3 Coastal processes

3.1 Introduction

The past, present and future forms of the East Solent shoreline are the result of natural forces acting on the sea bed, beach and backshore, modified by man's activities and coastal vegetation.

The natural forces include:

- swell and locally generated waves
- tidal currents
- tidal and meteorologically induced water levels
- winds
- fresh water flows.

These forces act on the mobile surface material or solid geology causing erosion, accretion and flooding. Since Roman times these natural processes have been influenced by man's activities, including:

- construction of ports
- maintenance of navigation channels
- construction of coastal defences to protect shoreline property and structures
- removal of beach and sea bed material for construction
- reclamation of land.

The physical forces are also influenced by biological processes, including:

- development and breakdown of saltmarsh communities and the formation of wetland habitats
- stabilization of backshore windblown sand by dune communities
- nearshore transport of gravel and cobbles by 'kelp rafting'
- erosion control by established vegetation
- cementation of seabed material.

These forces and processes are described in this chapter. The geological and historic evolution of the coast are presented first, followed by the present day situation. Possible future coastal developments are then considered based on potential changes to sea levels and the wind/wave climate. This volume concentrates on Chichester, Langstone and Portsmouth Harbours, while the companion Volume I covers the open coast and Pagham Harbour.

Much of the information presented is derived from the Pagham Harbour to River Hamble study undertaken for the Coastal Group by HR Wallingford (HR Wallingford, 1995a&b). This source is supplemented by referenced information from other publications and reports reviewed for the SMP.

3.2 Geological evolution

The underlying bedrock of the East Solent comprises chalk with overlying soft clay and sand Tertiary sediments and a mantle of Recent sediments. Figures 3 and 4 present the solid and surface geology for the area. The surface geology includes unconsolidated Recent drift deposits and exposures of underlying solid formations. Table 2 provides further details of the lithologies. This information has been derived from various maps produced by the British Geological Survey.

Table 2 Lithological descriptions of the East Solent

Recent	
Blown sand	modern deposits
Shingle and sand beaches	modern deposits
River, marine and estuarine alluvium	relict and modern deposits of fine material
River terrace deposits	mainly gravels
Brickearth	mainly loam and clay
Raised beach	coarse flint gravels above sand at about 5m OD, Ipswichian transgression (100,000 BP?)
Tertiary	
Brackleham Beds	clays and clayey sands
Bagshot Beds	sands and gravels, with seams of clay
London Clay	sandy clays, with occasional pebble beds
Reading Beds	clays, sand with occasional flint gravels
Mesozoic	
Upper Chalk	thickly bedded chalk with regularly spaced bands of flint nodules

The East Solent represents the drowned channel and flood plains of the ancient Solent River that flowed across south east Dorset and southern Hampshire and into a major "English Channel" river. The Solent River developed during the late Devensian glaciation when sea levels were as much as 120m below the present level. Rising sea levels during the Holocene transgression from 15,000 years BP to 5000 years BP caused the river valley to become drowned and infilled by fluvially deposited gravels. The river deposited vast quantities of sand and gravel throughout its flood plain. These deposits are the major source of beach material throughout the region, and remaining offshore deposits are the focus of the regional dredging industry.

The rate of global sea-level rise due to post-glacial meltwater slowed some 5000 years BP, but general subsidence of the land mass of south-east England has continued. The resultant relative sea level rise has been about 250mm per century.

As sea-levels rose, large quantities of sand and shingle were combed up and driven landwards. These are thought to have formed a series of massive shingle spits, forelands, barrier beaches and major offshore shoals located several kilometres seaward of the present shoreline and protecting marshy lowlands. Relict beach bases have been identified on the sea-bed in Bracklesham and Hayling Bays. Tidal channels through the barriers facilitated inundation of the Solent and the harbours, as suggested by various dated organic deposits that have been related to ancient sea-levels. Indeed, the connection of a tidal channel through the western Solent to isolate the Isle of Wight at between 8,000 to 6,000 years BP probably marks the beginning of the present complex tidal regime within this area. Thick sequences of fine sediments have infilled the estuaries and large harbours of the region since that time.

Over the past 2,000 to 3,000 years, it is thought that the barrier beaches within Bracklesham and Hayling Bays were driven progressively landward by continuing sea-level rise and wave activity, and perhaps also by relative sediment shortages. Fresh coarse sediments are only available through erosion of the low lying soft cliffs, so with declining rates of sea level rise, transgression would have occurred in response to continuing wave activity upon the depleting barriers.

Figure 4 Surface geology

Since sea level rise slowed some 5000 years BP the harbours have received little fresh water inflow and the input of fluvial sediment has been insignificant. By contrast there has been significant input of sediment from seaward. Fine material is transported in suspension by the flood tide and accumulations of this material in the harbours appear to have kept pace with the rate of sea level rise. Deposition has given rise to saltmarsh and wetlands. There is also transport of coarser material, mainly on the margins of the harbour mouths as a result of littoral drift. Some material is transported further into the harbours forming flood tide sandbanks which shift position over time. These flood tide banks are small by comparison with the ebb tide deltas outside the harbours, which are part of the open coast transport regime.

As the geology of the harbour areas is predominantly easily erodible then any changes to the hydrodynamic conditions will affect the shoreline causing either erosion or development of the saltmarshes. The long term situation is not only affected by conditions within the harbours but by the processes active on the open coast around the harbour entrances.

With widespread coastal protection over the past 100 years, erosion no longer supplies much additional sediment, and groynes interrupt many transport pathways. Furthermore dredging for navigation (Portsmouth, Langstone and Chichester entrances) and aggregate (especially Horse and Dean Sand for Portsmouth Harbour reclamations) have removed large quantities of sediments from the system. Littoral sediments within this system are therefore both finite and depleted. The natural protection afforded by beaches will diminish unless countered by management actions.

In the absence of artificial protection, the geomorphological response would involve continued shoreline retreat. This would eventually tend to increase regional coastal stability through adoption of a flatter, more dissipative shore face profile, the release of eroded sediments and formation of a shoreline in equilibrium with the wave and tidal regime. However the complexity of this coast means that it is not easy to predict where transgression might occur first, the amount of transgression that might be needed to achieve stability and the possible consequences for neighbouring areas of permitting natural processes to operate in this manner.

This summary is compiled from the work of Allen and Gibbard (1993), Dyer (1975) and Bray et al (1991).

3.3 Historical evolution

Historical changes to the harbour shoreline have been dominated by two factors. The first is the long history of human intervention, such as land reclamation for farming, port development and construction of transport routes. The second is the growth and dieback of the saltmarshes. The harbours have been subject to different levels of change, with Portsmouth being most affected by reclamation work and Chichester being subject to more natural changes.

Information comes from several sources including Hooke & Riley (1987) which examines map evidence and Haynes & Coulson (1982) and Collins & Fontana (1996) which describe changes to the marshes.

The following sections summarize the available information on shoreline evolution and its relevance to the SMP. Each harbour is discussed separately. Figure 5 presents the areas of land reclamation in Portsmouth and Langstone Harbours.

Portsmouth Harbour

Much of the shoreline of Portsmouth Harbour has been reclaimed over the past 130 years for port development, naval facilities and land fill sites. Prior to that most of the low lying land around the harbour had been drained and protected by flood banks for agriculture; this former agricultural land has now been turned over to residential, industrial or recreational use, particularly over the past 40 years. Figure 4 shows the reclaimed areas, while flood area maps presented later in the report, show the low lying areas that have been developed and are now at risk from flooding. As a result of shoreline works, the present day High Water Line has no significant areas of retreat, while the low water channels have only altered where navigation dredging has been undertaken.

Much of the reclamation for the Royal Navy occurred in the late 19th century with the development of the Dockyard, Whale Island and the torpedo test facility at Horsea Island. Smaller sites included part of Haslar Lake, the shipyard at Portchester and the upper reaches of several tidal creeks.

Civil reclamation works have included further parts of the tidal creeks and lakes, both banks of Portcreek connecting Portsmouth and Langstone Harbours to the north of Portsea Island (north bank now the M27/A27 embankment), the M275 route into Portsmouth, several small sites up the harbour arm to Fareham and, most recently, the major reclamation and land fill site at Port Solent north of Horsea Island.

In association with these reclamation works there have been major capital dredging operations to form the harbour basins and navigation channels. Maintenance dredging is ongoing, with the spoil being dumped at sea. It has been suggested that uncontaminated spoil could be used more productively, and at lower cost to the dredge operator, by dumping within the harbour to form mudflats both for habitat creation and for wave dissipation.

Much of the higher ground on the Gosport frontage has been protected against erosion by low masonry, stone and timber walls. Residential, commercial, recreational and infrastructure development has extended to the edge of these walls making their continued maintenance important.

Low lying areas, originally reclaimed for farming, were developed for the post-war housing expansion, particularly in Hilsea, Tipner and Portchester. Original earth embankments were strengthened using a variety of materials, many of which have now come to the end of their useful life. Replacement schemes have been undertaken around Portchester and along sections of Haslar and Forton Lakes.

Only two extensive areas of natural coastline remain in Portsmouth Harbour. These are the MoD area of Fleetlands north of Gosport and the east shore of the upper reaches of Fareham Lake. Fleetlands rises gradually from saltmarshes, through coastal scrub to higher ground, while the shoreline of Fareham Lake rises steeply to the higher ground of Cams Hall.

The entrance to the harbour is defined by the Haslar seawall on one side and by the various walls protecting Old Portsmouth on the other, some of which have been in place since the 15th Century.

Langstone Harbour

Land reclamation sites, mainly for landfill purposes, form much of the western and northern shoreline of Langstone Harbour. A large part of the remaining shoreline is formed by transport routes, with the A27 along the north shore, the disused “Hayling Billy” rail line along the Hayling Island shore and the Eastern Road along the Portsea Island shore. The roads are protected by revetments or walls, while the shore below the rail line remains largely natural, with short sections of revetments, walls and breastwork to reduce erosion and/or flooding. There are three commercial jetties, used mainly for aggregate transfer: Great Salterns Quay and Kendalls Wharf on Portsea Island and Brockhampton Quay near Langstone. Maintenance dredging is undertaken in the channels to each jetty and to the Southsea Marina at Eastney; this work is undertaken on an ad hoc basis and quantities are not recorded by the Harbour Board. The remaining shoreline tends to be low lying, with varying levels of protection.

Eastney Spit on the west shore of the entrance channel has been reasonably stable over the past 100 years. It provides natural protection to Eastney Lake, but land reclamation and development for housing, marinas and moorings has resulted in the need for walls and revetments along most of the shore. The only remaining natural shoreline is within the Milton Locks Nature Reserve (Hampshire Wildlife Trust). North from Eastney Lake is Milton Bund, built in 1962 across a former inlet to provide a land fill site. Beyond this frontage is the Eastern

Figure 5 (section a) Location of landfill and reclamation sites
Ref: V3-Fig 05

Figure 5 (section b)

Road protected by a variety of lengths of wall, mainly rebuilt over existing walls, between the 1960s and 1980s. The only remaining older section, running up to the south side of the Great Salterns Quay, suffers severe overtopping and is structurally unsound. Anchorage Park, in the north east of Portsea Island is a further low lying area, formerly the site of Portsmouth airport but now a residential and commercial development.

Apart from the A27 road embankments, the north shore comprises the former upper saltmarsh area of Farlington Marshes, the land fill sites of Broad Marsh and Budds Farm, and the former saltmarsh of South Moor. All of these areas are protected by walls or revetments of varying standard.

The eroding remains of the disused Hayling railway embankments extend from either side of the channel separating the Island from the mainland (and joining Langstone and Chichester Harbours). On the Hayling side the rail embankment runs inland of the reclamation site formerly used as oyster beds. The original beds fell into disrepair in the early part of this century, but were redeveloped in the 1970s. The banks were rebuilt of building rubble but the ponds were never used. The outer banks suffer severe erosion and have been partially removed as part of a scheme to enhance both the landscape and the natural environment.

The rail embankment continues south along the shoreline, providing some flood protection to the west side of the island, as well as being a public access trail. The shoreline benefits from some natural protection due to the intertidal mudflats and saltmarshes in the harbour, but is still subject to minor erosion.

The south east shoreline of Langstone Harbour comprises further low lying land, partly protected by various structures and partly in a natural state. The marsh area extends up to the sand and shingle spit forming the east bank of the harbour entrance channel. The tip of the spit is now fixed by walls and jetties that protect houses, holiday facilities and the harbour office.

Apart from the maintenance dredging mentioned earlier, aggregate dredging of about 6000T/year occurred on the flood tide bank opposite the entrance channel. This operation stopped in 1994. The entrance channel has never been dredged for navigation purposes as it is swept by strong currents.

Chichester Harbour

Unlike the other two harbours, Chichester Harbour has not lost any substantial areas to reclamation schemes for ports or landfill sites, but has lost former upper saltmarsh areas to farmland over many centuries. Most of the shoreline is defined by flood embankments or erosion protection works, although there are some lengths of natural coastal transition. The harbour was important for commercial and military shipping in Roman times, with Dell Quay being a major port, but today the only commercial vessels within the harbour are small fishing boats.

Sandy Point spit forms the west shore of the entrance channel. The neck has narrowed over the past century but the head has extended north and west due to natural accretion. The spit provides natural protection to the low lying, but heavily developed, land around the Eastoke inlet. To the north walls, revetments and embankments define the shoreline along almost the full length of Hayling Island, preventing flooding of low lying reclaimed farmland, holiday developments and housing. The Northney marina has been built over a reclaimed saltmarsh area.

Across the channel to Langstone, walls and revetments protect further low lying areas and sections of slightly raised lands east to Emsworth. Enclosed marshes join the MoD land at Thorney Island to the mainland. Recently upgraded flood embankments continue past Prinstead to Nutbourne and older embankments run down the Chidham peninsula.. The southern tip of the peninsula is above flood levels but suffers erosion. An embankment was built across to Thorney Island from here in the 1870s to allow reclamation of marshes up to Prinsted, but the embankment failed and the area returned to its natural state. The long narrow island off the point is all that now remains.

Flood embankments continue up both banks of the Bosham and Chichester Channels, with some sections of natural shoreline or erosion protection. Areas of healthy saltmarsh provide additional protection. West of Itchenor there are larger sections of natural shoreline with short lengths of embankments and walls towards West Wittering.

The shingle and sand spit of East Head forms the east side of the harbour entrance channel. The area in its lee is very sheltered and contains well developed saltmarshes.

Maintenance dredging has been undertaken within the inner channels to remove fines and within the entrance to remove coarse material. 20,000m^3 were removed from the channel in 1988 and a further operation is now required to maintain the published safe navigation depth.

3.4 Natural defences and saltmarsh changes

Changes in the condition of the natural defences have had an impact on coastal protection and flooding. Loss of saltmarsh or lowering of the mudflats increase maintenance costs of the flood embankments and coastal protection which form the boundaries of the harbour. The following sections chart the historical changes in the natural defences, particularly *Spartina anglica* saltmarsh, and outline the consequence of these changes to flood and coastal protection.

Saltmarsh

Before the turn of the century the area occupied by saltmarsh (depositional intertidal habitats colonised by salt-tolerant plants) in the harbours was low. Upper saltmarsh communities did exist in the highest, sheltered intertidal areas, however much of the natural marshland had been lost due to land drainage and reclamation to provide grazing and agricultural land. The introduction of *Spartina anglica* at the beginning of the century rapidly increased saltmarsh coverage in the harbours, but after peaking in the middle of the century there was a dramatic decline in the vigour and health of this hybrid.

Figures 6 and 7 show the current distribution of saltmarsh vegetation in Langstone and Chichester Harbours. Unfortunately, Portsmouth Harbour has not been mapped, but saltmarsh is found in the north central area.

The rise and fall of Spartina

Spartina anglica is a vigorous hybrid of saltmarsh cordgrass which originated in Southampton Water in the latter half of the last century. Its rapid spread can be partly attributed to the fact that it was physiologically able to invade and occupy a position low in the intertidal zone (around mean high water neaps) where other pioneer saltmarsh species like *Puccinellia, Armeria* and *Plantago* found it difficult to survive (Gray *et al.*, 1989, 1995: Gray, 1992). The spread of the introduced *Spartina anglica* across previously uncolonised mudflats lead to the creation of substantial areas of saltmarsh in all three harbours.

Initially *Spartina anglica* was very vigorous, two or three times larger than its current height, but during the middle of this century it began to die-back, reducing the area of coverage and the height of the plants. As the plants lost vigour they became more susceptible to wave action. A vicious cycle was instigated; greater wave energy damaged the plants and this in turn reduced the degree to which the sward could dissipate wave energy and thus wave action on the weakened plants increased. The plants did not immediately die, rather they became stunted and some swards have managed to survive in a reduced state for decades.

Figure 8 shows the changes in area occupied by *Spartina* in Langstone Harbour between 1870 and 1994. The coverage was stable until the introduction of the vigorous hybrid *Spartina anglica* around 1900. After its introduction there was a rapid increase in area followed by a plateau period which lasted until the 1950s when there was a rapid drop. The loss of *Spartina* coverage between its peak and its low point are shown in Figure 9.

Figure 6 1994 Vegetation cover – Langstone Harbour

Figure 7 1994 Vegetation cover – Chichester Harbour

Figure 8 Change in area occupied by Spartina (after Domjam, 1983)

The rise and deterioration of *Spartina* has affected hydraulic and sedimentary processes. Healthy *Spartina* was a very effective natural sea defence. The tall dense fronds exerted frictional drag which dissipated waves and tidal currents to such an extent that the water column was calm enough to deposit fine clay particles. This situation reversed as *Spartina* lost vigour. Shear stresses then became sufficient to erode the fine particles which were deposited during calmer conditions induced by the presence of healthy *Spartina*. Unfortunately, there is no existing data on mudflat levels before *Spartina* colonisation with which to compare to the present situation to see whether the mudflats have eroded to pre-*Spartina* levels.

As *Spartina* in the harbours continues to die down, the risk of coastal erosion and the frequency and volume of wave overtopping increases. The erosion of fine sediments accumulated by *Spartina* increases water depth and hence the potential wave height. The loss of the shoots reduces wave and tidal current dissipation.

Many stretches of the embankments defending reclaimed land are now showing signs of severe erosion, particularly those which had been protected by extensive *Spartina* beds (for example the stretch of Chichester Harbour between Nutbourne and Cobnor Point). Most of the houses built in the areas liable to flooding were constructed after 1945 during or just after the period when *Spartina* distribution was widespread and its growth luxuriant.

It is unlikely that the trend for *Spartina* die-back experienced over the last 50 years will reverse. Moreover, the potential for larger wave heights is likely to continue to increase in the future due to the erosion of the muds accumulated by *Spartina*. Therefore it is likely that the risk of coastal erosion and flooding will increase in the future.

Upper saltmarsh

A study conducted for the RSPB by Portsmouth University (Collins and Fontana, 1996), analysing aerial photographs of Langstone Harbour from 1968 to 1992 concluded that the area of intertidal mud has not changed significantly. This suggests that the low water mark has remained constant, thus the erosion seems to be confined to the higher area formerly occupied by *Spartina anglica*. It is likely that the foreshore levels in the harbours will in time flatten and lower to what they were before colonisation of *Spartina anglica*.

Change in elevation of the mudflats will have a significant effect on wave height. For areas in which degenerate *Spartina* beds are being eroded, the increased water depth will allow larger waves to reach the shore while the wave dissipation

Figure 9 Change in distribution of Spartina (from Haynes and Coulson, 1982)

Upper saltmarsh is now only found in sheltered areas of the harbours such as the lee side of spits and in areas where flood embankments have breached, allowing saltmarsh plants to recolonise (this is the situation at Prinsted Point on Thorney Island).

Historically, upper saltmarsh habitat (characterised by plants such as sea purslane, *Atriplex portulacoides*; sea lavender, *Limonium vulgare* and grasses such as *Puccinellia* and *Festuca rubra*) has been lost through reclamations. Replacement upper saltmarsh has not developed in front of the erected flood embankments due to the low sediment supply. Some of the remaining areas of upper saltmarsh, for example the islands in the RSPB reserve in Langstone Harbour, are suffering edge erosion due to wave attack (average 0.16m/y over the last 7 years - personal communication with RSPB Warden).

Mudflats

There is visual evidence that the level of the mudflat drops after the death of *Spartina* and decay of the roots that bind the sediment. A numerical model study (HR Wallingford, 1994) for Chichester Harbour Conservancy investigated movement of the mud eroding from the area between East Head and the main shoreline, on the east side of Chichester Harbour. The model estimated that 35% - 60% of the mud in suspension was flushed from the harbour. It is thought that the closer the eroding mud is to the harbour mouth, the greater the proportion will be flushed from the estuary. The model predicted that any suspended sediment retained in the harbour moves towards the head of the estuary.

provided by the accreting mudflats at the head of some of the harbour inlets will increase. Hence, coastal erosion and wave overtopping is likely to increase in some areas and reduce in others.

Gravel spits/sand dunes

The mouths of Langstone and Chichester harbours are framed by shingle spits formed from longshore drift. These geomorphological features provide a natural form of sea defence by:

- narrowing the harbour mouths thus restricting the propagation into the harbours of waves generated in the open sea
- protecting areas of coastline in their lee from waves and tidal currents.

If East Head, the largest of the spits was destroyed, the residential area of West Wittering would be at risk from coastal erosion. The erosion risk would be particularly severe as the coastline in this area faces the prevailing west winds, and the harbour is wide at this point so the fetch is significant. This stretch of coastline would be among the most exposed if it was not for the protection afforded by the spit.

Like most coastal features, the shape and orientation of the spits has changed through time in response to fluctuations in forcing factors. Attempts to stabilise the spits with fixed structures have failed as their naturally dynamic form becomes out of equilibrium with the hydrodynamic climate. Obstruction of longshore drift feeding the spits leads to their deterioration and hence a reduction in the degree of coastal protection provided in their lee.

Smaller shingle spits also occur in several locations within Chichester and Langstone Harbours, for example between West Wittering and West Itchenor where they are fed by the erosion of local outcrops of shingle rich formations. The spits are curved to run roughly parallel to the shore, thus creating natural wave breaks that protect the coastline. Added coastal protection is provided by the saltmarsh which develops behind the spit.

Sand dunes have developed on top of the gravel spits on either side of the entrance to Chichester Harbour. If allowed to develop, dune vegetation traps wind-blown sand and raises the height of the spits, thus increasing the degree of flood protection. Dunes also act as a reservoir of sand which can provide extra material to the beach during winter storms. The dunes on East Head significantly enhance the protection that the spit provides to West Wittering. Dune management conducted by the National Trust has successfully built up the dunes.

Figure 10 Tide currents – Peak spring tide flow contours and vectors

3.5 Tidal regime

Tidal currents

Tidal currents for the East Solent were investigated in detail in HR Wallingford (1995a&b). The study used the TELEMAC 2D depth averaged tidal flow model with a variable density mesh to improve resolution in areas of complex bathymetry. The model was run to simulate spring and neap tide flows, plus storm surge conditions, for the existing sea levels and for a projected 260mm sea level rise. The model was calibrated and verified against available Admiralty tidal stream data and field data collected in 1994.

Figure 10 presents the ebb and flood current vectors and speed contours for a spring tide under existing sea level conditions. The contours are for peak flow at each grid point (i.e. not at a single time) while the vectors represent flow at each point at the moment of peak flow in the entrance to Chichester Harbour. The model can also be used to predict: flows at any state of the tide; residual current velocities; the interaction between waves and current, and their combined effect on sediment transport; the impact of surges, future sea level rise and changes to the shoreline or nearshore bathymetry.

The model shows that:

- the strongest currents are found within the harbour entrance channels, with peak speeds at over 1.5m/s
- ebb currents dominate in the harbour entrance, but flood currents are stronger in upper channels
- currents are unlikely to change significantly if sea level rises, and that currents during storm surge conditions are not significantly stronger than existing spring tide currents.

It should be noted that the existing TELEMAC grid has different densities in each of the harbours. Portsmouth and parts of Chichester are represented in detail, while Langstone is represented by a much lower density grid.

Water levels

The tidal regime in the Solent is extremely complex with an extended high water and spatially variable tidal ranges along the coastline (Geodata, 1991). The previous study (HR Wallingford, 1995a & b) investigated extreme water levels and the effects of sea level rise in considerable detail. Table 3 summarizes the available water level information for the locations marked on Figure 9. It is apparent that high water levels and tidal ranges generally increase from west to east. The extreme water levels are important in determining flood risk areas.

Future relative sea level rise, due to the combination of global warming and the ongoing post-glacial movements of the earth’s crust, has been predicted at between 5mm/year (Houghton et al, 1990) and 13mm/year (Bray et al, 1991 & 1992). The accepted level for MAFF funded schemes is 6mm/year for the Solent area. The SMP assumes this level, except for Portsea Island where MAFF have accepted a 10mm/year rise. Given that most coastal schemes will be designed for a 50 year life, then a relative sea level increase of 300mm should be used for design except for Portsea Island where 500mm is considered to be more appropriate.

Comparison of the HR Wallingford study with other tidal data sources (Graff and Blackman, 1977 and Graff, 1981, Coles and Tawn, 1990) indicate that there are some inconsistencies in definition of extreme levels. As definition and evaluation of both mean and extreme water levels is very important to shoreline management, then a field programme should be instigated to improve the regional distribution of long term tide monitoring stations with the aim of establishing future trends in sea level rise and reappraising predicted extreme levels. This work is particularly important for Portsmouth and Gosport as there is some doubt associated with the data used in estimating a 10mm/year rise and the extent of the area over which this value should be applied.

Table 3 Tide levels and predicted extreme water levels (m OD)

Point	LAT	MLWS	MHWS	HAT	Return Period					Estimated 50 year rise (m)
					1	5	10	50	200	
2		-1.84	2.16	2.57	2.70	2.98	3.05	3.18	3.35	0.3
3		-	2.36		2.85	3.13	3.20	3.33	3.50	0.3
4		-1.84	2.16	2.57	2.70	2.98	3.05	3.18	3.35	0.3
5		-	2.36		2.80	3.08	3.15	3.28	3.45	0.3
6		-	2.36		2.90	3.18	3.25	3.38	3.56	0.3
7		-2.14	2.16		2.69	2.96	3.02	3.14		0.3
8		-2.14	2.16		2.69	2.96	3.02	3.14		0.3
9		-2.14	2.16		2.69	2.96	3.02	3.14		0.3
10		-2.14	2.16		2.69	2.96	3.02	3.14		0.5
11		2.14	2.16		2.69	2.96	3.02	3.14		0.5
12	-2.73	-1.93	1.97	2.37	2.46	2.78	2.78	2.90	3.05	0.5
13		-1.93	1.97	2.37	2.46	2.72	2.78	2.90	3.05	0.5
14		-1.93	1.97	2.37	2.46	2.72	2.78	2.90	3.05	0.5
15		-1.93	1.97	2.37	2.46	2.72	2.78	2.90	3.05	0.5

Figure 11 Wave climate

3.6 Wave climate

The processes of wave generation and transformation from offshore to inshore are particularly complex in the East Solent. Storm waves reaching the coast can be generated locally under winds from the southwest through to the east, or in the English Channel. Swell waves generated further afield will also penetrate the area, though heights will be modest.

The narrow entrances to the harbours, particularly in the case of Portsmouth and Langstone, exclude much of the externally generated wave energy. Internal generation (i.e. waves created by wind across the water surface within the harbour) is the most important method of wave creation. Chichester Harbour entrance is wider than the entrances to the other two harbours and allows some external wave energy to enter, predominantly around High Water when waves can pass over East Pole Sands. Due to the direction of the prevailing winds, the west and south facing stretches of coastline in each harbour are most exposed to wave attack.

The wave climate in the harbours between 1971 and 1991 has been predicted from wind data (HR Wallingford, 1995a&b; HR Wallingford, 1996). The HINDWAVE and TELURAY models were used to predict inshore wave conditions at a number of points seaward of the normal wave breaking zone (Figure 11). These models take account of refraction, diffraction and shoaling due to the bathymetry, local wave generation and the presence of tidal currents and the tidal cycle of water levels. Table 4 presents the significant wave heights for different return periods at each point. Figure 12 presents the variation in three categories of wave height (waves exceeded 1%, 10% and 50% of the time) for two of the wave prediction points. The trend has been calculated by linear regression analysis and is represented as a dotted line on the graphs. It should be noted that the vertical scale varies on the two graphs.

Table 4 Extreme wave heights

Point	Depth (mOD)	Significant wave height (m) for given return period			
		1	10	50	200
1	-0.02	1.44	1.67	1.82	-
2	-12.1	2.82	3.42	3.84	-
3	-2.7	1.06	1.26	1.40	-
4	+1.5	0.49	0.55	059	-
5	0.0	0.81	0.94	1.03	-
6	+0.7	0.70	0.82	0.90	-
7	-12.7	2.10	2.42	2.62	-
8	-6.2	0.78	0.90	0.98	-
9	-4.4	0.97	1.13	1.24	-
10	-3.2	0.89	1.06	1.18	-
11	-6.2	0.69	0.80	0.87	-
12	-12.3	1.20	1.34	1.43	-
13	-9.8	0.83	1.00	1.10	1.19
14	0.9	0.62	0.72	0.78	0.83
15	-0.2	0.88	1.02	1.10	1.17

Analysis of the modelled wave conditions over the 20 year period suggest a general increasing trend in wave height in all three harbours, however, there is a marked variation in the rate of increase. Future increases in wave energy and changes in dominant wave directions are likely as a result of increased storminess, shifts in North Atlantic weather patterns and rising sea levels. Erosion of mudflats and further losses of saltmarsh are probable, with consequent increased exposure of the shoreline to wave attack.

Changes in the nearshore wave climate, whether short or long term, will have significant implications for sediment transport and for the effectiveness of the existing coastal defences. Short term monitoring of the local wave climate at several nearshore and inshore locations would allow detailed verification of the existing wave models. Long term monitoring of nearshore waves and of local winds would allow trends in the wave climate to be continually re-evaluated in the management plans.

Figure 12 Trends in wave height from 1971 to 1991 for prediction points 3 and 10

3.7 Sediment transport

Sediment transport within the harbours comprises two processes. Fine suspended material is transported by tidal currents, while both fine and coarse material are transported by waves. Previous studies (HR Wallingford, 1994 and 1995a&b) have investigated transport pathways.

Fine material, which is the predominant sediment type in all of the harbours, is derived from erosion of existing mudflats and the shoreline within the harbours, or is transported in suspension from the East Solent. Model studies indicate that fine material will not settle near the entrance channels and will tend to be drawn out of the harbours on the ebb tide. Further up the harbour channels and in the lee of the spits fine material will tend to settle, resulting in nett deposition. Field observations corroborate these predictions.

Sand can be transported in suspension under the turbulent wave and tide current conditions found in the harbour entrances, or in other parts of the harbours during storm events. Some deposition occurs as flood tide sandbanks opposite the entrance channels of each harbour, but the dominant transport pathway will be seaward out to ebb tide deltas. Small volumes of sand will also be carried further into the harbours to form narrow beach deposits in areas exposed to wave attack. Local erosion of the shoreline provides additional material for these small deposits.

Shingle is only transported when there is significant wave action or very strong tidal currents. Longshore drift along the open coast provides feed to the entrance channel spits, but negligible amounts are carried further in to the harbours. Shingle deposits along the harbour shorelines are derived from local erosion. Weak transport pathways carry material along the shore in a general north and east direction as a result of waves generated by south and westerly winds.

3.8 Joint probability conditions and existing defence standards

The previous HR Wallingford report (1995a&b) assessed the effectiveness of the existing defences during extreme storms. This was done using numerical models of beach response and wave overtopping.

The greatest risk to the shoreline occurs when high waves coincide with high water levels. The probabilities of the joint occurrences of extreme events are expressed in terms of their likely return period in years, and coastal defences are usually designed to resist storms up to a pre-determined return period. As a general guide defences for urban areas are normally designed to prevent significant risk to property or life under conditions with a 1 in 200 year probability of occurrence, while rural areas with predominantly low grade agricultural land might only be protected against 1 in 50 year events, beyond which some property damage would be accepted.

As a first step in assessing defence standards, the areas of risk must be defined. This is not a straightforward matter as risk combines the complex matter of the failure mechanisms for a given type of defence and the consequence of different types of failure. For example, undermining of a short section of seawall may only cause localized damage to a section of promenade, while a major breach of a flood embankment may cause extensive flooding of farmland or damage to major holiday facilities. Within the scope of a SMP it is only possible to consider relatively simple situations and therefore a conservative approach must be taken.

Joint probability

The joint probability of wave and water level extremes requires an informed assessment of the degree of correlation between the two variables, based on long term records and an understanding of the forcing conditions. The conditions set out for the SMP are for guidance only as they are based on worst case conditions for specific overtopping or beach erosion tests.. More rigorous definition is required for design of coastal structures or management operations, particularly in areas of high risk.

Most of the shoreline in the harbours is fronted by shallow water relative to the extreme wave conditions. This means that wave heights will be limited by water depth as they approach the shoreline, therefore making extreme water levels the more dominant condition. Table 5 sets out the extreme water level (SWL) and wave (significant height - H_s and mean period T_m) conditions for return periods of 5, 50 and 200 years for the points shown in Figure 11. The table assumes present day water levels.. Actual conditions at the shoreline will depend on wave transformation inshore from the prediction point.

Areas at risk

The areas considered to be at risk from erosion, overtopping or flooding have been determined from published data (including HR Wallingford 1995a&b, the Environment Agency flood maps, the MAFF Coast Protection Survey and the NRA Sea Defence Survey), site observations and discussions with the responsible engineers. For the purpose of the SMP a conservative approach has been adopted which should be refined for later strategy plans.

Figures 13 and 14 present the potential flood areas and the frontages at risk from erosion. The flood areas are taken as the extent of land below the maximum 1:200 year water level, but the probability of flooding to the extent shown would be much more remote for most areas. Flooding to the extent shown would require major breaches of the defences allowing inundation over the peak of the storm event although there are some areas where the existing defences are not up to the level of the predicted 1:200 year water level. In addition it must be noted that there is no adequate land survey data to support the flood contours shown, except on Hayling and Portsea Islands. Areas of particular concern based on land use, residual life of existing defences and extent of flood area include the following:

- Old Portsmouth, Paulsgrove, Hilsea, Forton, Alverstoke and Portchester in Portsmouth Harbour
- Anchorage Park, Eastney, Farlington Marshes and Stoke in Langstone Harbour
- Eastoke, Tournerbury Farm, North Hayling and other areas along Hayling Island, Emsworth and West Wittering in Chichester Harbour.

Seawall overtopping risks are not included in the figure but were calculated for the HR Wallingford study (1995a&b). Overtopping of walls can cause extensive flooding, particularly if the sea level is close to the wall crest. Unfortunately there are considerable lengths of the coastline where the defences are not even as high as the predicted 1:200 year level, so flooding will occur without the need for a breach or wave induced overtopping. Areas of particular concern with respect to overtopping include:

- Paulsgrove and Portchester in Portsmouth Harbour
- Eastern Road, Portsea Island in Langstone Harbour
- Emsworth, most of east Hayling Island and Langstone in Chichester Harbour.

The erosion risks indicated on the figure are based on a combination of existing erosion and the potential for erosion if the present day defences are not maintained. The shoreline is broken into three categories from moderate actual or potential erosion to no significant erosion. The harbour shorelines are not affected by the high energy wave conditions found on the open coast, so there are no areas of high erosion risk. Future erosion will depend on changes to the wave climate and changes to the saltmarsh distribution. Areas of particular concern include:

- the landfill sites west of Wicor in Portsmouth Harbour, due to potential environmental and landscape damage
- Milton Bund and Broadmarsh in Langstone Harbour due to potential landfill exposure, and the shoreline along the West Hayling rail line due to flood risk and loss of amenity (the oyster beds are to be improved under a 3 year contract from 1997)
- the southwest faces of Thorney Island and the Chidham peninsula in Chichester Harbour, though neither area is developed (the MoD plan to strengthen and raise the Thorney Island defences).

Table 5 Worst case joint probability conditions

Point	Return period (years)	SWL (mOD)	Storm waves	
			H_s (m)	T_m (s)
1	5 50 200	2.81 3.11 3.15	0.95 1.08 1.20	3.49 3.72 3.92
2	5 50 200	2.81 3.11 3.18	1.74 2.00 2.25	2.82 3.02 3.21
3	5 50 200	2.96 3.26 3.50	0.69 0.78 0.87	1.92 2.04 2.15
4	5 50 200	2.91 3.21 3.28	0.34 0.38 0.42	1.91 2.01 2.12
5	5 50 200	2.91 3.21 3.41	0.58 0.58 0.58	1.75 1.75 1.75
6	5 50 200	3.01 3.35 3.66	0.43 0.43 0.43	1.51 1.51 1.51
7	5 50 200	2.69 2.98 3.04	1.47 1.63 1.78	3.97 4.18 4.36
8	5 50 200	2.69 3.02 3.14	1.57 0.64 0.65	1.74 1.85 1.86
9	5 50 200	2.79 3.08 3.14	0.65 0.73 0.80	1.86 1.97 2.07
10	5 50 200	2.79 3.08 3.14	0.57 0.65 0.72	1.74 1.86 1.86
11	5 50 200	2.79 3.08 3.14	0.44 0.51 0.57	1.53 1.65 1.74
12	5 50 200	2.57 2.83 2.90	0.88 0.97 1.04	2.50 2.63 2.72
13	5 50 200	2.09 2.46 2.72	0.79 0.86 0.86	2.90 3.03 3.03
14	5 50 200	2.72 2.90 3.05	0.39 0.46 0.46	2.04 2.22 2.22
15	5 50 200	0.82 0.90 1.02	0.82 0.90 1.02	3.23 3.36 3.55

3.9 Future changes

An understanding of possible future situations is important to the development of sustainable management. As present trends cannot necessarily be taken as a guide to the future then it is important to consider a range of likely changes.

Recent research studies (Houghton et al, 1990; Bray et al, 1992; Jelliman et al, 1991; Brampton, 1993) have considered possible changes to water levels and waves. It is generally accepted that present rates of sea level rise are likely to increase. Predicted future rates vary from 5mm/year to 13mm/year. Similarly it is also accepted that the wave climate is changing. Although long term predictions are not consistent, it is likely that storm frequency and offshore wave heights will increase. No predictions have been accepted for shifts in wave directions.

Given these potential developments then a number of shoreline changes are likely:

1. Increased water levels will increase potential overtopping rates, causing significant areas, including developed residential areas, to have an unacceptable risk of flooding. If wave energy also increases this effect will be magnified.

2. Increased wave energy and water levels will tend to increase erosion of the upper foreshore, saltmarshes and mudflats, leading to greater overtopping and greater risk of structural damage to seawalls, revetments or embankments.

3. Increased water levels will tend to increase tidal flows through the harbour channels, possibly leading to a widening of the channels, with consequent increased wave penetration into the harbour basins.

3.10 Existing monitoring programmes

There are no coordinated existing monitoring programmes within the harbours. Each of the authorities undertakes *ad hoc* surveys of defences. There have been several research projects on the state of the saltmarshes within the harbours and various environmental groups maintain records of bird populations. Chichester Harbour Conservancy are undertaking photogrammetric surveys of habitats in association with Portsmouth University. None of this work has been coordinated and the data is not centrally stored.

Figure 13 (section a) Flood and erosion risk – Portsmouth and Langstone Harbours
Ref: V3-Fig 13

Figure 13 (section b)

Figure (section a) 14 Flood and erosion risk – Chichester Harbour
Ref: V3-Fig 14

Figure 14 (section b)