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Appendix M
Review of Coastal Processes and Associated Risk at Hengistbury Head

Review of Coastal Processes and Associated Risks at Hengistbury Head

Poole & Christchurch Bays Shoreline Management Plan Review
Sub-cell 5f

Bournemouth Borough Council

September 28th 2009

Report V1

9T2052

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Poole & Christchurch Bays Shoreline Management Plan Review

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HASKONING UK LTD.
COASTAL & RIVERS

26 Beatrice Road
Bodmin
Cornwall PL31 1RD
United Kingdom
+44 (0)1208 75947 Telephone
+44(0)1208 269498 Fax
info@exeter.royalhaskoning.com E-mail
www.royalhaskoning.com Internet

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Drafted by	J Ridgewell	
Checked by	N Cooper, T Eggiman, JGL Guthrie	
Date/initials check	………………….	.
Approved by	H Hall	
Date/initials approval	………………….	………………….

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Preface

The Shoreline Management Plan (SMP2) Review for Poole and Christchurch Bays will review and assess all the policies and recommendations set out in the first SMP produced ten years ago. The new SMP2 aims to set high-level strategic policy for coastal erosion and flood risk management, through the development of a well-researched and considered document. The principal objective is policy setting that promotes sustainable management of erosion and flood risks over the next 100 years and assists with adaptation to the effects of climate change.

An important aspect of the SMP Review is the production of a number of technical reports, which underpin and support the development of policies. This report – the 'Hengistbury Head Assessment' is one of these documents and is an important part of the work undertaken during Stage 2 of the SMP2 development for Poole and Christchurch Bays.

1 INTRODUCTION

1.1 Background

This study considers the implications and likelihood of a breach at Double Dykes near Hengistbury Head. It has been developed as part of the wider SMP Review for Poole and Christchurch Bays. Although it forms an Appendix of the larger overall SMP2 document, it is also intended to be accessible as a standalone document.

Concerns regarding the implications of a breach at Double Dykes, Hengistbury Head, are raised due to the low lying character and high-value nature of Christchurch Bay and its immediate hinterland, which lie behind Hengistbury Head and are protected by it from the more extreme open coast conditions. Hengistbury Head is also very influential as a headland control on the embayments of Poole and Christchurch to either side of it. Any breach would have an impact upon the plan form of Hengistbury Head itself and therefore the influence it exerts on the Bays.

This study considers the risk from flooding and erosion in line with the principal objectives of the SMP review and gives consideration to impacts upon the natural and historic environments within Christchurch Harbour and upon Hengistbury Head.

1.2 Scope of Study

This study firstly provides an overview of Hengistbury Head and its surrounds, considering the geology, geomorphology, wave climate, tidal regime, sediment transport, defences, natural environment and historic environment. It does not give a detailed description of hydrodynamic conditions and sediment transport for Christchurch Harbour - this is done within the main coastal processes report (Appendix C – Annexe I).

Hengistbury Head is the geological promontory that extends east of the lower-lying area known as Double Dykes (Figure 1.1). However, it is the Double Dykes section that is generally identified as a possible breach route through to Christchurch Harbour. Therefore this study considers the general site conditions in relation to the possibility of a breach occurring within that specific area. The study then considers the impacts that would be associated with a permanent breach, particularly relating to Christchurch Harbour, but also to the processes and morphology of the open coast.

1.3 Definitions

An important aspect of the consideration of risks made in this report is the definition of what constitutes a 'breach'. Historically there are many references to the 'breaching' of spits, dunes or defences within the Poole and Christchurch Bays area. In most cases these events are technically 'overtopping' or 'overwashing' because no new channel has been formed which allows uninhibited flow of water from one side of a barrier to the other. Although genuine breaches have occurred very occasionally, e.g. at Mudeford Spit where new tidal channels have on occasion been formed, the authors are not aware of any such breach having occurred at the much wider Double Dykes area through to Christchurch Harbour. Please see Section 5.1 for a more detailed explanation of what constitutes a breach.

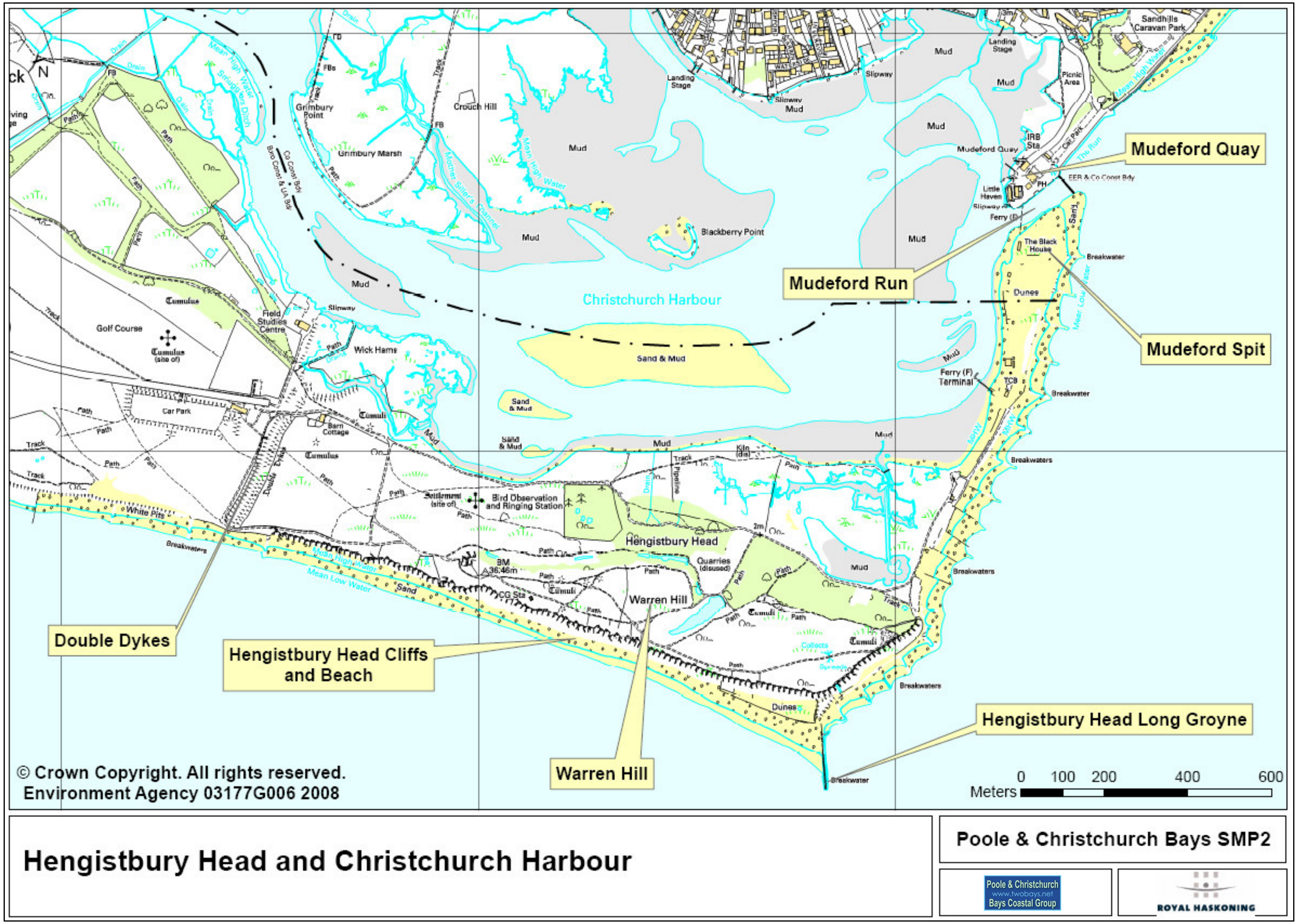

Figure 1.1. Map of study site and key areas

As with the main coastal processes assessment for the SMP review, this study draws together the most up to date knowledge and presents it in a simple and independent assessment. No additional modelling has been carried out, however the report does apply some analytical thinking and interpretation of the evolution of breach scenarios based on the current knowledge.

1.4 Information sources

A full list of references and bibliography is provided at the end of this document, however several key texts and data sources have been central to this study. These include:

- Futurecoast - The Futurecoast report provides a broadscale assessment of coastal processes and coastal changes over the next 100 years for England and Wales. It was developed to support the work of coastal authorities and particularly to assist with the review and updates of the SMPs.
- Hengistbury Head Consequences of Breaching (Halcrow, 2006)
- South Coast Sediment Transport Study (Carter, Bray, Hooke (SCOPAC) 2004)
- Poole Bay Strategy Study (Halcrow, 2004)
- Hengistbury Head Management Plan (Bournemouth Borough Council, 2005)
- LiDAR data (provided by the Environment Agency)
- Aerial photography (provided by the Channel Coastal Observatory)

2 SITE DESCRIPTION

2.1 General Overview

Hengistbury Head is less than one square kilometre in area (West 2009). In the context of its location (just to the east of Bournemouth), it is a particularly important, unspoilt natural landscape area, with important archaeological, geological and environmental designations.

Hengistbury Head is a key feature within the Poole and Christchurch Bays SMP frontage (see Figure 2.1 below) and plays an important role in dictating the morphology of the adjacent shoreline. It is a key geomorphological controlling feature, one that has been very influential in fixing in place (albeit artificially) the current plan forms of both Poole and Christchurch Bays. Christchurch Bay itself still appears to be adjusting to a form of natural equilibrium, demonstrated by a pattern of continuing retreat.

Several different key areas with their own characteristics are seen to make up the study site, and are referred to throughout the text. These are as follows:

- Hengistbury Head Cliffs and Beach
- Double Dykes
- Mudeford Spit
- Mudeford Quay
- Christchurch Harbour

Figure 2.1 Aerial view of Hengistbury Head and Christchurch Harbour
(Source: Channel Coastal Observatory)

2.2 Geology and geomorphology

Hengistbury Head Cliffs and Beach:

Although Hengistbury Head exerts control on the plan forms of both Christchurch and Poole Bays, it differs from many controlling headlands in that it is a relatively erodable feature. The natural resistance that it does display is attributed primarily to the presence of ironstone nodules (the focus of previous mining activities). These nodules lend resistance to what is otherwise a rather un-resistant feature comprised mainly of unconsolidated, erodable material (Futurecoast 2002).

Figure 2.2 Hengistbury Head Cliffs and beach looking east

The cliffs at Hengistbury Head are of Tertiary origin and are primarily composed of Barton Clay, Hengistbury Beds, with overlying Boscombe Sands. These deposits are capped by Plateau Gravels. The cliffs rise to a height of 36m OD in the area known as Warren Hill. Figure 2.3 shows the topography of the study site.

A shallow-sloped, dissipative mixed sand and shingle beach fronts Double Dykes and the south-west facing cliffs of Hengistbury Head. Maintaining the width of the beach reduces the erosion of the Hengistbury frontage due to the protection it affords the soft cliffs from waves. Some contemporary erosion is ongoing at Hengistbury Head and Double Dykes (see Section 3 for more detail) but it is largely held in check by the current management practices. A key feature here is the Long Groyne, built in 1938 at the southerly most point of Hengistbury Head (see Figure 2.3). It has assisted in retaining sediments and consequently beach widths to the west of the groyne. The Long Groyne and its influence on sediment levels and beach width can be seen clearly in Figures 2.1 and 2.3. It is discussed further in Section 4.1.

Figure 2.3 Hengistbury Head beach, looking toward the Long Groyne

An extensive shore platform, known as the Christchurch Ledge, extends offshore in a south-easterly direction for around 4 kilometres. This sub-surface feature is indicative of the previous more south-easterly position of the headland.

Historically, erosion of the Hengistbury Head cliffs led to the accumulation of ironstone nodules on the fronting beach, affording the toe of the erodable cliffs some protection from wave attack. Mining and removal of these mineral resources led to increased erosion of the fronting cliffs. It also resulted in a net increase in material transported in a north-easterly direction around the headland. This allowed the shingle barrier at the mouth of Christchurch Bay, known as Mudeford Spit to grow.

Figure 2.4 Double Dykes frontage, west of Hengistbury Head cliffs

Double Dykes: To the west of Warren Hill there are lower cliffs derived from Valley Gravels. These gravel deposits rise from Solent Road to the east and reach an elevation of 4.5m OD at the Double Dykes section (Carter et al, 2004).

Wind-blow sand has formed dunes landward of the low gravel cliffs (see Figure 2.4). This section is approximately 0.4km wide at its narrowest point (relative to mean sea level).

The Double Dykes area is particularly low lying compared to adjacent areas and at a width of only some 400m between the sea and the estuary it is perceived as posing the greatest threat of a breach into Christchurch Harbour. The topography across this section ranges between 5m and 8m OD (see Figure 2.4 above).

Cross section profiles of the Double Dykes area at risk of breaching can be seen in Figures 5.3, 5.4 and 5.5 in Section 5.

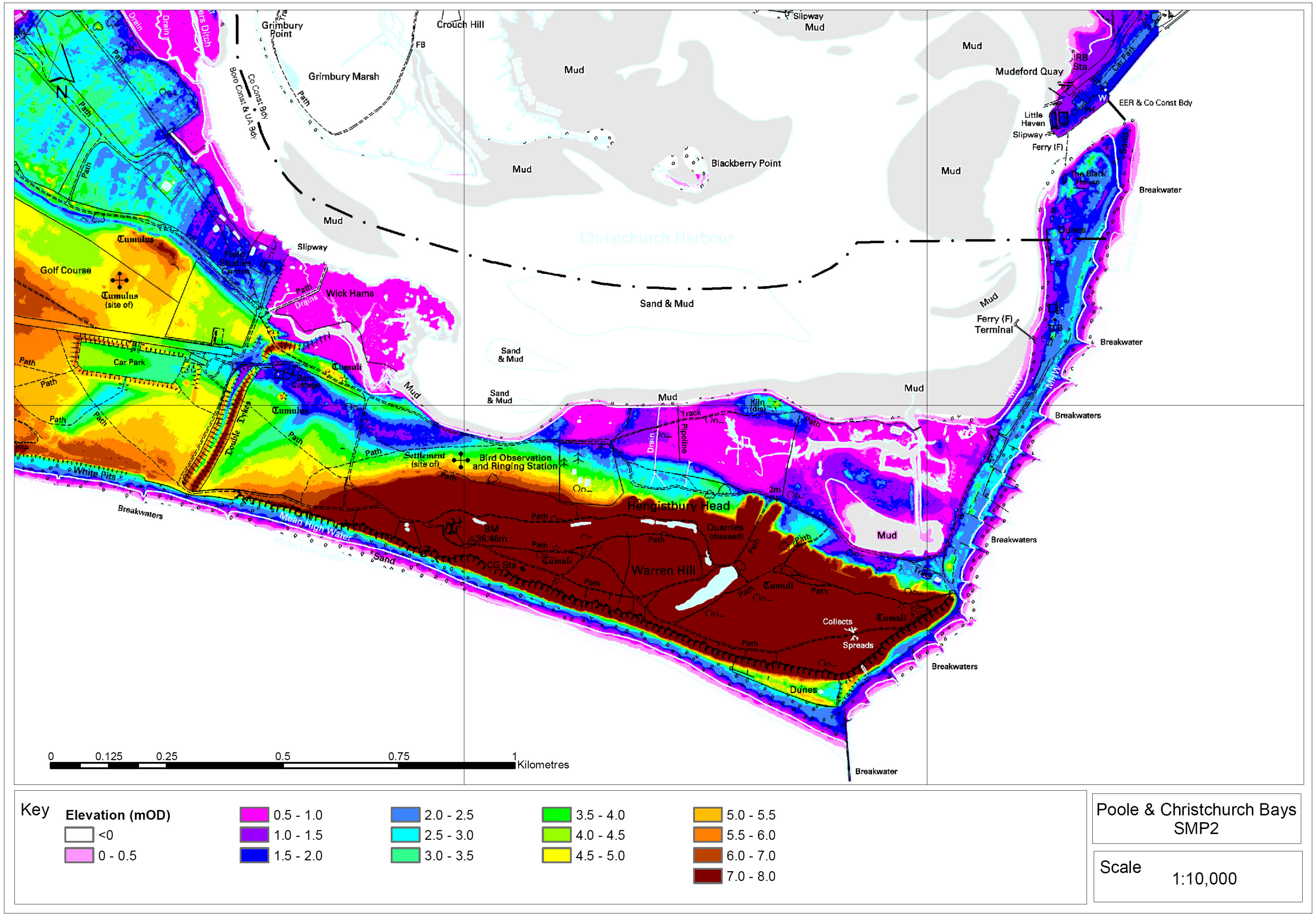

Figure 2.5 Topography of Hengistbury Head (derived from LiDAR)

Figure 2.6 Christchurch Harbour, looking from Warren Hill

Christchurch Harbour: Christchurch Harbour is a spit-enclosed estuary. It was formed by the flooding of the downstream floodplains of two large, lowland rivers; the Avon and the Stour, by rising sea levels during the late Holocene.

The Harbour has two spits at the mouth, Mudeford Spit and Mudeford Quay Spit, which separate the Harbour from the sea. Both are composed of sand and gravel and formed by littoral drift on the open coast,.

The mouth of the Harbour (known as 'The Run') has a very narrow entrance and is subject to rapid tidal flows. Figure 2.7 shows the entrance channel and the controlling spits. The width of the mouth is controlled by the presence of Mudeford Quay, and coastal erosion management works on Mudeford Sandbank. Apart from the mouth, the Harbour is largely natural in character, although the upper parts of both of the river valleys have been reclaimed, effectively limiting the tidal volume of the estuary.

The Harbour itself is shallow with a water depth of less than 2m (Mean Water Level) over much of the estuary, with extensive intertidal mudflats and saltmarshes, and low-lying margins, and a significant area of grazing marsh in the north-east of the Harbour.

Tidal currents and freshwater discharge principally control sediment transport within the Harbour. Wave action from the open coast has very little penetration into the Harbour and locally generated wave action within the Harbour is weak due to the limited fetch lengths. Flood and ebb tidal deltas, composed primarily of sandy sediments, are present close to the mouth; however, the channel itself is characterised by gravel-sized material due to the water flows in this area. Both the ebb tidal delta and the Mudeford Sandbank are dynamic and have undergone periods of growth and erosion. In the past, these episodes are likely to have been related to variations in the quantities of material drifting around Hengistbury Head. More recently this has been governed by beach renourishment that has taken place along the Mudeford Sandbank frontage and the recent coastal management works at the northern end of the spit.

The extent of existing tidal flood risk within the Harbour is confined to the low-lying land and sand spits forming the margins of the Harbour and to the floodplains located along the lower banks of the two rivers. The Harbour is subject to significant seasonal freshwater discharges from these two rivers, producing notable salinity variations.

The nature of the ebb and/or flood dominance of the Harbour is complex. The mouth is generally ebb dominant, due to higher flows on the ebb tide, and the influence of high fluvial flows. However, both ebb and flood deltas are present on either side of the Harbour Mouth – Figure 2.6 below demonstrates this well. There is the potential for flood dominance through the mouth during surge and storm events, when there is an import of sediment into the Harbour, and the relatively coarse composition of the flood delta is considered to be evidence for this. Generally speaking, the northerly part of the Harbour is characterised by coarser sediments and flood dominance, whereas the sediments of the southern, ebb-dominated parts of the Harbour are generally finer.

Figure 2.7 Christchurch Harbour Mouth, showing the Mudeford Run entrance channel, Mudeford Spit (bottom centre) and Mudeford Quay

Changes in the future tidal prism due to any future reclamation, realignments or sea level change would affect the tidal currents at the Harbour entrance and therefore the configuration of the ebb tidal delta (and the flood delta).

Changes to the tidal prism may also create further issues related to flooding and alterations to the erosion and accretion patterns within the Harbour.

The possibility of a breach at Double Dykes or at Mudeford Sandbank would therefore significantly affect the regime of the open coast and the Harbour, if a permanent tidal channel were to be established. Therefore the Harbour is very dependent on shoreline management strategy for both the open coast, and that for the harbour side of the Spit.

Mudeford Spit: This Spit (also known as Mudeford Sandbank) is located at the mouth of Christchurch Harbour, orientated north – north-east, with its base attached to Hengistbury Head. It marks the western end of Christchurch Bay and the stretch of navigable water known as Mudeford Run, which provides access to Christchurch Harbour. The spit is primarily of a mixed sand and gravel composition. Finer sands have accumulated on top of the spit forming dunes and sandhills up to 7m in height (SCOPAC 2004).

Figure 2.8 Mudeford Spit, looking north

It currently extends approximately 900m in length, although historically it has been much longer and evidence shows it has been a dynamic and mobile feature. Futurecoast (2002) reports that Mudeford Spit has gone through up to five cycles of bay-mouth bar building and breaching in the 100 years leading up to 1938.

Earliest records of the Spit's existence date from around 1660. It was breached on several occasions in the last century (1911, 1924 and 1935). The mining of ironstone nodules on Hengistbury Head and then the installation of the Long Groyne originally caused sediment saturation at the Spit but then ultimately starved the Spit of sediment.

Mudeford Spit has developed in association with the slower erosion of Hengistbury Head and the supply of sediment around the head and the estuary. The Spit acts to deflect the estuary entrance. This dictates that the estuary's ebb dominated delta influences the shape of the coast to the east. Therefore it is not just the presence and influence of Hengistbury Head that needs to be considered when looking at the influences shaping the Christchurch Bay coast.

Formal protection of the Spit began in 1931. Installation of concrete and rock groynes on the seaward face in combination with a replenishment programme has been ongoing between 1945 and 1996. These protection works have effectively stabilised its morphological form. The site of the final breach in 1935 is the present day location of Mudeford Run.

Mudeford Spit is an important site in terms of recreation and tourism, with a large number of beach huts present (see Figure 2.8) with each hut having a financial value of tens of thousands of pounds. Such use of the Spit has helped to justify the cost of protection works along its seaward edge.

Mudeford Quay: To the north of the Mudeford Spit is the Mudeford Quay Spit, also referred to as Haven House Spit, which provides a boundary for the north-western side of Mudeford Run.

As can be seen from Figure 2.9, although initially a natural spit feature, Mudeford Quay is now heavily modified through manmade protection and no longer has any natural evolution occurring. It protects a significant number of pleasure craft moorings to its Christchurch Harbour leeside and is defended along its seaward side, firmly fixing the north-western boundary of the Mudeford Run in its current position. An access road, car park and other assets are built on top.

Figure 2.9 Mudeford Quay Spit, showing position of the Mudeford Run entrance to Christchurch Harbour
(Source: Channel Coastal Observatory)

2.3 Wave climate

The shoreline fronting the Double Dykes area is dominated by a south to south-westerly wave climate. Both long period swell waves generated over long fetch in the north Atlantic, and short period wind waves generated more locally within the English Channel, are influential. The general alignment and aspect of Christchurch and Poole Bays are related to these dominant patterns of wave action. However, although south to southwest waves dominate, the more infrequent storms that originate from the east to southeast can be highly energetic in terms of erosion, and the amount of material which can be moved, in a single event.

Hengistbury Head is sheltered to a certain degree from the south-westerly originating waves due to the sheltering and refraction that occurs due to the presence of Durlston Head and the Isle of Purbeck landmass.

Christchurch Bay is shallower than Poole Bay, the 10m depth contour for Poole Bay is between 500 ~ 1000m offshore compared to 3 ~ 5km offshore for Christchurch Bay. Depth limitation to waves is therefore more pronounced in Christchurch Bay despite its greater exposure to the south-westerly wave climate.

The Channel Coastal Observatory operates a series of waverider buoys in nearshore areas along the south coast. Two of these buoys are located at Boscombe, to the west of Hengistbury Head and Milford-on-Sea, to the east. The Boscombe buoy is located in approximately -10.4m CD water depths. The Milford buoy is located in approximately -10m CD water depths. A range of parameters, which characterise the wave climate in each location, are summarised in Figure 2.10 below. Comparing the mean values for significant wave height (Hs) and wave period (Tp), it can be seen that Milford displays a higher-energy wave climate than Boscombe. The difference can be explained by the sheltering effect that the Isle of Purbeck has upon the Poole bay frontage and how this reduces from west to east.

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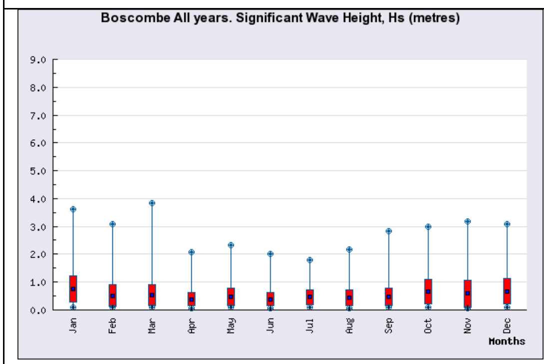
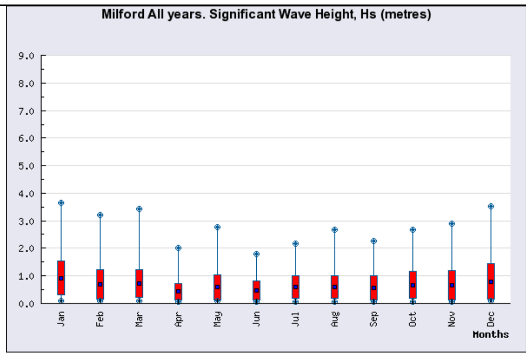
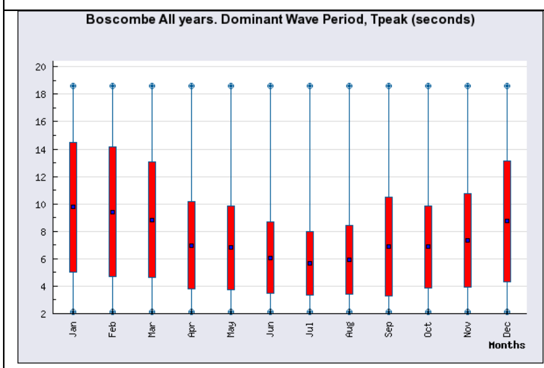
Figure 2.10 also shows the wave directional values for each location. The dominant due-south direction (~180^0) of incident wave approach at Boscombe, provides evidence that waves approaching from the south-west are still undergoing some refraction (and therefore attenuation) due to the sheltering effect of the Isle of Purbeck at that point. The Milford buoy records a dominant south-south-westerly wave approach (~212^0), demonstrating that there is effectively very little shelter provided from the dominant south-westerly wave climate at this location.

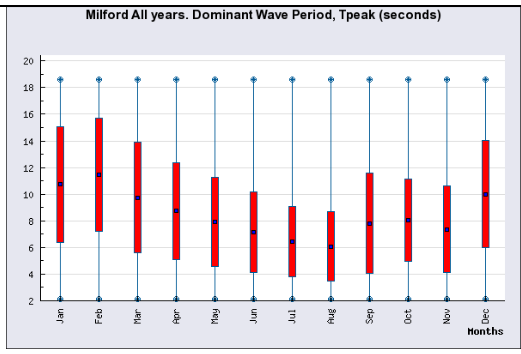
However the difference in wave climate energy between Boscombe and Milford overall is not great. The buoys are not quite equidistant from Double Dykes (Boscombe is closer) but interpolating west to east between the two buoys locations, indicates that the general sheltering effect of the Isle of Purbeck is much reduced by the time one reaches the Double Dykes and Hengistbury Head frontages. At that point it would be expected that only a slight refraction is being induced and therefore attenuation of the wave energy is slight. It is suggested that the Beerpan Rocks provide some shelter to Hengistbury Head (Harlow, 2009), however due to their location approximately due south of the Long Groyne, they would not provide any shelter to the Double Dykes area from south-westerly waves.

Boscombe wave climate (2000 – 2009)	Milford-on-Sea wave climate (2002 – 2009)
- Significant wave height - Dominant wave period - Wave direction ***Source: Channel Coastal Observatory***	- Significant wave height - Dominant wave period - Wave direction ***Source: Channel Coastal Observatory***









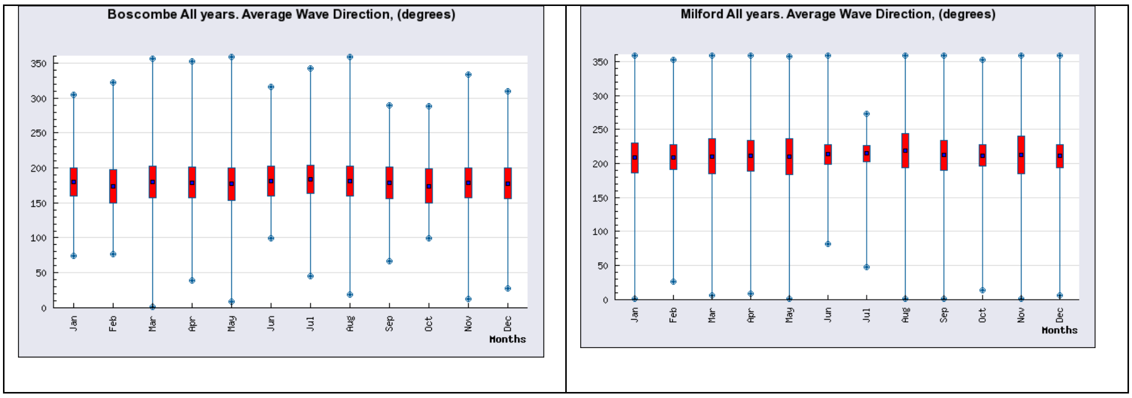


Figure 2.10 Comparative wave climates from Boscombe and Milford-on-Sea

Figure 2.11 below shows the Hengistbury Head and Double Dykes frontage together with wave roses displaying indicative wave climate (significant wave height versus direction) recorded during January (all years) at Boscombe and Milford.

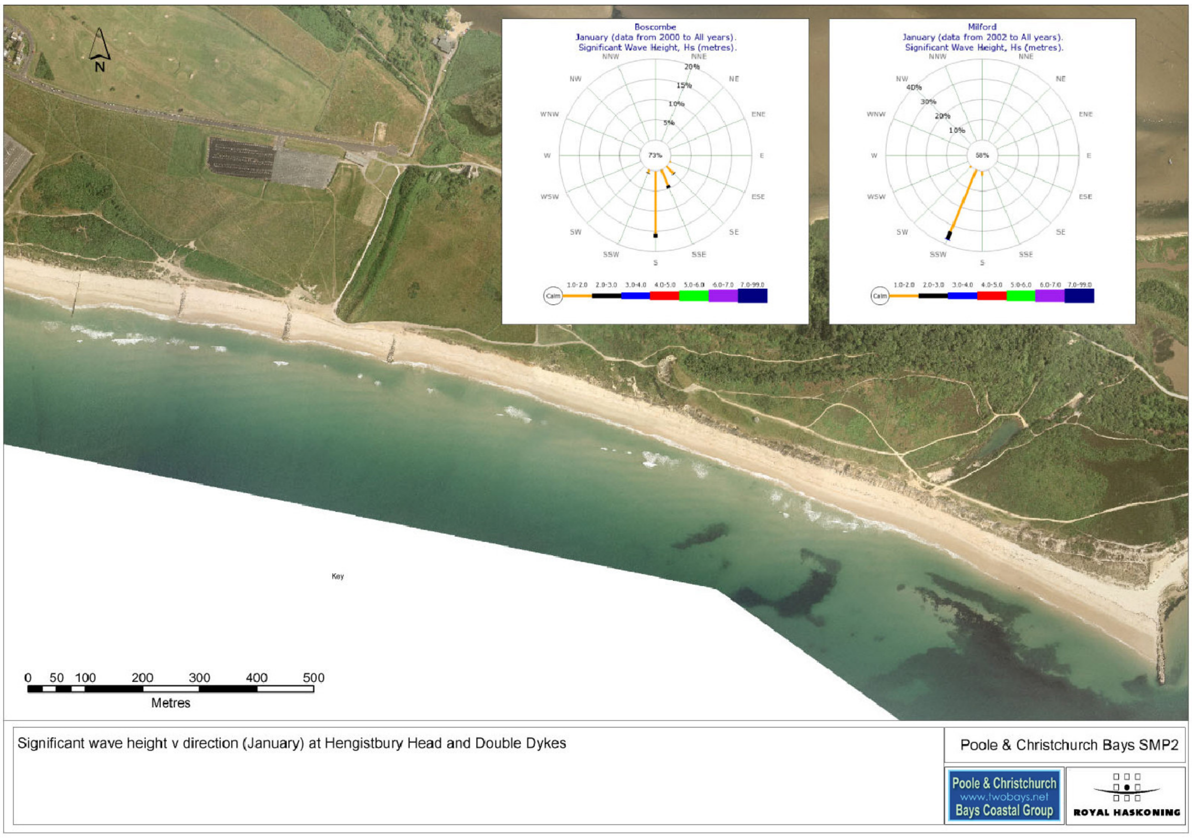


Figure 2.11 Hengistbury Head and Double Dykes frontage displaying wave rose data (Hs v direction) from Boscombe and Milford

(Photography source: Channel coastal Observatory)

(Wave data source: Channel Coastal Observatory)

2.4 Tides

A small tidal range is experienced around Hengistbury Head - approximately 2.0m during spring cycles and 1.0m during neaps. A weak "double high water" tidal component occurs. Tidal currents alone are not enough to mobilise and entrain sediments but they do combine with waves to transport material both onshore and offshore. The most rapid currents are found offshore from the Long Groyne (Carter et al, 2004).

Within Christchurch Harbour, average tidal range is around 1.1m (which classifies it as micro-tidal). Mean spring range is 1.4m. Mean neap range is 0.8m. The total tidal prism is calculated as 1.43Mm^3 during springs (ABPmer 2009). Christchurch Harbour has the lowest tidal range along the central south coast and it experiences the double high water effect seen elsewhere in the area. The double high water contributes to the ebb-dominant regime that is observed. Peak tidal currents occur within the Mudeford Run (the navigable entrance channel to Christchurch Harbour).

Table 2.1 below shows the range of still water tide levels for Hengistbury Head and Christchurch Priory Quay up to the 1 in 1000 year extreme.

Table 2.1 Predicted Extreme Still Water tide levels for study site (Source: Royal Haskoning, 2003) ***italics in bold have low confidence attached**

Location	OS Grid Reference	MLWS	MHWS	Tidal Still Water Level (mOD) for Annual Exceedance Percentage (AEP)								
				100%	20%	10%	4%	2%	1%	0.5%	0.2%	0.1%
Hengistbury Head	SZ164903	-0.31	0.89	1.39	1.57	1.65	1.75	1.83	1.91	1.99	2.09	2.17
Christchurch Priory Quay	SZ158923	-0.11	0.89	1.39	1.57	1.65	1.75	1.83	1.91	1.99	***2.09**	***2.17**
Return Period (years)				1	5	10	25	50	100	200	500	1000

2.5 Cliff behaviour

Average erosion rates since 1978 for the 1km cliff section east of Double Dykes is estimated to be around 0.15m/yr (Halcrow 2004). Futurecoast reports that the likely rate of recession for the south–westerly facing Warren Hill cliffs (and eastward to Southborne) is around 0.5 to 1.0 m/yr. Tables 2.2 and 2.3 below have been adapted from the information provided in Futurecoast and give general overview of the cliffs and likely recession rates.

Table 2.2 Hengistbury Head Cliffs – overview (Source: Futurecoast 2002)

Cliff Location	Cliff Type	Max height	Cliff protection works	Materials
East face (270m of cliff adjacent to Mudeford Spit)	Simple cliffs	28m	Toe protection	Unconsolidated and weak sandy strata.
East face (80 m of cliff adjacent to Long Groyne)	Simple cliffs	28m	None	Unconsolidated and weak sandy strata.

Warren Hill	Simple cliffs	35m	None	Unconsolidated and weak sandy strata.

Table 2.3 Hengistbury Head Cliffs – sensitivity to climate change and potential recession (Source: Futurecoast 2002)

Cliff location	Failure mechanisms	Activity	Sensitivity to climate change	Recession Potential	Recession event frequency
East face (270m of cliff adjacent to Mudeford Spit)	Erosion, falls and slides	Active	Medium	0.1 – 0.5 m/yr (annual recession rate). <10m (single landslide event)	1 – 10 yrs
East face (80 m of cliff adjacent to Long Groyne)	Erosion, falls and slides	Active	High	0.5 – 1.0 m/yr (annual recession rate). <10m (single landslide event)	<1 yr
Warren Hill	Erosion, falls and slides	Active	High	0.5 – 1.0 m/yr (annual recession rate). <10m (single landslide event)	1 - 10 yrs

2.6 Sediment sources and transport

A well-established net eastwards drift operates throughout most of central and eastern Poole Bay which transports littoral sediments towards Hengistbury Head. The Long Groyne retains significant amounts of material, but sand is also moved offshore and the remaining material drifts into Christchurch Bay, see Figure 2.12.

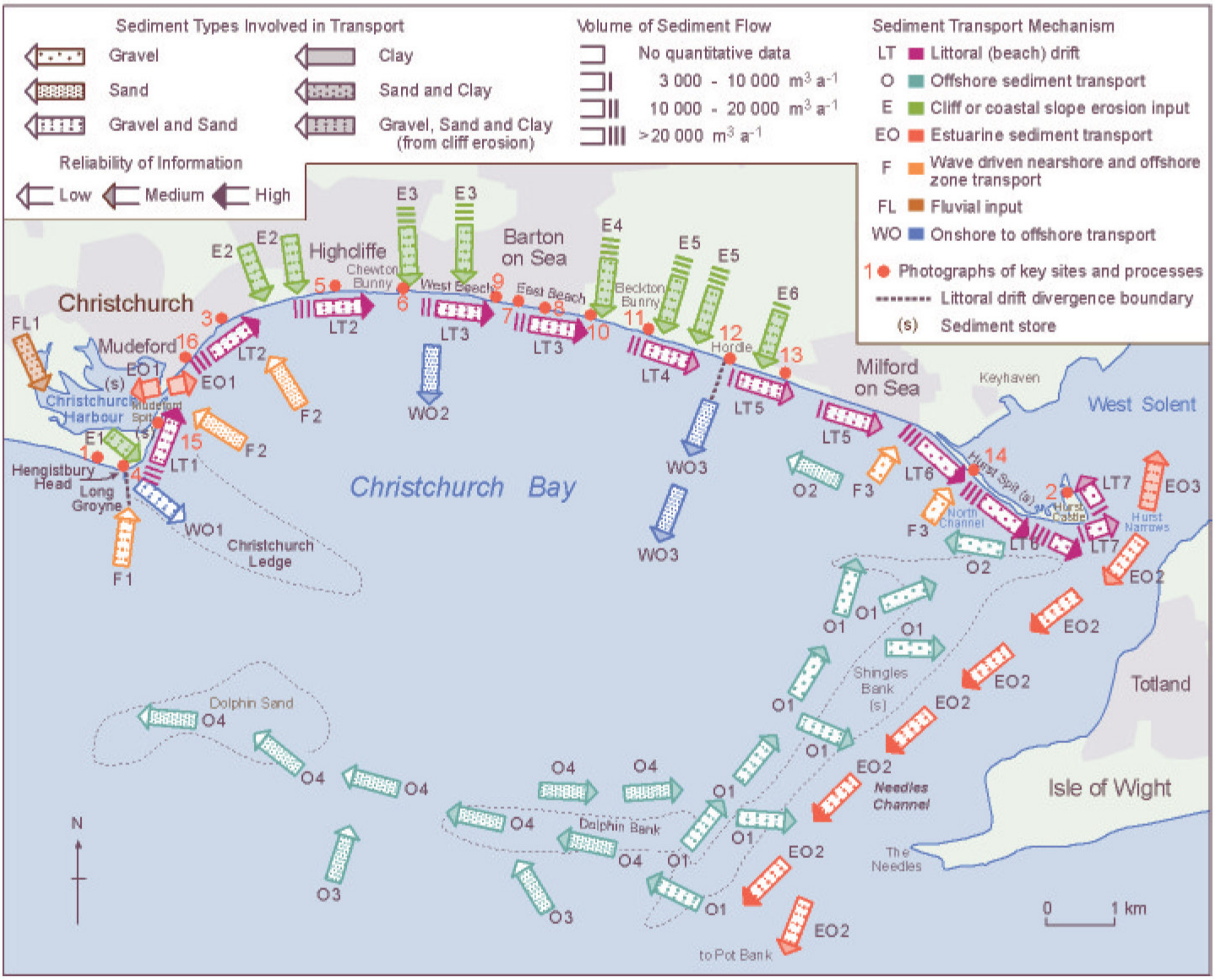
Volumes of material moving on to the beaches of Hengistbury Head via the eastwards long-shore drift has reduced dramatically during the last 100 years due to the intense shoreline and cliff stabilisation and protections works carried out in Poole Bay. This general trend in reduced natural input has been interrupted by short-term sediment gains due to beach replenishment activities.

There are localised sediment inputs from the cliffs and dunes around Hengistbury Head and Mudeford Spit and there is some offshore transport of gravel and some onshore wave driven transport of sand and gravel. SCOPAC (2004), indicate that offshore transport mechanisms tend to move sand in a westerly direction, across Dolphin Bank, with accumulations at Dolphin Sand.

There are fluvial inputs into Christchurch Harbour from the main river systems, and some of this material is transported to the open coast where there is limited sediment exchange at Christchurch Harbour mouth within the Mudeford Run.

Figure 2.12 shows the known patterns of sediment transport around Hengistbury Head, Christchurch Harbour and Christchurch Bay. Figure 2.13 shows the sediment transport potential within Poole Bay.

Hengistbury Head to Hurst Spit (Christchurch Bay): Sediment Transport



MMIV © SCOPAC Sediment Transport Study

Figure 2.12 Nearshore and offshore sediment transport pathways within Christchurch Bay

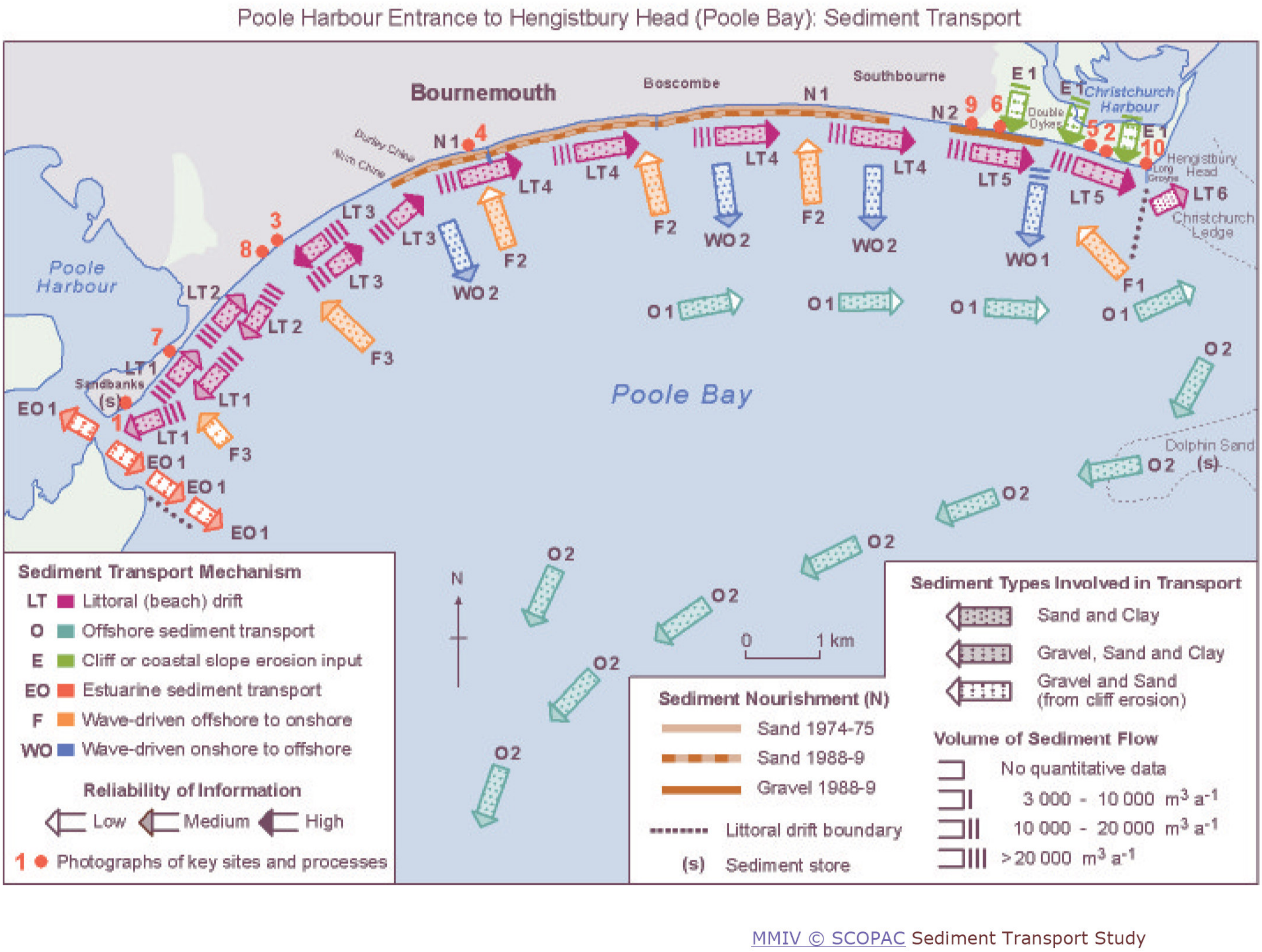


Figure 2.13 Nearshore and offshore sediment transport pathways within Poole Bay

2.7 Defences

There are a number of defences present around the seaward facing shoreline of Hengistbury Head and Mudeford Spit, including the influential Long Groyne, located at the southernmost point. For a more detailed description of the defences and the role they play within the current management regime, see Section 4.

2.8 Natural Environment

Within the study area, both Hengistbury Head and Stanpit Marshes (within Christchurch Harbour) are designated Local Nature Reserves (LNRs).

Christchurch Harbour contains extensive intertidal mudflats and saltmarshes, and low-lying margins, and a significant area of grazing marsh in the north-east of the Harbour.

Other habitats found within Christchurch Harbour include reed beds, ditches, wet meadows, sand dunes, dry and neutral grassland, heath, woodland and scrub. These habitats support diverse plant and animal communities, and the site is of great ornithological importance (ABPmer 2009).

The entire Christchurch Harbour area, including Hengistbury Head and Double Dykes, holds the designations of a Site of Special Scientific Interest (SSSI) and geological SSSI. Most of the harbour area is currently in a favourable condition with the exception of the seaward facing cliffs and Double Dykes, which have been assessed as in an unfavourable condition (though recovering).

Natural England describe how "the relic dunes are becoming more and more dominated by scrub, predominantly by bramble, bracken and gorse. Direct management is required to restore (and maintain) the special interest of this part of the site and open up areas of dune grassland again. A detailed scrub management plan should take account of the breeding bird interest and identify areas for retention/coppicing of scrub. Whitepits would benefit considerably from a light grazing regime and this is an important element of the management of this unit. The popularity of the site and the fragile nature of the soils and vegetation mean that trampling and erosion are also a problem in this part of the SSSI (erosion quite severe in places) and this needs to be addressed".

Most of the Hengistbury Head site is designated as a Special Area of Conservation (SAC) as part of the Dorset Heaths SAC. The Avon Valley RAMSAR site is located at the north-west corner of Christchurch Harbour.

The whole study area is also extensively designated under the UK's Biodiversity Action Plan Priority Habitats scheme. The habitats include:

- Maritime cliffs and slopes
- Mudflat
- Coastal floodplain grazing marsh
- Lowland dry acid grassland
- Reedbed

2.9 Historic Environment

The entire Hengistbury Head feature is listed as a Scheduled Monument, covering an area of 87 hectares. There are two round barrows to the north west of Double Dykes, which are also listed as Scheduled Monuments. A number of properties along the north eastern shore of Christchurch Harbour are Grade II listed buildings and there are 4 Grade II listed properties (1-4 Haven Cottages), at the far south-western tip of Mudeford Quay. The Blackhouse, at the northernmost part of Mudeford Spit, is also a listed building.

Archaeological interest in Hengistbury Head is significant and is considered to be of international significance for many reasons. Dating back to well before the Iron Age the site is rich in archaeological remains including a late Palaeolithic camp and evidence of Bronze and Iron Age Man, including pottery finds and a settlement. Hengistbury Head is the only non-cave occupation site known in the region that dates back to the earliest (Palaeolithic) period. The discovery of a rich range of artefacts from the Iron Age promontory fort constructed at Hengistbury Head, reveals that the promontory was a trading centre for goods, such as wine and glass, from the continent and Mediterranean with copper goods from Cornwall.

A considerable number of isolated finds such as worked flint and pottery have also been discovered along the coast from Hengistbury Head to the Poole Borough boundary. None of these finds are significant in terms of their archaeological importance, but they do provide a valuable insight into the historic use of the area.

2.10 Fluvial Influence

Fluvial influence is significant on the accretional and erosional patterns within the Harbour. The River Mude, River Avon, River Stour and Bure Brook discharge into Christchurch Harbour and deliver sediment to the water body in both suspension and bed load. There is large uncertainty in the actual amount of sediment derived from fluvial input. ABPmer (2009) state a potential input of 60,000 m^3/yr or greater of sediment – there is however uncertainty attached to this value as it is a ‘potential’ input rather than a measured input. This uncertainty makes it difficult to predict how the tidal prism within the estuary and Harbour will respond to rising sea levels and/or a new breach channel.

There is significant fluvial input into Christchurch Harbour from the Rivers Stour and Avon. Together they deliver an average combined discharge of 30m^3/s. This can fall to 7.5m^3/s during times of low flow but during extreme rainfall and river flooding events it can rise to 220m^3/s (SCOPAC 2004). This level of extreme fluvial flow significantly enhances the flood risk within the Harbour during extreme tidal events. When high rainfall and fluvial flows coincide with high spring tides and/or storm surge, tide locking will enhance water levels within the harbour. The restricted exit from the Harbour for fresh water flows will exacerbate this situation. Extreme tide levels are therefore generally observed to be higher inside the Harbour than outside during an extreme tidal event.

It is recognised that at present, extreme water levels within the Harbour more often relate to high fluvial flows, rather than tidal surges (ABPmer 2009). This demonstrates how important fluvial flow is within the consideration of management of water levels within the Harbour. These flows are likely to become more severe with time as extreme rainfall events become more frequent due to climate change.

3 BEACH AND CLIFF PROCESSES

The evolutionary processes, which have shaped and influenced Hengistbury Head and Double Dykes, are key in understanding the risk of a future breach.

3.1 Historical

Essentially, the two Bays (Poole and Christchurch) are still immature and not yet fully developed in their plan form. A process of glaciation and the rising and falling sea levels associated with these climatic episodes has shaped the present day coastline. Three periods of glaciation have occurred during the recent geological timescale, but it was the final period of glaciation and the subsequent retreat of the icecap around 9000 years ago, which led to rising sea levels and the breaching of an extensive chalk ridge, which ran westwards from The Needles (Isle of Wight) to Ballard Down. As a result of this breaching, over 220 km^2 of land has been eroded (Harlow 2005), leading to the present plan from and configuration of the Poole and Christchurch Bays frontage.

Human intervention in the last 100 years or so has halted significant further evolution in the configuration of the Bays. Hard engineered coast protection structures and sea defences, plus the replenishment of beach material, hold the frontage in a modified but stable form.

3.2 Present Day

Directly in front of Double Dykes, the low cliff line is strengthened and defended by gabion baskets (Figure 3.1).

Figure 3.1 Gabion defences at Double Dykes (note cutback of low gravel cliffs immediately adjacent to defences)

The low cliff line displays clear signs of being eroded and cut back on those sections to the east and west of the area defended by gabions (see Figures 3.1) and this is particularly noticeable immediately adjacent to the gabions (see Figure 3.1). The recession of the low cliff line is irregular and is more severe adjacent to access points on to the beach (see Figure 3.2 and Figure 3.3).

Figure 3.2 Low cliffs at Double Dykes displaying erosion

Figure 3.3 Access point showing enhanced erosion

In addition to the area immediately to the front of Double Dykes, the higher cliffs to the east also show evidence of erosion – see Figure 3.4. Although the evidence of active erosion is readily observed, there are also indications of at least some short-term stability within the frontage, examples being the vegetated, tussocky cliff toe (Figure 3.5) and sand accumulations on the upper beach against the low cliffs (Figure 3.6). The sand accumulations are known to have resulted following the recharge episodes along the Bournemouth frontage during 2006. Similar accumulations which followed the recharge in 1988 persisted for some 5 years before eroding away (Harlow, personal communication, 2009). This further reinforces the role the Poole Bay recharge plays in maintaining beach levels at Double Dykes and Hengistbury Head.

Figure 3.4 Hengistbury Head cliffs displaying exposed strata and evidence of erosion

Figure 3.5 Vegetated cliff toe west of Double Dykes

Figure 3.6 Upper beach sand accumulations, Double Dykes, looking west

3.3 Future

To have the soft, erodable promontory of Hengistbury Head dictating the plan form of the two Bays is a modified situation. Without defences and with no further intervention of any kind, Hengistbury Head would continue to erode. Using the more conservative rate of 1m/yr from Table 2.3, within 200 years or so one Bay would eventually form from the existing two. Hengistbury Head would eventually disappear, as would Christchurch Harbour in its current form.

The effects of this would reach further alongshore in both directions. To the east, large volumes of additionally released material from the Hengistbury frontage would, at least in the short to medium term, naturally replenish the frontages of Barton on Sea, Chewton Bunny, Milford-on-Sea and as far as Hurst Spit. Breaching and erosion of Hengistbury would be naturally beneficial to these frontages, creating wider beaches and slowing erosion of the cliffs at those locations. To the west, the defended Bournemouth and Poole frontages would come under increasing pressure and erosion of these frontages would inevitably occur as Poole Bay continued to adjust its shape within the log spiral form.

The current conurbation of Christchurch (and to a lesser extent Bournemouth) is established adjacent to a dynamic, immature, receding coastline – (albeit one artificially held in place) – and one still searching for equilibrium. If a No Active Intervention approach were to be adopted in the longer term then it would be expected that the Hengistbury Head frontage would recede and at some point in the future the sea would break through to create a new tidal inlet to Christchurch Harbour. However, maintaining a regime of beach recharge of the Bournemouth and Poole frontages to the west will continue to supply sediment to the Hengistbury Head beaches, assisting in maintaining width to those beaches, therefore affording the cliffs some protection and slowing the rate of recession.

3.4 Past examples of overtopping

Of importance are any historical examples of breaching at this location, involving the removal of sediment on a large scale. The Hengistbury Residents Association (2005) identify that the cliffs at Double Dykes have been overtopped on five occasions in the past 129 years. These events occurred in 1883, 1911, 1924, 1935 and 1976. However, as far as the authors are aware, these examples all relate to overtopping (or over-washing). Although such events would be likely to result in some localised flows and ponding of seawater beyond the low cliff line, none of these events has constituted a full breach through to Christchurch Harbour.

Frequent and repeat overtopping, however, would probably lead to a breach scenario developing.

4 CURRENT MANAGEMENT POLICY

The current SMP policy for Hengistbury Head (which sits within the SMP management unit PBY3) provides a 'retreat the line' policy for the 'Landform' (Hengistbury Head), while holding the width of the intertidal area through 'limited intervention'. This was adopted for the Warren Hill to Long Groyne frontage.

This effectively acknowledges holding the width of the beach in place through the presence of the Long Groyne. The current SMP Policy for the two management units to the west of Hengistbury Head (PBY1 And PBY2), which cover the remainder of the Poole Bay frontage, is to hold the line. The recharge activity which takes place within these management units provides a source of sediment to the beaches fronting Hengistbury head and a significant amount of this is retained by the Long Groyne, although much of the finer material appears to bypass the Long Groyne and enter Christchurch Bay.

4.1 Shoreline defences

The Long Groyne, located at the southern most point of the headland, was built in 1938. Its main function is to intercept and trap the sediment which drifts eastwards. This assists in maintaining beach levels westwards from the groyne along the south-westerly facing aspect of the Head. The Long Groyne is particularly effective at trapping gravel and coarser grained sediment, with finer grained sediment more able to pass around it into Christchurch Bay.

To the west of Warren Hill there are a series of gabion baskets and earth bunds at Double Dykes along the back of the beach (see Figure 3.1). Three rock groynes are present on the beach directly in front of Double Dykes (see Figure 3.1) and a series of timber groynes then continues westwards through the Southbourne frontage toward Boscombe, which assist in retaining the sediment transported eastwards.

To the north-east of the Long Groyne, there are a series of 17 shore-normal rock groynes located along the south-east facing shoreline of Hengistbury Head and Mudeford Spit. Rock is also used along this section to defend parts of the upper beach and cliff toe. Rock placements are also used in combination with sheet steel piling to stabilise the position of the Spit at the entrance to the Mudeford Run. Mudeford Quay is heavily modified and stabilised with a range of protection structures.

Beach recharge episodes have been undertaken across the Poole Bay frontage regularly throughout the last four decades. The first pilot recharge scheme was carried out during 1970 (Cooper, 1998). Full-scale recharge then occurred in 1974 – 75, followed by a third phase during the period 1988 – 1990. The most recent recharge activities have taken place during February/March 2009.

5 LIKELIHOOD OF BREACH DEVELOPMENT

5.1 Definition of a breach

A breach occurs when a body of water breaks through a barrier of some description, either a natural barrier such as a coastal spit or low-lying area of ground (such as Double Dykes) or a man made barrier such as a bank or seawall. It may break through to another water body on the other side, or it may break through to flood an area of land that lies below the current level of the water. Within a coastal context, Kraus and Wamsley (2003) define a breach as “a new opening in a narrow landmass such as a barrier spit or barrier island that allows water to flow between the water bodies on each side”.

Hydrodynamic forces act upon the barrier, and cause a break through point. A breach will then allow water to travel across or through the barrier – generally the water will then seek to find equilibrium of level on both sides of the barrier. It is important to state that overwashing, overtopping or wind driven spray in isolation does not constitute a breach. A breach will let water flow through unhindered, although it may not necessarily need to have a bed level at or below MSL, as a breach may only let water through during high flows or tides.

5.2 Mechanisms of breach development

Breaches would generally occur via one of two mechanisms; **overtopping** or **seepage and liquefaction**. Kraus and Wamsley, (2003), identify that seeping and liquefaction may occur where a barrier feature is narrow and difference in water level on each side of the barrier may result in seepage through porous material, promoting the liquefaction of material (thereby reducing it’s cohesiveness). This makes it easier for the erosion and removal of large volumes of material and subsequent development of a breach. However as the Double Dykes area is very wide in comparison to most coastal barrier features this mechanism can be largely ignored (although sustained high water levels on the Christchurch Harbour side may promote this type of behaviour).

Overtopping therefore is the primary process that may lead to the development of a full breach at Double Dykes. Overtopping can lead to the scouring of a trough between the sea and the water body that is protected by the barrier. Kraus and Wamsley (2003) identify that a certain duration of inundation is required, along with strong flow velocities and wave action. Localised areas of pre-existing low elevation within the topography of the barrier can confine the flow and intensify the flow velocities and the erosive and scour potential. Strong winds, wave set-up and wave run-up will add to the pressure placed on a barrier during periods of high water inundation and storm wave attack. Inundation may also advance from inside the harbour if the inner water level were to be raised sufficiently by extreme fluvial flows.

5.3 Local factors for breach development

There are a large number of localised factors that would dictate occurrence of a breach at Double Dykes. Some of these factors are predictable and some are unpredictable. These factors will dictate how a breach would develop, the route it would take and the effect it would have following breakthrough into Christchurch Harbour. They can be split into three categories:

Physical characteristics:

- Barrier width
- Intertidal and back-of-beach slope
- Backshore cliff height
- Barrier elevation above mean sea level
- Topographic variation of barrier (high points, presence of existing channels)
- Sediment grain size
- Volume of material above mean sea level
- Geology and 'erodibility' of material

Hydrodynamic and climatic factors

- Frequency and duration of storm events
- Residual tidal surge height
- Timing of peak surge
- Number of tidal cycles affected
- Extreme wave heights
- Extreme wave periods
- Wave direction
- Nearshore bathymetry and wave focussing
- Direction and track of low pressure systems
- Associated change in wind directions
- Extreme fluvial flows

Management regime factors

- Presence of gabions and groynes
- Change in future management practice (e.g. reduction/increase in beach recharge within PBY1 & PBY2)

5.4 Breach potential at Double Dykes

Breaching potential at any given site is determined by the range of factors identified in 5.3 above. However as Kraus and Wamsley (2003) point out, the breaching potential at any site is minimised if the barrier is high and wide. The elevation and volume (of material) above mean high water level is key in resisting inundation and erosion during extreme storm events.

The large set of factors/variables introduces complexity into the consideration of a breach occurring. However one primary factor is the topography and this can give a clear picture of the route a breach channel may take. Figure 5.1 below shows three examples of possible routes for such a channel. Figures 5.3, 5.4 and 5.5 show these in cross section. It is generally thought the most likely route is the longest route, which would follow the lowest topography. The shorter routes would both encounter higher elevations on the Christchurch Harbour side. When viewed in plan form, it can be seen that the longer, more convoluted route may in fact produce a 'dog leg' channel that did not allow direct penetration of wave energy into Christchurch Harbour - although this may be expected to erode into a straighter channel after a period of time.

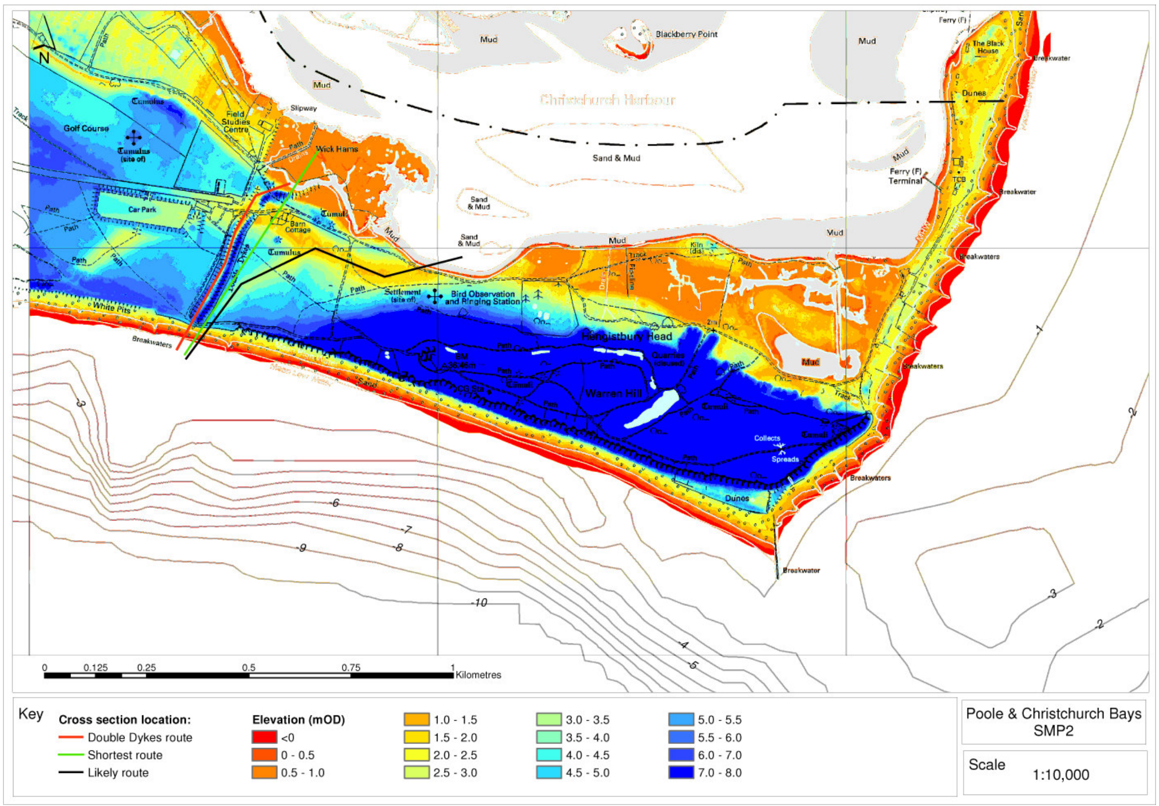


Figure 5.1 Topography and bathymetry of Hengistbury Head showing three considered routes for a breach

Figure 5.1 above shows UK Hydrographic Office bathymetric data for the nearshore from approximately 1990. Figure 5.2 shows bathymetric data for the nearshore area captured in 2008.

The permanence of any breach which occurred would very much depend on the geometry of the channel. Where a bon fide breach had occurred, a narrow, steep sided channel may well partly re-seal itself via collapse of the channel wall, due to instability in the sands and gravels. It may then only flow under extreme conditions. However, a wider shallower breach may be more stable in its form in the longer term (although the bed level would be more elevated and would still be unlikely to flow under any conditions other than very high spring tides or storm surges).

Figures 5.3, 5.4 and 5.5, show the cross sectional topography of three possible breach routes. This type of graphical representation of the risk has been given previously, by Halcrow (2006) and Harlow (1999). There is general agreement that although it represents the longest route, Figure 5.5 shows the most likely topographic route that a breach would follow. It should be noted that the graphs are not to scale and show a much exaggerated elevation compared to the barrier width. It is therefore useful to refer to Figure 5.7 in order to appreciate the dimensions of the barrier.

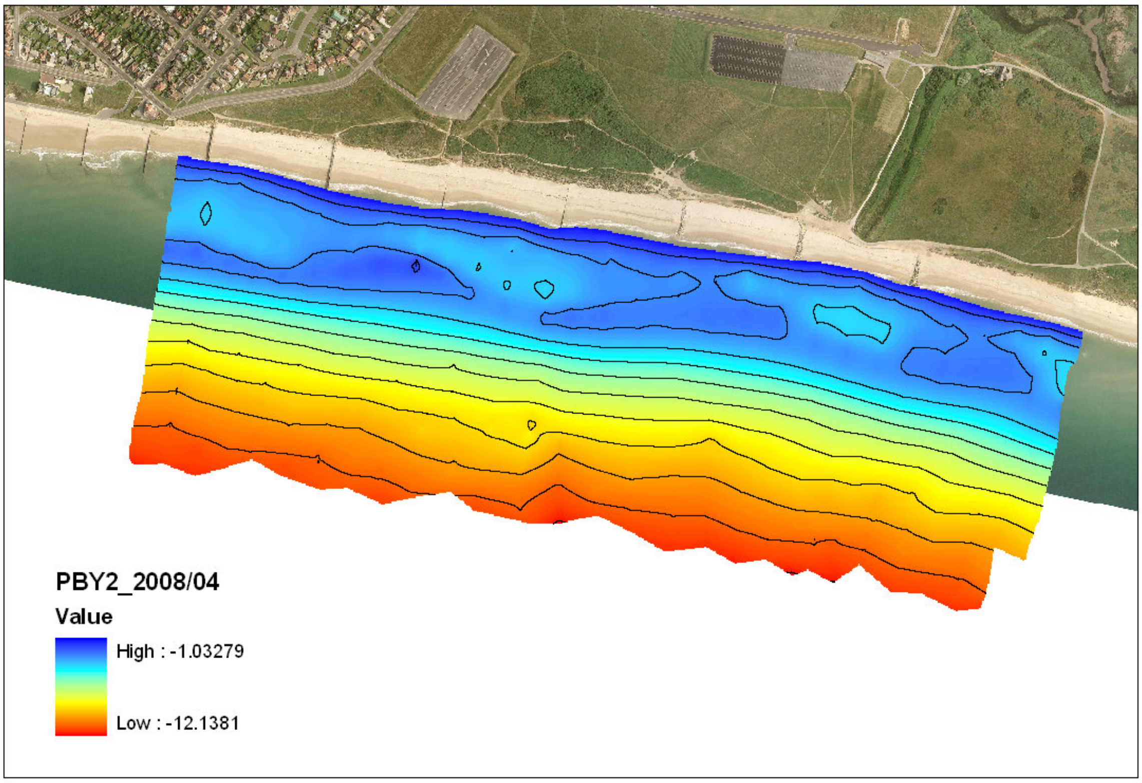


Figure 5.2 2008 Bathymetry of Double Dykes foreshore and nearshore
(Photography source: Channel Coastal Observatory)
(Bathymetry source: Channel Coastal Observatory)

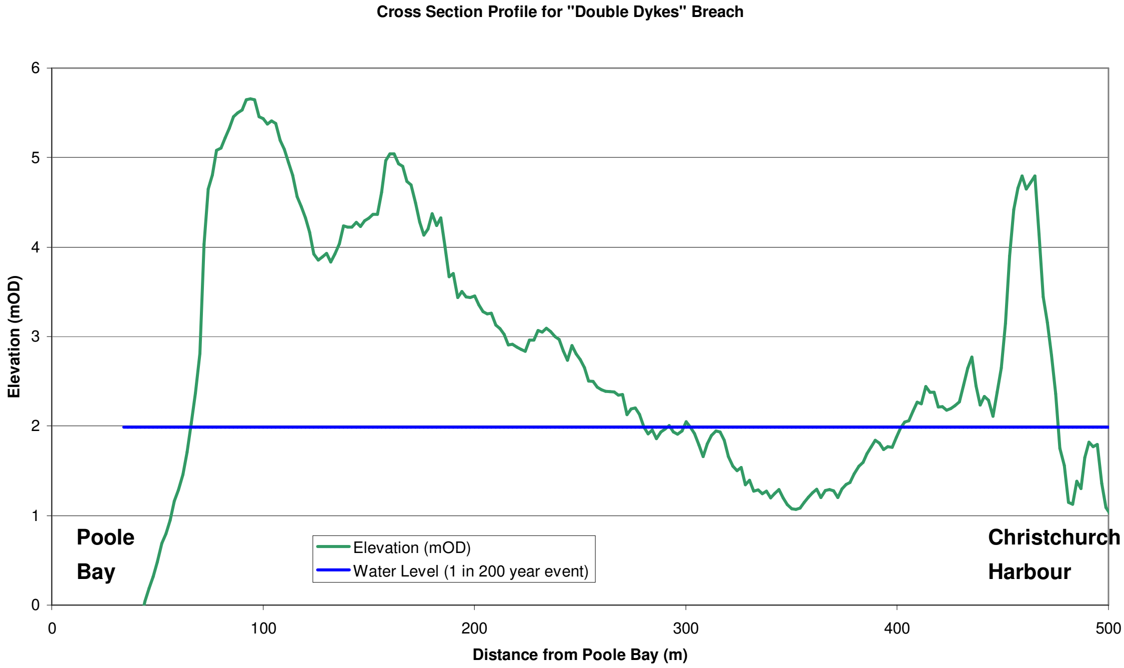


Figure 5.3 Cross-sectional topography through Double Dykes showing height of 1 in 200 year extreme tide level (1.99mOD)

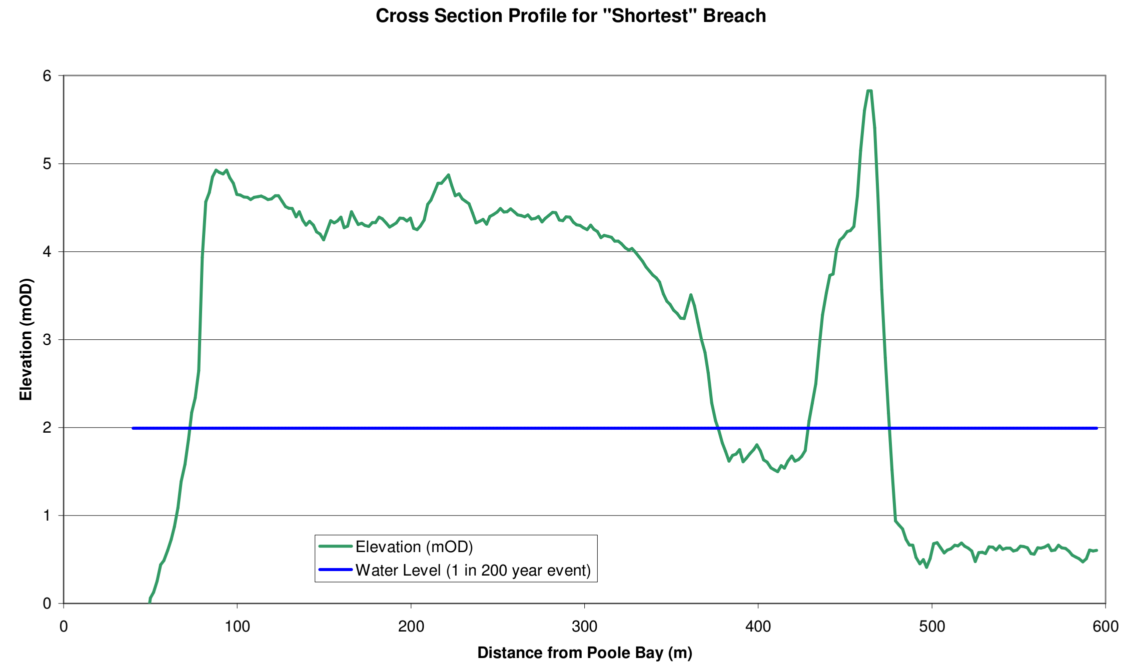


Figure 5.4 Cross-sectional topography through shortest distance breach route showing height of 1 in 200 year extreme tide level (1.99mOD)

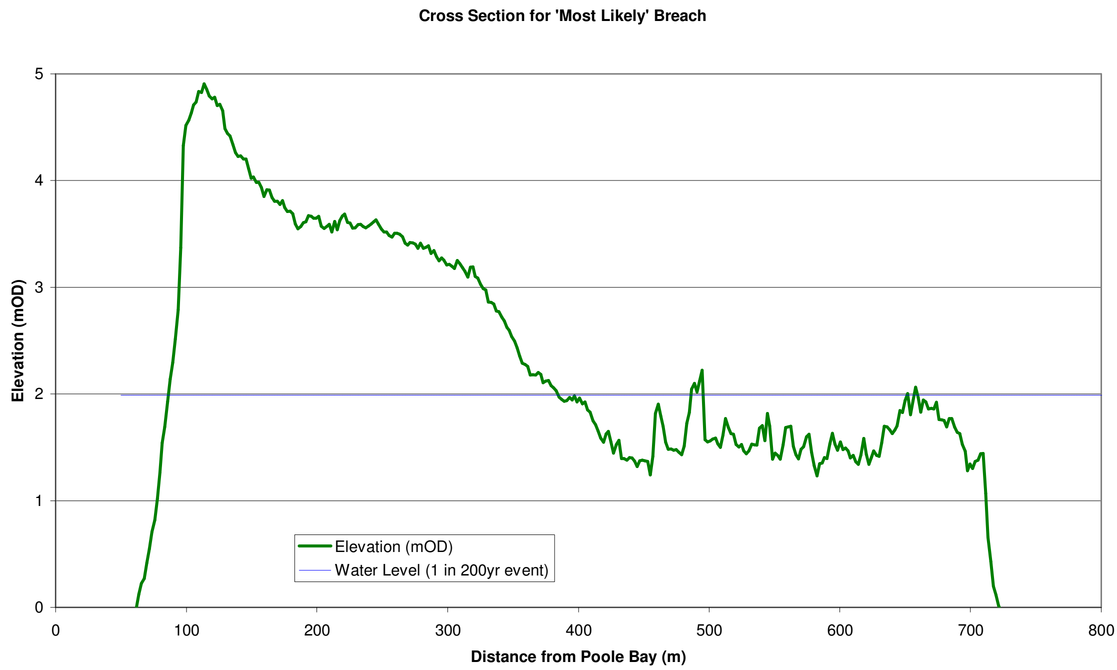


Figure 5.5 Cross-sectional topography across 'most likely' breach route showing height of 1 in 200 year extreme tide level (1.99mOD)

Whilst some of the literature considers two or three potential flow routes for overtopping seawater, it generally considers them each in isolation. As Harlow (1999) points out, the topography of the site may produce a confluence of these flows, resulting in a stronger flow of water through the 'most likely' route, thereby increasing the risk of a full breach through to the Harbour during the course of one event.

The width and depth, in addition to the final bed elevation of any potential breach would dictate how much additional energy would be received by Christchurch Harbour, e.g. flooding may occur through the breach only on MHWS.

Consideration of risks in relation to current day extreme water levels and cliff toe position and the hinterland topography can help present a picture of the *present day* risk. However the SMP considers the time period to 2105. Therefore Figure 5.5 above has been reproduced below (Figure 5.6) and 1 in 200 year water level for 2105 has been superimposed, along with the assumed cliff toe position for the same year. The assumed cliff toe position is calculated using the erosion value of 1.0m /yr which would apply under a 'No Active Intervention Policy'. The 1 in 200 year water level and cliff toe position are also shown for 2150 to give some perspective to how risk increases further with time, due to both cliff recession and sea level rise.

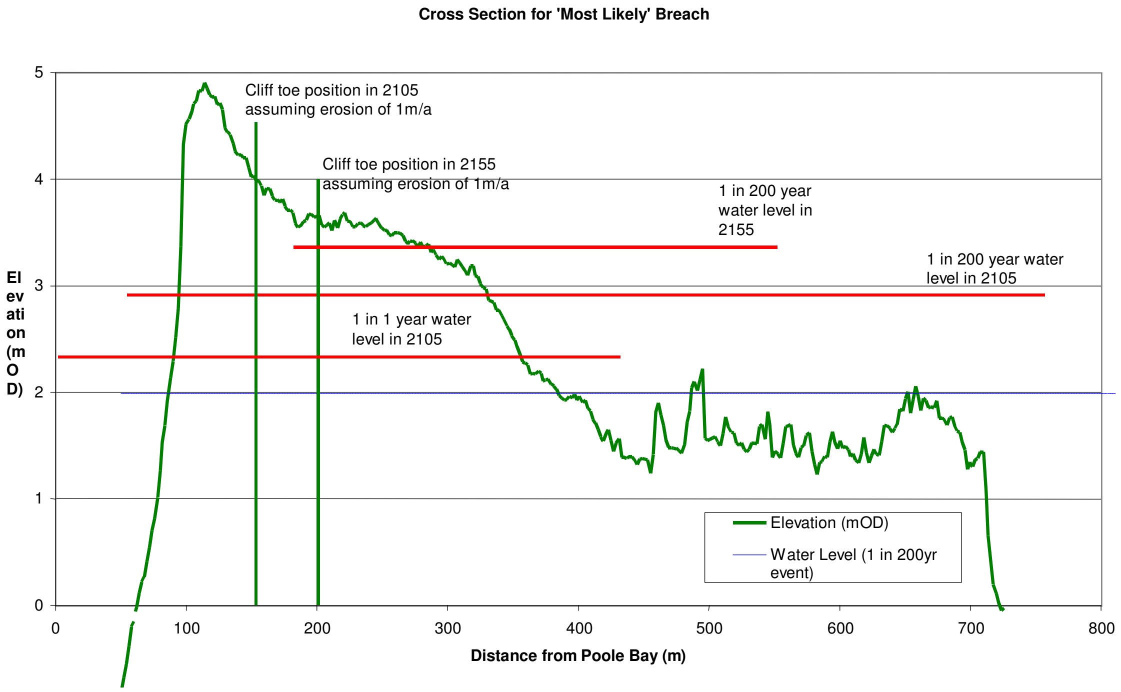


Figure 5.6 Indication of increased risk over time for the 'Most likely breach route'

It can be seen that by 2105, the theoretical intersection of assumed cliff toe position and enhanced water level experienced during a 1 in 200 year event presents a greatly enhanced risk. The 1 in 1 year water level can be seen to present a significantly higher risk in 2105 than the 1 in 200 year water level does at the present time.

The indications for 2155 indicate how extremely vulnerable the frontage would be by that stage.

Figure 5.7 indicates the theoretical plan view position of the cliff line under the NAI scenario at the end of each SMP epoch (assuming an erosion rate of 1m/a). It provides an indication as to the extent of the overall narrowing of the barrier that could occur during the next 100 years.

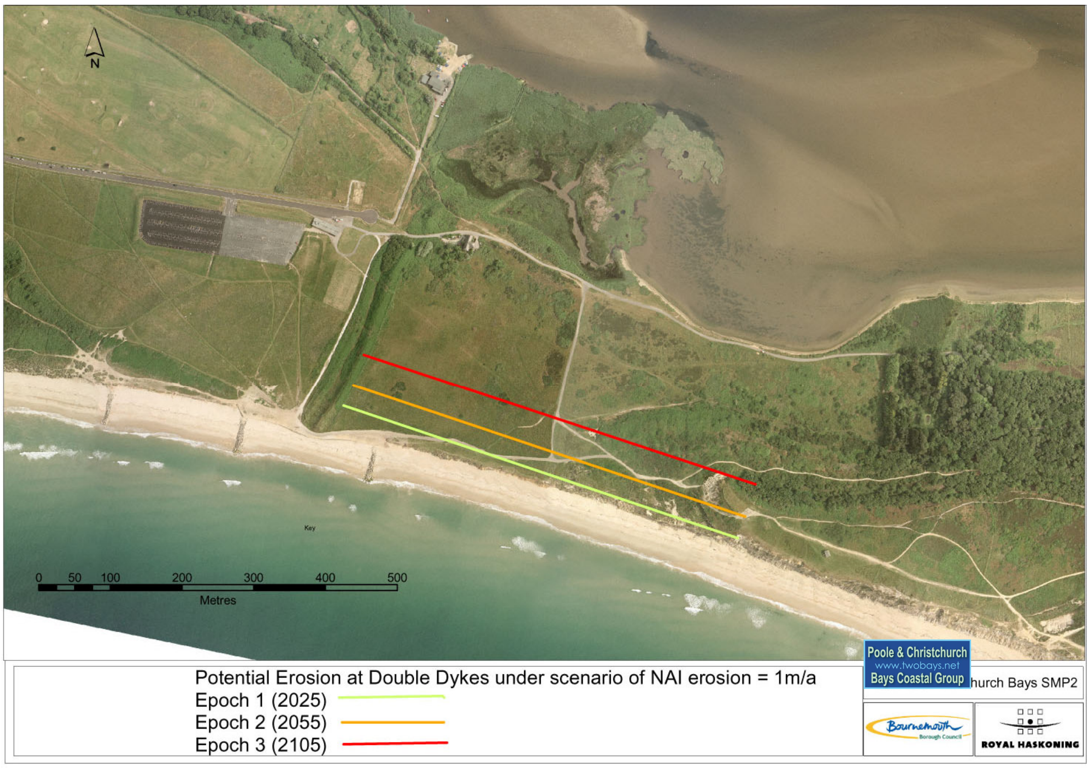


Figure 5.7 Theoretical cliff line position at Double Dykes under a NAI scenario
(Photography source: Channel coastal Observatory)
(Wave data source: Channel Coastal Observatory)

The above assumes a rate of sea level rise commensurate with the levels currently advised by Defra in their Flood and Coastal Defence Appraisal Guidance; FCDPAG3 Economic Appraisal; Supplementary Note to Operating Authorities – Climate Change Impacts (October 2006). For 2155 another 50cm of sea level rise has been assumed, however due to the nature of the expected accelerating growth curve for sea level rise beyond the second SMP epoch (due to the time-lag effect experienced with thermal expansion of the oceans), it could well exceed this.

5.5 Probability of a breach

This report has undertaken no additional modelling to calculate the probability of a breach occurring. It provides a qualitative assessment only, based on knowledge of the topography, geology, defences etc., plus the sensitivity of the Hengistbury Head frontage to climate change.

It is useful to provide an overview of the existing predictions of breach probability that have been given within the reviewed literature. Table 7.1 below sets out what the previous reports and studies have stated.

Table 5.1 Estimates of breach probability within previous reports

Source	Prediction	Comment
Halcrow, 2006	1:100 or greater	Refers to Poole Bay Strategy
Poole Bay Strategy Study	1:100	
HR Wallingford	1:166	Report EX 3116, Nov 1998
Halcrow, 2004	0.3 – 1.0%	Given as perceived scale of risk over space of 300 years

A pre-occupation with identifying an exact probability of breaching may almost be counter-productive within the effective management of Hengistbury Head. It could induce a false sense of security or alternatively create a panic situation. It should also be acknowledged that as sea levels rise year on year, so return periods and probabilities associated with a certain magnitude event would change. These 'moving goal posts' make it difficult to ascertain with any certainty the scale of event likely to cause a breach.

As an indication of the likely risk, it is suggested that it is likely to take an extremely severe storm event in the order of at least 1 in 100 year probability (and possibly closer to a 1 in 200 year probability) to cause a one-off breach through the Double Dykes area. An event of this return period is likely to be associated with extreme tide levels, extreme surge characteristics and the extreme wave heights that would normally be associated with lower latitude, North Atlantic hurricanes. Such an event is thought to have occurred during the winter of 1824 (West, 2009) when severe flooding, damage and loss of life occurred along the south central coast of England (there is no record of a breach occurring at Double Dykes during that event).

An event of this hurricane-type magnitude must be seen within the context of the whole SMP frontage. Conditions required to cause a breach through Double Dykes to Christchurch Harbour would also be likely to breach Sandbanks Spit, Hurst Spit, and with raised water levels inside Christchurch Harbour, due to the Hengistbury Breach, overtopping and breach of Mudeford Spit. It could also cause a massive loss of sediment from the beaches and significant cliff failure between the Southborne to Barton on Sea frontage. In summary, it could dramatically change the entire SMP frontage, at least for a period of time.

The SMP is a strategic document that considers all physical controls; both natural processes and human interventions. Present management practice of beach renourishment (and the encouragement of retention of this sediment through the use of groynes) has proved itself to be relatively successful. It should be acknowledged therefore that with the continuation of present management practices, a major breach through the Double Dykes section of Hengistbury Head remains a very low risk.
It is more likely that periodic overtopping would start to mobilise the gravels in a landward roll back retreat, rather than a one-off catastrophic breach. Management policy that gives long-term accommodation to this natural coastal morphology will be far more sustainable (and economically viable) in the long term than engineered solutions that aim to hold the cliff-line and the MHW line in their current positions. With current practices, there is unlikely to be significant retreat of either cliff line or MHW during the short to medium term (0 – 50 years). As sea level rise accelerates beyond the medium term (50 years onward), risk will increase and ultimately present measures may not be

sufficient to prevent gradual breaching occurring in the long term (and within the 100 years consideration of the SMP).

Of critical importance is the continued availability of new sediment both from replenishment activities and natural sources (from eroding cliffs in central Poole Bay) – therefore management decisions which affect the rate of erosion of such new sediment sources will ultimately have an impact on the longevity of Hengistbury Head in its current form and position. However, as sea level rises and storminess increases, such management techniques become less sustainable. In addition the very extreme event could potentially overcome any defences that are present, at any point within the next 100 years.

Continued use and maintenance of groynes, plus monitoring of beach levels and volumes along the seaward face of Hengistbury Head remains the most effective solution in the short to medium term. In the long term however, sustainability of this approach has to be considered. However maintaining Hengistbury Head in its current form and position is seen to provide a more sustainable way of providing defence to the Christchurch, Bournemouth and Poole frontages in the longer term and these considerations should form part of the longer-term strategic management of Hengistbury Head.

5.6 Timescales of breach development

The period of time over which a breach developed would inform how and when it could be addressed. Review of the mechanisms and factors for breach development suggest that there are three main breach scenarios. These are discussed below in order of most unlikely to most likely.

1. A breach, which occurred over the period of one or perhaps two tidal cycles during a storm with a coincidence of very high astronomical tide and surge: planned intervention for managing such an event would be very difficult and there would only be time for an emergency management reaction. However this type of event remains very low risk due to the coincidence of a number of extreme conditions (sustained extreme water levels, extreme nearshore wave climate, sustained extreme local wind speeds) which would be required for sufficient overtopping to occur and provide sufficient flows across the barrier to promote the sudden erosion and development of a full breach channel.

2. A breach that occurred over the period of an extremely stormy winter, would also allow little in the way of time to manage the problem: this scenario is more likely than one extreme event causing a breach. Although this scenario is also of relatively low risk at present, the likelihood of it occurring in the second and third epochs of the SMP increase. This is because sea levels are expected to rise, which will increase the potential for erosion. In addition the magnitude and frequency of storms is also likely to increase, which coupled with deeper water due to sea level rise will mean that higher wave energies will reach and probably erode the foreshore.

3. A very gradual breach progression and development of erosional runnels and channels: this scenario would give time for reactive repair works to be undertaken or for temporary repair works followed by an options appraisal study, before irreversible impacts were sustained by Christchurch Harbour.

6 CONSEQUENCES OF A BREACH

In assessing the consequences of a breach, there are any number of different scenarios which could be considered. As an example, three such scenarios are provided below:

Scenario 1. A breach occurs during an extreme event over one or two tidal cycles. No action can be taken to stop the breach occurring, but following the breach, emergency works are instigated to repair and seal the breach.

Scenario 2. A breach occurs during an extreme event over one or two tidal cycles. Following the breach, it is decided to allow natural processes to continue and the new tidal channel would be left open.

Scenario 3. A breach occurs over the period of a stormy winter or over the course of several consecutive stormy years.

In reality, much would depend on the amount of vertical erosion that took place along the bed of the breach. It may have achieved a depth that would allow it to act as a new tidal channel on every high water, or alternatively it may only have become deep enough for high spring tides to flood it. Of course each subsequent tide cycle which did flood the new channel, would act upon it both laterally and vertically.

For the purposes of the following section however, in considering the consequences of a permanent breach, Scenario 2 is used.

6.1 Impacts on inner Christchurch Harbour hydrodynamics

One of the principal impacts of a new tidal passage into the harbour on a south-west orientation would be the possibility of enhanced water levels during future storm events, due to enhanced wave set-up effects. This effect could increase the likelihood of a breach occurring across the lowest lying section of Mudeford Spit. However the reduced resistance to outflows from the Harbour could counteract this effect.

The breach could significantly alter wave climate within the Harbour. Presently, wave action within the harbour is very limited, due to the sheltered nature of the current entrance (very little open coast wave energy penetrates through the Mudeford Run). Exposure to south-west waves through the new tidal passage could be quite significant (although they would be depth-limited). The south-west facing frontages of Mudeford and Stanpit would be particularly vulnerable during instances of elevated water depths within the Harbour, i.e. at times of combined high spring tides and storm surge. At most times, the extremely shallow nature of Christchurch Harbour would attenuate energy and shoal waves before they reached the Mudeford and Stanpit frontage. Of course this shoaling and energy attenuation would have large impacts on erosion and sediment transport patterns with the Harbour. Increased wave heights could also result in increased flood risk, particularly to the low lying areas of Christchurch and Mudeford.

Tidal regime would be changed significantly within the Harbour. It is suggested that once the breached channel was established, water within the Harbour and fluvial inflow from the rivers would commence draining through the new tidal channel during most tides, dependent on the depth of the new channel bed. This would be due to the new tidal channel providing a shorter route to the sea with a steeper gradient (Harlow 2005).

It is believed that an ebb dominant regime would persist. If this happened, an ebb tide delta may form just offshore of the new tidal channel entrance. However the potential breach location is a much higher wave energy environment than the existing Harbour entrance channel and it should not be expected that the same morphological behaviour would be exhibited or the same type of bathymetric feature to evolve. Timescales for this occurring would probably be decadal or longer. Much would depend on how much additional sediment was liberated from within the Harbour due to increased wave energy inside and the altered tidal regime. As a delta developed, it would provide some protection to the new channel mouth, decreasing wave energy entering the Harbour and slowing erosion rates and therefore reducing sediment released for continued formation of the delta. Clearly, these factors are linked and an effective feedback mechanism could be established.

Water levels inside the Harbour during an extreme event may not necessarily increase with a new breach channel open. A wider and more direct route to the sea for fluvial flows through the Harbour may encourage less tide locking within the Harbour. However wave set-up effects would more easily be translated to within the Harbour. Much would depend on breach channel width.

6.2 Impacts on sediment transport

With the persisting presence of a new tidal inlet at Double Dykes, interruption in the west to east transport of sediment may occur, due to the flow velocities exiting the channel mouth, producing a partial barrier to the littoral drift. On the open coast therefore, it is likely that there would be an increase in the level of accretion to the west of the channel mouth. Therefore there would be less material reaching and being trapped by the Long Groyne. This in turn could reduce the width of the beach fronting Warren Hill, increasing erosion potential at that point.

Localised erosion and net offshore movement of sediment could occur, with the possibility of the formation of a nearshore bank or delta below MSL, if ebb dominance continues to be demonstrated through any new breach. The actual form and position of such a feature would be dictated by the sediment grain size being transported, the width of the breach mouth and the associated ebb tidal flow velocities. This feature could potentially then attenuate extreme wave activity during subsequent large events, effectively providing some protection to the mouth of the new tidal inlet and immediately adjacent coasts.

6.3 Impacts on the plan shape of the harbour

Increased wave energy reaching the north-eastern side of Christchurch Harbour (around the Mudeford and Stanpit frontage) would cause increased risk of both erosion and flooding to those residential areas. This is a primary consideration for the SMP and has economic assessment attached to it. The inner face of Mudeford Spit may also experience some erosion, threatening to reduce the level of protection it provides from the east-southeast storm track. The Mudeford Run may eventually become blocked with silt and close due to the new breach creating slack water around the eastern side of the Harbour during times of low wave action, encouraging deposition of material.

6.4 Impacts on the natural environment

A breach may have environmental implications for the designated sites due to salinity variations introduced by the new channel.

The Avon Valley RAMSAR site is located at the north-west corner of Christchurch Harbour – any changes to tidal regimes and salinity and sediment accretion processes within the Harbour could therefore affect this site.

Former landfill sites are located on both sides of the Harbour, landward of the marshes and in some of the low-lying floodplain areas. A changed hydrodynamic regime, which introduces more energy within the harbour, could potentially erode these sites and present a risk of contamination from the waste materials contained within them.

6.5 Impacts on the historical environment

The most significant impacts upon the historic environment would be the substantial land area loss of the internationally important scheduled site of Hengistbury Head. The ongoing erosion both from the sea and from a new tidal inlet would slowly remove the feature. However, this ongoing erosion may also provide opportunities through the exposure of previously unrecorded archaeology and give access to previously inaccessible historic sites or remains.

6.6 Impacts on the amenity value

If a new channel were to form and the exiting channel silt up, the Mudeford Quay and car parking area could potentially become redundant. The current location of the foot ferry would have to change. There would also be impacts upon navigation and visitor trends to the area. There impacts are likely to be initially high, but people and businesses are likely to quickly adapt and new amenity benefits would become available, such as easier access to Mudeford Spit.

7 DISCUSSION

7.1 Main points

That a breach will occur *at some point* in the future at Hengistbury Head is fairly certain. The timing of such an event depends primarily on the continued management of the coastal protection structures and continued beach recharge activities to the west. Section 5 identifies how risk becomes enhanced through time due to the combination of cliff recession (under a No Active Intervention Policy) and sea level rise. However when considering the implications of a NAI policy, it should also be stated that by adopting a policy such as Hold The Line (which would facilitate management intervention along the Double Dykes and Hengistbury frontage directly), the risk could be either sustained at current levels or possible reduced through time, depending on the scale of the intervention and availability of funding.

It is widely accepted that Christchurch Bay and Poole Bay are still trying to reach a point of equilibrium between wave energy, exposure and sediment supply. Essentially, if left to natural processes, the two bays would become one bay and Christchurch Harbour, as we know it, would eventually cease to exist.

At present, Hengistbury Head is held in position primarily through the use of protection structures, in order that it behaves like a resistant geological feature. In reality, it is a relatively weak and erodable feature and in the sudden absence of coast protection structures, the first major changes observed along the SMP coastline would probably be at Hengistbury Head, probably starting with overwash at the low cliff sections and fairly rapid erosion of the whole frontage.

An initial breach may not remain open, instead it may close again for several years and be in-filled by material transported eastwards from central Poole Bay and moved up the beach profile by means of small swell action and aeolian processes. However this would be entirely dependent on the frequency of return of severe storms following a breach. Once an initial breach had been cut, it would be very prone to further inundation by high waves and surge and would eventually be eroded below mean sea level, providing a new permanent tidal channel out to the sea.

As part of this discussion, it is valuable to introduce the view given in the SCOPAC (2004) Sediment Transport Study:

"*Thus, to avoid the impact of a second tidal pass on the ecological balance of Christchurch Harbour, it will be essential to enhance the defence standard offered by the present mix of rock groynes, gabions and periodic renourishment. There may also be an increasingly more compelling case for innovative management measures, such as beach dewatering or offshore breakwaters. However, all proposals will require very careful numerical modelling based on higher quality data for nearshore wave climate and sediment transport than is currently available.*

A breach at Double Dykes also has far-reaching socio-economic and environmental implications. Most cost benefit calculations support the case for investing in defences, thus maintaining the existing mix of freshwater and saline habitats in Christchurch Harbour".

As indicated in Section 2.10, extreme fluvial flows enhance the flood risk within the Harbour during extreme tidal events and the restricted exit from the Harbour for fresh water flows will exacerbate this situation through 'tide locking'. Extreme tide levels are generally observed to be higher inside the Harbour than outside during an extreme tidal event.

The fact that extreme water levels within the Harbour more often relate to high fluvial flows, rather than tidal surges demonstrates how important fluvial flow is within the consideration of management of water levels within the Harbour. These flows are likely to become more severe with time as extreme rainfall events become more frequent due to climate change. Therefore the risk to the low-lying area of Christchurch and its surrounds is significant. It is possible that a new tidal inlet would allow a more direct route for flows to the sea, however it is unlikely, given the small tidal prism within the Harbour, that sustaining two channels would be possible without a great deal of dredging and management effort.

It may be seen that allowing a breach to occur is not the most significant management decision that needs to be taken for Hengistbury Head. Rather, the more important decision would be whether or not, *once a breach had formed*, to defend Hengistbury Head itself. If so, then protection afforded to Christchurch, Bournemouth and Poole from the Headland would remain. A breach, or new tidal channel alone would not be disastrous for Christchurch Harbour. The additional risks it may introduce within the Harbour could be managed and navigational issues, for instance, could be managed by keeping the Mudeford Run open.

7.2 Uncertainty

An important aspect of this study is how uncertainty is accommodated and dealt with. The principal uncertainty we deal with is climate change, i.e. relative sea level rise and increased storminess and increase in significant wave heights and the magnitude and return frequencies associated with them.

The majority of previous studies believe that a critical event leading to a breach is low risk during the short to medium term, but the question cannot be answered with certainty. Probability dictates that a severe event could just as easily occur next week as opposed to in 100 years time. Due to the potentially serious impact on Christchurch Harbour, Mudeford Spit and Hengistbury Head itself, it must be regarded as a *low-risk, high-impact* possibility that cannot be ignored.

Assessing the joint probability of extreme fluvial events coinciding with extreme coastal surge events is problematic and difficult to calculate. There are many variables and uncertainties that have to be dealt with. What common sense dictates however, is that coincidence of high terrestrial rainfall occurring together with stormy coastal conditions is not unusual.

There is also large uncertainty in the actual amount of sediment received by Christchurch Harbour which is derived from fluvial input. Large variations in the estimates of *potential* sediment supply make it difficult to predict how tidal prism within the Harbour will respond to rising sea levels and how this may affect a new breach channel.

8 CONCLUSIONS

The main implications for the general Hengistbury Head and Christchurch Harbour area associated with a breach would be the following:

- Increased difficulty of access to Hengistbury Head
- Increased flood and erosion risk to residential areas around Christchurch Harbour
- Partial loss of internationally important heritage site
- Changes to hydrodynamics and salinity for designated nature conservation sites
- Navigational access/egress
- Damage to infrastructure

It is likely to take an extremely severe storm event in the order of at least 1 in 100 year probability and possibly closer to a 1 in 200 year probability to cause a one-off breach through Double Dykes near Hengistbury Head *at the present time*. An event of this return period is likely to produce extreme tide levels, extreme surge characteristics and the extreme wave heights that would normally be associated with lower latitude North Atlantic hurricanes. However, it is very important to acknowledge how the risk increases throughout the lifetime of the three SMP epochs. By the end of the third epoch, the risk of a one off breach occurring is greatly increased.

An event of this magnitude would also be likely to severely affect Sandbanks Spit, Hurst Spit, and possible overtopping and breach of Mudeford Spit. It could also cause massive loss of sediment from the beaches and significant cliff failure along the Southborne to Barton on Sea frontage.

It is more likely that periodic overtopping will gradually erode the frontage, causing recession of the cliff line, narrowing and lowering the crest height of the barrier and therefore increasing the risk over time. Management policy that gives long-term accommodation to this natural coastal morphology will be far more sustainable (and economically viable) in the long term.

If a full breach were to occur (and be allowed to persist) increased wave energy reaching the north-eastern side of Christchurch Harbour (around the Mudeford and Stanpit frontage) would cause increased risk of both erosion and flooding to those residential areas.

One of the principal impacts of a new tidal passage into the harbour on a south-west orientation would be the possibility of enhanced water levels during future storm events, due to enhanced wave set-up effects. This effect could increase the likelihood of a breach occurring across the lowest lying section of Mudeford Spit. However the reduced resistance to outflows from the Harbour could counteract this effect.

The Mudeford Run may eventually silt up and close due to the new breach creating slack water around the eastern side of the Harbour during times of low wave action, encouraging deposition of material.

Extreme fluvial flows significantly enhance the flood risk within Christchurch Harbour during extreme tidal events and extreme water levels within the Harbour more often relate to high fluvial flows, rather than tidal surge. Fluvial flows are likely to become more severe with time as extreme rainfall events become more frequent due to climate change, increasing the flood risk to low-lying Christchurch and its surrounds. A new tidal inlet at Double Dykes may in fact reduce flood risk within the Harbour, by allowing more rapid discharge of high fluvial flows.

There would be environmental implications for the designated sites due to changes in salinity and hydrodynamics introduced by a new channel.

The most significant impacts upon the historic environment would be the substantial area loss of the internationally important Hengistbury Head scheduled site itself and the ongoing erosion likely to occur on its seaward and possibly inner face. However, instances of erosion may also provide opportunities through the exposure of previously unrecorded archaeology and give access to previously inaccessible historic sites or remains.

A particularly important scenario for the SMP review to consider is what type of management regime should be put in place if a breach were to occur at any point during the next 100 years. Defence and management approaches at Hengistbury Head cliffs and Mudeford Spit need to be considered, under the scenario of a permanent breach.

9 THE WAY FORWARD

This document does not provide a specific value relating to breach probability or an indication of a time/date window when breach development may occur under a No Active Intervention scenario, however it is recognised that it is important to indicate how the understanding may be developed to an appropriate strategy study level.

There have been recent advances in the thinking applied to the breaching of coastal barrier beaches. Bradbury, 2000, Bradbury et al, 2005 and Cope, 2004, have undertaken studies looking at the predicted response, overwashing and breaching of barrier beaches in southern England. However these studies relate primarily to the response of more dynamic, mobile, shingle features and probably provide little in terms of understanding the dynamics of breach development at Double Dykes.

A series of steps therefore need to be undertaken in order to develop an approach that will deliver information appropriate at a strategy level. The following activities have been suggested (Bradbury, personal communication, 2009) to be necessary in order to develop a 'hybrid' methodology that will deal adequately with the Hengistbury Head and Double Dykes frontage. Individual stages of investigation to assess overtopping and then breach development could be as follows:

- A joint probability assessment of waves and water levels (using appropriate software such as JOINSEA).
- Identification of conditions that have caused overtopping in the past. Use this to determine a wave and water level threshold curve based upon the current geometry of the site.
- Calculations of wave run-up to determine the amount of overtopping that would occur under a range of water levels, wave heights and wave periods. This would help to understand the volumes of water that may be involved during an overtopping event and assist with the consideration of breach development, which might occur via formation of channels. Use of the seawalls manual may provide suitable surrogate geometry for undertaking the overtopping assessment. Theoretical overtopping volumes and the return periods of events causing overtopping could then be determined. Use could also be made of modelling software such as AMAZON together with profiles derived from the topographic and bathymetric surveys.
- Based upon the existing measured data, establish historical erosion rates for past 30 years. Using these rates, determine projections for future rates and include an allowance for sensitivity to sea level rise through each epoch. The overtopping analyses described above, could then be iteratively applied to each new geometric representation of the receding cliff line at regular temporal intervals (e.g. 10 years). This will provide assessment based upon the continued narrowing and lowering of the barrier against a backdrop of rising sea levels. Continuation of this procedure will provide an eventual date window for breach formation.
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- In addition to the above it would be useful to consider the UKCIP 2009 probabilistic sea level rise curves once they are available. Consideration of the risk presented by the joint occurrence of extreme fluvial flows together with extreme open coast water levels may also help to provide information on to what extent breach development could be influenced from within Christchurch Harbour.

It is suggested that a probabilistic assessment of the rates of erosion at Double Dykes would be a useful study to consider. The summary description given below indicates how the basis for such a study could be developed (Walkden, personal communication, 2009).

Undertake a series of probabilistic sampling (possibly applying the Brunn rule or the SCAPE model described by Walkden and Hall,2005) to run a model in a multi-scenario simulation. This would involve running a minimum of 1000 simulations. Each simulation would involve feeding in a probabilistic sea-level rise curve (from UKCIP 09) to provide a simulated erosion rate. This would allow production of a probability density function that would indicate the time elapsed until a breach occurred.

This approach could be adopted for the open coast beach and cliffs of Hengistbury Head. The inner harbour shoreline could be accounted for using a non-probabilistic approach, utilising a topographic digital elevation model derived from Lidar. The shoreline slope could be used to simulate inundation (simulation of erosion would not be necessary within the harbour).

The current wave climate would need to be used within the simulations as there are too many uncertainties attached to future changes in significant wave heights, wave periods etc.

Influx of sediment (due to longshore transport) from Poole Bay would need to be considered as an input to the probabilistic model. This could be done via the use of a coupled one-line sediment transport/consolidated rock erosion model. Using simplified assumptions about the sensitivity of the Hengistbury Head frontage to sea level rise and feeding these into the erosion model via the one-line equation could provide a more basic approach to the problem.

Future management practices are obviously very influential on future rates of erosion and these could be represented either explicitly in the model or through a further series of simplified assumptions, again implemented via the one-line equation.

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