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Preparing for the Impacts of Climate Change on the Central South Coast of England: A Framework for Future Risk Management

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ABSTRACT

There has been considerable research into the science of global climate change, however, there is presently little guidance for coastal authorities on accounting for the physical impacts of ongoing climate change in future land use planning and coastal defence policy.

For the central south coast of England, this paper briefly identifies 'coastal climate change scenarios'for the next 80 years. A qualitative geomorphological appraisal of the potential impacts of these changes on coastal landforms and processes is presented, based upon generic 'coastal behaviour systems' that take account of the various sensitivities to change of the natural and managed coastline. Functions such as the sensitivity of coastal slopes to increasing effective rainfall, and barrier beaches to increased water levels, are considered. The likely future 'behaviour' of these systems, and in particular the potential for climate-induced changes, are identified.

The likely response of the coastal systems then provides an objective framework for evaluating hazard and risk. The levels of risk are strongly linked to the historic pattern of land use and development, which in many cases will not accommodate natural adjustment of coastal features. Without effective management, hazards will increase and coastal communities will be vulnerable and at risk under future climate change.

Recommendations are made regarding improving the risk management framework in the face of climate change impacts. Recommendations include issues such as compensation, the planning framework, coastal defence provision, nature conservation, data collection and education.

Although the results are specific to the study area, the methodology developed is transferable, offering a valuable model for other coastal managers.

ADDITIONALINDEXWORDS: *Geomorphology, Sensitivity, Risk Management*

BACKGROUND

SCOPAC, which stands for 'Standing Conference on Problems Associated with the Coastline', is the group of Coastal Defence Operating Authorities and other interested parties responsible for shoreline management along the central south coast of England, between Lyme Regis and Shoreham. In commissioning the research study entitled 'Preparing for the Impacts of Climate Change', SCOPAC stated that it "believes that the question of climate change impacts is probably the most important issue to be faced by coastal local authorities and communities they represent, alongside other organisations, in the coastal zone". SCOPAC recognised that it is essential to carry out research and investigation work on climate change now, in order that appropriate decision making can be implemented through the planning and political process. The study aims to inform coastal managers, along the central south coast of England, of the likely impacts of climate change, and its implications for future management.

The key aims of the study were to: develop climate change scenarios for the next 80 years; identify generic impacts on the coast; determine hazard and risk along the

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SCOPAC coast; and, identify future risk management requirements.

A two-stage approach was adopted for the study. The first was identification of future climate scenarios and their likely physical impacts on the coast, and the second was assessing the impacts of these on assets and the implications for management. Whilst outlining the climate change scenarios, this paper concentrates on the geomorphological assessment of impacts upon coastal landforms and systems. The potential impacts on risk management, and the key recommendations and conclusions of the study are also outlined.

COASTAL CLIMATE CHANGE SCENARIOS

Climate change is a natural phenomenon. However, there is a growing body of evidence that the atmosphere is changing significantly and that human activities that result in the emission of so-called greenhouse gases are implicated strongly. The majority of scientific opinion agrees that human influences on global climate are now detectable above and beyond natural changes. Over the last fifteen years a very considerable amount of work has been published on climate change and its potential impacts, and much research is presently underway. This study has reviewed a wide range of sources and has carried out new analysis of data to derive scenarios of climate change for the central south coast of England up to 2080. This has focused on the potential changes in temperature, rainfall, wind, waves and sea level, as these parameters are most likely to influence coastal change.

Published estimates of future climate change have been reviewed and where possible a best estimate applicable to the SCOPAC coast has been derived. The key expected changes up to 2080, identified from the review of existing studies, areas is presented below.

- Rainfall is likely to be greater in winter (up to 23% increase) but less in summer (up to 20% reduction), with an increase in effective rainfall (precipitation minus evapotranspiration) (HULME and JENKINS, 1998). There is also likely to be an increased incidence of high rainfall events.
- The global temperature is predicted to increase by 3.7°C (upper modelled average, IPCC, 2001), with an upper prediction of 4.7°C.
- There has been a considerable range of estimates of future global mean sea level rise published over the last decade. The latest IPCC (2001) predictions use a wide range of potential greenhouse gas emissions scenarios (SRES). These give global mean sea level rise of 0.35m by 2080 for the average upper band modelled scenario, and 0.65m as the upper extreme allowing for land-ice uncertainty. The 'medium-high' estimate by UKCIP is 0.41m by 2080. The UKCIP98 report (HULME and JENKINS, 1998) suggests that for the south coast mean sea level rise could be expected to be 10% greater than the global. The current rate of relative sea level rise is between 1.3 and 2mm/year.
- Relative land movements will also influence sea levels. For the SCOPAC region, an additional 1mm/yr relative mean sea level rise is appropriate (BRAY *et al*., 1997).
- FLATHER and WILLIAMS (2000) modelled changes in tides that would occur due to a 0.5m rise in mean sea level. The change predicted for the SCOPAC region was minor, with increases in mean high water less than 2cm.
- A modelling study of climate change impacts on storm surges by LOWE and GREGORY (1998) suggests that the 1 in 5-year surge height may increase by 0.1 to 0.2m and the 1 in 50-year surge by 0.2 to 0.4m, with the lower figure representing the western part of SCOPAC and the higher the eastern part of the area.
- The combined effect on extreme sea levels for the central SCOPAC coastline gives an increase in extreme sea levels of around 84cm for the 1 in 50-year event. This represents a significant increase due to the relatively flat extreme water level curve on the central south coast.

A potential increase of more than 0.8m in extreme water levels is of great concern in terms of impact on the many coastal defence structures in the SCOPAC region. For the SCOPAC coast, the extreme tide level curves are very flat, with little absolute differences between the present day predictions for extreme water levels for say 1 in 200 years and 1 in 1 years. Because of this it is likely that coastal defences in SCOPAC will have less resilience to sea level rise than for example defences on the East Coast of England, where surges are much larger and there is a greater level difference between return periods.

A wave hindcasting study was also undertaken for the study using wind data output from the Hadley Centre Regional Climate Model. Ten year periods of wind data, covering a control period with current atmospheric forcing, and a future period representing the 2080s under the Medium-High UKCIP98 scenario were obtained for two locations. The wind data were used to derive equivalent offshore wave conditions for four locations along the SCOPAC coast. The model outputs have been used to derive offshore extreme wave conditions. These indicate an increase in extreme wave heights in the western part of the region and slight decrease in the east. These trends reflect the degree of shelter of the sites considered, and this is thought to be an important factor.

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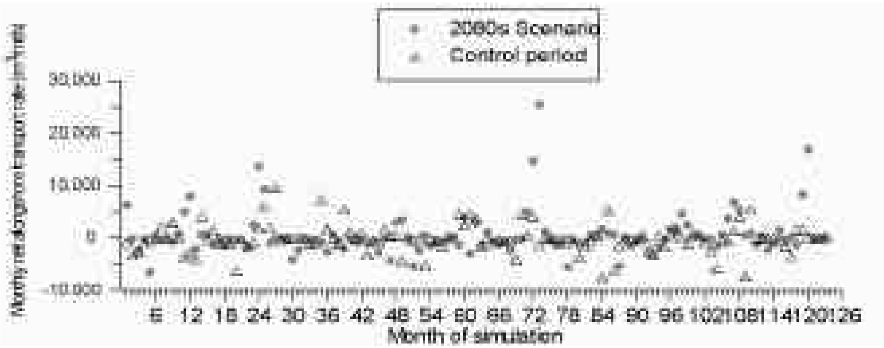

	Control	2080's
Mean Wave Height	0.85m	0.92m
Mean Wave Energy Direction	214.9°	213.3°
Mean Net Longshore Drift	**1,000m3/yr(E)**	**7,800m3/yr(W)**
Mean West Drift	21,100m3/yr	31,600m3/yr
Mean East Drift	22,100m3/yr	23,800m3/yr

Figure 1. Potential alongshore drift rates at West Bexington, Dorset

The offshore wave data were also transformed inshore to several example sites to derive differences between present and predicted future alongshore drift rates. The offshore waves were first transformed to nearshore points and then used to calculate potential alongshore transport rates. The results for West Bexington, Dorset, (Figure 1) illustrate the potential impact of, primarily, a small shift in mean wave direction. This shows a change from a net east to a net west drift. Such a change would clearly have significant implications for management.

In reviewing impacts on the coast the actual numbers will not be used, rather taken as an indication of changing frequency, magnitude, etc of driving forces.

GEOMORPHOLOGICAL CHARACTERISATION AND IMPACTS

Climate change has the capacity to alter almost all coastal processes and landforms. Clearly, there is a need to determine the extent to which these changes could affect the future occurrence and distribution of flooding, deposition and erosion hazards. The approach adopted by this study has involved definition and sensitivity analysis of a series of coastal behaviour systems (CBS). Based on a detailed understanding of these, the possible climate changes described above can be used to make a qualitative evaluation of the nature and distribution of coastal behaviour system responses, and to identify the extent to which coastal hazards are likely to change.

Coastal Behaviour Systems

Each CBS is composed of several landforms e.g. beaches, cliffs, saltmarshes etc. linked by processes e.g. sediment transport, operating at different scales. The overall behaviour of the system is a function of the inter-linkages and feedback responses between processes and landforms. Change in any one element may affect the form and position of the whole system. A CBS is composed of interlinked landforms that make up the following cross-shore elements:

- Shoreface (active profile);
- Shoreline (beach or intertidal shore); and
- Backshore or hinterland.

The sensitivities of landforms to climate change and the extent to which their behaviour could be modified by management practices has been assessed in the definition of each CBS.

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LANDFORM BEHAVIOUR AND SENSITIVITY TO CLIMATE CHANGE

The behaviour of the key coastal landform types occurring along the SCOPAC coast was evaluated from a desk study together with an analysis of historic extreme coastal events. The following comprises a selective summary.

Shoreface

The shoreface comprises the active portion of the nearshore profile, extending seaward of mean low water. Steeply Sloping and Gently Sloping types are identified, with the latter predominating. The capacity of gently sloping shorefaces to store sediments allows for accumulation as sea-level rises so as to maintain a constant water depth. Where the shoreface is wide, a larger quantity of sediment is required to build up the bed and this may deplete adjoining shorelines.

Shoreline

The shoreline represents the zone from mean low water to the landward limit reached by wave run-up or tidal waters on an annual basis. Sediments stored at the shoreline in the form of beaches, tidal flats, saltmarshes and tidal deltas perform important functions in protecting the backshore or hinterland from erosion or tidal inundation. Each shoreline type was analysed, but the examples here focus on beaches, which were classified by their characteristics as follows:

- Fringing, or Restrained by a coastal slope, cliff or static coastal defence structure such that the beach forms a relatively narrow linear berm immediately at the cliff toe. It is controlled primarily by the restraining feature and beach sediment budget.
- Free standing linear accumulations of sediment having a distinct seaward face, crest and backslope. The beach generally rests upon bedrock or marsh sediments close to or below mean sea-level. The hinterland is low-lying. Sediment supply is dependent on longshore sources and/or reworked materials from the land transgressed by the migrating beach.
- Fronting a significant accumulation of clastic sediments e.g. a dune system or a cuspate foreland. These systems are relatively resilient to change due to the abundant backshore sediment that can become incorporated within the beach during periods of erosion.

Beaches also behave differently according to the grain size(s) of their sediments. Five types are recognised comprising sand, shingle, mixed, composite and boulder beaches. Each has distinct characteristics and sensitivities. For example, sandy beaches are sensitive to sea-level rise and are generally understood to adjust their profiles upwards and landwards to maintain constant nearshore water depths.

These characteristics translated into some ten generic beach types within the SCOPAC area. The analysis suggests that irrespective of material type the free-standing beaches are the most sensitive. Sandy beaches are rather more sensitive than shingle types and all beaches suffering sediment depletion become increasingly sensitive. Local factors such as wave climate and exposure as well as the prevailing sediment budget clearly need to be considered when making more detailed predictions of impacts.

Table 1. Sensitivity of Cliff Behaviour Types to Climate Change

Cliff Type	**Periodicity of major recession events (years)**	**Response to increased toe erosion**	**Response to elevated groundwater**	**SCOPAC examples**
Hard Rock Cliffs	>103	very slow	none	Isle of Purbeck, S Isle of Portland
Soft Rock Cliffs				
Simple cliff face	1 - 101	very rapid	moderate	Hill Head, Hengistbury
Simple landslide	101 - 102	rapid	rapid	SW Isle of Wight, Alum and Whitecliff Bays
Composite	102 - 103	slow/moderate	moderate	St Aldhem's Head, Ringstead Bay
Complex	102 - 103	moderate	moderate to rapid	Blackgang, W Dorset, Naish Cliffs
Relict	Variable	moderate to rapid	moderate to rapid	Undercliff and N Isle of Wight, Lyme Regis

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Table 2. Composition of SCOPAC Coastal Behaviour Systems

Landform Element	Hard Cliff	Soft Cliff	Lowlands and Barriers	Spits, Inlets and Tidal Deltas	Estuaries and Tidal Rivers
Shoreface	Steep	Gentle	Gentle	Gentle	Gentle
Shoreline	Fringing boulder beach and/or shore platform	Fringing sand, shingle or mixed beach	Fringing sand, shingle or mixed beach. Free-standing shingle barrier. Fronting sand or shingle beaches	Inlets Tidal Deltas Free-standing shingle beach	Tidal flat Saltmarsh Tidal River
Backshore	Hard Cliff	Soft Cliff	Lowland	Lowland	Lowland

Backshore or Hinterland

The backshore acts as a buffer against erosion and contributes sediments to the shoreline. As the backshore recedes it becomes the foundation upon which shoreline and shoreface landforms develop. Relief in excess of 5m is likely to result in formation of cliffs on eroding shorelines, whereas relief lower than 5m is classified as lowlands. The examples here concentrate on cliffs (Table 1).

Hard Rock Cliffs

Hard resistant lithologies tend to form steep cliffs that evolve slowly by falls and toppling failures resulting in a simple cliff form. Due to their material strength they are unlikely to be sensitive to climate change.

Soft Rock Cliffs

Formed in soft bedrock or drift and subject to recent or continuing erosion, soft rock cliffs are classified according to their morphology and recession potential into four active and one relic type, as follows (RENDEL GEOTECHNICS, 1998).

- Simple cliff face systems: a single sequence of inputs from falls or slides leading almost directly to foreshore deposition. There is usually a steep cliff face, narrow degradation zone and rapid response to toe erosion.
- Simple landslide systems: a single sequence of inputs and outputs with variable amounts of storage. A marked degradation and storage zone is usually apparent affording limited buffering against toe erosion.
- Composite systems: partly coupled sequences of contrasting simple sub-systems typically involving interbedded hard and soft rocks. Within the SCOPAC area this type occurs where hard rocks rest upon clayey strata giving a steep upper cliff face and a tendency for high magnitude, low frequency failures.
- Complex Systems: strongly coupled sequences of scarp and bench sub-systems, each with their own inputs, storage and outputs of sediment. Sub-system storage results in significant buffering against the immediate effects of enhanced toe erosion, although elevated groundwater levels can trigger major events that transform the behaviour of the whole system.
- Relic Systems: sequences of pre-existing landslides susceptible to reactivation by progressive marine erosion at the toe and/or elevated groundwater levels.

THE SCOPAC COASTAL BEHAVIOUR SYSTEMS

Five types of CBS have been identified (Table 2 and Figure 2) along the SCOPAC coastline. Soft cliff CBS types dominate western parts, whereas lowlands and barriers prevail in eastern parts. Inlets, spits and tidal deltas are most frequent around the Solent, as are estuaries and tidal rivers. Hard rock coasts are limited to outcrops of Portland and Purbeck Limestone. In the west, defences are discontinuous and concentrated around coastal resort towns, whilst in the east they are near continuous due to the desire to defend the soft, low-lying land. These distributions generate significant differences in the nature of the coastal hazards and of the resilience to external forcing of the coastal systems.

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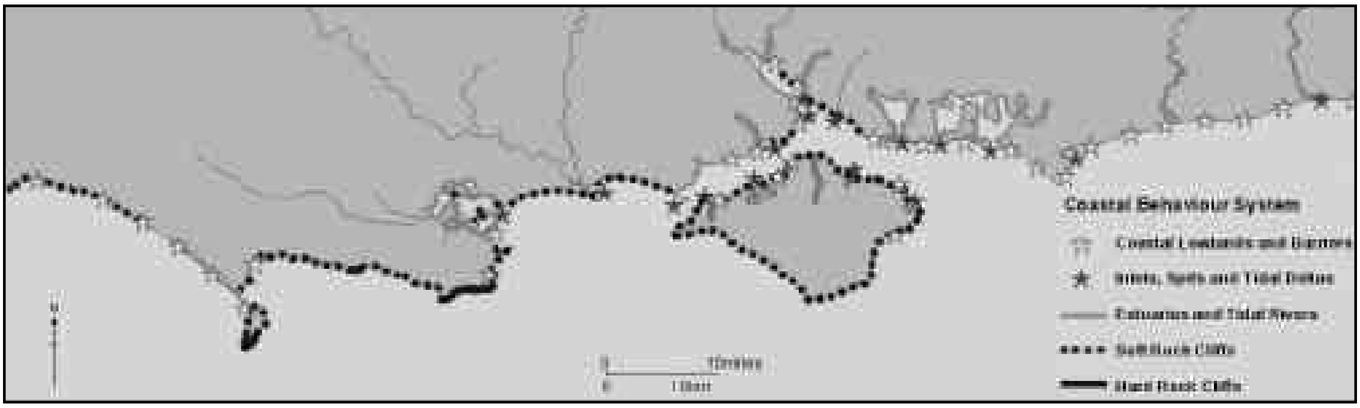

Figure 2. Distribution of SCOPAC Coastal Behaviour Systems

Table 3. Coastal Change Potential

Category	Shoreline Trend	Shoreline Processes and Landform Changes
1	Static Resistant	Landforms resistant to change e.g. hard rock cliff
2	Static Dynamic	Cyclic change with balanced sediment budget e.g. seasonal cut and fill cycles on a sandy beach.
3	Static Declining	Static or restrained shoreline, with a declining shoreface and negative sediment budget e.g. saltmarsh undergoing squeeze due to constraining backshore topography.
4	Net advance	Accreting shoreline e.g. saltmarsh growth, dune building resulting in seaward movement of the shoreline.
5	Net retreat	Eroding shoreline migrating landward, but maintaining characteristic form and function of landforms e.g. a retreating barrier beach.
6	Variable trend	Transient change towards a new characteristic form e.g. breaching and/or fragmentation of a barrier or spit.

Coastal Change Potential

A detailed understanding of the historical, contemporary and likely future behaviour of each CBS can be used to evaluate coastal change potential or shoreline trend (Table 3).

Shifts between categories over time clearly indicates the direction and pace of changes in hazards that might be anticipated in the future and alternative pathways or "scenarios" of behaviour are developed according to the future management strategy. Shifts away from categories 1, 2, and 4 towards categories 3, 5 and 6 indicate increasing hazards that may have implications for future risks. Seven categories of implications for hazards have been defined (Table 4). An example of the results of this type of analysis is given in Table 5.

Within the example given, dramatic increases in hazards are likely to result from reactivations of relict cliffs and resumption of recession wherever defences are abandoned. Where defences are maintained, beach levels are likely to fall in the long-term as the cliffs can no longer contribute to the sediment budget. Unprotected cliffs are likely to retreat more rapidly at up to double their historical rates according to local conditions (BRAY and HOOKE, 1997).

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Table 4. Implications for Hazards and Potential Rate of Change

DI	SI	sI	NC	sD	SD	DD
Dramatic Increase	Significant Increase	Slight Increase	No Change	Slight Decrease	Significant Decrease	Dramatic Decrease

Table 5. Cliff Behaviour and Hazard Potential

Cliff Type	**Historic Behaviuor Category**	**Contemporary Behaviour Category**	**Future Behaviour Category**	**Scenario**	**Rate**	**Size of Event**	**Type/Style of Event**	**Reactivation Probability**	**Size of Event**	**Probability of first-time failure**
Simple, Composite and Complex Cliffs										
Protected	5	1	1(3)	C1	NC	NC	NC			
Abandon defences			5	C2	DI	DI	SI			
Unprotected	5	5	5	C3	SI	sI	NC			
Construct defences			1(3)	C4	DD	SD	DD			
Relict Cliffs										
Protected	3	1	1(5)	C5				SI	sI	sI
Abandon defences			3, 6, 5	C6				DI	DI	DI
Unprotected	3	3	3, 6, 5	C7				SI	SI	SI
Construct defences			1(3)	C8				DD	DD	DD

IMPACTS SUMMARY

The following points summarise the main impacts and sensitivities for the SCOPAC coastline.

- Beaches fronting coastal lowlands are especially sensitive. This is the result of three main factors: (i) inherent sensitivity to change of free standing barrier beaches and spits; (ii) limited natural supplies of fresh sediment, often due to updrift defences; and (iii) stabilisation of many beaches by defences preventing them from adjusting their profiles by migrating landwards. These beaches protect some of the locations most vulnerable to flooding within the region. Recorded flooding events cluster repetitively around a relatively modest number of locations where development has occurred on lowlands behind such beaches. It is anticipated that future impacts under conditions of climate change will follow a similar, but intensifying pattern. This raises a major question concerning the sustainability of attempting to hold the defence line at such locations for the long term.
- Existing trends for erosion of saltmarshes in estuaries are likely to accelerate in future with sea-level rise. This is because: (i) fresh sediment supplies may not be sufficient to allow marshes to accrete vertically to keep pace with rising sea-levels and (ii) most perimeters are defended or backed by rising topography preventing landward migration of marshes and generating problems of "coastal squeeze." Although marshes may persist within inner estuary areas it is likely that climate change will considerably accelerate existing patterns of habitat loss. Furthermore, as the protective marshes are lost, so many defences are likely to be exposed to increased wave attack. Again, this raises a question over

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attempting to hold the existing line of defence in the long term.

- Soft rock coastal cliffs are likely to retreat more rapidly in future due to: (i) increased toe erosion resulting from sea-level rise; and (ii) higher winter groundwater levels due to increased effective precipitation. It is thought that recession rates could increase by up to 100%, although there might be a lag before the cliff top responds to conditions at the toe. Although this would increase hazards at the cliff top, it has the potential to supply valuable additional sediments to local beaches and estuaries.

- One of the major hazards identified by this study is the potential for reactivation of coastal slopes mantled by relict landslides due to increased toe erosion and elevated groundwater levels. Such slopes are identified around Lyme Regis, and the Undercliff and north coast of the Isle of Wight. The exceptionally wet winter of 2000/01 has already resulted in intensification of reactivations at some locations and is an analogue of the conditions that might be expected to occur more frequently in the future.

- Wherever decisions are made to hold the defence line, it is likely that future climate change will make it technically more difficult and increasingly expensive to achieve this in practice. Key pressures are identified as follows: (i) overtopping due to rising sea-levels; (ii) growing potential for interaction of tidal and fluvial flooding on tidal rivers (iii) losses of beaches and marshes in front of defences, (iv) increased wave forces on structures due to reduced depth limitation, (iv) changing patterns of drift resulting in altered patterns of erosion and deposition (vii) possible reduction of toe support and increase in groundwater levels within stabilised cliffs (viii) potential for "flash flooding" of low-lying urban areas by intense rainfall events.

- Changes in the climate and coastal landforms will also result in changes in habitats. The potential impacts include: (i) loss of freshwater and brackish habitats as a result of either coastal retreat or saline intrusion; (ii) loss of terrestrial habitats as a result of erosion; (iii) ‘squeeze’ of intertidal habitats between rising sea-levels and defences; (iv) changes in habitat and species distribution as a result of climatic alterations; and (iv) habitat impacts from changing patterns or distributions of tourism or agriculture.

Relatively few beneficial impacts of climate change can be identified at the coast. Eroding cliffs should supply additional sediments to the foreshore where they remain free to erode. Increased tidal prisms of estuaries may assist in tidal flushing and maintenance of navigable channels. Warmer conditions may encourage coastal tourism.

IMPLICATIONS FOR COASTAL RISK MANAGEMENT

Understanding the risk management framework and the broader social and political context provides a basis for speculating about how climate change may impact upon SCOPAC over the next 50 years or so. Because of the nature of social systems, there is probably more uncertainty as to how society and politicians will respond to these changes than their impact on coastal processes. The following are some of the key changes to the risk management framework that may be expected over the next 80 years.

- It is uncertain as to whether the funds allocated for coastal defence will match the future demand. It seems likely that over the next 80 years the risk management framework will need to adjust to increased competition for financial resources.
- There may be modifications to what are considered to be acceptable risks and suitable standards of protection. It follows that there may be a need to improve the standards of protection in high-risk urban areas to reflect these trends. This would lead to increased polarisation in the exposure to risk experienced by individuals in built-up and rural areas.

- Climate change is likely to generate additional pressures on a variety of coastal zone uses, from tourism and amenity uses, marine aggregate extraction (e.g. for beach nourishment programmes), port and harbour operations to nature conservation and the protection of historical sites and monuments.

- It is possible that increasing reluctance of society as a whole to accept the costs (financial and environmental) of coastal defence, more restrictive environmental legislation (e.g. the Habitats Directive and its successors) and the desire to avoid tying future generations into expensive and unsustainable defence commitments will trigger a re-appraisal of the need for a compensation mechanism.

- Following trends elsewhere in society it seems likely that there will be legal challenges to operating authorities decisions, especially where limited resources or environmental concerns lead to changes in the standard of protection provided to individual properties or communities. This may extend to challenging the power of operating authorities to remove an individuals right to protect their own property, at their own expense.

These changes could occur irrespective of climate change. Thus, despite the uncertainties associated with the natural hazards, coastal operating authorities should be aware that their ability to manage the associated risks will not remain constant. The changes in society and the political

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economy that will inevitably occur over the next 80 years will be as significant as climate change and sea-level rise in determining how coastal risks are accepted, tolerated and managed.

SUMMARY RECOMMENDATIONS

Building on the physical impacts and management implications, a series of recommendations have been presented to improve future risk management. The following points briefly outline the key areas for which recommendations were made. The detailed recommendations are presented in the full study report (HALCROW GROUP, 2001).

- Driving Future Guidance. SCOPAC can play a key role in influencing the way in which the risk management framework develops in the future. This could involve research, influencing legislation and policy, and identifying possible solutions for risk management (e.g. compensation).
- Planning and Development. There is a role for the planning and development process in the management of future risks. There is the capacity within the existing planning framework to adapt to climate change, however, it will require better and more consistent application of existing legislation and guidance.
- Coast Defence. There are a number of key stages in the development and implementation of coastal defence policies, all of which will need to take account of the potential impacts of climate change. In general this will involve inclusion of the scenarios and impacts within the existing procedures.
- Nature Conservation. Recommended actions are aimed at meeting statutory obligations placed on local authorities, meeting biodiversity targets and maintaining the existing nature conservation resource in the face of climate change.
- Monitoring and Education. One of the central themes of discussions on future climate change has been the uncertainty with current predictions. In order to assess changes in the coastal climate it is necessary to monitor key variables. It will also be necessary to inform the community of coastal risks, e.g. through future reviews of Shoreline Management Plans and advice notes.

With regard to future risk management, SCOPAC have a key opportunity to be pro-active in recognising the potential impacts of climate change and ensure that their needs are considered in any changes to the management framework.

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