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# The prediction of future coastal evolution for Shoreline Management Plan (SMP) reviews: The Futurecoast Project

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## Abstract

Funded by DEFRA and led by the Halcrow Group, Futurecoast is one of the largest R&D project of its type awarded by the department. The consortium includes prominent organisations such as the British Geological Survey (BGS), Associated British Ports (ABP) Research & Consultancy and Risk & Policy Analysts (RPA) Ltd. The project will use an improved understanding of coastal processes and behaviour around England and Wales, to provide a 'vision' of the long-term evolution and characteristic changes of the shoreline. The overall aim is to provide a sound scientific baseline and comprehensive framework with which to develop the second round of SMPs. As an alternative to the 'coastal cell' concept, this project seeks to identify broader 'behaviour systems'. This requires recognising the different elements that make up the coastal structure, the processes influencing them and how they interact. Existing data has been used to describe process-*forcing* conditions, such as tides and meteorology, together with process-*response* factors, such as sediment transport, cliff and seabed response. In addition a large-scale data capture exercise from historical mapping has been undertaken to assess coastal change rates. Combined interpretation of the process and retreat data will drive the prediction of future coastal evolution.

## 1.0 Introduction

The state of this country's coastline is currently a newsworthy topic: "More than 69,000 homes and 7000 businesses in England are at risk from coastal erosion, according to Government statistics. More than £7 billion of residential and agricultural land and property is in danger of crumbling into the sea." (*Britain falling into the sea*, The Times 03/01/01). Sensational news stories, such as homes being lost at Birling Gap in Sussex, or a sea-level rise prediction of 88cm (IPCC, 2001) over the next 100 years, tend to overlook the fact that the loss of land to the sea is not always dramatic, with rates of change varying significantly around the country.

Shoreline Management Plans (SMPs) have been produced for the coastline of England and Wales in order to determine the nature of the coast and how this knowledge might best be employed in its future management. However, a key recommendation from the review of SMPs, was the need to 'utilise an improved understanding of both coastal processes and coastal morphology information (including long-term predicted evolution, and the implication of future sea level rise and climate change) to identify sustainable shoreline management policies' (MAFF 2000). The review also concluded that there was relatively little vision presented in the existing SMPs of how the coast is likely to evolve over the longer time frame (e.g. 50 to 100 years). In response to this DEFRA commissioned the current research to improve current understanding of the major natural influences upon evolution over the next century for the open coastline of England and Wales. This will be achieved through the following tasks:

- Appreciation of coastal systems, their dynamics and influences
- Identification of behavioural systems
- Identification of the evolutionary characteristics and the resultant pressures and dominant influences.

- Use this understanding to make forecasts of future trends in natural shoreline response (both position and characteristics) for specific areas
- Assessment of how current defence management is constraining this natural response.

A key tool in this project is the use of GIS, in particular for the assessment of historical coastal change.

## 2.0 Background

An extensive data capture exercise has been carried out to identify positional changes of the coastline for all of England and Wales using the Ordnance Survey (OS) historical mapping archive. One of the greatest impediments to the definition of coastal behaviour has been the lack of data. Many of the sensors that could provide the all-important fourth dimensional element (time) required, simply have not existed (Bartlett, 1993). While this has improved in the last three decades the collation into a single environment to allow a unified appraisal of coastal development at a national scale has been a considerable undertaking.

There is now an enormous archive of remote sensing data, allowing the investigation of spatio-temporal changes to coastlines and coastal features. Mills *et al* (2001) for example are currently using a combination of multiple aerial surveys and ESA data to model, at the micro scale, the development of Filey Bay. Remote sensing data does lend itself to change studies but the processes influencing shoreline change operate over longer time periods and remote sensing archives are limited to the last 30-40 years for satellite imagery and 60 - 70 years for aerial photos.

El Raey *et al* (1995) did manage to use a combination of satellite images and aerial photos to investigate the impact upon sediment fluxes in the Nile between 1955 and 1991. Meanwhile Alam, *et al* (1996) was able to capture movements to the coastline of Bangladesh over a 70-year period. However few studies could claim to have access to such a temporal range of data.

An alternative is the historical map. Sims *et al* (1995) for example, sought to look further back in time at changes to the Dawlish Warren sand spit in Devon and incorporated historical map data into GIS dating back to 1743. On a much larger scale Halcrow examined OS maps back to 1880 as part of the Anglian Sea Defence Study (1989). There are difficulties in dealing with historical data (even in the UK where mapping standards have existed for well over a century) as changes in projection and a shift to metric need to be accounted for. However the value of historical map data has risen dramatically since being captured in digital format from the original OS paper maps by organisations such as the LandMark Group and Sitescope.

*Table 1. OS historical data is classified into Epochs, each of which covers the main edition series (LandMark Group).*

| | |
|---|---|
| Epoch 1 | generally refers to first County Series survey published between 1846 and 1901 |
| Epoch 2 | generally refers to first revision County Series survey published between 1888 and 1915 |
| Epoch 3 | generally refers to second revision County Series survey published between 1900 and 1949 |
| Epoch 4 | generally refers to third revision County Series survey published between 1922 and 1969 |
| Epoch 5 | refers to first National Grid re-survey published dates from 1945 |

Put simply, an assessment of the historical movement in the shoreline at the national level would not have been possible before the release of the historical mapping archive in its digital format. Even then the data set required the processing of over 14,500 map tiles and 8.47GB of data (LandMark tiles covering a 1km wide swath of the UK coastline, and the current OS colour 1:10,000 scale raster mapping).

## 3.0 Methodology

For the purposes of this project the coastline has been divided into a number of units, operating at three key scales. At the local scale Geomorphic Units have been defined. A dynamic segmentation model (Sherin 2000) has been used to map the relationships of the various data themes along a defined (coast) line.

### 3.1 Definition of Geomorphic Units

The geomorphic unit represents the basic building block of the coastline for this study. The GU data set has been derived from the British Geological Survey (BGS) digital maps (Becken and Green 2000) as well as newly interpreted data for the inter-tidal zone.

Use was made of the solid and drift geology layers from DigMap50 covering the entire country. This represents 141 published maps at 1:50,000 scale. From these layers, detailed lithological data has been extracted where it intersects a management line, again making use of dynamic segmentation.

The new data captured characterises the inter-tidal zone at 1:25,000 for all of England and Wales. The synthesis of this data into GU's was based around nine geomorphic and two null classes, and was mapped to inter-tidal polygons (derived from OS Landline Mean High Water and Mean Low Water vectors). These classes when combined allow along-shore and cross-shore sequence relationships to be characterised for the GU's. Further detail is added with attributes for the backshore and foreshore geomorphology, as well as the solid and drift geology and an interpretation of the presence or absence of coastal cliffs and slopes.

### 3.2 Historical coastal change data

In order to build up a picture of coastal evolution over recent history, current and historic OS 1:10,000 scale (or equivalent) mapping was reviewed to identify the extent and nature of shoreline change. Along pre-defined profile lines, four coastal constituents (Table 2) were recorded for each 'map year' (the latest identifiable publication date).

*Table 2: Coastal Constituents*

| | |
|---|---|
| Mean Low Water (MLW) | Together they indicate changes in the inter-tidal zone |
| Mean High Water (MHW) | |
| Back of Beach (BoB) | Indicates backshore width |
| Top of Cliff (ToC) | Cliff top positions are not considered here as this classification is based upon movement of the beach/intertidal area. |

The profiles were selected to be geomorphologically representative of the length of coast (i.e. not the most active areas). There is at least one profile for every GU and management unit in the country, and one is never more than a kilometre from another profile (amounting to over 3500 profiles in total).

#### *3.2.1 Change Classification*

The huge quantity of numbers generated by the retreat rate analysis simply makes it difficult to assess shoreline movement from the actual rates calculated. Therefore a classification scheme has been developed.

The main consideration is the movement and rotational behaviour of the intertidal area, with the backshore included to consider the issue of 'squeeze' (determined separately). Three intertidal parameters have been assessed for each profile location: Mean Low Water (MLW); Mean High Water (MLW) and steepening rate. MLW and MHW are classified as advancing, retreating or no movement, and the intertidal is classified as steepening, flattening or no rotation.

Based upon these classifications a mode of intertidal movement has been defined based upon the ranking system:

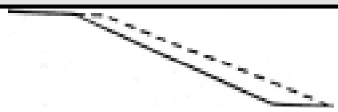
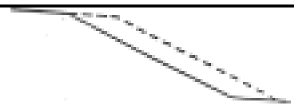
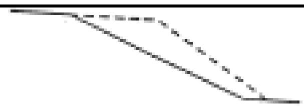
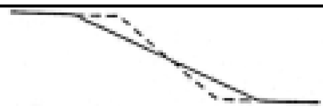
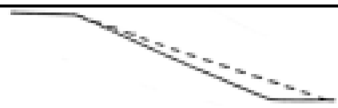
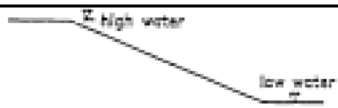
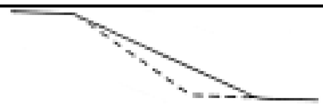
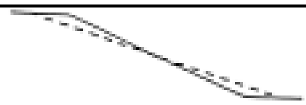
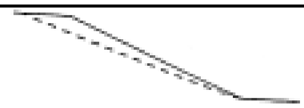
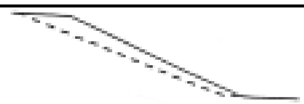
1. MHW movement is more important than MLW, as MHW is the feature more likely to directly affect the backing hinterland/defence

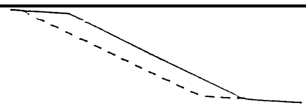
2. Intertidal flattening is more desirable than steepening, as flattening generally reduces destructive shoreline energy (Flattening is negative [angle decreasing] and steepening is positive)

3. Movement of MLW is the least important of the three variables.

Using this ranking system a 13 point classification has been defined (Table 3), with -6 generally having the greatest implications for increased vulnerability of the backing hinterland and +6 the least (i.e. in coastal defence terms –6 is a worse case and +6 a best).

*Table 3. Shoreline movement modes*

| Mode | MHW | MLW | Intertidal | Profile Change |
|---|---|---|---|---|
| +6 | Advance | Advance | Flattening |  |
| +5 | Advance | Advance | No Rotation |  |
| +4 | Advance | Advance | Steepening |  |
| +3 | Advance | No movement | Steepening |  |
| +2 | Advance | Retreat | Steepening |  |
| +1 | No movement | Advance | Flattening |  |
| 0 | No movement | No movement | No Rotation |   |
| -1 | No movement | Retreat | Steepening |  |
| -2 | Retreat | Advance | Flattening |  |
| -3 | Retreat | No movement | Flattening |  |
| -4 | Retreat | Retreat | Flattening |  |

| | | | | |
|---|---|---|---|---|
| -5 | Retreat | Retreat | No Rotation |  |
| -6 | Retreat | Retreat | Steepening |  |

The historic change of the BoB has also been considered to give an indication of backshore change. The backshore is defined as the area between MHW and BoB and is classified as widening, narrowing or no change. This parameter gives an indication of the 'whole profile' historic change, and also the occurrence of coastal squeeze. Treatment of the backshore separately from the intertidal reduces the complexity of the mode definition. The suffix 'n' (narrowing), 'w' (widening) or 'o' (no change) is added to the intertidal mode. For example a beach with retreating MHW and MLW, steepening intertidal and a narrowing backshore would be classified as '–6n'.

### *3.2.2 Positional accuracy tests*

Making use of historical maps has a number of accuracy problems that need to be addressed. As a working figure, it can be stated that OS mapping, at the 1:10,000 scale has a relative accuracy of 3.5m. This figure increases to about 5m when dealing with historical data. This is the result of bringing the data into the digital environment and performing the necessary shifts/warps so that it shares a common spatial framework (the National Grid). Considerable processing of the data is required in order to remove the data (below this threshold) this process removes the data that indicates a level of accuracy greater than can actually be achieved with the mapping. In addition to this it is important to remove data which is incorrectly positioned due to errors in the warping etc of the historic maps.

It is not possible to automate this process as movements due to map shifts are not detectable above natural shoreline movement. Therefore it is necessary to attempt to identify the erroneous maps and define the error. Table 3 lists the qualitative checks carried out to identify those maps (and hence data) which are not correctly positioned.

*Table 4. Qualitative positional accuracy tests*

| | |
|---|---|
| 1 | Whilst identifying the historic point locations, digitisers overlay and compare map editions. From this, any significant difference between the maps is immediately obvious as the displacement makes the image appear blurred. |
| 2 | Identification of any data that appears to show a seaward migration of the cliff-top position. This is very unlikely to occur in reality, therefore it is highly likely that such data will be identifying incorrect mapping. |
| 3 | Identification of any data that appears to indicate movement of hard defence structures. Again, we would not expect this to happen (except where a defence has been rebuilt on a new alignment) and the data is likely to represent error. |
| 4 | Identification of data indicating a single reversal in the overall movement trend of a feature, e.g. if the MLW position as shown retreat on all but one map editions. Although it is quite reasonable for a feature to display non-linear behaviour, it is more likely that a trend would continue over time, and therefore this may be due to error. |

The first test is carried out whilst the data is being captured whereas tests 2 to 4 are based upon analysis of the gathered data. These tests are simply used to identify those maps that have been greatly effected by the warping process. It is then necessary to quantify the error, in order to filter out those deemed greater than tolerable levels, through measurement of the movement of known fixed features (e.g. churches, houses).

Although referenced from the historical data, the predictions of future evolution being made for Futurecoast are qualitative, and consider the nature and direction of change. As such the tolerance of mapping errors is higher than if we were attempting to generate exact future movement rates. In terms of the Futurecoast project, importance is placed on generating the correct shoreline movement in terms of the nature, and approximate magnitude, of historic change.

A judgement has been made to set an upper tolerance level of 10m. Given the mapping periods we are considering (up to 170 years) less than 10m equates to a minimal rate of shoreline change and, more importantly, one which will have no bearing on the final predictions made. In terms of the maps being appraised, this is also considered to be a value which whilst removing the most significant errors will not result in removal of large parts of the dataset.

## 4.0 Summary

The focus of this paper has been on the collation of the national historical coastline change data set and the synthesis of existing data in order to help define the various units. The Futurecoast project itself has many additional facets to which GIS is being deployed (the delivery of the project to its end-users being a particularly important one). The use of GIS for coastal change analysis is obviously not a new idea, but it has only been done for small sections of coastline and never on the scale in which the present study is being carried out. The size of the project has meant that we have had to accept certain levels of accuracy as acceptable. It should be noted that the sources of error discussed above do not form an exclusive list (one of interest is the changing definition of the MHW/MLW line by the OS [OS 1998]).

It should also be noted that the Futurecoast project is still a number of months from completion. We are currently completing the data capture exercise, and the present definitions have been based on the analysis of the data collected to date. There has been development of the definitions of mode and change, which we expect to continue until an assessment of the final data set, has been made.

## Acronyms

| | |
|---|---|
| BoB | Back of Beach (a beach constituent) |
| DEFRA | Department of Environment, Food and Rural Affairs (formerly MAFF) |
| ESA | European Space Agency |
| MAFF | Ministry of Agriculture, Food and Fisheries |
| MHW | Mean High Water (a beach constituent) |
| MLW | Mean Low Water (a beach constituent) |
| OS | Ordnance Survey (National Mapping Agency) |
| ToC | Top of Cliff (a beach constituent) |

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