# D Shoreline interactions and response

**CONTENTS**

## *D.1 Introduction*

This appendix provides supporting information on the assessment of shoreline interaction and response and outlines methodologies and tools that can be used in such assessment and their application.

The study of shoreline interactions and response forms an integral part of the SMP and the appreciation of the coastal behaviour and dynamics underpins the whole SMP development. There are 3 key stages in the SMP development where this understanding is specifically applied:

- Baseline understanding of coastal behaviour and dynamics (Task 2.1)
- Development of two baseline response assessments: ‘no active intervention’ and ‘with present management’ (Task 2.2)
- Policy scenario assessment (Task 3.2)

## *D.2 Recommended approach to analysing shoreline response*

### *D.2.1 Introduction*

Coastal landscapes are the product of process and responses over a variety of temporal and spatial scales. Changes in the character and position of the coast occur as it strives towards a state of ‘dynamic equilibrium’, in response to the flows of energy and sediment. It is also the flow of sediment, driven by energy at the shoreline, which will usually be the factor most altered by different defence management scenarios (i.e. changing controls) and induce different shoreline responses. Within the system there can be different controls and a number of feedbacks, both positive and negative, which complicate these interactions. The coastal environment is further complicated by the fact that these controls, feedbacks and subsequent responses act on a number of different scales, both spatial and temporal.

Large-scale and long-term understanding is necessary to assess the sustainability of management options and to take into account any long-term trends or drivers of coastal change, which may vary from short-term and local observations. For instance, trends of shoreline movement, purely based upon recent beach monitoring, or sediment movements derived from a decade of wave data, are not necessarily representative of long-term processes. Shorter-term and smaller-scale understanding is therefore also important because it identifies local detail and variations from the larger-scale. For example, long-term prediction of change from high-level studies, such as Futurecoast, may not reflect variability at the shorter timescales, which may be a key factor in setting policy for the 0 to 20 year period.

The SMP also needs to recognise and assess issues that could potentially alter coastal processes significantly, but which may be little understood, e.g. offshore sand banks.

A *“Behavioural Systems”* approach, as adopted in Futurecoast (Halcrow, 2002), is therefore advocated, which 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.

### *D.2.2 The Behavioural Systems Approach*

This approach as detailed in Futurecoast, focuses on the understanding interactions and linkages within a system to develop the overall framework of coastal system functioning. As such, it can accommodate changes in forcing, sediment storage and supply, rates of movement, and provide the information to assess the consequential morphological response of features throughout the coastal zone. It provides a framework for completely defining a coastal system, but allows for some gaps / uncertainty in understanding, for example, it is possible to identify 'other' processes due to lack of balance in the sediment budget (i.e. sediment losses), but not necessarily resolve them. The identification of a behavioural system is an attempt to integrate geomorphological units that are spatially contiguous into a single entity; it is the interaction between the units that is central to determining the behaviour. Feedback invariably plays an important role and changes in energy/sediment inputs that affect one unit can in turn affect other units, which themselves give rise to a change in the level of energy/sediment input.

Whilst the starting point for a behavioural system is the energy and sediment pathways, it is important to identify the causative mechanism as a basis for building a robust means of predicting the response to change. This must take account of variations in sediment supply and forcing parameters, such as tide and wave energy. However, it is also important to look for situations where the system response is to switch to a different state, for example, the catastrophic failure of a spit, or the switching of channels as a consequence of episodic storm events.

In analysing shoreline response, each feature and its influence upon coastal evolution must be considered, including management practices. An essential requirement of this approach is to consider the coast as a whole system; not to treat each feature in isolation.

In addition to considering short-term changes and sediment movements (as may be derived from monitoring and modelling), there also needs to be appreciation of the longer-term behaviour and evolutionary tendencies that may ultimately drive the system and cause morphological changes. It is therefore important to assess decadal change, rather than focus upon short-term fluctuations, although the potential for non-linear change must be considered, for example a step-change in the geomorphology such as the deterioration and complete loss of a shingle barrier, or the nature of non-linear cliff failures. Therefore, and as a result of the different influences upon shoreline response resulting from different management approaches, there will generally be a need to construct a chronology of potential change, so that any sequential influences can be properly evaluated.

This approach can be applied at many levels and can be either semi-quantitative (e.g. examining *relative* sediment transport rates or volumetric changes) or fully quantitative (i.e. numeric calculation of quantities and transport rates) and Box D2 (Section D.2.5) illustrates typical levels of accuracy in predicting shoreline position using different techniques. However, should a quantitative approach be adopted, it should be noted that conducting an accurate quantitative analysis can be heavily data dependent, but the quality of available information on sediment pathways, stores and sinks can be poor thereby still limiting its accuracy. There can also be considerable variability in rates of movement predicted by different methods and models. Further information on the different techniques available to supplement the Behavioural System approach, is provided in Section D.2.5.

### *D.2.3 Delivering the baseline understanding of coastal behaviour and dynamics*

#### ***(a) Coastal processes***

In order to address the above and enable the assessments of shoreline interactions and responses, the following knowledge is required:

- Identification of the features, both natural and man-made, which are present within the coastal area being examined (see Futurecoast mapping and aerial imagery).
- Understanding of the natural controls upon shoreline evolution (assessment of this has been undertaken as part of Futurecoast).
- Understanding of the response of the coastal system (e.g. from Futurecoast Geomorphology Manual, studies to assess barrier overtopping, washover, breaching etc.).
- The natural forces presently driving shoreline change i.e. wave, tide, water level and wind data (e.g. from past modelling).
- Sediment budget dynamics, i.e. the sources, stores, sinks and sediment pathways, ideally with an understanding of rates (e.g. from coastal process studies). Details should also be provided on potential longer-term influences, for example how long-term re-alignment of the coast (e.g. as proposed by Futurecoast) may alter the budget and the dynamics of sediment transport. There is also a need to consider the movement of different sediments (non-cohesive and cohesive) and understand the different processes that govern this.
- Past and present shoreline changes (e.g. from historic mapping, shoreline monitoring data) together with documentary evidence of coastal change especially responses to extreme events, e.g. records of erosion and flooding events.

Review of the available information may indicate a lack of knowledge regarding some of these factors and some additional work may be required to mitigate this (this should be identified as part of Task 1.2 (see Volume 2)). It is essential that this review is undertaken by competent staff, experienced in analysis of coastal processes and shoreline response.

The understanding derived from this assessment needs to be communicated in a transparent fashion, and full references to information sources clearly identified, so that subsequent assessments of shoreline evolution for policy option analysis are auditable. To enable this auditability and achieve consistency between SMPs, a series of standard pro-formas have been developed which are included in Appendix L.

#### ***(b) Defence assessment***

Annex D1 identifies possible sources of defence data. Whilst this data may hold information on residual life it is suggested that this is reconsidered as part of the SMP. Table D1 below uses the condition data (available from annual coastal authority surveys, NFCDD) together with NADNAC *condition deterioration curves* (CDC). Some informed decisions may need to be made; therefore it is essential that this assessment is undertaken by an experienced coastal engineer.

This information should be used in the 'No Active Intervention' assessment as a first approximation of when defences will fail.

**Table D1 Estimate of deterioration for assessment of residual life for example structures**

| **Defence Description** | **Estimate of residual life (years) under NAI policy** | | | | |
|---|---|---|---|---|---|
| | **Existing Defence Condition Grade:** | | | | |
| | **Grade 1** | **Grade 2** | **Grade 3** | **Grade 4** | **Grade 5** |
| Seawall (concrete/ masonry) | 25 to 35 | 15 to 25 | 10 to 15 | 5 to 7 | 0 |
| Revetment (concrete/ rock) | 25 to 35 | 15 to 25 | 10 to 15 | 5 to 7 | 0 |
| Timber groynes and other timber structures (e.g. breastwork/ revetments) | 15 to 25 | 10 to 20 | 8 to 12 | 2 to 7 | 0 |
| Gabion | 10 to 25 | 6 to 10 | 4 to 7 | 1 to 3 | 0 |
| *Note: Grade 5 is not used in the CPSE, but is included here as a measure of failure.* | | | | | |

For the 'With present management' scenario, it is assumed that all existing structures and management practices remain. For this assessment it is the function of the defence 'practice' that should be considered rather than specifics of the structure itself. Therefore information in the Defence Assessment report needs to be thought of in broad terms, relating to how present defences and management practices affect shoreline processes and behaviour, i.e. as:

- 'Linear stoppers'
- 'Linear reducers'
- 'Cross-shore interrupters'
- 'Changers'

Table D2 makes recommendations on the assumptions that should be used for each defence type. No assumptions are made for natural features (apart from those that are maintained, see Shingle barrier below).

**Table D2 Assumptions for the 'With present management' baseline assessment**

| Defence type | Example Structure | Assumptions |
|---|---|---|
| Linear stoppers | Seawall | ▪ Continues to prevent cliffline retreat<br>▪ Stops (reduces) sediment input<br>▪ Structural integrity remains and the wall is rebuilt at a similar standard of effectiveness<br>▪ Exposure may change, i.e. due to changes in beach levels<br>▪ Outflanking needs to be considered for each site, but in general for significant length of seawall, assume Bullet 3 includes response to possible outflanking |
| | Flood wall/ embankment | ▪ Structural integrity remains and the wall is rebuilt at a similar standard of effectiveness<br>▪ Continues to minimise tidal flooding (prevent a breach)<br>▪ Exposure may change, i.e. due to changes in beach levels |
| Linear reducers | Rock bund | ▪ Continues to reduce erosion, although level of effectiveness may change and therefore rate of erosion may also change (could either increase or decrease)<br>▪ Structure is rebuilt in a suitable location if it fails totally (unlikely) |
| | Timber revetment | ▪ Continues to reduce erosion, although level of effectiveness may change and therefore rate of erosion may also change (could either increase or decrease)<br>▪ Structure is rebuilt in a suitable location if it fails (i.e. not necessarily in the same position) |
| | Maintained shingle barrier | ▪ Re-profiling continues until <u>technically</u> impossible |
| Cross-shore interrupters | Groyne (with seawall) | ▪ Continues to interrupt drift but not necessarily the same amount (could both increase or decrease)<br>▪ Maintenance when necessary to maintain *potential* effectiveness<br>▪ Once a beach disappears, groynes may be considered to be redundant |
| | Groyne (without seawall) | ▪ Continues to interrupt drift but not necessarily the same amount (could both increase or decrease)<br>▪ Maintenance when necessary to maintain *potential* effectiveness<br>▪ Structure is rebuilt in suitable position when fails or becomes detached<br>▪ No extension of the groynes<br>▪ No change in groyne cross-section<br>▪ Once a beach disappears, groynes may be considered to be redundant |
| | Reefs/ breakwaters | ▪ Continues to interrupt drift but not necessarily same amount<br>▪ Structure is rebuilt in a suitable location if it fails totally (unlikely) |

| | | |
|---|---|---|
| | Harbour Arms | ▪ Structural integrity remains and the structure is rebuilt at a similar standard of effectiveness |
| Changers | Recharge | ▪ Continue to recharge with same amount, sediment type and timing |
| | Recycling | ▪ Continue to recycle same amount, with same timing, and to and from the same locations until technically impossible (e.g. source exhausted) |

### *D.2.4 Assessment of baseline and policy scenarios*

#### ***(a) Analysis***

The SMP should adopt the Behavioural Systems approach as the primary mechanism for assessing shoreline interactions and providing information from which morphological responses can be defined, for both the baseline assessments (Task 2.2) and the policy scenario assessments (Task 3.2).

The process of evaluation for any one scenario will necessarily be an iterative one to investigate response of the coastal morphology to changes in energy and sediment exchange as a result of feedbacks within the system. A simplified step-by-step explanation of the application is provided in Box D1. Informed decisions and judgements need to be made so it is essential that this analysis is undertaken by experienced team members.

When undertaking this assessment, the following influences should be accounted for:

- **Controls**: There is a need to identify the key human and natural influences on coastal behaviour, and how changes in these key influences could affect shoreline evolution. Geological formations, such as headlands or shore platforms, may fundamentally control both the present morphology and the nature/rate of future response to environmental forcing. Other controls include offshore banks and estuaries. There should also be consideration of the influence of changes in long-term shoreline-alignment or position, e.g. as identified by Futurecoast, on sediment movement.
- **Sediment budget modifications:** Key information to consider throughout the shoreline area being examined will be:
    - Any change in sediment input from the backshore or from offshore
    - Any change in sediment outputs to offshore or to the backshore
    - Any change in longshore transport, both volume (rate) and direction

  A primary aim should be for all SMPs to develop a sediment budget where possible; therefore where such information is not available it may be appropriate to conduct basic modelling studies (e.g. wave climate and tidal currents etc.) to gain some appreciation of sediment movement potential. It may also be necessary to look at impacts on and effects of adjacent SMP areas.

- **Backshore response:** Having assessed changes in the beach sediment exchanges, the impact and subsequent response of the backshore needs to be considered. This will depend not only upon the change to the beach, and therefore the possible changes in sediment and energy transfer, but also on the characteristics of the backshore, e.g. cliff composition, land levels and flood potential.

- **Feedbacks:** Feedbacks occur as the result of change in a system and can affect the net morphological response of the coastal zone. Positive feedbacks amplify the change, whereas negative feedbacks tend counteract initial changes and reduce the net change. An example of a feedback is where cliff erosion releases sediment, which allows the beach to build up, thus reducing the amount of wave energy reaching the cliff toe and thereby reducing cliff erosion.
- **Management techniques:** In order to fully assess the suitability of a particular policy, there will need to be some consideration of the possible management approach, as each could yield a different response on other parts of the coast. Guidance should be provided by the identification of objectives (see Task 2.4, Volume 2), which may identify certain constraints or requirements, e.g. the presence of a beach for recreational reasons. Alternatively, it will be necessary to define a generic management option (see below) through this assessment process, as it directly influences achievement of the policy options being considered. If necessary, alternative management approaches can be developed without changing coastal defence policy.

The analysis will often require a number of iterations (this depending upon site specific complexities), as the impacts of each of the above factors will feedback and induce different responses. In conducting this analysis, sediment exchanges or feature behaviour can be altered to reflect these factors and the shoreline response re-evaluated accordingly, until such point that a state of “functioning equilibrium” is determined. Application of this approach will ensure that the cumulative impacts of defence management practices are established for the entire coast. It may be possible to “close out” sections of coast and only re-analyse certain sections as different variations on scenarios are developed.

The analysis must continually consider each of the following:

- what is there (i.e. features, geomorphology etc.)?
- how is it reacting to circumstances around (i.e. typical response, long-term trends and response to extreme events)?
- why is it reacting in this manner (e.g. is the reaction controlled by factors such as sediment supply, geological/ geomorphological controls, coastal movement)?
- what are the consequences elsewhere of this reaction (e.g. features updrift and downdrift)?

The output from this assessment will be a chronology of shoreline response for each section of the shoreline; it is recommended that this be delivered for the three defined epochs (see Tasks 2.2 and 3.2 in Volume 2)

**Box D1 Recommended steps in analysing shoreline response**

This outlines the key steps in conceptual analysis of shoreline response, using the Behavioural Systems approach, for the assessment of policy scenarios (including the baseline assessments of ‘no active intervention’ and ‘with present management’). These steps assume that the baseline understanding of coastal behaviour and dynamics has already been undertaken and that the analysis is undertaken by experienced coastal engineers/scientists

***Step 1 Assess large-scale coastal behaviour: For the policy to be tested, a***ssess the wide-scale potential coastal realignment resulting from the new constraints, i.e. changed controls and linkages. This may be undertaken for the whole SMP area (recommended if there are strong linkages) or for isolated frontages (only recommended where there are no or weak alongshore linkages). This requires a good understanding of coastal plan-form change/response processes. As a first stage this can be undertaken as a broad overview and should be considered for the 50 to 100 year period. Information from Futurecoast (both the ‘unconstrained’ and ‘present management’ scenarios) can be used to help guide the analysis – see also Futurecoast User Guide section on Using Futurecoast Results.

***Step 2 Assess impact on large-scale sediment transport regime:*** Using the assessment of large-scale coastal change, determine any modification to present-day sediment transport regime throughout the whole area as a result of realignment and constraints, considering any change in the foreshore sediment balance for each local area as a result of the changes to coastal behaviour and realignment. This should be considered initially for the 50 to 100 year period.

***Step 3 Consider coastal response:*** Use generic understanding of geomorphological feature behaviour (e.g. use the Geomorphology Reference Manual provided by Futurecoast) to assess probable behaviour of the various landforms in response to the new constraints, modified linkages, realignment potential and altered sediment regime. It is also important to consider response to extreme events.

***Step 4 Consider local impacts:*** Considering first the 0 to 20 year period for the entire coast, and then the 20 to 50 year period, determine the local impact of the policy on the sediment balance, i.e. identify any change in sediment input, e.g. if cliffs are no longer defended, sediment output, or sediment transport path, e.g. due to interruptions such as groynes or a new inlet forming.

***Step 5 Predict backshore response:*** Combine understanding from step 3 with sediment balance information from step 4 to predict the type of backshore response, in particular any potential change in geomorphological form and subsequent alteration to the backshore/foreshore sediment exchanges that will take place. Determine any likelihood for the backshore response altering the controls and further modifying shore alignment.

***Step 6 Consider impact on adjacent areas:*** Using the approach and information from Step 2, assess any potential impacts on adjacent areas and the wider area for both the 0 to 20 and 20 to 50 year periods.

***Step 7 Consider feedbacks/ interactions:*** Ideally the analysis process will need to be iterated until a state of “functioning equilibrium” is reached. This involves the reiteration of steps 2 to 6 to ensure interactions are fully accounted for, for each period, and check consistency with the prediction made for the 50 to 100 year period. This procedure may identify interactions or responses which require a re-evaluation of the initial 50 to 100 year prediction, for example if a system change threshold occurs as a result of the intervention policy scenario.

***Step 8 Predict shoreline position:*** Establish the extent of shoreline movement for each of the time periods.

### *(b) Consideration of management techniques*

Broad defence / management techniques will need to be considered when assessing policy, e.g. if the policy is ‘hold the line’, there needs to be some consideration of how this may be achieved, or at least an assumption made, in order to assess impacts of this decision on the coastal processes. There is no constraint upon the option variations that might be considered but, depending upon the particular circumstances for any individual SMP, in most instances management options may be limited to construction or maintenance of:

- Hard linear defence (e.g. seawall, embankment)
- Soft linear defence (e.g. managed shingle barrier)
- Retention of beach (i.e. control structures)
- Replenished beach (i.e. introducing additional sediment through artificial re-nourishment)

Consideration should be given to the long term viability of (or risks associated with) some techniques; for example long term sustainability of dredging material for continued beach material.

### *D.2.5 Additional techniques and tools*

The Behavioural Systems approach can be developed in either a quantitative or qualitative form (i.e. tailored to suit the characteristics of the local area, needs and available information of the Coastal Group). In general, a good understanding of coastal interactions and response sufficient for SMP analysis can be developed from an experience-based interpretation of existing information, perhaps with some additional numerical work to produce better knowledge of forcing conditions (e.g. waves) and sediment movement where this does not already exist.

However, in adopting a purely experience-based interpretation of existing information, the following points should be recognised:

- Ability to assess interactions is dependent upon type and quality of information available.
- Prediction of landform change is also dependent upon information available, although Futurecoast provides a basis for determining this.
- It is usually possible to develop a quantitative prediction of positional change, although unlikely to provide precision with regard to quantitative change.
- It is possible that future changes may differ significantly from those in the historical record; a sensitivity analysis, based upon expert judgement, is required to address this potential omission.

There will, in some cases, be scope to improve upon the assessment made and quality of predictions resulting from interpretation of existing information through employing additional techniques.

Shoreline position in response to different influences, which does need to be quantitative, can be more difficult to accurately establish, as changes are usually site specific and not possible to validate when considering long timescales and changing influences such as different management policy. A common approach in the past has been the extrapolation of historic mapping or even monitoring data, although this can sometimes be inaccurate because (i) linear change is often assumed and (ii) responses to historic influences may not reflect the likely responses to different future influences. Consequently, some of the methods and tools presented in Annex D2 may be useful if it becomes necessary to improve confidence in the extent and timing of shoreline change.

Many analytical techniques have been developed to predict future shoreline changes; these range from expert opinion to highly complex computer-based models, and have very different demands upon data and time. Some commonly used techniques are:

- Geomorphological extrapolation
- Numerical modelling of shoreline response
- Extrapolation of historical data
- Parametric equilibrium models

Further discussion on the merits of each technique and comparison of these techniques is provided in Annex D2.

The choice of technique/s to adopt depends upon the accuracy and precision required to inform future planning, and in some cases to differentiate between policy scenarios. It must be recognised that in many cases, the policy decisions taken at SMP level do not require a high level of precision, whilst the accuracy of predictions will vary over time. Box D2 provides a broad indication of the typical levels of accuracy that may be obtained.

**Box D2 Typical levels of accuracy in predicting shoreline position**

| **Quality of data and method** | **Probable maximum error in accuracy of prediction** |
|---|---|
| HIGH<br>*Example: Numerical modelling using high quality and density data (over short to medium timescales)* | ± 20% |
| MEDIUM<br>*Example: Analysis of historical data on a coastline exhibiting linear evolutionary tendencies* | ± 50% |
| LOW<br>*Example: Geomorphic analysis using sparse data set.* | ± 100% to 200% |
| NB. It should be noted that these are estimates of accuracy and that accuracy or suitability of applying these methods will be site-specific. | |

In general it is not easy to increase accuracy without improvements in data, but precision of output can be improved and confidence in results stated through employment of a range of different tools, although this may not necessarily be desirable. When using numerical modelling, uncertainty can be more easily assessed by considering both the errors inherent in the original data sets and also by applying sensitivity tests to the models. In general, numerical models will all make assumptions, simplifications and omissions. It is essential that the results are interpreted by experienced coastal scientists/engineers/geomorphologists. With more interpretative analysis, such as Geomorphic Analysis, the accuracy is more difficult to define, because conclusions are ultimately based on expert opinion rather than actual data.

Examples of output for both No Active Intervention and With Present Management are given below. A third example of how the baseline appraisals could feed into the policy assessment and the expected shoreline interactions and response is also detailed for the same locations (refer Appendix I for more details). Further details can be found in the three pilot SMPs.

| | SCENARIO REF: BASELINE SCENARIO 1 – NO ACTIVE INTERVENTION | | |
|---|---|---|---|
| Location | Predicted Change for | | |
| | Years 0 – 20 (2025) | Years 20 – 50 (2055) | Years 50 – 100 (2105) |
| Poole Place to Littlehampton Harbour (River Arun) | Annual shingle recycling at Climping from the west side of the harbour entrance westwards would cease. The seawalls, the timber groynes (west section of frontage) and the western harbour training wall would fail during this period. | No defences. | No defences. |
| | The beach would be expected to narrow, steepen and move landwards once the timber groynes and seawalls failed. This would be likely to be a piecemeal process, as the structures would fail at different times on different sections of the frontage due to their age and condition. Retreat of 0-10m could occur by 2025.<br><br>The shingle beach ridge might breach as it moved landward, particularly at Poole Place because of the lack of sediment input caused by the Elmer breakwaters and groyne.<br><br>Rollback of the dunes west of Littlehampton Harbour entrance would be outpaced by the rate of shoreline retreat, which would accelerate at the | Landward retreat of the shoreline (approximately 20m by 2055) would continue under the influence of sea level rise and the lack of sediment supplied to the frontage from the coastline to the west. There would be a greater probability of breach, overtopping and associated flooding of land behind the beach.<br><br>The shoreline retreat would continue to supply sediment to the coastal system. It would be expected that much of this sediment would feed the continued growth of spit/bar/delta complex at the Littlehampton Harbour entrance. The spit/bar/delta complex would interrupt longshore transport to the east initially but would then be expected to establish natural bypassing across the | The rate of landward retreat would be expected to slow and the frequency of breaching to reduce as the pulse of sediment released by the failure of the Elmer breakwaters and groyne reached the frontage. By 2105, the shoreline could be some 30m landward of its current position.<br><br>The western spit/bar/delta complex would be expected to continue to grow, undergoing cycles of breaching and changes in entrance location. |

| | SCENARIO REF: BASELINE SCENARIO 1 – NO ACTIVE INTERVENTION | | |
|---|---|---|---|
| Location | Predicted Change for | | |
| | Years 0 – 20 (2025) | Years 20 – 50 (2055) | Years 50 – 100 (2105) |
| | end of the period with failure of the harbour training wall.<br><br>Sediment released by the failure of the groynes, beach narrowing/steepening and landward retreat would be available for transport eastwards by longshore drift. Failure of the west harbour training wall at the end of this period would release a large quantity sediment into coastal system, probably resulting in the growth of a western spit/ bar/delta complex eastwards across the existing harbour entrance. Some sediment would also be transported by longshore drift further eastward past the entrance. | entrance. It would also deflect the harbour entrance to the east. The spit would be prone to breaching, with breakdown of the barrier and redistribution of that material which might result in closure of the existing harbour entrance. | |

| SCENARIO REF: BASELINE SCENARIO 2 – WITH PRESENT MANAGEMENT | | | |
|---|---|---|---|
| Location | Predicted Change for | | |
| | Years 0 – 20 (2025) | Years 20 – 50 (2055) | Years 50 – 100 (2105) |

<table>
<tr><td colspan="4">SCENARIO REF: BASELINE SCENARIO 2 – WITH PRESENT MANAGEMENT</td></tr>
<tr><td rowspan="2">Location</td><td colspan="3">Predicted Change for</td></tr>
<tr><td>Years 0 – 20 (2025)</td><td>Years 20 – 50 (2055)</td><td>Years 50 – 100 (2105)</td></tr>
<tr><td>Poole Place to Littlehampton Harbour (River Arun)</td><td colspan="2">The seawalls, timber groynes (west section of frontage) and western harbour training wall would remain. Recycling at Climping from the west side of the harbour entrance would continue.</td><td>Some timber groynes and western harbour training wall would remain. The seawalls could become redundant. Recycling at Climping from the west side of the harbour entrance would continue.</td></tr>
<tr><td></td><td>The beach at Climping would not be expected to change during this period, as recycling would be expected to be sufficient to offset the effects of sea level rise in the short term.<br><br>In areas backed by seawalls, the beach would begin to narrow and steepen and beach levels would begin to lower during this period, due to sea level rise. For most of the frontage, these changes would be small and the beach would not appear significantly different to its present state. However, at Poole Place, immediately east of the Elmer breakwaters, the beach would not receive a supply of sediment from the west and could be lost completely by the end of this period.<br><br>In areas without seawalls, mainly the central section of this frontage, the beach would narrow</td><td>The beach at Climping (subject to increased recycling) and the eastern beach adjacent to the harbour training wall would be expected to maintain their present condition.<br><br>Where present, the seawalls would fix the landward limit of the beach. The beach in these areas would continue to narrow, steepen and lower with ongoing sea level rise. It would be expected that, by the end of this period, these beaches would be lost and the shoreline would lie at the foot of the seawalls. The groynes in these areas would therefore become redundant at the end of this period.<br><br>Landward retreat of the shoreline would continue at the sections of beach not backed by seawalls, with some 20m of retreat potentially taking place</td><td>The beach at Climping and the eastern beach adjacent to the harbour training wall would be expected to begin to steepen and narrow, as sediment supply/recycling would be unlikely to be able to sustain both areas against sea level rise.<br><br>Upgrading and an increased commitment to maintenance of the seawalls and the harbour training wall would be required in order to maintain their integrity against wave attack and outflanking. It could prove technically infeasible to continue to maintain the seawalls. These areas would then be expected to erode rapidly, with the shoreline retreating landwards to realign with the adjacent retreated shoreline. Breaching and overtopping, with associated flooding, could occur.<br><br>Landward retreat of the shoreline would continue on</td></tr>
</table>

| SCENARIO REF: BASELINE SCENARIO 2 – WITH PRESENT MANAGEMENT | | | |
|---|---|---|---|
| Location | Predicted Change for | | |
| | Years 0 – 20 (2025) | Years 20 – 50 (2055) | Years 50 – 100 (2105) |
| | and steepen and the shoreline would begin to retreat landward, although this would not be at a detrimental rate to the shoreline. These retreated sections of the frontage would form embayments between the areas with seawalls.<br><br>The beach erosion and shoreline retreat would release sediment into the coastal system at a similar rate to the present. This sediment would be moved eastwards by longshore transport and trapped by the western harbour training wall, as presently occurs. | by 2055. The embayments would become more pronounced. There would be an ongoing requirement for removal and reconstruction of the groynes in the embayments, as they were rendered redundant by shoreline retreat. As the beaches retreated and sea level rise continued, the shingle beach ridges could breach, flooding areas behind the beach.<br><br>Flooding from overtopping would be likely to occur more frequently due to sea level rise.<br><br>The beach loss and shoreline retreat would continue to release sediment into the coastal system, which would be trapped by the harbour training wall. The seawalls would prevent release of material from the land behind the structures, reducing the sediment supply to the east during this period. | the sections of beach not backed by seawalls, with some 30m of retreat potentially taking place by 2105. Reconstruction of the groynes in retreated areas would be necessary as the shoreline retreat rendered them redundant. The extent and frequency of flooding due to breaching of shingle beach ridges and overtopping would increase.<br><br>The shoreline retreat would continue to release sediment into the coastal system. This sediment would continue to be trapped by the western harbour training wall. |

| Policy –option scenarios |
|---|

| Location | Predicted Change for | | |
|---|---|---|---|
| | Years 0 – 20 (2025) | Years 20 – 50 (2055) | Years 50 – 100 (2105) |
| Poole Place to Littlehampton Harbour | | | |
| Policy Scenario A | Hold the Line | Hold the Line | Hold the Line |
| | The terminal groyne (east of Poole Place), the timber groynes, timber breastwork and training walls would be maintained. Discontinuous lengths of old masonry and concrete blocks that extend the length of the would not be maintained.<br><br>Periodic recycling of material around Atherington would continue. | The terminal groyne, timber breastwork and groynes would be maintained and upgraded. Recycling would continue throughout this period.<br><br>New set-back defences would be required by the end of this period to hold the line. The amount of recycling would have to be increased to keep pace with sea level rise. | Maintain and upgrade new set-back defences and the training wall. Continue with beach recycling scheme. |
| | The landward limit of the beaches would be fixed in its present position by the existing defences along the length of the coastline and by the training wall at the eastern end of this frontage. The beach would begin to narrow and steepen, as sea levels rise, except between Poole Place and Atherington, where the placement of recycled material would mitigate against the pressures of sea level rise. The groynes would slow the rate of narrowing/lowering of the beach. Overall, the beach would not appear significantly different to its present state, since there would be little change from the current sediment input from | The defences would continue to hold the landwards position of the beach, but would require significant maintenance and upgrading to withstand the impacts of sea level rise and increased wave attack. This would be helped by increasing the amount of material recycled to the beaches between Poole Place and Atherington.<br><br>Along the remainder of the coastline, implementation of a beach renourishment scheme could be used to achieve a hold the line policy.<br><br>The beaches would continue to narrow and | The beach would experience increased narrowing and steepening, as sea levels rise and the beach is squeezed against the linear defences behind. An increased commitment to maintenance and upgrading of the new set-back defences would be required, as sediment supply from updrift is reduced due to the hold the line policy at Elmer. Continuation of beach recharge along the length of this frontage would help to mitigate against beach losses due to sea level rise, and the subsequent exposure of the defences. |

| Policy –option scenarios | | | |
|---|---|---|---|
| Location | Predicted Change for | | |
| | Years 0 – 20 (2025) | Years 20 – 50 (2055) | Years 50 – 100 (2105) |
| Poole Place to Littlehampton Harbour | | | |
| | updrift.<br><br>There would be some narrowing and steepening of the beach which would supply sediment to the coastal system at a similar rate to the present. Much of this sediment would be moved eastwards by longshore transport, with some remaining temporarily on local beaches. | steepen as sea levels rise, but at a reduced rate immediately updrift of the Littlehampton training wall. By the end of this period, the amount of recycling would need to be increased to keep pace with increased beach loss due to sea level rise. The groynes would retain some material on the beach.<br><br>Continued narrowing and steepening of the beach would supply sediment to the coastal system at a slightly increased rate to present. Much of this sediment would be moved eastwards by longshore transport. | |

# Annex D1: Data and information

## INTRODUCTION

All available information needs to be reviewed to develop an understanding of coastal processes, shoreline responses and changes at various temporal and spatial scales, with discussion of any conflicting results and conclusions drawn.

It should also be recognised that information collected at different scales may appear to conflict and indicate differing behavioural trends. Information collected at a local level may form the basis of local knowledge on the coast and may cause disagreement where strategic investigations do not take account of the small-scale change and impact. However, the local or short-term data set may not be sufficiently broad to have identified wider influences, longer-term trends or the full range of possible behaviour during extreme events. Therefore all of this information needs to be considered in parallel. Whilst there needs to be clear identification of the temporal, and spatial, boundaries of the data sets used, key to the development of the SMP is this integration of the long-term, high-level assessments with the more local, short-term data and knowledge, to gain an overall understanding of coastal behaviour and dynamics across the range of scales.

The level of analysis required for data and information will be variable. No specific guidance can be provided on this except that each source of information must be reviewed to consider the nature, extent, timescale and applicability to the SMP. One of the key issues will be the inconsistency in the data and information between areas. Again there is no prescriptive guidance that can be given on this, except to note that it is important to understand the nature, accuracy, format, and source of any data used. This does not preclude the use of any particular source, but helps in interpreting any outcome from its use. The purpose of this stage of analysis is to draw together both factual and interpretative information from various sources to form the baseline understanding of physical interactions along the shoreline, which will be used to inform subsequent scenario analysis.

## KEY DATA AND INFORMATION SOURCES: LARGE-SCALE/LONG-TERM

### Futurecoast

Futurecoast (Halcrow, 2002) provides a conceptual understanding of long-term coastal behaviour and underpins not only this guidance but informed the overview described in reports such as Foresight. Conclusions are based upon a developed understanding of large-scale evolution, but it also provides local detail on geomorphological features and their likely evolutionary response.

The key sections that should be reviewed are within the Shoreline Behaviour Statements (“Coastal Behaviour Systems”, “Large Scale Unconstrained Behaviour”, Local Scale Shoreline Response”). In particular the ‘unconstrained’ scenario (which is <u>not</u> equivalent to the ‘no active intervention’) provides a vision of how the coast could evolve if not controlled by man-made structures such as coastal defences. This is a key step is understanding the ‘natural’ response of the coast. This needs to be considered in light of what is actually constraining coastal behaviour and how the coast might respond to changes in management. Table D1.1 summarises the key information available from Futurecoast.

**Table D1.1 Key information/ data provided by Futurecoast**

| | | |
|---|---|---|
| Interpretative reports/ predictions | Coastal behaviour | Shoreline Behaviour statements include a section on Coastal Behaviour Systems, which describe the broad characteristics of the coastal system(s) and identify large-scale interactions and drivers of change over the very long-term, i.e. the Holocene.<br>There is also a section on Assessment of Shoreline Behaviour, which includes information on past evolution and controls and linkages.<br>Local-scale Shoreline Response Statements describe shoreline behaviour at the local-scale, considering the geomorphological elements. |
| | Future unconstrained large-scale shoreline behaviour | Shoreline Behaviour statements include a section on Future Unconstrained Shoreline Behaviour, which identifies both large-scale evolution and assesses the influences of this upon the different geomorphological features that are present along the shoreline. |
| | Local-scale shoreline response | Local-scale Shoreline Response Statements include an Assessment of Future Geomorphic Evolution, which provides 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. |
| Data | Cliff behaviour assessment | A broad assessment of cliff erosion, potential failure mechanisms and contribution to local sediment budgets. |
| | Shoreline movement assessment | Graphs at 1081 locations, illustrate both changes in the position of MLW, MHW, back of beach and cliff top, and changes in backshore and foreshore width; derived from OS historical mapping. The mode of foreshore change has also been identified. |
| | Nearshore wave analysis | Offshore Met Office wave data has been transformed inshore to 68 nearshore locations and frequency distribution tables produced. Possible impacts of 10 climate change scenarios on shoreline energy conditions have been assessed at each location. |
| | Coastal geomorphology reference manual | A brief reference guide to assist coastal engineers and planners in gaining an improved understanding of the general principles of coastal geomorphology and of the key behaviour characteristics of specific coastal landforms. |
| Thematic Reports | Onshore geology | Regional review reports, which summarise the main geological characteristics of the coastline, and a macro-scale review of Holocene coastal change. |
| | Offshore geology | Reports for ten offshore regions, which summarise bathymetry and physical regime, seabed sediments and offshore sediment transport trends. |
| | Coastal processes | Regional review reports, which summarise key process information. |
| | Estuaries | Regional reports which assess the main estuaries in terms of general estuary characteristics, role of the estuary as a sink or source of sediment and interactions with the adjacent shorelines. Key data is also available for each main estuary. |
| | Review of climate change and sensitivity | A review of key climate change research with regional coastal climate change scenarios proposed. Includes a generic assessment of the sensitivity of different landforms to climate change. |
| Additional Map Data | Bathymetry | Provided by the Hydrographic Office. |
| | Physical controls and linkages | Identification of the key geological and physical controls that may influence shoreline evolution over the century timescale and key sediment linkages. |

| | | |
|---|---|---|
| | Tidal data | Tidal ellipses (and tidal residuals for the Bristol Channel and English Channel areas). |
| | Seabed sediments | Broadly mapped from the BGS offshore sediment mapping. |
| | Seabed features | Defined from published Admiralty charts. |
| | Offshore transport | Broad overview of regional offshore sediment transport. |
| | Onshore geology | Both solid and drift geology, broadly mapped from BGS map data. |
| | Nearshore transport | Derived from Shoreline Management Plans and other studies. |
| | Backshore and intertidal geomorphology | Classifications of backshore and intertidal geomorphology as identified from a number of sources. |
| | EA indicative coastal flood plain mapping | Data provided by EA: the tidal flood plain mapped for a 1:200 year event. [NOTE: more up-to-date data may be available and should be obtained directly from the EA] |
| | Future shoreline change (unconstrained/ present defence scenarios) | Mapping of predictions showing tendency and magnitude of shoreline movement. For the present defence scenario, an assessment has also been made of the future mode of foreshore change. |
| | Hot spots | Areas where there is potential for a key change or a breakdown an existing morphological form. |
| Aerial CDs | Aerial images | Oblique aerial images, taken during 2001, covering the entire open coast of England and Wales, which are accessed via a digital interactive map-based viewing system enabling easy location of coastal sections. |

**Coastal Habitat Management Plans (CHaMPs)**

CHaMPs provide a view of coastal change over 30 to 100 years, primarily based upon an assumption of continuation of present management, but with some consideration of unconstrained response and 'feasible' alternatives. Although primarily aimed at looking at potential habitat loss/gain (see Appendix H), they do provide alternative hypotheses from Futurecoast. The CHaMPs are, however, limited by the small number of local areas that they have been produced for and although they provide a strategic view, generally they have not looked as wide-scale as the SMPs need to.

**Historical mapping**

At a minimum level, historical Ordnance Survey (OS) data is available for the whole of the coastline of England and Wales and in many areas, where change has been rapid, measurements of coastal change may extend over 100 to 150 years.

Analysis of historical information already exists in various forms for many locations. Some analysis of historical OS maps has been undertaken as part of Futurecoast (Halcrow, 2002) for a large number of points around the coast. Along some coasts, it may be necessary to increase the coverage of points to improve upon this data set. It is also recommended that original maps be viewed, in addition to any extracted data in order to take account of alongshore as well as cross-shore change, for example the extension of a spit. Where highest quality historical information is required, e.g. for MHW, MLW or cliff top, it is recommended that 1:2500 scale (or 25" to the mile County Series) mapping is analysed. This has a typical accuracy of 2 to 3m, as compared to >5m accuracy with the 1:10,000 (or 6" to the mile) mapping.

## KEY DATA AND INFORMATION SOURCES: LOCAL-SCALE/SHORT-TERM

### First round Shoreline Management Plans

Whilst ostensibly large-scale and long-term planning documents, information and conclusions contained within many of the first round SMPs tend to be relatively local-scale and short-term. Nonetheless, they provide a significant source of information, which should be utilised as fully as possible.

Data may include rates of historic coastline change, potential sediment transport, sediment characteristics, geomorphology features, waves, tides and defence information (although this may only be referred to, and not necessarily included within the SMP). Many of these original SMPs recommended further coastal process studies and a first step should be to review these and appraise what studies have been undertaken since the SMP (if any) to address the issues.

Information in the SMPs may also help to consider interconnected sediment transport pathways and hence allow consideration of how these may be affected by changes in management. Applying this information, and that from other sources detailed below such as strategy studies, in parallel with the Futurecoast information, will help to identify some integral components in the sediment transport that may need to be communicated to the decision makers so they understand the scale of impact that decisions on the coast may have and how certain approaches to coastal management could affect the wider processes.

In some cases the original SMP information focuses on more recent events rather than historical analysis (this is particularly true where data on coastal processes and historic coastal change was limited). It should be borne in mind that many of the existing SMPs projected coastal change to a 50-year horizon without taking account of coastal features exercising control on the processes and a key criticism of some of the SMPs was that few plans incorporated consideration of the geological constraints in predictions of the evolution of mobile landforms (MAFF, 2000). Many SMPs also failed to take account of wider-scale interactions or longer-term trends. Futurecoast has, however, addressed these latter two points to a large extent.

### Strategy studies

Following the first round of SMPs, a number of strategy studies have been carried out. These generally cover a much smaller area than the SMP, but in greater detail. Information from these individual studies needs to be interrogated and compared with studies on adjacent coasts, to check for consistency. The strategy studies draw significantly on the SMPs, but many include new additional local-scale studies, which must be fed into SMP reviews. Some strategy studies have attempted to predict future shoreline positions, but it is important to understand the assumptions made, when using this information. In some cases, shoreline response modelling will have been conducted as part of the strategy study, which may be useful for interpretation of policy scenarios subsequently developed by SMP reviews.

The review of strategy study information and data may require careful consideration to ensure information is used at the relevant temporal and spatial scale. In general, data from these studies will tend to be most useful for assessing behaviour on the 0 to 20, and possibly 20 to 50 year periods, but with many of the same limitations described above for the first generation SMPs.

**Regional modelling studies**
Regional sediment transport studies have been undertaken for long lengths of coastline, particularly the South and East coasts of England, e.g. Southern North Sea Sediment Transport Study (HR Wallingford, 2002) and Seabed Sediment Mobility Study – west of the Isle of Wight (CIRIA, 1998). Such studies are likely to be an appropriate strategic level to advise and inform the SMP process and, importantly, incorporate the offshore in considering transport pathways. Again data on a variety of parameters is available but is usually focussed on the driving forces for sediment movement (waves, tides) and the direction, rates, distances, volumes etc. of sediment movements. The reporting of this data may provide interpretation of the underlying processes and identify linkages with coastal features that may be critical in developing SMP reviews.

Although limited spatially, these studies provide insight into shoreline interactions and should be used in the interpretation of how changes in management may affect these interactions. Care should be taken on the applicability of these data sets to longer-term predictions, as modelling tends to be based upon short data sets, e.g. 10 to 20 years of information.

**Local modelling studies**
Local and scheme studies may also provide information of relevance to an SMP. In particular, complex sections of the SMP frontage might be better understood by taking account of the more detailed local controls and changes involved. Some schemes and studies cover a number of kilometres of coastline and can help in understanding other data sources that might be applied in SMP reviews, for example to consider if a strategic monitoring position is compromised by a local effect. It can also be useful to compile the results of available local studies as a cross-check on the strategic studies, e.g. to asses whether there are any areas of conflicting data.

**Monitoring studies**
Some sections of coast now have strategic monitoring programmes in place, particularly of beach profiles. This will provide data that can be applied in the SMP process and are likely to be useful in identifying contemporary change, but may only provide information relevant to the 0 to 20 year period. Care should be taken in using short data sets, as they may not provide a true picture of the overall trend of the coastline. In some instances data sets may be analysed to identify trends of change in on-off shore and alongshore directions. This may help in identifying critical controls on the coastal processes or highlighting where present management solutions are having detrimental effects along the coastline. This information may help in focussing decisions and understanding the impacts that decisions may have along the coast.

Strategic monitoring may also include aerial photography that can be invaluable in interpreting change and can compliment that provided by Futurecoast (by providing a time series). It may also include wave, tide, sediment, beach and bathymetric profiles, vegetation and other data that may help interpretation of coastal processes and the functioning of the system.

**Coastal defences**

The National Flood and Coastal Defence Database (NFCDD) should be used as the primary source of data on coastal defences. The aim of the NFCDD project is to provide a nationally consistent, single easily accessible and definitive store for all data on flood and coastal defences. Where this has not yet been populated, the relevant information will need to be collated via the EA and local authorities. Existing sources, such as the Coast Protection Survey of England (CPSE), Sea Defence Survey (SDS) and Welsh Defence Survey databases can assist with this.

Another source of information is NADNAC (National Appraisal of Defence Needs and Costs). This report has made assessments regarding likely future costs, which has been based on a predicted damages under a number of scenarios. As part of this study C*ondition Deterioration Curves* (CDC) were determined, which could be used in the assessment of residual life (See Section D.2.3(b)), if other data is not available.

# Annex D2: Techniques

There are a number of techniques available for the assessment and prediction of shoreline response and change; some commonly used techniques are compared in Table D2.1 and Table D2.2 provides a summary of how these tools may be used to improve confidence in the output and address gaps in understanding or to differentiate between scenarios. Further details on each technique are provided in the following sections.

**Table D2.1 Comparison of methods/ tools to analyse shoreline interactions and response**

| Method /Tool | Description | Attributes | Skill needs | Data needs | Comment on use |
|---|---|---|---|---|---|
| Geomorphic Extrapolation | Feature-focussed assessment of morphological behaviour and response. Involves expert interpretation | ▪ A consistent methodology can be applied and there is a limited data requirement, yet different data can be accommodated.<br>▪ It is an interpretative approach and multiple outcomes/ extreme events can be readily examined.<br>▪ Conclusions rely on the skills of individuals/ experts, whose views can differ. As a result it is difficult to reproduce and lack transparency and auditability.<br>▪ Assessment for some scenarios already exists in Futurecoast (Halcrow, 2002). | High | **Low – Medium**<br>No specific requirements, but can use all available data. | ▪ Assess all available data sets.<br>▪ Ensure that all conclusions are transparent and avoid 'black box' approach.<br>▪ Be aware of limitation in accuracy of predictions.<br>▪ Ensure that there is a plausible and transparent process reasoning behind predictions.<br>▪ Check for consistency between areas.<br>▪ Check for responses to extreme events. |
| Numerical Modelling of Shoreline Response | Process-based modelling of sediment transport | ▪ Modelling can be undertaken at a range of temporal and spatial scales.<br>▪ Set-up time can be slow, however, it is then easy to assess alternative options quickly, with a quick computational time.<br>▪ The process is auditable and models can be improved/ modified.<br>▪ There is a large data requirement and success is heavily dependent upon the quality of the input data. | High | **High**<br>Sediment size; beach slope; wave climate and water level; shore position over time. | ▪ Ensure quality of input data is adequate.<br>▪ Ensure process is fully auditable, e.g. record data source and methods applied.<br>▪ Undertake calibration of models and sensitivity tests and highlight confidence limits and uncertainties.<br>▪ Be cautious in extrapolations from 10-20 year wave climates.<br>▪ Consider sensitivity to future variation in wave climate.<br>▪ Heavily reliant on accurate nearshore modelling and knowledge of sediment availability. |
| Extrapolation of Historical Data | Interrogation of time series data to predict future shoreline movements; either through direct extrapolation or statistical analysis | ▪ Quick, easy, transparent.<br>▪ Can use long-term data sets, which are nationally available and which are commonly in a suitable form for analysis. This enables consistent analysis.<br>▪ Can also incorporate local scale data.<br>▪ Assumes linear change.<br>▪ Assumes no change from past forcing/controls or evolution. | Low | **Low**<br>Historical OS data; shoreline position data; beach profiles. | ▪ Ensure data are subject to rigorous quality checks.<br>▪ Be aware of inherent errors in data sets.<br>▪ Assess confidence limits associated with results.<br>▪ Be careful when using data for low-angle beaches and non-cliffed coastlines.<br>▪ Take care when merging data from various sources.<br>▪ Don't use short-term data sets for long-term extrapolations – recommended limit is to twice the interval covered by the data.<br>▪ Extrapolations assume that forcing and management in the future will be the same as in the past.<br>▪ Interpretation may need a higher level of skill. |
| Parametric Equilibrium Models | Geomorphological models which express relationships between forces and response | ▪ Established models that can be quickly applied and provide direction of change and can also be used to test sensitivities.<br>▪ Models are sensitive to the parameters used, so set-up is key.<br>▪ Models assume an equilibrium response, but often do not indicate how long this response may take to occur. There may be lags in some systems, e.g. complex cliffs, whilst others may respond quickly. | Medium | **Low – Medium**<br>Dimensional data, e.g. beach slope, volumes etc. | ▪ Parameters need to be carefully defined.<br>▪ Be aware of empirical basis of models and their applicability of various situations.<br>▪ Be aware of poor adaptation to constraints, e.g. geology / management. |

**Table D2.2 Use of methods/ tools to improve quality of predictions**

| Technique | Applicability | | | | |
|---|---|---|---|---|---|
| | **Assessing Interactions** | **Predicting Land Form** | **Predicting Future Position** | **Where/ when to use** | **Comment** |
| Geomorphological extrapolation | OK | | | ▪ Coasts where sediment movement is not a major control.<br>▪ Coasts with potential for non-linear change. | ▪ There are no boundary constraints, although as a result the degree of influence of different factors is not necessarily fully established. |
| | | GOOD | | ▪ All coasts to various levels.<br>▪ Long-term assessments of change. | ▪ Generic behavioural models are well established which assist in defining land form response to changes in the coastal environment. |
| | | | POOR | ▪ Coasts subject to minor movement, e.g. hard rock cliffs. | ▪ Quantification of change, particularly short-term is difficult, as the methods do not generally utilise measurement data. |
| Numerical Modelling of Shoreline Response | GOOD | | | ▪ Coasts with complex and highly variable sediment exchanges.<br>▪ Areas where multiple options will require examination. | ▪ Using this approach it is possible to quantify interactions.<br>▪ Management options can be readily included and analysed.<br>▪ Feedback mechanisms and backshore changes are poorly represented.<br>▪ However, limited by availability of data on sediment size. |
| | | NO | | | ▪ It is difficult to incorporate geomorphological change other than the beach. |
| | | | GOOD | ▪ Situations where high level of precision required for comparing options. | ▪ Ability to provide precise positional change and calculate confidence limits.<br>▪ Consider multiple scenarios. |
| Extrapolation of Historical Data | NO | | | | ▪ Provides no indication of external influences upon historic change unless combined with other understanding. |
| | | NO | | | ▪ Measurement data alone does not distinguish between landform types. |
| | | | OK | ▪ Coasts where linear change (or nature of change) is well understood.<br>▪ Often not very suitable for non-cliff areas, where features are often poorly picked up, e.g. dunes, MLW etc.<br>▪ If only using historical OS data use for prediction of long-term change only.<br>▪ Monitoring data can sometimes be used for short-term change. | ▪ Provides an overall picture of change and resolves complexity of processes, however the data is only a snapshot and smoothes short-term irregularity.<br>▪ Extrapolation assumes linear change, based on limited data.<br>▪ Numerical approach provides degree of precision and allows error bands to be calculated.<br>▪ Limited ability to predict change in response to changes in management, although can use generic case studies to resolve new issues elsewhere, e.g. removal of defence structures. |

| Technique | Applicability | | | | |
|---|---|---|---|---|---|
| | **Assessing Interactions** | **Predicting Land Form** | **Predicting Future Position** | **Where/ when to use** | **Comment** |
| Statistical Analysis of Historical Data | POOR | | | ▪ Usually coasts where substantial changes have taken place and good quality data exists.<br>▪ Assessing regional level changes rather than local change. | ▪ Influence Function techniques can provide some indication of sediment sources, sinks and thus interactions.<br>▪ Not possible to introduce alternative policy options. |
| | | NO | | | ▪ Measurement data does not distinguish between landform types. |
| | | | OK | ▪ Some level of precision and statistical errors is required.<br>▪ High levels of good quality data available. | ▪ Provides statistical analysis of future changes with error bands, i.e. reasonable precision.<br>▪ Relatively inflexible - does not necessarily represent changes due to future policy/ management approaches. |
| Parametric Equilibrium Plan-form Models | LIMITED | | | ▪ Well-defined "classic" systems close to equilibrium state.<br>▪ Potentially useful for assessment of management options or trend in shoreline movement due to geological controls. | ▪ Models usually based upon response of shoreline to defined controls, e.g. headland-bay-headland.<br>▪ Does not describe the complexity of processes or nature of changes that will take place. |
| | | NO | | | ▪ No consideration of landform type within the model. |
| | | | LIMITED | ▪ Long-term and large-scale change. | ▪ Delivers long-term equilibrium position.<br>▪ Provides no indication of the timing of changes. |
| Parametric Equilibrium Profile Models | NO | | | | ▪ 1D cross-shore assessment that does not consider any wider external influences. |
| | | LIMITED | | ▪ No changes in landform type expected, e.g. cliff or dune. | ▪ Provides equilibrium profile for simple landforms.<br>▪ Tend to be applied locally and are not easily adapted to changes in configuration. |
| | | | LIMITED | ▪ Long-term sensitivity tests such as the impact of sea level rise upon local profile and rate of change. | ▪ Provides indication of profile and thus potential change in position for dynamic equilibrium.<br>▪ Does not include historic movement nor external influences so will not resolve total change. |

**Ranking:**

GOOD – OK - POOR – NO.

LIMITED represents methods that may have some applicability under certain situations.

## DETAILS ON TECHNIQUES

### Geomorphological extrapolation

Geomorphological Analysis is a feature-focussed assessment of morphological behaviour and landform response. It is three-dimensional and seeks to identify the interactions between features to establish their collective response. The form of analysis does not generally attempt to determine the actual extent of change, rather the tendency for change.

Geomorphological Extrapolation uses the results from many different methods, e.g. morphological and sedimentological indicators of processes, together with the understanding of generic coastal behaviour to assess the expected development of a coastal system. It is also very easy to build in various scenarios and also to predict and explore multiple outcomes. This type of approach can assess the likely consequences of extreme events and non-linear systems, although the timing of exceedence of thresholds/step changes cannot be readily identified. Sometime extreme behaviour can be interpreted from the forms of features without other data, e.g. identification of relict landslides on a coastal slope or relict inlets on a barrier.

The strength of this method is that large-scale changes can be predicted without requiring detailed information about the whole system. Interaction and links between features are defined, and are not boundary constrained, although the degree of influence of different constraints may not necessarily be fully established. The analysis can have a tendency to smooth over local irregularities and not give consideration of the full range of complex variables. It is generally difficult to use this technique to predict localised changes; it is therefore more suited to predicting behaviour on larger scales and over long time periods. As the method does not necessarily involve numerical data, quantification of change is difficult and there is a lack of precision with regard to short-term changes. The method is extremely important in being able to provide rapid initial estimates of potential iterations and responses to alternative policies. It can identify potentially complex or uncertain outcomes, where alternative methods may be needed to improve precision.

The analysis is simple and deals with observable features. As such the approach is both cheaper and more readily accepted than some analytical methods. However, being interpretive and based upon limited information over long timescales, a key disadvantage is that conclusions are less auditable than some other methods and could be made without sufficient information to validate them. Conclusions often rely upon the skills and opinions of individual experts, whose views can often vary, and it is not possible to mathematically reproduce and test confidence levels in the conclusions.

### Numerical modelling of shoreline response

Numerical models of shoreline response are based upon physical processes, usually using wave driven sediment transport to predict changes in shoreline systems in response to changes in forcing and material availability. There are various types of numerical model, and variations of these, which include:

- plan-shape (one-line) models;
- cross-shore models (which can be linked to the plan shape models or adapted to produce n-line models);
- coastal area models;
- fine sediment models.

As the complexity of models increase, the ability to reproduce system behaviour may increase (although this is not universally agreed), but so will the data requirements and the time and cost. This can make them impractical for simpler uses, e.g. the SMPs where larger areas will be modelled and a large number of runs may need to be undertaken. A review of these different types of model is described in *“Coastal Morphology Modelling – A Guide to Model Selection and Usage” Report SR570, HR Wallingford, 2001”*, and is therefore not repeated here. If numerical modelling is to be employed other than for developing the baseline understanding of coastal dynamics, the level and type of analysis appropriate for SMP development will generally be satisfied by the plan shape models.

The key advantage of applying numerical models is that they allow quantification of interactions and positional change in response to altered conditions. They can be modified relatively quickly, for example to introduce alternative defence management scenarios, and the resulting consequences rapidly determined. Plan shape models can be set up to operate at a range of time and space scales. Many continually update the beach morphology at each computational point in response to the forcing conditions and sediment availability and therefore provide a useful prediction tool for taking multiple interactions over a large area into account.

The success of numerical models depends upon the quality of input data and as such they can be heavily data-dependent. There may be problems at boundaries to the models, and these need to be carefully defined. Set-up and calibration of 1-line models can be slow, as complex interactions and dependencies are resolved by simple expressions through the calibration process, but after this stage computation can be rapid allowing a number of scenarios to be assessed very quickly. However, if these models are applied over long periods errors may begin to accumulate, as input data tends to only cover 10 - 15 years at best, although this can be mitigated to some extent through carrying out probabilistic response analysis rather than repetitive time-series. Therefore models run should be limited a maximum length of twice the length of the time series. They should be viewed as a tool to examine the impacts of various scenarios, rather than providing precise detail.

A disadvantage of most numerical models is an assumption of linear change and the difficulty of incorporating geomorphological features other than beaches, and in some cases cliffs. As a result, the interactions, responses and feedback mechanisms of these features, and larger-scale geological controls are not well represented. Consequently, numerical models of shoreline response must be recognised as providing only *some* elements of coastal behaviour and change, *not* the entire picture, and also tend to focus on short-time scales, due to data-availability. These models can, however, be nested within a broader framework provided by geomorphological extrapolation.

**Extrapolation of historical data**

In this approach historical data is used to predict future shoreline movements; this can be either through direct extrapolation of the historical data or statistical analysis, such as regression analysis, derivation of influence functions or probabilistic (e.g. Monte-Carlo) analysis.

The nature of the data enables consistent analysis and an ability to quantify conclusions. There is also great transparency in this analysis and it is quick to understand. However, extrapolation of historic rates to predict future change is flawed by an assumption of continuation of same management practices and processes. There is no ability to account for future changes in management or changes in forcing, such as might be induced by climate change, through this direct extrapolation approach.

Although past rates may not be the key to the future change, particularly where changes in policy are considered, they do give a baseline against which to work and in some situations could be used to quantify conclusions. However, the impact of anthropogenic influence on coastal change must be considered, even where undefended, i.e. the mapped response of the shoreline does not always reflect 'natural' change. This can be difficult to extract from the historical record, particular if only OS data is used, which is only available for a few time steps (often only 4 to 6 records actually cover the entire period of mapping) and information provided by maps is only a snapshot in time; there is no knowledge of the changes that took placed between map surveys. Care must therefore be taken when presenting results from this type of analysis as changes are often not linear and predictions especially over shorter timescales may vary from local perceptions of change processes.

The timescales over which this approach could be applied depends upon the data set used. If only historical OS data is used then only a limited number of time steps are available, extending back to the mid 19$^{th}$ century, and predictions should be made over the longer term. One of the advantages of this data type is that the complexity of processes resolved as the mapping provides a picture of total shoreline response. However, where local records have recorded annual change over several decades, this could be used in prediction for the decadal scale.

There should also be awareness that errors in the base mapping can exist, which may even exceed actual changes taking place (this is dependent upon scale of mapping from which the data has been obtained and the density of mapping points). Therefore, when using this information, statistical error bands can be extremely large. Also, different features are mapped with different accuracies, for example low water line may be very poorly represented, whereas mean high water and especially the cliff top tend to be more reliably represented. In general the extrapolation process is usually more applicable for cliffs, but less accurate on other features which are (i) more difficult to map and (ii) subject to greater variability in their mode of change.

One distinct advantage of this information is that it does provide an historical record of measurable change and the data lends itself to different analytical techniques, such as Monte Carlo simulations or other statistical treatments. In these circumstances, there is some potential to address probabilistic changes with different defence management in the future. Analysis of the data using other techniques, such as influence functions can take some account of how sediment sources and sinks may change in the future, although this analysis is only applicable to source/ longshore transport/ sink coasts, and ability to introduce constraints is again limited by the source data.

Analysis of beach and bathymetry monitoring data can also be useful to assess future changes, although the length of prediction depends upon the length of the data that varies from occasional measurements through to comprehensive records covering 10 – 30 years. In many cases therefore, confidence may only be placed in using this to extrapolate for short-term predictions. Many of the points raised regarding extrapolation of historical mapping also apply to monitoring data, although the latter has other advantages, for example most monitoring concentrates on beaches and softer feature details, which are those not so well defined on OS mapping. The data can be relatively accurate and may help to determine seasonal and short-term variations and the nature of events that cause major changes, providing good metadata is held. It can also provide a good representation of how the coast is actually behaving at present.

The limitations on extrapolation using this type of information, other than temporal extent, are that data sets can be inconsistent and the volume of data makes the identification of errors difficult. As such, analysis can be very time-consuming. The information is also often constrained by poor definition of seaward extent of profiles (although recent monitoring schemes have introduced bathymetry surveys), limiting its usability, and, depending on monitoring approach, may not pick up longshore variability in features or influences.

**Parametric equilibrium models**

These models fall into two main categories: plan form and profile models. They encompass both equilibrium models, which describe a morphological response using relatively simple expressions, and empirical models, which are based on observed (field or laboratory) data.

Examples of such model types include:

- The Bruun Rule (Bruun, 1954) and later Dean (1977) which defined a model which describes the response of a sandy coast to sea level rise, assuming the beach maintains an ‘equilibrium profile’. Vellinga (1986) used the concept of ‘equilibrium profile’ to model the dune/beach profile change and erosion volume due to storm events.

- The log spiral bay models of Yasso (1965), Silvester (1970; 1974) and Hsu et al. (1987), describe “equilibrium coastal plan form in response to the interaction between wave energy and headland controls”.

There are many other models and expressions that exist both for the open coast and estuaries, which can be applied to help understand shoreline tendency (e.g. Powell, 1990), extent of influence (e.g. Hallermeier, 1981) and even potential for tidal inlet formation and development (e.g. O’Brien, 1969). These are reported in various standard coastal texts, such as CIRIA Beach Manual 1996.

The advantage of these models is that many are well established and are easy to use, although suitable guidance may be required to correctly define input parameters. They provide a direction of change and are commonly used to test sensitivity of a system, e.g. to rising sea level.

The key disadvantage is the assumption that a dynamic equilibrium position will eventually be reached – therefore they may not take into account the perturbations resulting from man’s interference with the natural system. Although they can give a long term view on the resultant shoreline, they do not provide any information on the timing of changes nor the complexity of the processes that occur as the system strives to that equilibrium state. They are not adaptive to altered configurations, e.g. changes in controls, or to variable constraints, e.g. geology.