relationship. The first is the presence of structures which can force a localised reversal on the natural perturbation (eg the accretion updrift and erosion downdrift of an outfall), or exaggerate the perturbation (eg where a coastline is over-constrained by a seawall). The second variation occurs at natural features such as nesses, spits and points which involve major changes in coastal orientation. Again these can be explained in terms of the interaction of cyclic perturbations on a line which changes direction.

The exciting mechanism for the perturbations is unclear, as is the reason for the variation in the periodicity on different lengths of coast. The understanding of this phenomenon is at a very preliminary stage. Its presence on the whole of the Anglian coast is seen as particularly significant and may well be of major importance for a proper understanding of the morphological genesis of the coast. Given the interaction with structures that has been noted, such an understanding will also aid the proper planning of coastal works.

iv) Tides and Waves

No correlation could be established between the wave energy incident on the shore and the long term retreat. Furthermore only on the Lincoln coast and from Blakeney Point to Gore Point is the potential of alongshore littoral drift clearly uni-directional. Elsewhere the variations are such that the direction of net drift can reverse from year to year.

The presence of beach steepening on both accreting and retreating features, together with the fact that rates vary significantly with the presence of channels in the nearshore seabed, suggests tidal currents (and most likely tidal residuals) play a dominant role over much of the coast from Flamborough to the Thames. Much local evidence and data for individual lengths of coast supports this finding.

A study of beach volume changes around the coast indicated that growth and depletion of the beach on a given stretch of coast shows more coherence in time than it does alongshore. This therefore suggests that major beach volume changes are due to onshore/offshore movement.

These various findings lead to the conclusion that waves are significant for moving material locally and over short time-scales. However, the major movement of material and consequently the long term geomorphological development for the majority of the coast is tidally dominated. This movement is back and forth in the nearshore, interacting with the foreshore by onshore/offshore movement. The material supplied to the beach is then moved by alongshore wave activity, the significance of which will vary according to the amount of material available for movement on the beach and the consistency of the drift direction. For example when beach levels are low on the Lincoln coast (such that the clay layer is exposed) there is little drift despite the high drift potential. In contrast when beaches are full, the groynes play an important role in reducing alongshore movement. Alternatively on the beach between Great Yarmouth and Lowestoft, the drift direction is highly variable such that the movement on the beach due to alongshore wave energy is back and forth. (Note: the strong interaction with the nearshore on this frontage results in a net southerly drift for the system as a whole).

v) Sea Level Rise

It might be argued that rises in mean sea level, and hence the levels on the beach swept by the tide, has induced the observed coastal retreat. However, an examination of potential retreat due to sea level rise based on the "Bruun rule" (Bruun,1962), shows that generally this is less than the rate actually experienced. This suggests that the retreat is not due to sea level rise alone. Indeed, work on the Dengie Flats has shown that although the margins are eroding, the main body of the marsh is accreting at a rate in excess of the rise in sea level (Reed 1988).

vi) Coastal Structures

The retreat/advance classification data was used to evaluate the influence of coastal structures on the extent and type of movement which is occurring. The deductions that have been made took advantage of the similarities between the Lincoln and Clacton coasts and the Holderness and North Norfolk cliffs. Certain other data sets, such as the actual rates of retreat and the description of backshore widths led to further amplification of the conclusions.

a) Where there are no structures on an open cliff coast, then the cohesive shoreline is retreating and steepening, whereas the non-cohesive shore is retreating uniformly (no steepening).

b) On cohesive shores which supply material to the coastal system (Holderness, North Norfolk), the type of structure has no discernible effect on the type of erosion taking place, but does locally slow the rate of retreat.

c) On cohesive shores which receive sediment from other sources (Lincoln, Clacton) then the type of erosion is dependent on both the type of structure and the presence or absence of a backshore. Where there is no backshore then all structures result in beach steepening. In contrast where there is a backshore, then walls were found to induce retreat and steepening (similar to cliff coastlines) whereas lengths with revetments or embankments exhibit only steepening (no significant movement of the high water mark); the latter not necessarily being a consequence of the structures presence. This correlation is illustrated for the Lincoln and Clacton coastlines in Figure 6.

vii) Offshore Banks

A study of the offshore zone has suggested that the region can be divided up into a number of areas based on the different type of bank systems which are present. The most significant areas with respect to the Anglian coast are the Great Yarmouth banks and the series of linear banks further to the north-east.

The linear bank system may well derive from the Anglian coast via the nearshore banks at Great Yarmouth (Townend and McLaren, 1990). It is postulated that material is in circulation off Great Yarmouth, where the amount of sediment being moved is substantially greater than the present supply from the north at Winterton and south at Benacre. This circulation cell initiates new banks in the vicinity of North Cross Sands and Winterton Overfalls (to the northeast of Great Yarmouth), which evolve as linear banks moving offshore in a north-easterly direction. By examining sea level rise and historic shoreline positions it has been estimated that the supply from the coast would have been sufficient to progressively develop the bank system over the last 7-8,000 years.

Changes in Time

Not only the coast itself, but the processes which influence the coast are changing with time. Indeed the conclusions with respect to a number of the governing mechanisms described above suggest that the coast is not in dynamic equilibrium with the environment. Rather the changes taking place are altering the shore from flat and low-lying, characteristic of a low energy dissipative shore, towards a much steeper, high energy reflective shore. This change is on a geological timescale and seems to be a consequence of the initial setting of the coast, prior to, and during the Flandrian transgression.

The Anglian coast is all to the south of what was once the main sea basin which now forms the northern North Sea. It sits alongside the ridge which divides the northern and southern basins of the North Sea, and the southern basin itself. The latter developed as a tidal river estuary and only following the rise in sea level and coalition with the northern basin could it be considered as a sea basin. Thus the coastal setting is one of a shoreline on the edge of a newly formed sea basin and still adjusting to this much more dynamic environment.

CONCLUSION

There have been a number of aspects to the Stage II studies which have each seen significant advances. The first is the development of a methodology which allows the data (either raw or in some summary format) to be freely explored. This has involved the use of a sophisticated database and much has been learned about both the limitations and potential of mapping analysis. The application of this approach has led to an extensive interpretation of the coast both on a regional and a local scale. With the understanding that this has provided, there are a number of implications for the efficient and cost-effective management of the coast. These include:

- Beaches on cohesive shores are generally steepening, although this may also be a consequence of the geological setting.

- The rate of retreat exhibits a cyclic variation along the coast and this is related to the rate at which the coast changes its orientation.

- Tidal influence has been found to play a major role in the long term development of the coast.

- Retreat rates were found to be in excess of that which could be attributed to sea level rise.

- The type of structures found on the shoreline influence both the rate and type of erosion which takes place.

- The bank system off the North Norfolk coast has an important interaction with the coast.

These findings are all important for the proper management and, where appropriate, design of works, in the coastal zone. A more localised interpretation was developed in order to divide the coast up into a series of coastal units. These are not necessarily independent units but are based on the presence of coherent characteristics within the unit (Figure 1).

The basis of the short term management strategy, developed following the Stage II studies, has been described by Fleming and Townend (1989). The context of this development in terms of the overall formulation of a management framework is considered by Townend (1989, 1990).

In view of the substantial nature of some of the insights derived, a number of further investigations have been initiated as Stage III of the study. This comprises a wide range of tasks aimed at filling in data gaps, developing a better understanding of the coastal mechanisms identified, and refining the "management system" as a fully operational tool for coastal managers. There are essentially four aspects to the work; field measurements, detailed studies, preparation of monitoring guidelines and further development of the GIS based management system (Townend and Fleming, 1990). It is anticipated that these studies will lead to specific recommendations for future sea defence works, and provide a coherent framework for the long term management of this coast.

ACKNOWLEDGEMENTS

This work was funded by Anglian Water and is now the responsibility of the National Rivers Authority, Anglian Region. Their support and permission to publish this paper is gratefully acknowledged.

REFERENCES

Bruun P M, 1962, J Waterway Harbour Div. ASCE. 88, 117-130

Fleming C A, Townend I H, 1989, ASCE Coastal Zone '89 Proc.

Townend I H, 1990, EGIS '90 Proc.

Townend I H, McLaren P, 1989, Anglian Coastal Management Atlas, Sir William Halcrow & Partners.

Reed D J, 1988, Estuarine, Coastal and Shelf Science, 26, 67-79.

Townend I H, 1989, PIANC (UK) Gustav Willems Prize

Townend I H, 1990, Int Symp "Littoral 1990", Eurocoast Assoc.

Townend I H, Fleming C A, 1990, 1990 Flood Plain Management Conf, Canada.

Townend I H, McLaren P, 1990, The Relationship Between Bank Development and Coastal Response for East Anglia, UK. In Press.