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FUTURECOAST: PREDICTING THE FUTURE COASTAL EVOLUTION OF ENGLAND AND WALES

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Abstract: Analysis of shoreline change is often based exclusively upon the littoral cell concept and modelling of hydrodynamic processes. The Futurecoast study has considered fresh approaches to assessing shoreline evolution, which have been used to provide an analysis of future long-term evolution for the entire shoreline of England and Wales. This has been based upon an improved understanding of coastal systems and their behavioural characteristics.
The study has included a range of supporting studies, focussing upon maximising use of existing information and experience. A number of additional data sets have also been produced. The integration of leading expertise from different areas of coastal research to collectively consider this information has been the foundation for the study. The key outputs from this research are:

- Improved understanding of coastal behaviour;
- Assessment of future shoreline evolution;
- Supporting information and data;
- Delivery of results on an interactive CD-ROM.

Key words: Coastal geomorphology, Shoreline management, Strategic coastal studies

1. BACKGROUND

The Futurecoast study was commissioned in October 2000 by the UK national government Department for Environment, Food and Rural Affairs (DEFRA) to provide predictions of coastal evolutionary tendencies over the next century. A team led by consultants Halcrow Group Ltd carried out the study, which was completed in June 2002.

DEFRA are moving towards sustainable long-term planning of flood and coastal defences, and therefore require that decisions are made with due consideration of the decades to century timeframe. Shoreline Management Plans (SMPs) were undertaken between 1995 and 2000, targeted at determining broad-scale future coastal defence policy throughout the open coast shorelines of England and Wales. However, many of these first generation SMPs avoided making long-term decisions, partly due to the lack of data on long-term shoreline evolution (MAFF 2000).

The Futurecoast study was therefore aimed at addressing this issue, to ensure that the second round of SMPs are better informed and are therefore able to make strategic coastal management decisions in a longer-term and wider-scale context. This has involved providing an outline coastal process and geomorphological study of the whole of the open coastline of England and Wales, and using this as the basis for a prediction of coastal evolution over the next 100 years. A key objective was to allow contemporary coastal processes and past, present and future management decisions to be placed within a longer-term and wider-scale framework, providing a vision for the coast and a scientific basis for considering the 'direction' for sustainable strategic management response.

This information is to be fed into the second round of SMPs and thereby improve their consistency, quality and reliability. The output of this project is therefore primarily aimed at the coastal managers and organisations developing and implementing the SMPs, so that they

all have a sounder scientific base for subsequent analysis and long-term policy recommendations.

2. APPROACH

In order to make decisions on coastal management and land-use planning, predictions (or estimates) of long-term future coastal evolutionary tendency are necessary. The prediction of coastal evolution is difficult due to the range of spatial and temporal scales over which coastal changes occur, and the complex interactions that result in shoreline responses of varying, non-linear and often unpredictable nature. There is also inter-dependence between different geomorphic features that make up the natural system, such that the evolution of one particular element of the coast is influenced by, and influential on, evolution in adjacent areas. Often these influences extend in a number of directions, thereby further complicating the task of predicting change.

Whilst a variety of modelling techniques exist to assist in predictions of coastal evolution, many of these focus on short-term, relatively local-scale predictions based primarily upon contemporary hydrodynamic forcing, as opposed to considering larger-scale and longer-term evolutionary behaviour. Although such modelling provides vital information, it does not necessarily provide the complete picture of influence and change; it is also important to understand how the coastal zone functions on a wider scale both in time and space.

The complexity of the coastal system has led coastal engineers and scientists to recognise that accurate quantitative prediction of large-scale, long-term coastal behaviour (i.e. evolution of a stretch of coast tens of kilometres in length, over timescales of decades to centuries) is beyond our present capabilities. Where such quantitative predictions have been made, they have usually been based upon simple extrapolation of historical measurement without considering the composition and behaviour of the various forms that make up the physical system. This research has therefore focused upon providing a qualitative, conceptual picture of how the shoreline could evolve over the next century both in terms of the coastal morphology and potential for changes in shoreline position.

In the past, information has often been analysed and used in a piecemeal way. Therefore the focus of this research has been to make fuller and appropriate use of existing information and combine this with an appreciation of the characteristic behaviour and sensitivity of geomorphological forms, rather than undertake additional modelling or field data collection.

2.1 CONCEPT OF BEHAVIOURAL SYSTEMS

Development of the first round of Shoreline Management Plans (SMPs) was based upon littoral cell boundaries, which had previously been defined at zones of sediment convergence and divergence (Hydraulics Research, 1993). Since the littoral cell concept was used to define SMP limits, it has been subsequently used in many applications to analyse coastal change and assess future policy options and impacts.

The benefit of the cell approach was that it reflected regional processes on a basis that was easy to communicate and it was therefore quickly adopted. However, whilst the littoral cell concept is a valid approach, it is only one aspect of coastal system behaviour and other factors also need to be taken into account when assessing future shoreline evolution. Therefore, in terms of making large-scale or longer-term predictions of coastal evolution, the cell concept has a number of shortcomings. Unfortunately this point was not recognized by some of the first round SMPs, which focused upon the littoral transport regime, often omitting to fully consider other factors, particularly interactions at a range of spatial and temporal scales.

Therefore for this research a ‘behavioural systems’ approach has been explored, and ultimately adopted. This approach involves the identification of the different elements that

make up the coastal structure and developing an understanding of how these elements interact on a range of both temporal and spatial scales. It has been recognised that the influences upon the coastal processes that drive change are not constrained to the shoreline, nor are they necessarily adjacent to the feature that is affected. This approach concentrates upon understanding the sensitivities and characteristic behaviour of geomorphological features, in response to these processes, and their degree of maturity.

This approach has not sought to pre-define spatial or temporal boundaries, in recognition of the fact that such definitive boundaries rarely exist. Rather, it aims to change the way that people think about individual stretches of coastline and to understand that they sit within a much larger framework of influence and process.

2.2 ANALYSIS

In order to assess how defences affect long-term shoreline evolution, it is first necessary to understand the natural evolutionary trends of the coastline. However, the coastline of England and Wales has been heavily modified over the centuries, in particular the estuary areas, and this has affected how the coastline has evolved. Therefore assuming a coastline position and form, had defences never been constructed, would be unrealistic and of little value. The approach adopted has been to consider the 'unconstrained' scenario, which assumes an instantaneous total removal and discontinuation of human intervention along the entire shoreline of England and Wales, using the present shoreline position as a starting point. Whilst an unrealistic scenario in that all defences are never likely to be removed, this unconstrained scenario offers a baseline that can be used to appreciate the potential effects of coastal management, both current and future.

The first stage has been to understand how various influence factors, i.e. estuarine influences, hydrodynamics, nearshore and offshore sediment dynamics, geomorphology and geology (both onshore and offshore), interact to affect the coastal evolution over various timescales. Sections of coastline that exhibit characteristic behaviour tendencies have also been identified. This has been achieved through the review and interpretation of existing information and studies. The key controls and linkages have been identified and qualitative sediment audits developed, i.e. the identification of key sources, sinks and pathways. The past evolution of the shoreline has also been investigated to identify long-term controls, constraints and behaviour.

Appreciation of the likely evolutionary trends and the controls behind them provides a generic expression of how the coastline could develop if unconstrained and aids in understanding the influence of contemporary processes and the impact of human intervention. Evolution at the large-scale has been considered first, as this often drives the responses observed at the local-scale (Fig. 1). Geomorphological interpretation of the critical elements, behaviour and sensitivity at this larger scale enabled identification of potential areas of increasing, decreasing, continuing, ceasing or commencing pressure caused by the forcing factors. Such pressure often relates to re-alignment of the coast, possibly influenced by:

- changes in geological controls (e.g. emergence of headlands within eroding cliffs, recession of existing headlands or exacerbation of embayment curvature due to immaturity of development);
- existing hydrodynamic forcing (e.g. wave diffraction processes around headlands);
- new hydrodynamic influences (e.g. the interruption of littoral drift by newly created tidal inlets);
- sediment transport (e.g. natural changes in the rate or direction of sediment transport);
- changes in sediment budget (e.g. shorelines switching from drift- to swash-alignment due to exhaustion of relict sediment sources).

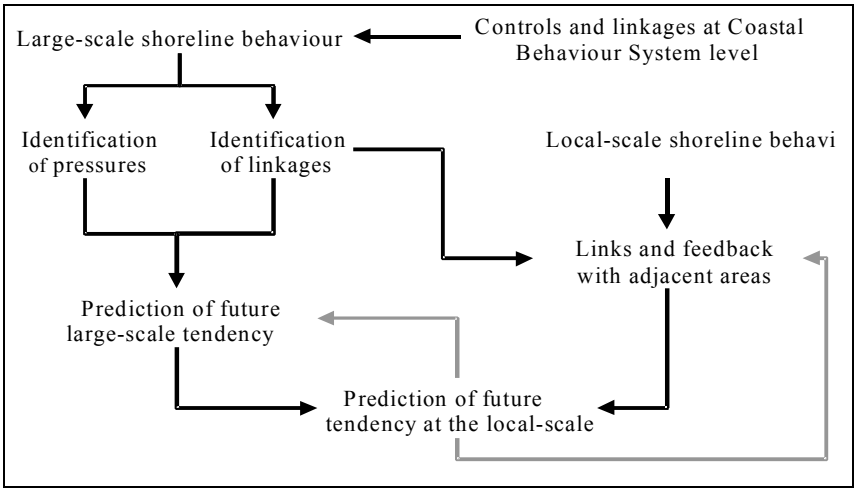

Fig. 1 The iterative approach to the prediction of potential shoreline evolution

Translation of these large-scale changes to the response at the local-scale involves consideration of the individual geomorphological units. Mapping of supra-tidal and inter-tidal morphology, together with an understanding of lithology and topography enabled the identification of these individual geomorphic features and combinations of these that could be considered together at the local-scale. Despite the complications associated with predicting shoreline response, there is a generic-level understanding of how various geomorphological features (such as dunes) may evolve and their sensitivity to change. Based upon this information, it is also possible to identify theoretical, or generic, responses of various coastal elements to changes in certain controlling parameters.

A key aspect of this stage of the analysis has been to consider the interactions and interdependence between adjacent areas, especially where these could influence the controls on the shoreline or alter the sediment regime. For example, the rapid and large-scale re-activation of cliff recession within one area could release significant quantities of sediment, possibly resulting in accumulation and progradation of a downdrift shoreline.

The main link between these features is the foreshore, which acts as the primary conveyor of non-cohesive sediment transport within a system. Any changes in pressure to this conveyor may have implications both alongshore and between the shoreline and backshore features. An iterative approach was therefore adopted to review the cumulative impacts and knock-on effects of the predicted large-scale pressures and individual local-scale responses within a wider context (see Fig. 1).

Through this approach a model of future shoreline evolution for the open coast of England and Wales has been developed for the 'unconstrained' scenario. Information about recent historic change has then enabled more specific conclusions to be made on the potential evolutionary tendency for specific lengths of shoreline.

3. RESULTS

The main outputs from this research are:

- A 'toolbox' of supporting information and data that can be used in future assessments of shoreline behaviour – this includes (1) the background thematic studies produced for this project and (2) the additional data sets and information generated (see Table 1).
- Improved understanding of coastal behaviour – this has used and built upon the information contained within the round one SMPs and other existing studies.
- Assessment of potential future shoreline behaviour for two scenarios: unconstrained (i.e. assuming no defences or management practices) and managed (i.e. assuming present management practices continue indefinitely).

Table 1 The 'toolbox' of supporting information and data provided by Futurecoast

THEME	DESCRIPTION OF ANALYSIS
Macro-review of coastal processes	Integrated understanding of the modern large-scale hydrodynamic regime.
Macro-review of Holocene coastal change	Assessment of the long-term, large-scale evolution of the coastline around England and Wales and identification of the impact of sea level rise over the Holocene on the inherited morphology.
Shore geology and morphological elements	Review of the shoreline geology and classification of morphological elements of both the foreshore and backshore.
Cliff behaviour assessment	Assessment of cliff erosion, potential failure mechanisms and contribution to local sediment budgets.
Past shoreline evolution	Review of change in shoreline position and characteristics, both over the Holocene and recent history. Analysis of historical OS maps to provide a consistent assessment of shoreline positions since the First County Series (published 1846-1901).
Offshore morphology and evolution	Review of existing literature and data on historical development, bathymetry and physical regime, sea bed sediments and offshore sediment transport trends.
Estuary influences	Definition of appropriate boundaries for predictions. Classification of estuary type and assessment of estuarine influences and their role as a source or sink of sediment.
Coastal processes	Analysis of the forces exerting influences on water movement in the coastal zone e.g. waves, tides and currents, including a review of shoreline characteristics and internal constraints, external forcing, and nearshore sediment transport.
Nearshore wave analysis (including climate change impacts)	Analysis of transformed nearshore wave data for 68 representative locations. Assessment of the possible impacts of 10 climate change scenarios on shoreline energy conditions, and thus sediment transport potential.
Climate change and sensitivity	Review of key climate change research applicable to the coastline of England and Wales and development of regional coastal climate change scenarios, considering natural variability, sea level rise, storm surges, wave climate and precipitation. Generic assessment of the sensitivity of different landforms to climate change and its impact upon future behaviour.
Uncertainty assessment	Assessment of the uncertainty of predictions, based upon the quantity and quality of existing information and the degree of understanding.

3.1 THEMATIC STUDIES & DATA

A series of thematic reports were produced to assist in the understanding of shoreline behaviour. Supplementing these reports are a number of data sets generated as part of this research, which have been provided as output for potential further use and development (see Table 1). Much of this information, and the information provided in the thematic reports, has also been provided as mapped data or is linked to maps.

3.2 SHORELINE BEHAVIOUR STATEMENTS

The key conclusions from the project are presented in a series of statements known as Shoreline Behaviour Statements. These statements describe both the current understanding of coastal behaviour and the predictions of future coastal evolution at both the large-scale and local-scale. This information has also been mapped. These statements have been written so as to ensure the user will gain an appreciation of the interactions within a system, at a range of

both temporal and spatial scales, and thus the external influences upon behaviour. These statements include three key sections:

- Coastal Behaviour System;
- Assessment of Shoreline Behaviour;
- Local-Scale Shoreline Response.

3.2.1 Coastal Behaviour System

These statements describe the broad characteristics of the coastal system(s) that presently exist, identifying the large-scale interactions and drivers of change over the longer-term, i.e. the Holocene, that have been influential upon the evolutionary behaviour of the shoreline presented in this statement. Generally these statements cover a much larger area than the specific length of coast covered by the Shoreline Behaviour Statement, and so provide the reader with an understanding of the wider influences that are acting upon this area.

3.2.2 Assessment of Shoreline Behaviour

This includes the following sections:

- Past Evolution – summarises the shoreline evolution over the centuries/millennia timescale, i.e. the origins of the shoreline that exists today.
- Controls and Linkages – identifies the key parameters influencing shoreline evolution over the century timescale, including geological and physical controls, sediment transport linkages and human intervention. It is these controls and linkages that are the main parameters for defining shoreline behaviour units and therefore shoreline response over the next century.
- Future Unconstrained Shoreline Behaviour – identifies both large-scale evolution and assesses the influences of this upon the different geomorphological features that are present along the shoreline. This prediction of future evolutionary trends is based upon the scenario that all shoreline defences are removed and management practices cease immediately. These sections of the Shoreline Behaviour Statements provide the basic conceptual model for unconstrained shoreline evolution over the next century. This draws upon the knowledge of past evolution and the understanding of the controls and linkages, together with information on the local geomorphological character of the area, to identify large-scale realignment tendencies and the subsequent response of different elements of the coast.
- Uncertainty – an indication of the main uncertainties associated with understanding of coastal behaviour. This includes comment on any implications arising from future climate change scenarios, other than a continuation of natural variability – the assumption upon which the primary assessments of shoreline evolution are all based.

3.2.3 Local Scale Shoreline Response Statements

These describe shoreline behaviour at the local-scale and consider the following:

- Assessment of Characteristics and Behaviour – identification of the geomorphological elements, present management practices, historic trends and wider scale interactions (i.e. influence of and influence upon this section of shoreline).
- Assessment of Future Geomorphic Evolution – predictions of potential future shoreline evolution over the next century assuming (a) all defence structures were removed and other coastal defence management interventions were to cease; and (b) all present defence management practices were to continue indefinitely. These predictions build upon the larger-scale conceptual evolution presented in the 'Future Unconstrained Shoreline Behaviour' sections of the Shoreline Behaviour Statements. As such the

conclusions reflect wider influences, which may not have necessarily been apparent had this length of shoreline been considered in isolation.

3.3 PREDICTIONS

A primary aim of this research project was to predict or estimate coastal evolution over the next 100 years (or longer where appropriate) assuming no major change in current management practices. This objective has been met by providing a prediction which includes the following information:

- Trend of shoreline positional movement (e.g. landward, seaward, stationary);
- Trend of foreshore change (e.g. intertidal narrowing, widening);
- Extent of shoreline positional change over next 100 years relative to current/recent magnitude;
- Description of coastal geomorphological response and wider interactions, together with identification of any changes in geomorphological forms;
- Level of uncertainty associated with the prediction (an assessment providing an indication of the present level of knowledge and understanding of coastal evolutionary processes at that location).

All of this can be imported directly into the SMPs as a baseline assessment of the impacts of continuance of present defence management policy. The SMPs can use this information to help assess social, environmental and economic consequences, allowing the technical viability and sustainability of a range of management options to be identified.

4. OUTPUTS

The deliverable includes reports, guidance, data and mapping at various scales. This represents a considerable volume of information and has therefore been presented on a single interactive CD-ROM, which forms the key deliverable from the Futurecoast project. This has many advantages in terms of the way data can be accessed and displayed, particularly for a project of this scale. Although this is a national project, many of the end-users will be interested in specific areas and the CD-ROM is designed to make it easy to access the relevant data.

The data is displayed as a series of reports, which can be viewed via a Browser Window, and mapped data, which can be viewed via a Map Window. The user can navigate through both the text and mapped data and there are links from the maps to the relevant sections of text. The user is also able to ‘design’ reports by adding sections of reports to a ‘Shopping Basket’. Therefore users will be able to print from the CD-ROM and produce reports to their own specification.

In addition to the main CD-ROM, there are two supplementary CDs, which contain oblique aerial footage for the whole of the coastline of England and Wales.

A continuous digital aerial video of the coast was collected in April 2001, to assist in identifying the current form of the coastline and to help in subsequent analysis of shoreline behaviour. This resulted in over 21 hours of digital video footage. In order to make this data set readily accessible, a map-based viewing system was used. Geo-referenced still images were extracted from the digital video at approximately 3-second intervals (ensuring an overlap between adjacent images), which were then linked to interactive mapping using SnapMap© software. The images can be accessed via overview and detailed mapping (as shown in Fig. 2) and an animated sequence can be activated. This system allows ready viewing of any part of the England and Wales coastline, providing an invaluable tool for all coastal managers.

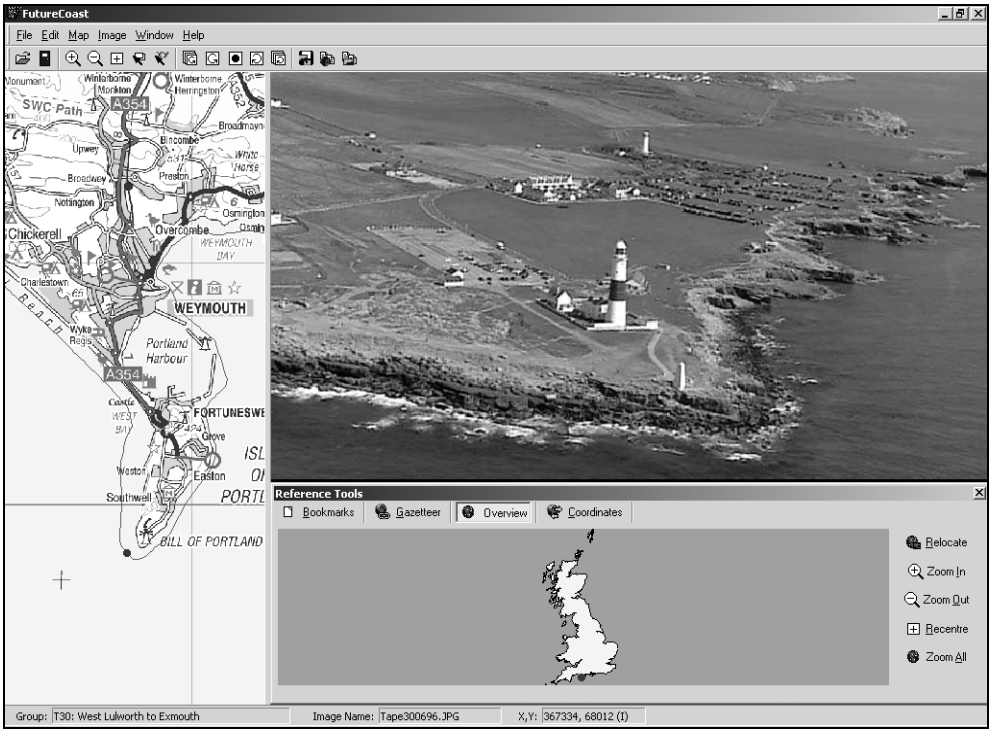

Fig. 2 Screen shot from the Futurecoast aerial photograph viewer

5.CONCLUSIONS

The main output from this research is the improved understanding of larger-scale coastal behaviour and geomorphological evolution of natural features on a consistent basis. This has been undertaken for the whole coast of England and Wales, although the basic principles and approach could be applied to any coastline. It is hoped that this will assist in raising awareness of key geomorphological issues that are relevant beyond the time horizon of existing plans and the design life of present coastal defence structures. Appreciation of these issues should help avoid tying future generations into inflexible and inappropriate coastal management decisions.

Futurecoast does not provide a definitive prediction of future coastal evolution, because this is dependent upon a number of factors, not least of which is the implementation and sustainability of existing coastal management policies. It does, however, provide a knowledge base that can be used by all coastal managers to help define sustainable policies.

The results of the Futurecoast study will be applied to underpin strategic shoreline planning and thus contribute to future coastal management decisions. These will help to ensure that the second round of Shoreline Management Plans, and indeed all coastal management within England and Wales, is better informed, therefore enabling strategic coastal management decisions to be made in a longer-term and wider-scale context.

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