Appendix I
Estuary Assessment

Haskoning UK Ltd
on behalf of Bournemouth Borough Council

Poole & Christchurch Bays SMP2 Sub-Cell 5f: Estuary Processes Assessment

Date: March 2009

Project Ref: R/3819/01

Report No: R.1502

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Version	Details of Change	Authorised By	Date
1	Draft	J A Holland	20.01.09
2	Final	H Roberts	05.03.09

Document Authorisation		Signature	Date
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1. Introduction

This report has been produced according to Task 2.1 of the Shoreline Management Plan Procedural Guidance (Defra, 2006a). The purpose of this report is to present a review of existing information on the processes, geomorphology and evolution of Poole and Christchurch Harbours, to provide the baseline understanding required for the development of management policies within the SMP. The two harbours represent the tidal estuaries within the SMP boundaries. The Harbours were included within the first round SMP, and have been included within this SMP, as per the SMP Review Scoping Report (NFDC, 2008). The Review of Coastal Processes and Geomorphology (Annex 1, this Appendix) presents the baseline information on processes and geomorphology of Poole and Christchurch Bays. Therefore the Coastal Processes Review provides the current understanding of processes that will affect the Harbours and also provides the boundary conditions for the Harbours. As with the Review of Coastal Processes and Geomorphology, this report aims to present information in a logical and concise format, and to be accessible to a non-technical audience. As such, this review utilises high-level reports such as the first round SMP and Futurecoast, as well as more localised information sources, where these provide additional confirmation or clarification, as required. In accordance with the SMP Guidance (Defra, 2006a) this review does not aim to provide any new analyses or quantification related to the estuarine processes.

1.1 Report Structure

The rest of this section provides a summary of the literature that has been reviewed and utilised in the production of the report, and brief description of the extent and scope of the report.

Sections 2 and 3 provide the local scale review of estuarine processes for Christchurch Harbour and Poole Harbour respectively, which highlights the underlying geology, past evolution over both long and more recent timescales, the major sediment sources, pathways and sinks, and the forces driving these processes, including tides and waves, and the present geomorphological forms within the Harbours.

1.2 Literature Sources

The report draws on a range of reports, at various scales, for each of the Harbours, including the first round SMP (Halcrow, 1999), Futurecoast (Halcrow, 2002), and various reports since this time, including the Coastal Sediment Transport Study (SCOPAC, 2004); the draft Christchurch Bay Strategy Study (NFDC, 2007) and the Poole Bay and Harbour Strategy Study (Halcrow, 2004). A full bibliography is given at the end of the report (Section 4).

1.3 Extent and Scope

The SMP2 Sub cell 5f covers the coast of Poole and Christchurch Bays, from Hurst Spit in the east through to Durlston Head in the west, a coastline of approximately 130 km including the Harbours of Poole and Christchurch. This report covers the estuarine processes of the two Harbours, the locations of which are shown in Figure 1. For information covering the processes on the open coast, see the Review of Coastal Processes and Geomorphology; however, relevant information, where particularly pertinent to the Harbours, is included in this report.

2. Christchurch Harbour

This section provides an overview to the Harbour, followed by a description of the geology and past evolution of the estuary, the processes occurring within it in terms of the hydrodynamic forcing factors and the sediment dynamics, including the sediment sources, pathways and sinks.

2.1 Overview

Christchurch Harbour is a spit-enclosed estuary formed by 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, both composed of sand and gravel and formed by littoral drift on the open coast, which separate the Harbour from the sea: Mudeford Sandbank to the south-west, a sandy extension from Hengistbury Head maintained by material transported from the west; and Mudeford Quay spit to the north-east. The mouth of the Harbour has a very narrow entrance, the channel through which is called The Run and is subject to rapid tidal flows. 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 is generally shallow with a water depth of less than 2 m 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. 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.

Sediment transport within the Harbour is governed by tidal currents, freshwater discharge and wave action from the open coast, although this does not penetrate very far into the Harbour, due to the protection provided by Mudeford Sandbank. Locally generated wave action in 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. Both the ebb tidal delta and the Mudeford Sandbank are dynamic and have undergone periods of growth and erosion. In the past these are thought to be related to variations in the quantities of material drifting around Hengistbury Head, although it is now more likely to be governed by beach renourishment that has taken place along Mudeford Sandbank frontage and recent coastal management works at the northern end of the spit.

The extent of tidal flooding 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 the 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 due to the influence of high fluvial flows. However, there is also the potential for flood dominance through the mouth on 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. The northerly part of the Harbour is characterised by coarser sediments and flood dominance, whereas the sediments of the southern parts of the Harbour are generally finer, and the area is ebb dominant.

The relationship of the Harbour to the open coast in the future will be determined by any changes to the strategy for the open coast and that of the Harbour, including changes in the tidal prism within the Harbour. For example, changes in the 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), which could therefore affect conditions both on the open coast and the Harbour. Changes to the tidal prism may also create further issues related to flooding and changes to the erosion and accretion patterns within the Harbour. The possibility of a breach at Double Dykes (Hengistbury Head) or at Mudeford Sandbank could 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 the strategy for the open coast, and that for the Harbour side of the spit. The consequences of a breach at Hengistbury Head are discussed further in Annex 4 of Appendix C of the SMP.

For the purposes of the Round 1 SMP and the more recent Strategy, Christchurch Harbour has been divided into the following Process Units, which are shown in Figure 2:

- CHB1 Harbour side of Mudeford Sandbank;
- CHB2 South side of Christchurch Harbour (to Grimbury Point);
- CHB3 Stanpit and Grimbury Marshes;
- CHB4 Mudeford Town Frontage;
- CHB5 Mudeford Quay.

2.2 Geology

The superficial geology of the area is composed of Recent and Pleistocene valley gravels and alluvium, which contact with the more resistant rocks of the Barton Group at Hengistbury Head. A major fault runs through the Harbour, which may control the form of Christchurch Ledge off Hengistbury Head. Rocks beneath the Harbour itself appear to dip gently eastward. Mudeford Sandbank is underlain by the Branksome Sands of the Bracklesham Group of Palaeocene strata, which can also be seen outcropping in the cliffs of Poole Bay. Lowland areas within the estuary consist of river gravels and old alluvium deposits and silt laid down over the last 3000 years to form the present day saltmarshes.

2.3 Holocene to Recent Evolution

The Harbour is a low energy accretionary environment, but contains only a relatively thin, recent sediment sequence of 1 to 2 m thickness. This suggests a low rate of sediment input since formation of the estuary.

Mudeford Sandbank is thought to have formed in response to north-north easterly littoral drift from Hengistbury Head, and the importance of the longshore drift has been demonstrated by the impact of the Long Groyne on evolution of the spit. Previously sediments forming the tip of the Sandbank have become separated from the spit and have welded onto the Avon beach to the north (and to the east of the Mudeford Quay Spit). The site of the spit, as it was prior to 1935, when there was a significant breach cutting off the distal downdrift sector, continued to be marked by a wide, submerged sandbank; this feature persists to the present time, confining the channel of The Run, and constitutes the major part of the ebb delta constructed by tidal current outflow from Christchurch Harbour. Since construction of the Long Groyne in 1938/9 to prevent further erosion to the seaward side of Hengistbury Head through a build up of sediment on the updrift side of the Groyne, there has been a reduction in the sediment supply to the spit, resulting in a reduction in the length of the spit to its present configuration. This build up of sediment on the updrift side of the Long Groyne has helped to reduce the possibility of a breakthrough by the sea into Christchurch Harbour at Double Dykes.

Mudeford Quay Spit is considered to be a type of apposition spit, i.e. offset to the Mudeford Sandbank spit. Three models have been suggested for the origin of the Mudeford Quay spit:

- A downdrift offset barrier formed through the processes of sediment by-passing and swash-bar welding. Littoral drift from the east (under south-easterly waves), supplied with material from the erosion of the cliffs at Highcliffe, might have assisted in the formation of the spit.
- Alternatively Mudeford Quay originated as the truncated northern part of the southern spit that extended across the embayed mouth of the Avon and Stour rivers, i.e. pre-dating the modern form of Christchurch Harbour. It was subsequently permanently breached by either storm waves from the seaward side or excessive hydraulic pressure on the landward side due to high river discharge.
- Formation of the spit through mid to late Holocene landward barrier migration, through onshore directed sediment transport. As Hengistbury Head would have been much larger in the past and therefore would have presented an impediment to sediment supply from Poole Bay, onshore sediment transport is possible.

2.4 Present Geomorphology

The morphology of the Harbour is primarily governed by the protection from wave attack provided by Hengistbury Head, which makes the Head an important feature both now and over evolutionary timescales. The tidal basin of the Harbour covers 1.9 km^2 at mean high water, with a tidal prism of 1.43 Mm^3 on a spring tide. Water depths are generally shallow, with extensive intertidal mudflats and saltmarshes.

Upstream of the confluence of the Rivers Avon and Stour, much of the floodplain and the low river terraces are built on. The central part of the Harbour includes extensive marshes (notably Stanpit Marsh) and reedbeds. On both sides of the Harbour, former landfill sites lie on the landward side of the marshes in some of the low areas of the floodplain. Within the main channel there are daily tidally-forced variations of the water levels and water salinity. The lower part of Christchurch Harbour is characterised by intertidal mudflats, with wider and deeper channels than elsewhere. There are low gravel banks along parts of the shore. At Mudeford there is extensive building on the lower terraces and floodplain.

The following sections provide a brief description of the geomorphology of each of the Process Units within the Harbour, shown in Figure 2.

CHB1: Harbour Side of Mudeford Sandbank

In the past Mudeford Sandbank has been of variable width and length; however, in recent years there has been no further growth or extension of the spit and the mouth of The Run has been further stabilised by the placement of defence works. However, the ebb tidal delta and associated offshore bar do fluctuate in position, moved periodically by the occurrence of high waves from the south or south-east combined with high water levels, when erosion of the distal tip of the Spit occurs. The Run (the channel) is known to be a mobile feature at its seaward end, but is more stable at the western end when the protection from the Sandbank from southerly waves becomes significant. The Sandbank has maintained a fairly constant form since the 1940s, particularly since construction of further protection works in the 1980s. The seaward side of the Sandbank is characterised by a net advance (landward) of MHW in recent years, which is due to the presence of rock groynes and to the recent programme of beach renourishment.

The Sandbank consists of mixed sand and shingle beaches, overlain by sand dunes and, on the inshore side, fronted by an area of mudflats, which characterise the eastern side of the Harbour. It forms an important natural coastal defence against the erosion and flooding of Christchurch Harbour.

At the northern end of the Sandbank a rock revetment protects the channel adjacent to The Run. The inshore beach provides the main line of defence along the frontage to the wave climate generated within the Harbour, although along the inshore face of the Sandbank the beach huts and beach access road are protected by a sandbank, reinforced in places with a small rock armour revetment.

The Sandbank is very low-lying and with no specific flood defences (although a concrete seawall exists along some sections of the Sandbank), is vulnerable to flooding in the future. In addition, the Sandbank itself forms an important function in protecting assets within the Harbour. The defences on the tidal reaches of the Stour and Avon Rivers have been developed assuming the continued protection of the Sandbank during periods of extreme waves and tides.

CHB2: South Side of Christchurch Harbour (to Grimbury Point)

This unit is characterised by nationally important saltmarsh (SSSI) to the east, fronted by a wide expanse of mudflats, which is vulnerable to coastal squeeze although protected from erosion by the presence of Hengistbury Head. Further to the west, there are large areas of reedbeds, backed by grasslands. The shoreline is undeveloped and undefended for much of its length, with the exception of a 160 m length of gabion wall protecting a section of the access road and the Hengistbury Head centre to the east of Wick Hams, and further to the west a length of timber revetment and an embankment, both in the River Stour. The area of Double Dykes is important as continued deterioration of the Hengistbury Long Groyne may lead to increased erosion and a potential breach at Christchurch Harbour. This issue is further discussed within Annex 4 of Appendix C of this SMP Review.

CHB3: Stanpit and Grimbury Marshes

Stanpit Marsh is the most extensive area of saltmarsh in the Harbour, and whilst areas of saltmarsh and reed beds within the Harbour are eroding, some areas of Stanpit Marsh are accreting, in particular on the western margins. The frontage of this unit is mostly undeveloped and undefended, and consists chiefly of grazing marsh of international importance, the edges of which are currently suffering some erosion, and intertidal saltmarshes and mudflats. The marshes are thought to form a sink for fluvial material which enters from the Avon and Stour, although the edge of Stanpit Marsh is currently suffering erosion (and therefore may form a source of sediment to the estuary). There is also a gravel embankment towards Stanpit and Grimbury Marsh on the western side, formed from river deposits. Some defences are present on the banks of the Rivers Avon and Stour, and include man-made structures such as embankments, revetments, floodwalls and sheet pile walls. Some defences form part of the banks, whereas others are set back from the river and are only active during extreme events.

In the future, an increase in sea level may result in an increase in the rate of marsh edge erosion and there is a risk of the loss of grazing marsh to saltmarsh as the marsh adapts to rising sea levels.

CHB4: Mudeford Town Frontage
This unit includes the developed frontages of Mudeford and Stanpit that are defended along much of their length by various privately owned defence structures, which include concrete floodwalls and embankments. The defences are fronted by intertidal mudflats.

CHB5: Mudeford Quay
This unit extends along the north eastern corner of the Harbour between east Mudeford and Mudeford Quay. The defences are mostly concrete floodwalls and embankments, along the inshore edge of the Harbour. A low-lying seawall of approximately 1m in height, built in 1958, provides some protection to the car park on the inshore side of the Quay. The wall is fronted by extensive mudflats. In the long-term due to sea level rise, there may be an increased risk of coastal squeeze to the intertidal habitats along this stretch, and the issue of breaching from the Harbour side through Mudeford Quay would need to be addressed.

The spit has an expanded distal head and is connected to Mudeford beach to the east by a narrow 'neck'; however, the natural form of the spit has been substantially modified by the protection structures of a seawall and promenade, which have effectively stabilised the spit. These structures were to prevent breaching of the spit. Underlying the Quay, the spit is primarily composed of gravelly sand and shingle.

2.5 Anthropogenic Intervention

2.5.1 Dredging

The majority of the Harbour is extremely shallow at less than 2 m deep. However, a navigable channel runs from The Run through the Harbour upstream to the Rivers Avon and Stour to enable larger craft to use the Harbour. The channel requires periodic maintenance dredging. In 2005/06, following an Environmental Impact Assessment, dredging took place at two sites in the Harbour: the mid-Harbour bar in order to re-instate the navigable channel to a safe width and depth, and at the moorings in the vicinity of Tuckton Bridge (on the Stour, in Christchurch). The dredged material was deposited within the Harbour, including on the inner shore of Mudeford Spit, in order to retain the sediment within the system.

2.6 Hydrodynamics

This section describes the hydrodynamic conditions experienced within Christchurch Harbour, including tides, water levels and wave climate.

2.6.1 Tides

Christchurch Harbour is a microtidal environment, with an average tidal range of 1.2 m, with a mean spring range of 1.4 m and 0.8 m on neaps and a tidal prism at springs of 1.43 Mm^3. In both Christchurch Bay and Harbour, a "double high water" effect (i.e. a high water long stand, followed by a second high water peak) is discernable, though less well pronounced than in Poole Bay. This contributes to the ebb-dominant asymmetry of the tidal regime of the Harbour. The duration of the flood tide is 6.4 hours, whilst the ebb phase occupies approximately 6 hours. Table 1 shows the tidal levels for Christchurch Harbour, as taken from TotalTide. It is important to note that these tidal levels for the entrance to the Harbour relate to a point inside the Sandbank, and that outside the Sandbank the water level falls about 0.6 m lower on spring tides, and therefore the mean tidal range within the Harbour is lower than on the adjacent open coast. This is due to attenuation effects set up by The Run.

Table 1. Tidal levels within Christchurch Harbour

Tidal State	Level Inside of Sandbank (mOD) (Mudeford Quay)	Christchurch Quay (mOD)
MHWS	+0.9	+0.9
MHWN	+0.5	+0.5
MSL	+0.3	+0.3
MLWN	-0.2	0.0
MLWS	-0.3	-0.1

Peak tidal currents in The Run at the entrance to Christchurch Harbour are around 1.6 m/s on an ebb spring tide, although they can reach 2.5 m/s with peak fluvial discharge and the threshold velocity for the entrainment of fine sand on the bed of the Harbour entrance channel has been calculated at between 1.7 and 1.9 m/s. Currents are much lower elsewhere in the Harbour and also in the adjacent part of Christchurch Bay. During high river flows the fluvial discharge apparently prevents the ingress of the flood tide into the Harbour and the flow is continuously ebbing in The Run. Under such conditions the water levels can back up in the Harbour, leading to flooding at Christchurch.

2.6.2 Wave Climate

The dominant offshore wave direction is south to south west, corresponding to the direction of the longest fetches and strongest winds, and longer period waves from the south-west are refracted and diffracted into the study area. The easterly facing coast between Hengistbury Head Long Groyne and Christchurch Harbour entrance may be expected to be more sheltered than the rest of Christchurch Bay from waves to the south west. However, it is relatively exposed to the south east, resulting in similar expected extreme wave heights. Table 2 presents significant wave heights (H_s) for various return periods, at the entrance to the Harbour.

Table 2. Extreme wave conditions outside the entrance to Christchurch Harbour (Halcrow, 1999)

Return Period (years)	Significant Wave Heights (H_s) (m)
1	4.1
5	4.8
10	5.0
20	5.2
50	5.3

Within Christchurch Harbour the wave climate is dominated by locally generated waves and due to the short fetch lengths, extreme wave heights are less than 0.8 m at high tide, calculated using wind data, and local hindcasts (using time-series wind data from Met Office from offshore wave data) (Figure 3).

2.6.3 Fluvial Flows

There is significant fluvial input into Christchurch Harbour, with an average combined discharge of the Stour and Avon into Christchurch Harbour of 30 m^3/s with a minimum flow of 7.5 m^3/s and a maximum of 220 m^3/s (SCOPAC, 2004). The River Avon is fairly consistent in terms of flows, whereas flows in the Stour vary considerably in response to periods of heavy rainfall. Table 3 gives indicative extreme freshwater flows into the Harbour for various return periods from a study carried out in 1999. However, peak river flows on flood events in the River Avon in December 2000 and January 2003 were 126 m^3/s and 128 m^3/s, respectively, and although the extremes analysis has not been completed, both were considered to be events with return periods of less than 50 years. Initial outputs from the 'Lower Stour Model and Flood Study' indicated that the 1:100 year flow from the River Stour at Christchurch is 380 m^3/s, and at the upstream Throop flow gauging station is 331.8 m^3/s (Halcrow, 2006), which is greater than the values given in Table 3. Variations in the freshwater discharges from the rivers can produce large variations in salinity in the Harbour.

Table 3. Extreme freshwater inputs to Christchurch Harbour (Halcrow, 1999)

Return Period (years)	Daily Mean Flow (m^3/s)	
	Stour (Throop)	Avon (Knapp Mill)
2	102	51
5	137	57
10	163	61
25	199	66
50	229	70
100	262	74

2.6.4 Extreme Water Levels

Extreme water levels within Christchurch Harbour usually relate to high fluvial flows in the Avon and Stour, rather than from surges, although surges are important for this area due to the small tidal range, for example a 1 m surge constitutes much of the tidal range for the Harbour. Due to the interaction of the tide and fluvial flows, extreme water levels and flooding are primarily tidally controlled at Mudeford Quay, whilst at Christchurch Quay fluvial flooding is more likely.

Extreme water levels have been calculated at the confluence of the River Avon and the River Stour, which is a location influenced by both fluvial and tidal water levels, utilising water levels recorded over an 8 year period. Table 4 compares these water levels with extremes previously calculated, which were significantly lower than the more recent data. The lower estimates were based on local tide predictions and transferral of 14 years of surge data from Portsmouth. The latest assessment is considered to be more accurate. No work has been done which describes the surge component separately but instead the surge component is included in the extreme water level analysis.

Table 4. Extreme water levels in Christchurch Harbour and Poole Bay (Halcrow, 2006)

Return Period (years)	Extreme Water Levels Offshore of Bournemouth (mODN) (1)	Extreme Water Levels within Christchurch Harbour (mODN) (2)	Extreme Water Levels within Christchurch Harbour (mODN) (3)
1	1.38	1.65	-
2	-	1.7	-
5	1.46	1.76	-
10	1.63	1.81	1.4
25	1.73	-	-
50	1.81	1.91	1.5
100	1.88	1.95	1.6
200	1.96	-	-

Sources:
(1) Halcrow (2004) Poole Bay and Harbour Strategy Study.
N.B. Data from PDMM (2003) Environment Agency, South West Region, Extreme Tidal Levels Report.
(2) Halcrow (2006) based on 8 years of data at SZ 160 924 water level gauge.
(3) Halcrow (1992) based on 14 years of data.

At low return periods, water levels in the Harbour are (up to 300 mm) higher than outside the Harbour entrance, potentially due to high river flows, constriction at the Harbour entrance, or a combination of the two. However, approaching the 1 in 200 year return period, the predictions for Hengistbury Head and Christchurch Harbour become similar, which may indicate that the tidal influence becomes more dominant at higher return periods and that high river flows and constriction of the Harbour entrance become less important. During high river flows the fluvial discharge prevents the ingress of the flood tide into the Harbour which can lead to flooding at Christchurch.

2.7 Sediment Transport Pathways and Budget

Christchurch Harbour, with a mean tidal basin area of 1.9 km^2 and a mean sea level of 0.2 mOD, is occupied by sandy gravels, sands, muddy sands and, towards its inner margins, silty muds. The average sediment thickness is 1.5 m, increasing to over 2.0 m in areas of bank accretion. The surface sediments in the Harbour are mainly sands and muddy sediments within channels, which are generally transported towards the east within the southerly areas of the river channel, (where the flows are predominantly ebb dominated) and to the northeast along the northern Harbour margin, (where the flows are flood dominant). Within this area of local flood dominance there may be significant net inputs of sediment from the open coast to the areas where it cannot be returned seaward by ebb currents. Therefore on balance the Harbour is thought to be a net sediment sink receiving small quantities of suspended fluvial sediments and some bedload sand, possibly during flood events, and limited inputs of marine-derived sand within the northern flood dominated portion.

Littoral drift to the east on the open coast has resulted in development of the two spits, enclosing the narrow entrance channel which is subject to rapid tidal flows and has a predominantly gravel bed. Flood and ebb tidal deltas are present close to the entrance and the presence of the flood tide delta, composed of sands and sandy gravels and immediately inside the entrance, suggests that sediment input into the Harbour is possible and is attributable to transport on both flood and ebb tides. Both the ebb tidal delta and Mudeford Sandbank spit are dynamic, and have undergone periods of growth and erosion thought to be related to variations in the quantities of material drifting around Hengistbury Head. The major effect of strong ebb currents through The Run is apparently to flush offshore any sediment transported longshore into the entrance channel from the opposing spits that confine the width of the mouth of the Harbour. Thus, the channel is a littoral drift barrier, but with bypassing possible via the offshore bar (ebb tide delta).

2.7.1 Sediment Sources

Offshore

The supply of coarse sediment from Hengistbury past The Run into the Harbour is thought to be negligible due to strong longshore currents in the nearshore. However, sediment input to the Harbour from offshore is likely, proven by presence of a significant flood tide delta of well sorted sands and sandy gravels located immediately inside the entrance. The delta is attributed to transport and deposition on the flood tide, although current metering at the entrance has shown that ebb flow is significantly stronger than corresponding flood (1.9 m/s peak surface velocity, in comparison with 1.15 m/s). However, flood and ebb currents occupy different parts of the Harbour and therefore sediment inputs on the flood may not be immediately removed by the ebb, allowing accretion is some areas. The marine sediment input under surge conditions may also be significant. Samples of exotic benthic foraminiferal tests taken from Harbour sediments (i.e. derived from marine sources) indicate that their percentage in comparison to estuarine species is highest close to the entrance. Thus, marine-derived sediment may not penetrate in quantity beyond the flood delta. However, fine sediment introduced by the flood tide may not settle out, and is likely to be moved out of the Harbour on the ebb tide, especially on spring tides, when the ebb currents have substantial capacity to entrain fine to medium sand in the vicinity of the flood delta.

Saltmarsh and mudflat erosion

Some erosion of the saltmarsh edge and the Harbour margins is taking place on the small islands on the north side of the Harbour, and on Stanpit Marsh, supplying suspended sediment to the Harbour. The erosion of the saltmarsh edge is likely to be caused by wave action within the Harbour, despite the relatively small maximum wave heights of 0.4 to 0.8 m. Only small areas of *Spartina anglica* are present, with no evidence of formerly more extensive occupation. The sedimentation system of Christchurch Harbour has not, therefore, been significantly affected by the spread and subsequent dieback of this species, as experienced in most other south coast estuaries.

Beach erosion

The ongoing erosion of the inside of Mudeford Sandbank is likely to supply little sediment to the system and recent defence works have also attempted to stabilise the system and reduce the rate of erosion.

Fluvial sources

Fluvial-derived sediments are thought to be low due to supply from chalk aquifers and interruptions to flow from structures, e.g. weirs. A maximum combined bedload input of some 150 tonnes/yr has been calculated for both rivers, but the actual quantity supplied is probably less than 10% of this total due to the structures on both rivers. The suspended sediment discharge potential is close to 70,000 tonnes/yr, but actual delivery is unlikely to exceed 10,000 tonnes/yr. Surveys have revealed sand and gravelly banks adjoining the river channels in close proximity to their points of discharge into the Harbour, and these may provide some supply to the Harbour. Annual siltation is reported in navigable channels in the Harbour and accelerated rates of deposition during the winter of 1990-91 on Grimbury Marsh are thought to have resulted from dredging of the lower River Stour. Fine sediments delivered by fluvial discharge are thought to be deposited within the estuary, and therefore contribute to the sedimentation rate of approximately 0.1 to 0.4 mm/yr.

2.7.2 Sediment Transport Pathways

Sediment transport is governed by the currents generated by tidal exchange, freshwater discharge and also wave action from the open coast, although this does not penetrate very far into the Harbour, and internally generated wave action is weak due to limited fetch lengths. In areas of local flood dominance, such as in the northern parts of the Harbour, there may be significant net inputs of sediment from the open coast to areas where it cannot be returned seaward by the ebb currents.

Longshore transport

The narrow entrance channel has had a relatively stable configuration, partly due to the protection of Mudeford Quay, and a stable cross-sectional area, since at least the late 1930s, thus indicating that it has achieved an equilibrium condition. However, the area of the ebb delta immediately to seaward of the channel is subject to considerable movement over time, suggesting variation in the supply of sediment to this area, from both the Harbour and the coast. Sediment arriving at the entrance via littoral transport, according to both observational evidence and mathematical modelling, is moved predominantly offshore. The strong ebb currents through The Run act to flush offshore any sediment transported longshore into the entrance channel from the Sandbank spit and Mudeford Quay spit that confine the width of the mouth of the Harbour.

Tidal currents, bed load and suspended load

Bedload and suspended load sediment transport are thought to operate in a net seaward direction, and theoretically sediments are lost from the Harbour, which may explain the limited accretion historically. It is uncertain how much of the sediments supplied by fluvial discharge, both by bedload and suspended load, are transported through the Harbour entrance; some is understood to be retained within the estuary system, where it contributes to inner Harbour mudflat and marsh sedimentation, although hydraulic conditions indicate a strong potential for bedload transport out of the Harbour. Net seaward transport is predicted due to the dominance of the ebb tidal currents through the entrance, which are sufficient to remove material entering the Harbour (mostly sands) that have not reached the flood tide delta and net transport of fine material, whilst low, is expected to be out of the Harbour. There may also be some resuspension of fine sediments, allowing the ebb tidal flow to remove sediments from the Harbour, and suspended sediments tend to be moved out of the lower sections of the Harbour.

The presence of the flood tide delta is attributed to transport and deposition on the flood tide, despite the peak ebb flow being significantly stronger than the corresponding flood flow and very little sediment transport being possible on the flood tide. Bedload transport is therefore expected to be predominantly out of the Harbour, unless ebb and flood flow follow different channels, or flood flow coincides with surge conditions to create intermittent sediment pulses into the Harbour.

The major effect of strong ebb currents is to flush offshore any sediment transported longshore into the entrance channel from the opposing spits that confine the width of the mouth of the Harbour and therefore the channel is a littoral drift barrier, but with bypassing possible via the ebb delta. A quantity of fine suspended sediment is supplied by erosion of the Harbour margins and seabed and by fluvial input, but despite this Harbour sediments are predominantly sandy. Qualitative observations indicate that fine sediments are readily resuspended by wave action inside the estuary and are efficiently discharged by ebb tidal flow; incoming flood flow from Christchurch Bay is significantly less turbid. Bedload transport at the entrance has been calculated to operate at a much higher rate when tidal and wave-induced currents act in combination and when maximum ebb currents combine with high freshwater discharge.

Within the estuary, there is some internal re-distribution of sediment, in the vicinity of the northern coastline.

2.7.3 Sediment Sinks

Quantification of the size of the sediment sinks within the Harbour has not been possible with the data available.

Beaches

Beaches within the Harbour are not well-developed, but the presence of gravel in places is probably derived from erosion of fluvial terrace deposits at a stage when the Harbour entrance was more open to wave action, i.e. pre-dating the development of the present-day spits.

Channels and banks

There are several subtidal features, including the sand and gravel bars that have formed inside the Harbour entrance and contribute to the flood tidal delta.

Intertidal flats, saltmarshes and tidal creeks

The saltmarshes and associated, extensive intertidal sandy mudflat areas that front them form sediment sinks, although no quantification has been possible of the amount of sediment stored annually.

Dredging

The channel requires periodic maintenance dredging. In 2005/06 dredging took place at the mid-Harbour bar and at the moorings in the vicinity of Tuckton Bridge (on the Stour, in Christchurch). The dredged material was deposited within the Harbour, including on the inner shore of Mudeford Spit, to retain the sediment within the system.

2.8 Impact of Sea Level Rise

Changes in past relative mean sea level for the area of Christchurch Bay are presented in Table 5, as recorded at Class A tidal gauges. Of those presented for the area, only the data for Portsmouth has a duration suitable for providing a reliable representation of sea level rise. There is a harmonic tidal constituent of periodicity of 18.4 years and amplitude in the range of 100 mm. Where data sets are shorter than this duration, as at Newhaven, Bournemouth and Weymouth, the variation in level due to this harmonic can be more significant than the relative sea level rise. Even when this source of uncertainty is disregarded, the values of standard error (being a measure of the scatter of the data either side of the trend-line) for these shorter data sets is 5-10 times higher than for the longer data set at Portsmouth. Therefore the most reliable estimate of past sea level rise from the 1960s to 2000s for Christchurch Harbour is 1.82 ±0.45 mm/yr (as downloaded from http://www.pol.ac.uk/psmsl/datainfo/rlr.trends).

Table 5. Changes in mean sea level

Station Name	Start Date	End Date	No of Years of Data	Linear Trend and Standard Error (mm/yr)
Newhaven	1993	2004	8	2.56 ± 0.98
Portsmouth	1962	2003	33	1.82 ± 0.45
Bournemouth	1997	2003	7	6.43 ± 1.41
Weymouth	1992	2004	11	5.09 ± 1.17

Future sea level rise for the area is given by the Defra guidance (2006b), shown in Table 6, in terms of the rate and the actual predicted sea level at each of the SMP epochs is given in Table 7.

Table 6. Future predicted sea level rise for the South West of England (Defra, 2006b)

Region	Assumed Vertical Land Movement (mm/yr)	Net Sea Level Rise (mm/yr)				Previous Allowances
		1990-2025	2025-2055	2055-2085	2085-2115	
South West	-0.5	3.5	8.0	11.5	14.5	5mm/yr constant

Table 7. Predicted sea level at each of the SMP epochs

Date (SMP Epoch)	Predicted Net Sea Level Rise (mm)
2025	70
2055	302
2105	925.5

The effects of the predicted increase in sea level may lead to changes in the tidal prism of the Harbour, changes to the residual currents at the Harbour mouth, and climate change may also lead to changes in storm frequencies. Changes in rainfall and therefore fluvial flows into the Harbour may also be important in the context of climate change, given the importance of the fluvial flows in determining the flood or ebb dominance of the sediment system within the Harbour. Changes to the tidal prism in Christchurch Harbour due to an increase in area as a result of sea level rise would affect the tidal currents at the entrance and therefore potentially the configuration of the ebb tidal delta and flood delta, which could in turn affect conditions on the open coast. Increased frequency of storm events may lead to increased erosion rates of the spits and increase the threat of breaching at Double Dykes. A breach here would affect the open coast regime, if a permanent tidal channel and ebb tidal delta were to establish, and as Hengistbury Head acts as a fixed point on the coast, affecting the shape of both Poole and Christchurch Bays, there is a possibility that increased erosion here would have consequences for the future evolution of the Bay.

3. Poole Harbour

3.1 Overview

Poole Harbour is a bar-built estuary covering a total area of nearly 4,000 ha, with an irregular, indented coastline of just over 100 kms. The Harbour occupies a shallow depression towards the south-western extremity of the Hampshire Basin, which has flooded over the last 10,000 years as a result of rising sea levels. There is one large and several small islands within the estuary. The entrance to Poole Harbour is defined by two barrier spits, with islands, channels and bars, sand and shingle beaches, intertidal mudflats, saltmarshes and sand dunes within the Harbour. Due to the enclosed nature of the Harbour, its coast is largely protected from wave exposure, although there is some littoral drift along sandy beaches caused by locally generated waves. Figure 1 shows the location of the Harbour, with respect to Christchurch Harbour.

The Harbour is a product of postglacial sea level rise, but its shape and plan form reflect both the original topography of the inundated basins of the Frome and Piddle Rivers, together with subsequent modifications by marginal erosion and accretion. Physical and biotic characteristics show a distinct west to east environmental gradient, reflecting the increasing marine influence and energy levels in that direction. Artificial reclamation and shoreline protection have modified much of the north-eastern section of the Harbour, although elsewhere natural processes and habitats have been preserved.

Tidal amplitudes are small, but long periods of rising and standing water result from a double high water, creating a lagoon-like character in the Harbour. There are extensive mudflats, representing long-term deposition, although at present the Harbour may be approaching a dynamic balance between deposition and erosion. There is sediment input from fluvial suspended sediment and from cliff and marsh edge erosion and also potential input from marine sources.

Tidal flows and currents are complex within the Harbour and as such so are the transport pathways, although littoral drift within the Harbour is generally from west to east (Halcrow, 2004b). Wave and tidal processes are important in sediment transport, although tidal scour is considered to be the dominant process as the Harbour has limited exposure to offshore wave action. There is loss of material from the Harbour on the ebb tide, although the net sediment transport at the entrance remains uncertain. The inner (western) and outer (eastern) sections of Poole Harbour are thought to have a negative sediment budget, whilst the central area is in positive balance (Halcrow, 1999).

It is thought unlikely that activities within the Harbour have the capacity to affect the offshore area, although changes to the Swash channel (at the entrance) or to the shoreline just outside the entrance may. Such changes may also affect the sediment budget regime within the Harbour.

For the purposes of the Round 1 SMP, Poole Harbour was divided into the following Process Units, which are shown in Figure 4:

- PHB1 The Islands (excluding Brownsea Island);
- PHB2 Brownsea Island (eastern half);
- PHB3 Brownsea Island (western half);
- PHB4 South Haven Point to Hydes Quay (south coast of Poole Harbour);
- PHB5 Hydes Quay to Holton Point;
- PHB6 Lytchett Bay;
- PHB7 Rockley viaduct to start of Defence 681/2442;
- PHB8 Defence 681/2442 to Hamworthy Quay;
- PHB9 Hamworthy Quays;
- PHB10 Holes Bay (east, north and west);
- PHB11 Town Quays;
- PHB12 Parkstone Bay and Baiter Park;
- PHB13 Parkstone Yacht Club to Salterns Marina;
- PHB14 Salterns Marina to Lilliput Pier;
- PHB15 Whitley Lake;
- PHB16 Whitley Lake to North Haven Point;
- PHB17 North Haven Point to Sandbanks Ferry Slipway.

3.2 Geology

Poole Harbour has the branched configuration of a valley system partly drowned by submergence. It rests on a portion of the Hampshire basin laid down in the Eocene, 60 million years ago, when this area was part of the bed of the Solent River, prior the beginning of the last Ice Age. The basin therefore contains a series of soft and unconsolidated sands, gravels and clays of fluvial origin (part of the Poole Formation). Bedrock is almost absent within the Harbour, with the exception of the sandstone outcrop in the Haven Channel.

3.2.1 Geological Evolution - 75,000 to 10,000 years BP

The Hampshire basin is composed of unconsolidated sands, gravels and clays laid down by the Solent River, and small outcrops of sandstone, forming knolls, laid down during the Tertiary Period. This soft deposit of alluvium and the contemporary climate (believed to be colder and wetter than today) provided the conditions for the development of moorland, in what is now Poole Harbour. Since the last Ice Age, which began approximately 75,000 years ago and ended nearly 10,000 years ago, the south coast, including the Hampshire Basin has undergone a series of substantial changes. These changes include a number of post-glacial transgressions (relative sea level rise) and regressions (relative sea level fall). The most significant sea level increase, known as the Holocene Transgression, started 10,000 years ago and is still continuing.

3.2.2 Holocene Evolution (10,000 years BP to Present)

Formation of Poole Harbour took place in several stages: the soft underlying bed of fluvial and moorland sediments, deposited above soft Tertiary sands and clays, initially became consolidated to form lowland heath. Following the onset of post-glacial sea level rise, this then formed a drowned river valley estuary. The low resistance of the soft Tertiary sands and clays to marine action resulted in their erosion and sea level rise (in combination with isostatic readjustment and slow local subsidence) led to the submergence of the lowland heath area, and the present shape of the Harbour is due to this submergence and the presence of the sandy knolls, which now exist as islands, including Green, Furzey and Brownsea.

As sea levels continued to rise during the Holocene Transgression, coarse sand and gravels were entrained from the sea floor and transported landward to form a series of barrier islands parallel to the coast. The barrier beaches migrated onshore at a rate set by that of the rising sea levels, until they met rising topography. Permanent breaching at the western end of the barrier led to further inundation of the low-lying land of what is now Poole Harbour. Development of the barriers under the influence of contemporary sediment processes have since formed spits, directed towards one another as material is supplied from the cliffs at Bournemouth and the seabed and cliffs around Studland Bay.

The maximum extent of the marine transgression, reached about 6000 years ago, is marked by low cliffs surrounding much of the Harbour above the present shoreline. The post mid-Holocene planform of the Harbour has been substantially modified by both erosional and depositional processes. Local sedimentary processes and reclamation have now extended the shoreline to seaward of the cliffs in sheltered areas with beaches or mudflats, and more recent deposits include layers of alluvium laid down by streams and in marshy areas of the Harbour, e.g. Lytchett Bay. Accretion has narrowed the Harbour mouth as a result of the growth of the Sandbanks and Studland spits, from approximately 3.5 km to 350 m, and sedimentation within the Harbour has since kept pace with rising sea levels to form a deep sediment column that covers much of the Harbour. Equally, erosion of low cliffs has occurred at a number of locations exposed to local wave action.

Accretion has also resulted in the creation of extensive mudflats, particularly as a result of colonisation and stabilisation by saltmarsh vegetation. This was especially important during the early 20th Century as a result of rapid invasion by *Spartina* between 1880 and 1924 (Hubbard, 1965), although this has been followed by subsequent retreat (die back), contributing to an overall net reduction in saltmarsh area since.

Land reclamation for agricultural purposes and to a lesser extent, for port development and urbanisation of the north-eastern shore is thought to have reduced the area of the Harbour at high water spring tides by 20% (1000ha) over the last 6000 years to its present area of approximately 4000 ha (Grey, 1985).

3.3 Present Geomorphology

Poole Harbour forms part of a complex system that comprises a number of different geomorphological land types, described here as geomorphic units, including:

- Barriers and spits;
- Islands and cliffs;
- Beaches;
- Intertidal flats;
- Saltmarshes;
- Tidal creeks;
- Sand dunes; and
- Coastal lagoons.

Poole Harbour is a 'V-shaped' estuary that widens and flattens towards its margins. The channels are deep and relatively narrow, whilst the margins are shallow areas of expansive intertidal mudflats and alluvial plains. The cross-sectional form of the estuary is both the result of the underlying geology and post-glacial sea level rise, as well as contemporary tidal and fluvial processes. Estuarine processes dominate within the Harbour, which are controlled by tidal flow, water levels, and fluvial inputs. However, the constraints of Sandbanks and Brownsea Island force the estuary mouth to be narrow, with a single channel upstream from the mouth up to the point at which it diverges into the Middle Channel, North Channel and Wych Channel to the north and north east of Brownsea Island. There are also a number of minor channels to the south of Brownsea.

The tidal regime within the Harbour is characterised by a double high water effect, with a mean spring tidal range of 1.8 m, and mean neaps range of 0.6 m, although these values vary across the Harbour.

The entrance to Poole Harbour is marked by the barrier spits of Sandbanks and Studland, which act as controlling factors to the behaviour of the Harbour. Both of the spits are constrained, Sandbanks by the fixing of its position by coastal defences and the underlying geology; and Studland to a lesser extent by the Training Bank at its northern end. Studland is also accreting at the northern end due to sediment supply from the south and from offshore (Halcrow, 2004b).

At a broad scale, the existence of the Harbour is controlled by the presence of cliffs at Durlston Head, Handfast Point and Hengistbury Head, which act to control the form of Poole Bay and therefore the Harbour. Within the Harbour, there are various cliffs, which provide a small supply of sediment to the Harbour. The majority of the cliffs form part of the Arne Peninsula, but cliffs are also present in Brands Bay, Shipstal Point and Goathorn Peninsula, and cliffs have also formed in response to erosion of the sandstone knoll islands, for example, along the south coastline of Brownsea, Furzey and Green Islands. The rate of erosion has been measured on cliffs on the north side of the Harbour, between Rockley and Ham Common, at 0.1 - 0.3 m/yr between 1947 and 1993, with an estimated 12,000 m^3 of material lost from the cliffs between 1972 and 1993, representing 200 – 300 m^3 of erosion each year. These cliffs are more exposed to wave action than other cliffs in the Harbour, due to the long fetch length towards the southwest, the direction of the predominant south-westerly winds.

Beaches in the Harbour are associated with the cliffs described above, where they are formed along sections of the eroding shorelines as stores of sediment are released from the cliffs. Clays, silts and fine sands are winnowed out of the beaches and add to the supply of fine sediment in the Harbour. Medium sands and coarser material are more likely to remain on the beaches and will be subject to limited longshore transport by wave action, where potential rates of 3,000 m^3/yr from west to east have been calculated (Halcrow, 2004b).

Intertidal mud and sandflats form approximately 54% of the Harbour area, with a total area of 2050 ha. The flats are formed at the edge of Harbour, where the tidal velocities are reduced to an extent that fine sediments are released from suspension. There are also areas of alluvial plain within the estuary, which are a product of the deposition of fine-grained material at the confluence of the rivers and the sea, e.g. where the River Frome enters the Harbour. Intertidal flats are predominant along the southern edge of the Harbour, due to the more sheltered and enclosed nature of the area. Large areas of intertidal flats in the northern parts of the Harbour have been subject to reclamation in the past. Saltmarshes have also formed in upper reaches of the Harbour, in areas of lower tidal energy.

Heavily vegetated sand dunes are present at Studland and are closely related to the process of formation of the barrier-spit. There are also smaller dunes at Sandbanks, the formation of which is related to the coastal defence works. Coastal lagoons at Studland have formed due to the presence of dune slacks, which allow the ponding of groundwater, and hence the formation of the lagoons.

The major changes in the Harbour over the last 50 years can be summarised as follows:

- Deepening of the Middle Mud area (just to the north of Brownsea), thereby reducing the ebb flow in the main (Middle) channel (Halcrow, 1999);
- Some migration to the east and north east, and narrowing of the North Channel (Halcrow, 1999);
- Shallowing of the entrance channel between North Haven and Salterns Beacon (to the west of Lilliput) (Halcrow, 1999);
- Land reclamation around Wareham River (Halcrow, 1999);
- Areas south of Wareham Channel, east of the Arne Peninsula and over Middle Ground have been deepening (Halcrow, 1999).

The following sections provide a very brief description of each of the Process Units within the Harbour, shown in Figure 4.

PHB1: The Islands (Excluding Brownsea)

Furzey, Green, Round and Long Islands are all undefended, and Furzey Island is part of the Wytch Farm oilfield. There is a small amount of defence work around the landing pier and development on Round Island.

PHB2: Brownsea Island (Eastern Defended Section)

This unit is defended by a sea wall, enclosing a large brackish lagoon at its north east corner. The lagoon is fringed by marshland, with small areas of saltmarsh and shingle vegetation associated with eastward projecting spits on the north shore. Where defences are not present, erosion is a problem.

PHB3: Brownsea Island (Undefended Western Sector)

This unit is fronted by narrow beaches of sand and shingle which are primarily undefended and currently being eroded. There are some old wooden palisade/timber stake and gabion type defences along the southern shore of Brownsea which are back-filled with broken pottery remains. Towards Pottery Pier there is approximately 100m of sheet piling. These are in a poor condition and not acting as coastal defences. The beaches are backed by wooded slopes and there is a sand spit at the north west corner of the island, which effectively encloses an area of saltmarsh, with more spit features further to the east.

PHB4: South Haven Point to Hyde's Quay

This unit is entirely undeveloped, and majority is undefended. The shoreline is flanked by mudflats and marshlands, and land behind rises up to form heathland and coniferous plantations. This unit is currently experiencing marsh edge erosion.

PHB5: Hyde's Quay to Holton Point

This unit is fronted by both tidal and reclaimed marshland and wetland, with some areas defended by stretches of flood embankments. A small eroding cliff line is present at the edge of the marshes near the south of the unit adjacent to the mouth of the Wareham Channel.

PHB6: Lytchett Bay

This unit is entirely undefended, although both the eastern and northern shores of the Bay are developed. There are no developments on western side except a sewage works in the north west. The railway line across the mouth of the bay on the Rockley Viaduct restricts sediment transport from the Sherford River, resulting in siltation within the Bay (Halcrow, 1999). Saltmarshes are present on both the north and western shores, which are currently eroding, partly due to dieback of the *Spartina*.

PHB7: Rockley Viaduct to Start of Defence 681/2442

Sandy beaches are present, backed by low cliffs with a natural tendency to erode and the potential for slip failure. There is a sand spit adjacent to the channel at Lytchett Bay. The cliffs are currently eroding and an increase in the small scale cliff erosion (through loss/removal of the defences) adjacent to Rockley Park would increase sediment supply to the beaches at the cliff toe and also downdrift, and may also increase siltation in the navigation channels over the long-term.

PHB8: Start of Defence 681/2442 (Lake Pier) to Hamworthy Quay

This unit is composed of low-lying land, most of which has been reclaimed in the past. The unit is fronted by a sandy beach, which at Hamworthy Park has been renourished in the past.

PHB9: Hamworthy Quays

This unit is dominated by quays, marinas and commercial developments all along the frontage, due to extensive reclamation in the past. A scheme to set back tidal defences was completed in 2006.

PHB10: Holes Bay (East, North and West)

This unit is largely reclaimed and developed. The bay contains mudflats and saltings, particularly on the north and western shores. The Bay is considered to be low energy stable environment and the sheltered northern section of the bay, protected by the railway viaduct, shows no sign of coastal erosion.

PHB11: Town Quay

This unit is composed of the Quays, fronted by vertical sea walls and linear defence structure with an offshore breakwater.

PHB12: Parkstone Bay to Baiter Park

This unit is low-lying, reclaimed land, with large areas of intertidal mudflats.

PHB13: Parkstone Yacht Club to Salterns Marina

The entire frontage defended, in order to protect Parkstone Clay. There is a bar feature, which may be subject to breaching in the future.

PHB14: Salterns Marina to Lilliput Pier

Vegetated slopes are found behind the foreshore, with coastal defences. The unit is fronted by intertidal mudflats, subject to easterly sediment transport drift.

PHB15: Whitley Lake

The Lake has a wide west-facing embankment. There is saltmarsh in centre of the bay with intertidal mudflats along the foreshore and dune vegetation along some of the backshore.

PHB16: Whitley Lake to North Haven Point

This unit is characterised by flat sandy foreshores and a defended backshore. The unit is fairly sheltered from wave attack.

PHB17: North Haven Point to Sandbanks Ferry Slipway

This unit flanks the entrance to Poole Harbour, and is mostly privately defended (by sea walls). The unit is subject to strong tidal conditions and waves from both within and outside the Harbour, and any changes here are likely to have some influence on the mouth of the Harbour.

3.4 Anthropogenic Intervention

The main anthropogenic impacts on the estuarine processes of Poole Harbour have been:

- Land reclamation;
- Dredging for navigation;
- Management of the shoreline outside the Harbour for coast protection; and
- Land use changes within the river catchments.

3.4.1 Land Reclamation

Reclamation in Poole Harbour has been mainly of marsh areas, and has resulted in loss of intertidal areas mainly at Poole town, Lytchett Bay, Parkstone Bay and Holes Bay, as well as some on the Wareham river banks. Between 1890 and 1930 natural infilling was associated with the expansion of *Spartina anglica*, resulting in considerable stabilisation of the mudflats although die-back has since reversed this stabilisation. Historic land claim has also straightened and shortened the shoreline of the Harbour. There is a marked contrast between the northeast and southwest shores: whereas the north-east shore is extensively urbanised, primarily backed by seawalls and has undergone large scale land claim, southern shores are mainly mudflats and saltmarsh, with areas reclaimed primarily for agriculture.

It has been estimated that the combined effect of natural and human induced reclamation over the past 6000 years has led to a reduction in the mean Harbour area at mean high water spring tides of 20%; a net reduction of 1000 ha to the present area of approximately 4000 ha. Artificial land reclamation has reduced the volume of the estuary and constrains the natural responses of the Harbour by removing areas potentially available for erosion and accretion.

The total land reclaimed was significantly greater before the 1800s when compared with more recent times; however, if the rates of reclamation are considered, it is apparent that a significant proportion of change has taken place since the 1800s. In recent times there were also greater amounts of reclamation due to natural activity, probably related to the growth of *Spartina anglica*.

3.4.2 Dredging

Dredging for navigational purposes has taken place over the last 100 years. As part of their duty to maintain and improve Poole Harbour, Poole Harbour Commissioners currently dredge the Harbour for the purpose of maintaining and improving navigation, removing obstructions and cleansing or scouring the Harbour. Four areas of the Harbour are subject to regular maintenance dredging: Swash Channel, Middle Ship Channel, the Hamworthy shipping basin and the quay area. Maintenance dredging in the Harbour is considered to result in the removal of 65,000 m^3 per annum, mainly from dredging of the Middle Channel, although small amounts are also dredged from a number of marinas within the Harbour.

Dredged material is generally moved to a licensed disposal site located 4 km offshore of Ballard Point (Swanage), a process that represents a loss of sediment from the Harbour. However, recently deepening of the Swash Channel and maintenance of the Middle Channel and Swash Channel have provided sand and gravels, subsequently used to recharge beaches at Bournemouth, Swanage and Poole (Sandbanks). Of these placement sites, only sediment placed at Sandbanks has the potential to be transported back into the Harbour on flood tide currents; any material placed further to the east is effectively lost from the Harbour system. However, as it is not possible to quantify the transport of sediment back into the Harbour any material that is deposited outside the Harbour is considered to be lost from the system.

The main capital dredging in recent years has been the deepening of the Middle Ship Channel to accommodate the cross channel ferry MV Barfleur; Hamworthy Port reclamations and Town Quay Marina, which since 1969 has resulted in the removal of 2,055,000 m^3 (in 2002), which equates to 60,000 m^3 per year over this time period. Since this time the channel deepening of Swash and Middle Channels has taken place (2005-2006) with approximately 1.1 Mm^3 removed. Modelling as part of the 2005-2006 dredging campaign EIA predicted the following changes to the hydrodynamic cycle as a result of the dredge (Borough of Poole & Poole Harbour Commissioners, 2004):

- Spring tide low water levels would be lowered by up to 20 mm.
- There will be a tendency for more water to be drawn through the approach channel which has the effect of reducing currents in the adjacent areas.
- Slight increase in tidal currents at and to the south of Brownsea Castle and a decrease in currents north of Brownsea Castle and along the south western coast of the island.
- Current speeds in the deepened Turning Basin are generally reduced.
- Waves from outside of the harbour will be slightly higher (1-2 cm) along the seaward edge of Brownsea Island.
- An increase in export of fine material out of the harbour (4,800 to 6,700 m^3/yr).
- An increase in deposition within the Turning Basin (5,700 m^3/yr).

3.4.3 Coast Protection in Poole Bay

The shoreline of Poole Bay and Studland Bay is believed to provide fine sediment to Poole Harbour, driven in by wave action and flood tide currents, which tend to be dominant over ebb tide currents around the shoreline either side of the entrance. Whilst much of the entrained sediment will remain in the water column and will subsequently be discharged from the Harbour on the next ebb tide, some sediment is thought to settle out within creek systems and saltmarshes, resulting in accretion. The construction of seawalls on the Poole Bay shoreline in the 20th Century has resulted in a reduction in the supply of sediments to the beaches and therefore also to the Harbour. However, beach recharge has provided a supply of sediment to the beaches over the last 30 years and as a result, beach recharge material is expected to provide a supply of sediment to the Harbour, as described above (Halcrow, 2004b).

3.4.4 Land Use Changes in River Catchments

Historical changes in land use and urbanisation in the catchments of the rivers of Poole Harbour may have affected the volume of sediment supplied to the Harbour by fluvial processes (Halcrow, 2004b). However, as the overall volume of fluvial sediment input is considered to be very low in comparison with the sediment exchange with the open coast, the influence of this potential change is also likely to be very small. There have been significant land use changes in the catchments of the rivers discharging into the Harbour since at least the 1930s. These changes may have resulted in a slight decrease in the volume of sediment load, although changes in the agricultural practices since the 1970s may have partially reversed this effect (SCOPAC, 2004).

3.5 Hydrodynamics

This section describes the hydrodynamic conditions experienced within Poole Harbour, including tides, water levels and wave climate.

3.5.1 Tides

There is a tendency for a double high water within Poole Harbour, which is related to the tidal regime outside the Harbour in Poole Bay. The short stand after the first high tide is followed by second high water which is usually lower than the first, and the tide is above mean water level from about 2 hours after LW to about 2 hours before the next. The tidal range in Poole Harbour is small and the estuary is classified as a microtidal environment, with a range of 1.6 m (Table 8, data supplied by TotalTide). It is suggested that the estuary is well-mixed in general, with some stratification between fresh and saline waters close to the rivers, although tidal flushing is poor due to the double high water and the small tidal range (Halcrow, 2004b). The tidal prism of the Harbour is 30.4 Mm^3 (Table 9), as calculated in 2003 (Halcrow, 2004).

Table 8. Tide levels at the entrance to Poole Harbour

Tidal State	Level at Entrance (mOD)
MHWS	+0.8
MHWN	+0.3
MSL	+0.2
MLWN	-0.1
MLWS	-0.8

Table 9. Tidal prism of Poole Harbour (Halcrow, 2004)

	High / Low Astronomical (m^3)	Spring Tide (m^3)	Neap Tide (m^3)	Average (m^3)
Tidal Prism	70,229,000	45,792,000	15,008,000	30,400,000

Tidal flushing is constrained by the microtidal tidal regime and the double high waters within the Harbour. The strongest tidal currents occur in the entrance to the Harbour on a flood tide and reach approximately 2.0 to 3.0 m/s, decreasing to 1 to 2 m/s along Middle Channel, on a spring tide and typical maximum tidal currents in the channels around Brownsea Island are 0.5 m/s, as the flow is dissipated over the intertidal flats and saltmarsh. However, outside of the main channels it is difficult to generalise the tidal flows, due to the complexity in the magnitude, direction and velocity. The ebb tide flows are generally slower, in the region of 0.1 m/s at the entrance on a spring tide. Neap tide current velocities are generally much slower than those on the spring tide.

Flows of approximately 0.5 m/s are directed through the Harbour entrance and into Middle and Wareham Channels. Flood tide flows to the south-western margins of the Harbour are in the order of 0.2-0.3 m/s. The Harbour is considered to be flood dominant with respect to both fine and coarse sediments (Halcrow 2004b).

The complex tidal conditions within the Harbour are typified by those that occur after a neap high tide, when the tidal waters at the upstream margins of the estuary (Wareham Channel and Lytchett Bay) start to ebb downstream. At the same time, the flood tide continues to enter the Harbour entrance for at least a further 3 hours. This inflow is mainly directed towards the south of the estuary to the south of Brownsea Island. These two opposing flows (ebb from upstream and flood from the Harbour entrance) create an area of standing water with current velocities of less than 0.1 m/s. This standing water is thought to occur between high water and to after low tide, when the flood tide enters the estuary; potentially 4 hours. The area of standing water extends from Poole in the north, Arne Bay in the west, Brownsea Island in the east and Middlebere in the south. It represents a reversal in the hydraulic gradient within the estuary, i.e. water levels at the mouth are greater than those at the head of the estuary. There is, at this time, a strong potential for deposition of fine-grained sediment from suspension and may explain the existence of the relatively large area of intertidal muds along the western margins of the Harbour.

Peak ebb flow generally occurs before low water, when there are strong currents between Poole Quay and Sandbanks. The flood tide commences about an hour after low water with peak flood tidal currents occurring at about 3 hours after low water. The first high water occurs at 6 hours after low water. Tidal flows change direction at about 7 hours after low water, but flow rates drop significantly at 9 hours due to the second high water. At 10 hours after low water, a strong ebb flow has set in, reaching peak current speeds at around low water.

Tidal flows around much of the periphery of the Harbour are generally low, except at the restricted entrance to Holes Bay and Lytchett Bay, where strong currents are limited to the main channel. Typical maximum currents in the main channel (Middle Channel) are approximately 0.5 m/s. Strong flows from the Backwater channel at the Holes Bay entrance affect the Quay frontage.

3.5.2 Wave Climate

Although the surface area at high water is large, the irregular planform, together with the presence of one large and several small islands, restricts the fetch distances within the Harbour. The narrow entrance to the Harbour and the sheltering effects of Sandbanks and Studland also means that wave action through the Harbour entrance is limited, and therefore has little impact on sediment transport in the Harbour. The wave climate is almost entirely dominated by depth-limited, locally generated waves within the Harbour, whose average heights vary between 0.2 m (south and west) and 0.2 to

0.5 m (north and northeast areas). Waves break along most parts of the shoreline and are affected by localised refraction in the shallow water.

Much of Poole Harbour is shallow with very flat bed slopes. At high tide water depths over the intertidal flats may be in the order of a metre, whilst at low water large areas of tidal flats are exposed. The shallow water means that even the small locally generated waves will be depth-limited at the shoreline. Extreme storm waves do not penetrate significantly into the Harbour entrance due to dissipation of the wave energy by diffraction and refraction around the entrance. Wind data has been used to derive extreme wave heights at various locations within the Harbour (shown in Figure 6). Northern and eastern parts of the Harbour tend to be the most energetic, due to their exposure to long fetches that coincide with dominant west and south-westerly waves. Extreme wave heights vary from 0.5 to 1.2 m for a 1 in 100 year return period, depending on the location within the Harbour with respect to wave fetch. Table 10 shows calculated representative extreme significant wave heights for the Harbour for various return periods at Poole Town Quay.

Table 10. Extreme significant wave heights (Halcrow, 2008b)

Return Period (Years)	Significant Wave Heights (H_s) (m)
1	0.65
2	0.69
5	0.73
10	0.77
20	0.80
50	0.84
100	0.87
200	0.90*
* Estimated Values	

3.5.3 Fluvial Flows

River flow is relatively low into the Harbour, although it receives fluvial input of water and sediment from several different sources, each of varying catchments size, length and flow. The sources are as follows:

1. River Frome: rises in West Dorset and flows eastwards towards Dorchester and into Poole Harbour. It has a number of tributaries including the Cerne, Sydling Water and Hooke Stream. The average monthly flow is about 20,736,000 m^3, with an average flow rate per day of between 3 and 24 m^3/s. The peak monthly flow is approximately 622,080,000 m^3. The lower Frome is characterised by a wide alluvial floodplain that represents a sediment store available for reworking; however, over the long-term fluvial sediment that would have been discharged into the Harbour has been instead trapped as alluvium.

2. River Piddle (Trent): rises near Buckland Newton and flows south-east towards Poole Harbour, with a total catchment area of 183.1 km^2. Major tributaries include Devil's Brook and the Bere Stream. The peak monthly flow is approximately 22 Mm^3, and the average monthly flow is 9 Mm^3.
3. Corfe River: enters the Harbour from the south at around Nath Point, from where it merges with Wych Channel and subsequently becomes predominantly saline.
4. Sherwood River: smallest catchment of the rivers entering the Harbour, and emerges on the east side of Lytchett Bay.

5. Minor land drainage: there are a number of land drains and streams that discharge into the Harbour throughout the urban centre of Poole. The catchment for each will be small, and therefore any effect on the Harbour will be small.

The presence of alluvial plains at the mouths of the Frome and Piddle indicates that there is reductions in the flow velocity as the rivers meet the Harbour; the carrying capacity of the flow therefore decreases and sediment is deposited.

The Rivers Frome and Piddle provide the two largest fluvial inputs to the Harbour, although together the rivers discharge a volume equivalent to only 1.5% of the tidal prism, and the total river and drainage discharges is probably in the region of 2%. The input of sediments from the rivers is likely to be a small part of the overall Harbour sediment budget.

3.5.4 Extreme Water Levels

Extreme water levels (Table 11) have been calculated for Poole Harbour, utilising data which takes account of the South West Regional Report on Regional Extreme Tide Levels (PDMM, 2003), and there are found to be only small variations in extreme water levels across the Harbour. Wind direction is an important factor in extreme water levels: strong and continuous winds from the east through south to south west may raise levels by as much as 0.2 m, whilst winds from the west through north to north east may lower levels by up to 0.1m.

Table 11. Extreme water levels in Poole Harbour (Halcrow, 2008b)

Return Period	Still Water Level (mOD)
1	1.39
5	1.46
10	1.63
25	1.73
50	1.80
100	1.88
200	1.95
1000	2.12

3.6 Sediment Transport Pathways and Budgets

Sediment is supplied to the estuary via the Harbour mouth from outside the Harbour and internally from sources within the Harbour (Halcrow, 2004b). Infilling of the estuary occurs in response to the transport of material into the Harbour by the flood tide and subsequent deposition on mudflats and saltmarshes. Outside the Harbour longshore currents transport material to Sandbanks and Studland spits, where it is temporarily deposited within the ebb tidal delta or immediately transported into the Harbour by the flood tides. Coarse material is transported by tidal currents along the main channels where it accretes or remains to be transported as bed load around the Harbour by internal currents. Fine material is either transported into the Harbour on the flood tide or supplied by cliff, beach, saltmarsh and channel erosion, from where it is transported out of the estuary by ebb currents or redeposited as alluvial plain, intertidal flats or on saltmarsh. Aeolian transport occurs across Studland Heath at the entrance to the Harbour, as well as within the Harbour, e.g. at Hydes Quay and the south west of the Arne Peninsula. However, much of the transport occurs inland of the shoreline. Figure 5 summarises sediment transport within Poole Harbour.

Coastal processes and tidal flows dominate sediment transport at the mouth of the Harbour. Inside the entrance modelling work shows that the sediment flux is into the Harbour and has a large range with a potential flux of between 60,000 – 600,000 m^3/yr (Halcrow, 2004b). From the entrance, sediment pathways along Middle Channel and to the south of Brownsea Island are available to transport sediment further into the estuary and there is potential for sand-sized sediment to be transported throughout much of the Harbour. The rate of sediment flux into the Harbour may double under storm conditions from the south-east within Poole Bay. The main sediment pathway through the Harbour runs from the entrance to the Wareham Channel (between Ham Common and Arne Peninsula), passes along the outside bend of Middle Channel around Brownsea Island to the north side of the Harbour entrance.

Potential net sediment transport in the higher margins of the Harbour, i.e. mouth of the River Frome, Wych Channel, Holes Bay and between the Goathorn Peninsula and Studland, is dominated by the flood tide. Sediment deposition and accretion tends to take place over the shallower and more sheltered areas of the Harbour margins.

Sediment grain size trends show a general fining up the estuary in response to decreasing tidal currents and carrying capacity of the main estuarine flow, with intertidal muds dominating along the western and southern margins of the Harbour and sand-sized sediment dominating the North, Middle and Wych Channels. There is some variation in this trend, on the north-eastern margin of the Harbour, and where restricted wave energy means nearshore sediments are more poorly sorted. Generally, fine-grained sediments are found in the channel centres with more coarse sediment deposited along the channel margins and upstream sediments are finer, including silt, silty clay and clayey silt, partially underlain by sand and gravel.

Intertidal muds and alluvial plains are found in the more sheltered parts of the estuary, including Holes and Lytchett Bays, upstream sections of the Wareham Channel, tributaries of Wych Channel, Arne Bay, Ower Bay, Newton Bay and Brand's Bay. The north eastern shoreline of the Harbour and the north coast of Brownsea Island are also afforded some protection from wave exposure and due to relatively slow tidal currents, consequently leading to deposition of fine grained silts and muds. Generally, intertidal muds vary in concentration from tide to tide, and tend to decrease on neaps and increase with wave action. There is a general tendency for the banks and flats to be composed of slightly coarser sediment where they form channel boundaries and to be finer in the intertidal zone. Mud deposition occurs over a wider area on mean and neap tides, but in most areas is re-mobilised on spring tides or by wave action.

Sand-sized sediment forms the ebb tidal delta that extends across the Swash Channel and into Hook Sands, although the sediment on Hook Sand is significantly coarser and therefore less mobile. Coarse sands, with gravels and stones are present where the Middle Channel and the Harbour entrance meet, with sediments fining towards Poole Quay, and generally towards the west. Towards the Harbour mouth, coarse sands may be armoured by fine gravel and shells. Sand shoals are also present along the inner margins of the North and Middle Channels. Muddy sands can be found along the northern face of Brownsea Island and within the Northern Channel. Restricted wave energy means nearshore sandy sediments are often poorly sorted.

Pebbly sand is found along the south western frontage of Poole, with cobbles to the west of Rockley Sands and towards Lower Hamworthy. Cobbles and gravels are otherwise found only at Brownsea Roads near the entrance. There are some superficial patches of gravel in the area adjacent to the entrance. Large cobbles and boulders are found at several locations derived from the erosion of the seawalls and breakwaters built up to 120 years previously.

3.6.1 Sediment Sources

Offshore

Much of the marine sources available to Poole Harbour were derived from the bed of Poole Bay during the Holocene period of sea level rise. Sand continues to be delivered through the Harbour mouth on a flood tide and there is further potential for increased input under storm conditions. The presence of sand and gravel flood tidal deltas immediately inside the entrance, combined with the prevalence of sandy sediments covering the bed of the Harbour near the entrance, would suggest that this is correct. Hook Sands is a shoal feature outside the Harbour but it acts to reduce wave energy and drive sediment movement onshore. Hook Sands also plays a role in refracting storm waves from the south-east, so as to approach Sandbanks from the south, contributing to the easterly drift of material in the open coast process unit.

From the west along the Studland shoreline, sediment transport potential has been calculated as being 4,000 – 10,000 m^3/yr of sand. It has not been possible previously to establish the potential sediment supply from the east along the Sandbanks shoreline, East Looe Channel and over Hook Sand, but the movement of sediment from the seaward to landward end of Hook Sand was found to be in the order of 20,000 – 200,000 m^3/yr. There is also potential supply from Swash Channel on a flood tide, which transports sediment some distance into the Harbour. As highlighted above, the potential for sediment movement upstream into the Harbour is the order of 60,000 – 600,000 m^3/yr.

There is also thought to be a net input of suspended sediments into the Harbour from Poole Bay; this is a function of the tidal regime where the flood tide enters more slowly, but over a longer duration, providing increased opportunity for input of fine sediments.

Cliff erosion

Within the Harbour erosion of cliffs is a sediment source, particularly Rockley Cliff, Brownsea Island, Furzey Island, Brands Bay, and the Arne Peninsula. The rapid expansion of *Spartina anglica* from the late 19^{th} Century to the 1920s significantly reduced the wave energy at some cliffed sites within the Harbour; this has been reversed by the subsequent *Spartina* dieback. The supply of sediment from cliffs between Rockley and Ham Common has been calculated at 200 – 300 m^3/yr, which is very small when compared to the potential offshore supply. Erosion on the southern and eastern shores of Brownsea Island is noted as an ongoing concern.

Saltmarsh erosion

The extent of saltmarshes has been measured from aerial photographs taken in 1947, 1973 and 1997 by Halcrow (2004b) and Born (2005). This analysis showed that between 1947 and 1993 there has been 215 ha of erosion (not including land reclamation), amounting to approximately 5 ha per year (Halcrow, 2004b and Born, 2005). This has been due to a number of factors including *Spartina* dieback, sea level rise, invasion by other species, wave erosion and anthropogenic causes. Cliffing at saltmarsh edges has contributed to sediment supply, for example at Keysworth Marsh and other areas of the Upper Wareham Channel. It is not known what contribution wave action has had to erosion.

There are extensive mudflats due to accretion, which has been created by colonisation and stabilisation by *Spartina* and the subsequent die back since the 1930s when the area extent of *Spartina* started to reduce. The associated erosion of the saltmarsh has increased levels of sedimentation elsewhere.

Beach erosion

There is ongoing release of sediment from beaches, including those between Rockley Point and Hamworthy on the northern side of the Harbour. Erosion of beaches has not been directly measured; however, sediment has not accumulated at either Rockley Point or at the east end of Ham Common. Therefore sediment recently eroded from the cliffs and moved by longshore currents is not stored on adjacent beaches, but is mobilised into sediment transport pathways in the Harbour. Many of the sandy beaches elsewhere are eroding, including those on the western and central sector of Arne Peninsula and the gravel beach on the south shore of Brownsea Island. However, there has been some accretion on beaches in Newtons Bay and the west coast of Goathorn Peninsula.

Channel erosion

The need for on-going dredging of the main navigational channels and for maintenance of the marinas on the northern fringes of the Harbour would indicate that overall the depth of the channels is not maintained by natural processes and therefore erosion of the channels is not expected to contribute to the supply of sediment to the Harbour.

Fluvial sources

Fluvial material is transported to the Harbour primarily by the Rivers Frome, Piddle, Sherford and Corfe, which are all underlain by erodible sands and clays. Potential for the sediment to be deposited across natural river floodplains is limited by the canalisation of existing embankments. The total river and drainage discharges are probably equivalent to 2% of the tidal prism. Turbidity of the fluvial and tidal inputs have not been compared, although it is likely that the sediment input from the rivers is likely to be a small part of the overall sediment budget of the Harbour. It has been estimated that the major rivers (Frome and Piddle) contribute 1492 tonnes/m of suspended load and less than 600 tonnes/m of bedload. Quantitative understanding of the contribution of fluvial material to the sediment budget of the Harbour is currently weak. Much of the suspended load received at present may temporarily be stored by mudflats and at the channel margins in the Upper Wareham Channel (SCOPAC, 2004).

3.6.2 Sediment Transport Pathways

Longshore transport

There is a net eastward component to littoral drift at most locations within the Harbour. Some littoral drift does take place around the margins of the Harbour, evident by the presence of sandy beaches that have formed along the northern edges, including from Rockley to Hamworthy, where the dominant sediment transport pathway is from west to east from Ham Common to Hamworthy. The shingle beach at Hamworthy is derived from erosion of the gravels at Rockley Cliffs. There is also a drift divide which results in net westward movement from Ham Common to Rockley Point. The transport potential is sufficient to allow longshore movement of all the material released by erosion of the cliffs, for example where sediments released by cliff erosion drift north-eastwards on the Arne Peninsula to form shingle spit structures.

Tidal currents, bed load and suspended load

Modelling has shown that there is a predominant downstream sediment movement within the Harbour channels and a predominant upstream movement in the shallower margins, therefore bedload transport may be in different directions in different areas of the Harbour. There is potential for sediment transport throughout the Harbour and into the Wareham Channel, Wych Channel, Hole and Lytchett Bays and the southern outer Harbour. There is therefore the potential for sediment from the shoreline outside the Harbour to be transported to and deposited on the estuary margins, on intertidal mudflats and saltmarshes.

3.6.3 Sediment Sinks

Barriers and spits

Longshore processes transport material to the spits at the entrance to the Harbour, but their extent is controlled by tidal flow through the mouth. Spits and cuspate elongations have also formed on some of the beaches within the Harbour, e.g. the western shoreline of Brownsea Island and at Rockley Point; and a shingle spit feature has formed on the north-east of the Arne Peninsula. However, due to their small size, barriers and spits within the Harbour will not contribute greatly to sediment storage.

Beaches

Mixed sand and single beaches have developed at several locations around the Harbour margins, usually associated with erosion of cliff material and littoral drift, although the supply of sediment on the flood tide is also a factor, for example, at Whitley Lake, where sandy beaches have accumulated. Some beaches are clearly relict, the major cause of which has been the growth of *Spartina* saltmarsh and mudflats in the adjacent intertidal allowing the build up of beaches to landward, a process which is now being reversed. Shingle beaches, throughout the Harbour, are poorly sorted, indicating limited wave action. However, any storage is likely to be very small compared to that in other units within the Harbour and the contribution of beach material to the sediment budget of the Harbour is considered to be small.

Channels and banks

In central and eastern parts there are well-defined banks and shoals composed of fine to medium sand, although thin and patchy superficial mud deposits are present, although the main channels which separate the banks are maintained for navigation which over time will remove any sediment temporarily stored. However, over the longer term prior to the spread of *Spartina anglica* the trend was for slow shallowing of the Harbour channels. This was effectively reversed by accretion and consolidation of sediment, due the growth of *Spartina*. Following the dieback of *Spartina*, the shallowing has become the net trend in the Harbour, restoring the previously expected tendency.

Alluvial plains and mudflats

Alluvial plains composed of mud and sand have formed at the confluence of the rivers and the Harbour, where the flow velocity is minimal and wave and tidal energies are significantly reduced. Clay and fine silt particles are supplied by erosion of the Harbour margins and reworking of Harbour bed deposits. The lower River Frome, Upper Wareham Channel and southern margins of the Harbour are typical of the mudflats that have formed in these conditions.

Intertidal flats, saltmarshes and tidal creeks

Extensive mud accumulations exist around the southern, western and north-western margins of Poole Harbour and represent a long-term net imbalance of the sediment budget in favour of accretion, although at the present time there may be a condition approaching dynamic balance between input and output. In the north-east, mudflats form eroded foreshores with limited horizontal development. Whilst saltmarsh erosion has been the dominant trend since at least 1947, there are areas of accretion within the Harbour. Furthermore historical and predicted change of saltmarsh represents a net supply of sediment, rather than a net sink.

Dredging

Dredging of navigation channels and marinas within the Harbour and dumping of sediment offshore represents a loss of sediment from the system. Typical annual volumes of maintenance dredging for 1990 – 2000 were 65,000 m^3. The timing and volumes of capital dredging vary considerably from year to year. Over a 33 year (1969 – 2002) period the total volume was 2,055,000 m^3. Since this time the channel deepening of Swash and Middle Channels has taken place (2005-2006) with approximately 1.1 Mm^3 removed.

3.7 Impact of Sea Level Rise

Changes in past relative mean sea level for the area of Poole Bay are presented in Table 12, as recorded at Class A tidal gauges. Of those presented for the area, only the data for Portsmouth has a duration suitable for providing a reliable representation of sea level rise. There is a harmonic tidal constituent of periodicity of 18.4 years and amplitude in the range of 100 mm. Where data sets are shorter than this duration, as at Newhaven, Bournemouth and Weymouth, the variation in level due to this harmonic can be more significant than the relative sea level rise. Even when this source of uncertainty is disregarded, the values of standard error (being a measure of the scatter of the data either side of the trend-line) for these shorter data sets is 5-10 times higher than for the longer data set at Portsmouth. Therefore the most reliable estimate of past sea level rise from the 1960s to 2000s for Poole Harbour is 1.82 ± 0.45 mm/yr (as downloaded from http://www.pol.ac.uk/psmsl/datainfo/rlr.trends).

Table 12. Changes in mean sea level

Station Name	Start Date	End Date	No of Years of Data	Linear Trend and Standard Error (mm/yr)
Newhaven	1993	2004	8	2.56 ± 0.98
Portsmouth	1962	2003	33	1.82 ± 0.45
Bournemouth	1997	2003	7	6.43 ± 1.41
Weymouth	1992	2004	11	5.09 ± 1.17

Future sea level rise for the area is given by the Defra guidance (2006b), shown in Table 13, in terms of the rate and the actual predicted sea level at each of the SMP epochs is given in Table 14.

Table 13. Future predicted sea level rise for the South West of England (Defra, 2006b)

Region	Assumed Vertical Land Movement (mm/yr)	Net Sea Level Rise (mm/yr)				Previous Allowances
		1990-2025	2025-2055	2055-2085	2085-2115	
South West	-0.5	3.5	8.0	11.5	14.5	5mm/yr constant

Table 14. Predicted sea level at each of the SMP epochs

Date (SMP Epoch)	Predicted Net Sea Level Rise (mm)
2025	70
2055	302
2105	925.5

The effects of the predicted increase in sea level may lead to changes in the tidal prism of the Harbour, changes to the residual currents at the Harbour mouth, and climate change may also lead to changes in storm frequencies. Sea level rise is likely to have impacts on both the developed and natural environments of Poole Harbour; for example the defended northern coastline cannot now naturally adjust to sea level rise as it is constrained. It is therefore likely to be subject to squeeze, through lowering and erosion of the foreshore.

The present rate of mean sea level change of 1.82 ± 0.45 mm/yr is predicted to increase over the timespan of the SMP (Table 14), and this increase in rate is expected to directly influence the volume of water passing in and out of the entrance of the estuary on each tide, i.e. the tidal prism, which will in turn affect sedimentation in the Harbour.

Three scenarios for change due to increased rate of sea level rise have been identified, which depend on the availability of fine sediments from river catchments and the adjacent shoreline:

1. Availability of sediments is high and vertical accretion within the Harbour exceeds sea level rise, resulting in a reduction in the tidal prism.
2. Vertical accretion within the Harbour is the same as sea level rise and the tidal prism remains the same.
3. Vertical accretion within the Harbour is less than sea level rise and the tidal prism will increase.

Another determining factor on changes to the tidal prism will be level of constraint on the landward movement of the edge of the Harbour, for example, the defended north-eastern shore and both the Arne Peninsula and Brownsea Island are constrained by their underlying geology.

It has been calculated that in order to allow the Harbour to continue to accrete and maintain its current tidal prism, the volume of sediment required would be 160,000 m^3/yr. This is thought to be a realistic potential sediment supply to the Harbour, as potential rates of sediment transport (although variable at 60,000 – 600,000 m^3/yr) in the Harbour entrance are sufficient to transport this volume and the volume of sediment within Hook Sand is at least ten times greater than this volume. Therefore, where possible, the response of the Harbour to sea level rise would not result in coastal squeeze of the intertidal habitats, as the intertidal habitats could receive sufficient sediment to maintain their position relative to sea level. However, if sufficient sediment is not available a substantial area of saltmarsh would be lost over the next 100 years. In addition, where there is insufficient space for landwards rollover of intertidal areas, due to geological or man-made constraints, coastal squeeze would occur; together with sediment supply this would be the critical factor in determining the future shoreline position.

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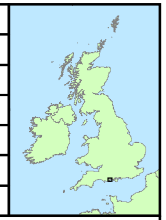
Figures



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3819 - Fig_LocationMap.mxd			
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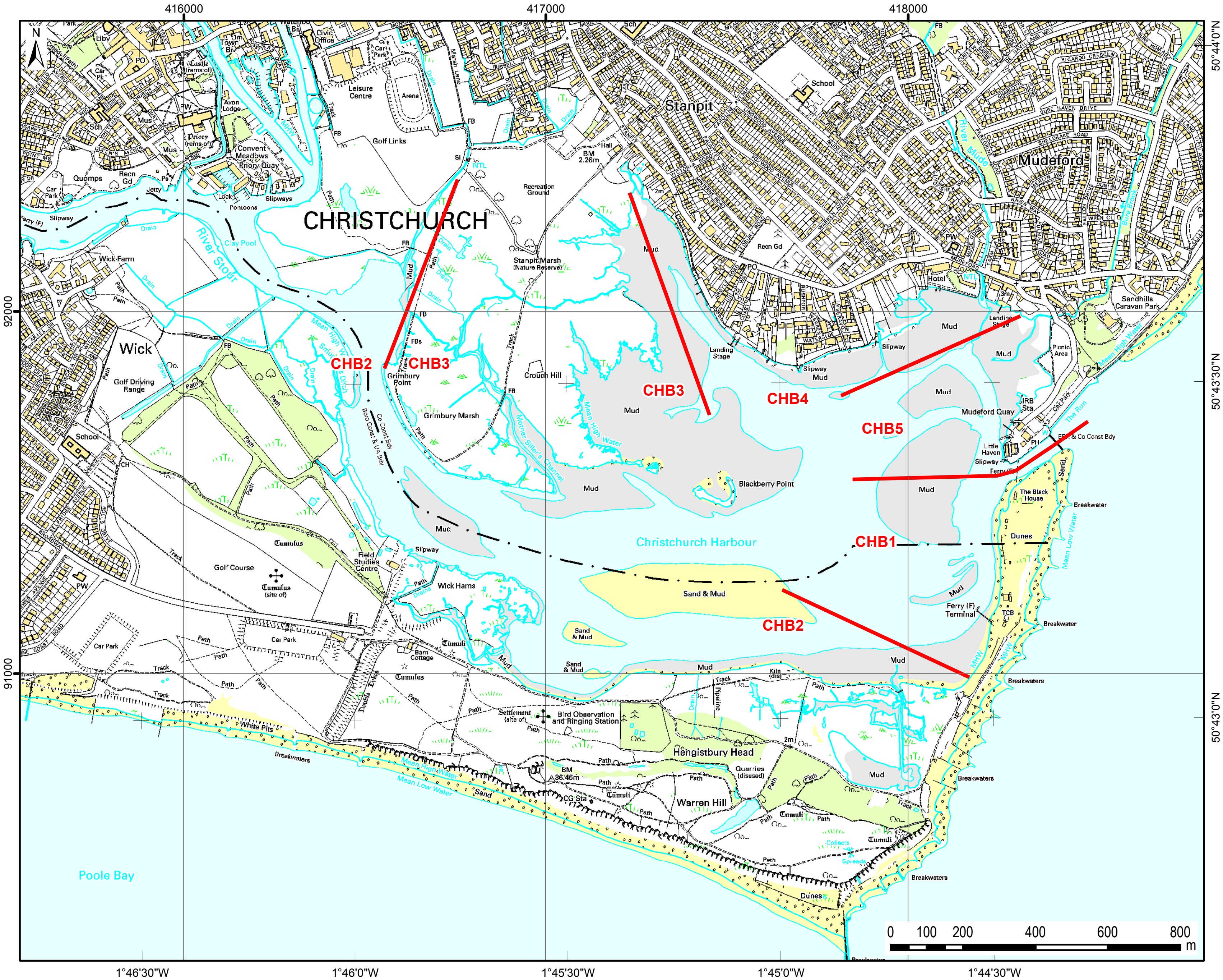
Location map of Poole and Christchurch Harbours

Figure 1



Boundary of Process Units

Data Source: Halcrow (1999)

Date	By	Size	Version
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Projection	OSGB 1936
Scale	1:15,000
QA	RJR

3819 - Fig_ProcessUnits_Christ.mxd

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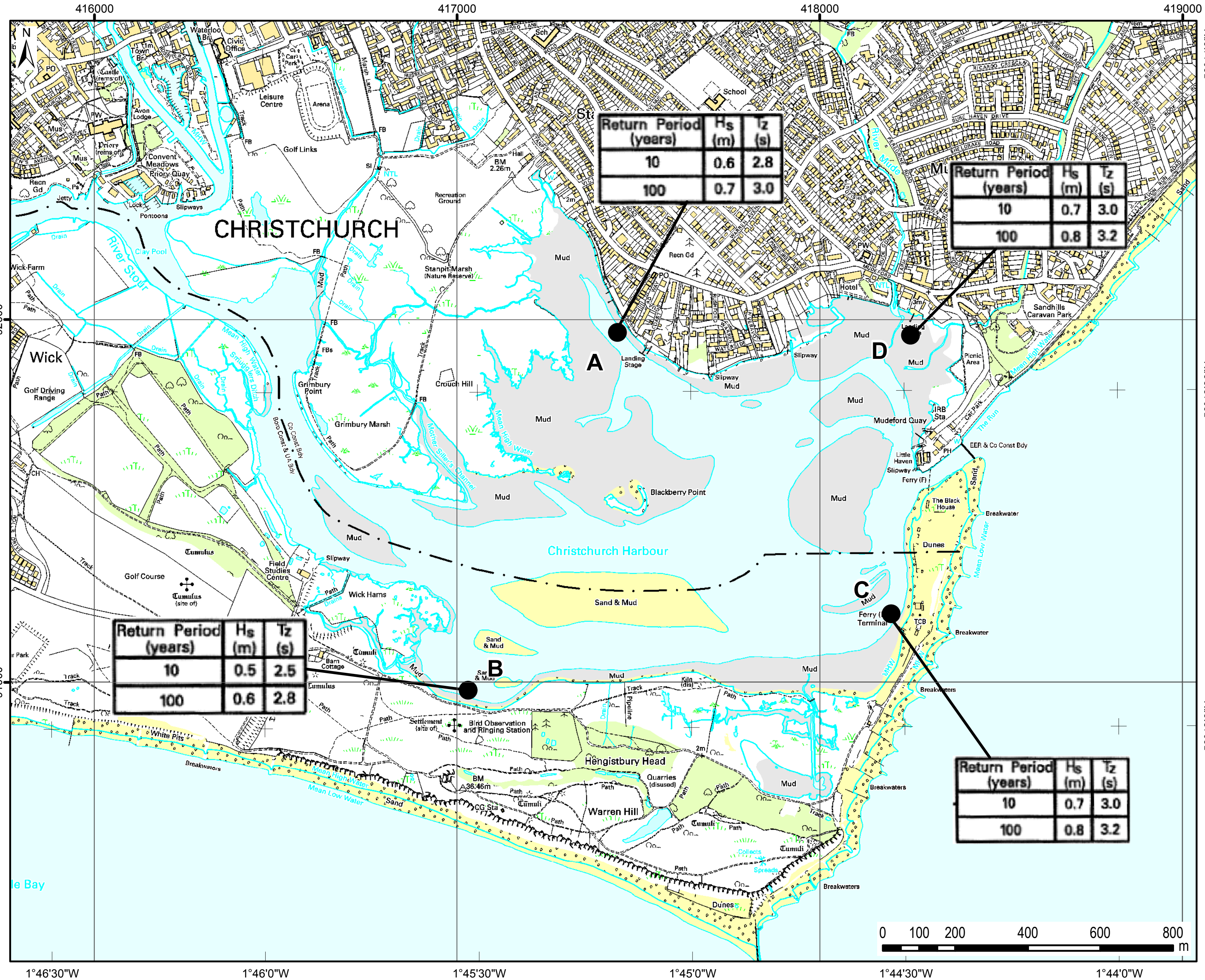
Location map of Christchurch Harbour, including Process Units

Figure 2



Point A

Return Period (years)	Hs (m)	Tz (s)
10	0.6	2.8
100	0.7	3.0

Point B

Return Period (years)	Hs (m)	Tz (s)
10	0.5	2.5
100	0.6	2.8

Point C

Return Period (years)	Hs (m)	Tz (s)
10	0.7	3.0
100	0.8	3.2

Point D

Return Period (years)	Hs (m)	Tz (s)
10	0.7	3.0
100	0.8	3.2

Data Sources: Halcrow (1999)

Date	By	Size	Version
Jan 09	DD	A4	1

Projection	OSGB 1936
Scale	1:15,000
QA	RJR

3819 - Fig_Waves_Christ.mxd

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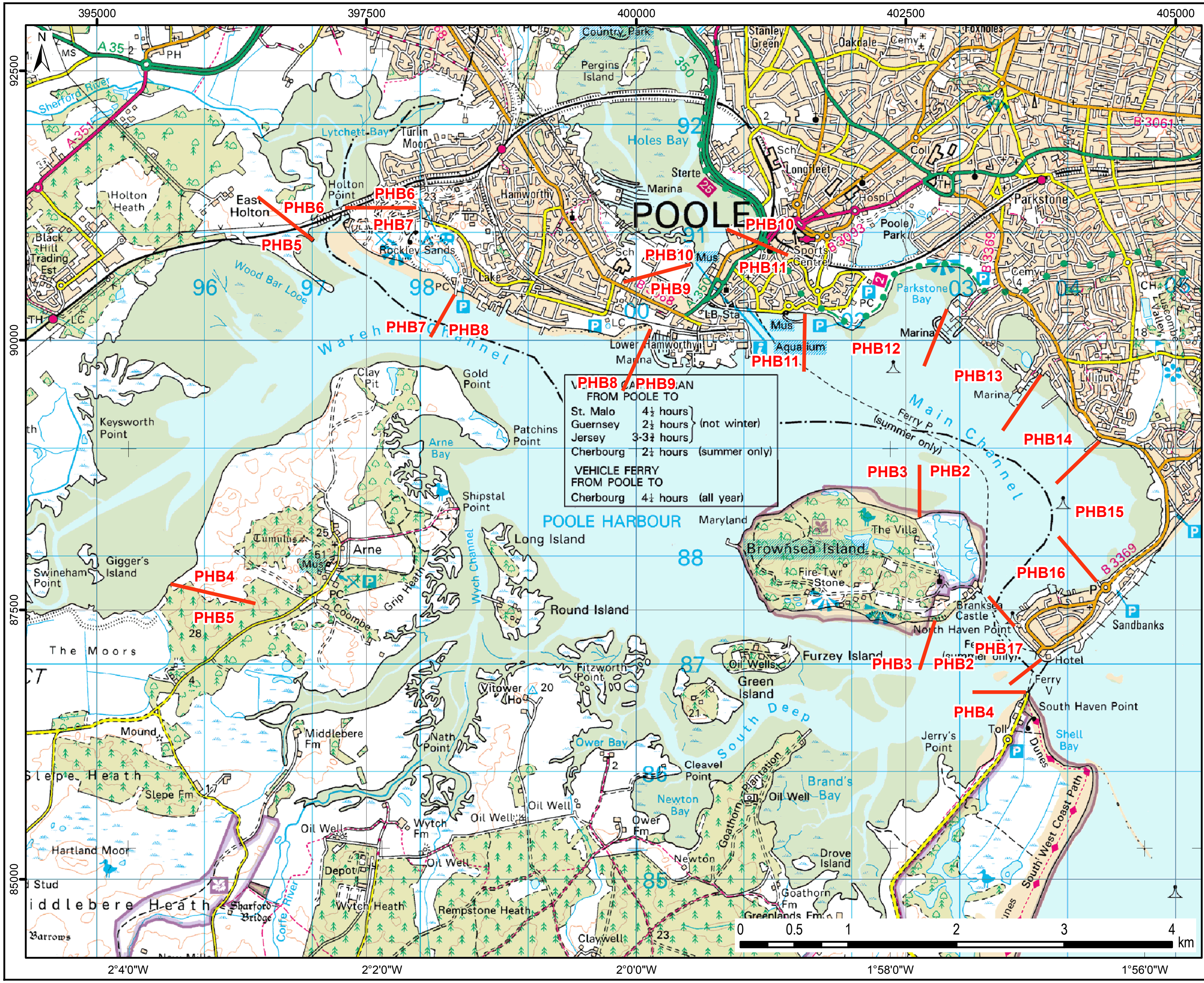
Extreme Wave Heights in Christchurch Harbour

Figure 3



Boundary of Process Units

Data Source: Halcrow (1999)

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3819 - Fig_ProcessUnits_Poole.mxd			
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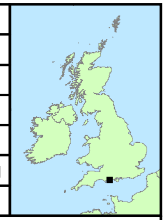

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Location map of Poole Harbour, including Process Units

Figure 4

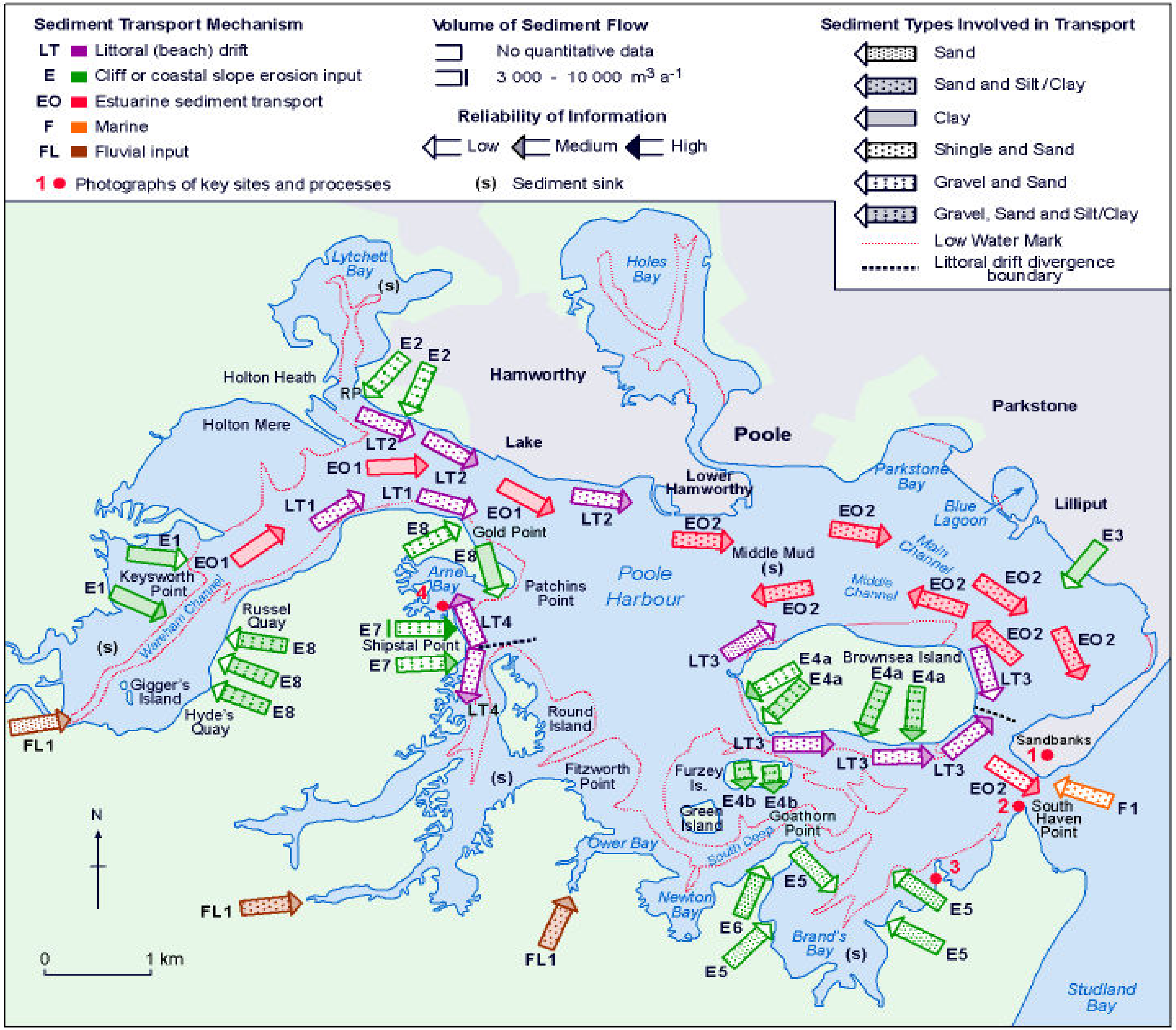

Figure courtesy of SCOPAC (2004)

Date	By	Size	Version
Jan 09	DD	A4	1

Reference

3819 - Fig_Sediment_Trans_Poole.xls

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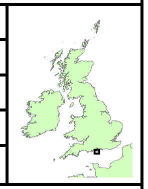

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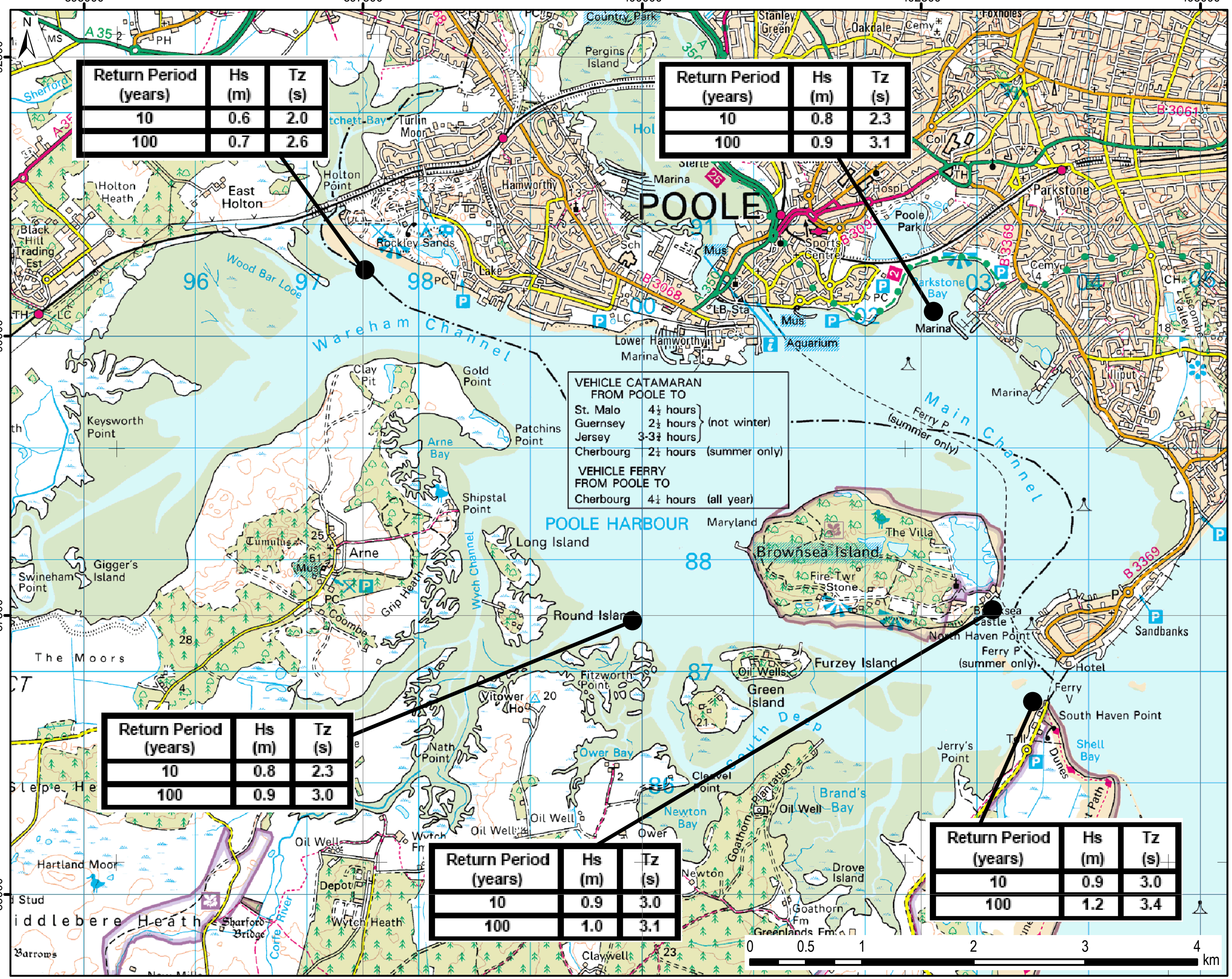
Sediment Transport within Poole Harbour

Figure 5



Return Period (years)	Hs (m)	Tz (s)
10	0.6	2.0
100	0.7	2.6

Return Period (years)	Hs (m)	Tz (s)
10	0.8	2.3
100	0.9	3.1

Return Period (years)	Hs (m)	Tz (s)
10	0.8	2.3
100	0.9	3.0

Return Period (years)	Hs (m)	Tz (s)
10	0.9	3.0
100	1.0	3.1

Return Period (years)	Hs (m)	Tz (s)
10	0.9	3.0
100	1.2	3.4

Data Source: Halcrow (1999)

Date	By	Size	Version
Jan 09	DD	A4	1
Projection		OSGB 1936	
Scale		1:50,000	
QA		RJR	

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Extreme Wave Heights in Poole Harbour

Figure 6

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