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
- stabilisation 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 the open coastline and Pagham Harbour, while the companion Volume III covers the situations in Chichester, Langstone and Portsmouth Harbours.

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. Figure 2 and Figure 3 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 Solid and drift formations

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 3 Surface geology

During this same period Selsey Bill would have been developing as a headland due to the local protection offered by scarps of resistant Bembridge limestone, now several kilometres seawards. The headland would have formed a drift divide and, over time, the supply of sediment from offshore would have been diverted eastwards towards Pagham with diminishing supply to Bracklesham Bay. Continuing sea level rise would have reduced the protection afforded by the limestone scarps, allowing the rate of erosion at Selsey Bill to increase. This erosion would have fed the beaches both to the east and west.

In its natural state, the Selsey - Portsmouth coastal system probably operated as a linked series of beaches and offshore stores (ebb tidal deltas) that cycled existing sediments towards sinks around the harbour entrances. The upper beaches were, and still are, primarily shingle, with a lower beach of sand overlying the sub-stratum. Erosion and onshore shingle movement would have provided materials.

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 and Chichester entrances) and for aggregate (especially Horse and Dean Sand for Portsmouth Harbour reclamations) have removed large quantities of sand and shingle 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 (1991a,b&c).

3.3 Beach sediment distribution

The beaches of East Solent open coast are mainly shingle upper and sand lower as a result of their geological evolution. Construction of seawalls and groynes, and the placing of recharge, have influenced the natural beach form resulting in a narrowing of the upper shingle beach in some areas.

Detailed sediment sampling has not been undertaken or otherwise investigated for this SMP. Beach types have been assessed by observation only. Information from laboratory analysis is not required for transport modelling as the influence of sediment size is only important in wide grading bands (i.e. sand *vs* shingle). Apart from being unnecessary in the context of an SMP, beach sampling can provide misleading results as sediment gradings vary rapidly both temporally and spatially. If detailed information is required for specific design purposes, then local field studies could be undertaken. Harlow (1978, 1979a&b, 1980) presents sediment information for some areas.

3.4 Historical evolution

Changes to the East Solent coastline have been recorded since Roman times, but the most reliable information is available from Ordnance Survey map analysis using the 1867-75 County Series as a baseline and the NRA (Environment Agency) photogrammetric data for recent changes. The Pagham Harbour to River Hamble study (HR 1995a & b) presents the changes in some detail as do Harlow (1980) and Hooke and Riley (1987). These studies concentrate on the development of the High Water line, but also consider the Low Water line where reliable information is available. The impact of coastal defence works and dredging on the shoreline are discussed.

The following sections summarise the information and its relevance to the SMP. Areas are discussed in accordance with dominant drift directions. Figure 4, Figure 5, Figure 6 present the changes to the High Water line since 1870. The inset figures indicate the rates of change for specific locations over the same period. Changes to the low water line are not mapped as this information is much less reliable. Notes are added to the map for areas of significant low water change.

Selsey Bill to Pagham Harbour

Comparison of historic maps of the Selsey area from Roman times through to the present shows that major changes to the shoreline have occurred. Rapid erosion of the “Raised Beach” deposits at the headland released vast quantities of shingle and sand to feed littoral drift eastwards to Pagham Harbour and the West Sussex coast and westwards towards Chichester Harbour. The main area of erosion prior to construction of the seawall and groynes in 1956 was along East Beach where the High Water line had retreated by about 150m over a period of about 60 years. As new beach material now arrives only sporadically from the nearshore banks to the south of the Bill then erosion continues although the High Water line is constrained by the seawall and groynes. Groyne maintenance and beach renourishment has been required in recent years to maintain an effective beach.

Downdrift from East Beach towards Pagham the shoreline has undergone periods of both erosion and accretion. Recently the shoreline has been either stable or accreting as it benefits from losses at East Beach, from onshore transport across the Inner Owers and from the construction of timber groynes. The shingle spit at Pagham Harbour has undergone many changes over time, but has been generally stable since the entrance channel was fixed by sheet piling in 1963. Recent evidence has shown some recession but this may only be temporary. The Pagham Harbour area is a major sink for shingle and sand, with material arriving from the Pagham Estates beach to the east as well as from Selsey to the south. The southern spit is relatively narrow and has been maintained in recent years by regular recycling operations.

Pagham Harbour has undergone many changes over time. Prior to construction of the flood embankments and the raised causeway for the road, Selsey was an island separated from the mainland by mudflats. From 1876 to 1910 the harbour was entirely enclosed by the spit and the present intertidal land was reclaimed for grazing. Breaching of the spit in 1910 and the maintenance of the present channel since 1963 have caused this land to revert to saltmarsh.

Selsey Bill to East Head

Erosion at Selsey Bill and onshore transport from the nearshore banks off the Bill have provided substantial volumes of drift to this frontage, but this has not prevented the soft cliffs northwest of Bracklesham from undergoing rapid erosion. The cliffs suffered erosion rates of 1-2m/year and the shingle bank between Selsey and Bracklesham has been breached, most notably in 1910 when Selsey temporarily reverted to being an island. Groynes were built along the West Wittering frontage in the last century and extensive groyne fields were constructed in stages along the shingle bank at Medmery and the Witterings up to 1938. The west beach at Selsey from the Bill to Mill House was protected by a seawall in the 1950s, leaving only a few short sections unprotected. Further major works were constructed at East Wittering in 1964 and a recharge scheme has been in operation between Selsey and Bracklesham since 1974. Cliff erosion continues along a short frontage immediately west of Selsey where no protection works are in place.

The lower foreshore from Selsey to West Wittering is undergoing a slow process of erosion, though there is little documented data on the rate of lowering of the sand over clay forming the lower part of the beach.

East Head has undergone a major change over the past 100 years. Early maps show a substantial shingle spit extending northwest across the Chichester Harbour entrance. In the late 19th century the spit apparently rotated by 90° towards its present northeastern orientation and altered in character from a shingle bank to sand dunes. This change occurred mainly before any significant coastal defences were in place and was therefore a result of natural changes to the coastal environment. The present sand spit is considered to be reasonably stable except at the neck, known as The Hinge. Since the turn of the century work has been carried out to prevent breaching, including construction of groynes and gabions. The dunes on the main spit have been actively managed since the 1970s.

Figure 4 (section a) Historical evolution – Pagham Harbour to East Head
Ref: V1-Fig04

Figure 4 (section b) Historical evolution – Pagham Harbour to East Head

Figure 5 (section a) Historical evolution – Hayling and Portsea Islands
Ref: V1-Fig05

Figure 5 (section b) Historical evolution – Hayling and portsea Islands

Figure 6 (section a) Historical evolution – Portsmouth Harbour entrance to River Hamble
Ref: V1-Fig06

Figure 6 (section b) Historical evolution – Portsmouth Harbour entrance to River Hamble
Ref: V1-Fig06

Chichester Harbour entrance channel and bay were dredged in 1988 to re-establish the published safe navigation depth. 20,000m^3 were removed and dumped as spoil.

Hayling Island

Hayling Island is low lying and has suffered rapid erosion and flooding. Residential and commercial development of the open coast began in the 1930s with the construction of beach huts and bungalows on the backshore of the wide shingle bank at East Hayling. By the late 1930s coastal defences, including a wall, revetment and groynes, had been built to protect the new properties. These defences were extended both west and east in stages until 1974 when they covered 2.6km of the frontage west from Eastoke Point. In 1985 a major shingle recharge was undertaken along East Hayling and further work involving rock revetments and groynes has been carried out recently at Eastoke Point to prevent a breach of the shingle bank.

East Hayling has been particularly difficult to defend as the nearshore and beach transport processes are subject to significant seasonal and annual change. Inshore wave transformation is influenced by strong tidal currents and shifting nearshore banks and channels; minor changes in offshore wave direction can cause beach drift directions to reverse with severe consequences for beach erosion and wave overtopping.

The central and western parts of the Hayling Island shoreline are largely undeveloped and have tended to accrete. This is particularly so at Gunner Point where the shoreline has moved seaward by some 200m this century, resulting in the development of multiple shingle ridges.

The East Winner bank was dredged for aggregate until 1994. Volumes of between 30,000m³ and 40,000m³ were removed annually between 1955 and 1994. Dredgers worked the bank before 1955 but records are not available.

Portsea Island

The open coastline of Portsea Island is largely formed by a substantial shingle bank, the eastern part of which has a history of stability or accretion. The major area of recent accretion is to the east between Fort Cumberland and the outfall at Eastney Point. To the west there is some long term foreshore steepening around Southsea Castle where a variety of defences have been built to stabilise the High Water line. Beyond these walls and groynes is a further area of shingle beach leading up to Clarence Pier which acts as a large groyne. From Clarence Pier to Old Portsmouth the High Water line is defined by sea walls and fortifications, some dating to the 15th Century. Little change of the foreshore is recorded for this frontage.

Offshore of Portsea Island are the Horse and Dean Sand which have been heavily dredged in the past to provide fill and aggregate for reclamation and construction works in Portsmouth Harbour. This area is a sink for sediment transport along the shoreline, and dredging has had little apparent impact on the shoreline.

Gilkicker Point to Portsmouth Harbour

The High Water line of this frontage is defined by the Haslar seawall, protecting MoD property. The wall has been in place for over 140 years. The low water line has moved shoreward over time requiring extensive footings along the seawall.

Solent Breezes to Gilkicker Point

The sandy cliffs of Bracklesham Beds topped by plateau gravels extending east and west of the Solent Breezes holiday camp are undergoing erosion. Apart from the frontage immediately along Solent Breezes the cliffs are unprotected. The erosion feeds a slow drift to the east with accumulations west of Titchfield Haven, and from the River Alver outfall to Gilkicker Point. Erosion has also occurred from Hill Head to Browndown with the highest rates at Crofton Cliffs southeast of Hill Head. Groynes, revetments and seawalls have been built at various times along this frontage to stabilise the High Water line. A beach recharge scheme with large rock groynes will be completed at Lee-on-the-Solent during 1996. Major outfalls affect the beach at Crofton Cliffs causing updrift accumulations and downdrift starvation.

The low water line has also retreated along this frontage. The greatest shift has been off Lee-on-the-Solent where the low water line has moved shoreward by 175m this century.

Solent Breezes to River Hamble

A littoral drift divide occurs around the Solent Breezes. As there is no significant onshore feed of fresh beach material then the area suffers a nett loss of material and erosion of the cliffs. Transport northwest of Solent Breezes is predominantly towards the River Hamble. Rapid accretion rates have given rise to a substantial shingle spit beyond the end of the low eroding cliffs. The spit, known as Hook Spit, extends for 1.5km and encloses a large area of saltmarsh which drains into Hook Lake near the mouth of the River Hamble. The lake is enclosed by a masonry wall with a sluice connection to the river.

The proximal end of Hook Spit is subject to breaching and concrete blocks have been dumped along the upper foreshore to breakup wave attack. The spit provides shelter to the low lying estuary margins up to Warsash. Low walls protect Hook Lake and the School of Navigation under normal conditions, but are subject to overtopping during storms and high water levels. The wall extends to Warsash Pier after which there is a short stretch of low cliff subject to slow erosion. At Warsash the shore road and car park area are subject to occasional flooding. The reclaimed land used for boat yards and light industry at Warsash provides a convenient endpoint to the SMP area.

Evolution summary

The present shoreline of the East Solent is a result of very active post-glacial processes of erosion and accretion, increasingly controlled by coastal defences and beach management activities during this century. Rapid erosion of soft cliffs has occurred around Selsey Bill, from Bracklesham to East Head, and from Lee-on-the-Solent to the distal end of Hook Spit. Substantial erosion and roll back of the shingle banks has occurred along the shoreline from Selsey to Bracklesham, at East Head, along the eastern frontage of Hayling Island and along part of the Browndown frontage. Concurrent accretion has occurred at Pagham Harbour, Gunner Point on Hayling Island, Eastney on Portsea Island and from the River Alver outfall to Gilkicker Point at Gosport.

Groynes, seawalls and revetments constructed over the past century have stabilised the high water line along most of the frontage, but continued erosion of the lower foreshore has resulted in a steepening of the beaches. A consequent spiral of increasing erosion puts ever greater pressure on the defences and emphasises the need for long term shoreline management.

Figure 7 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 over 20 years. The model was calibrated and verified against available Admiralty tidal stream data and field data collected for the study in 1994.

Figure 7 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.

Figure 8 presents the tidal current residual speed contours and directional vectors for a Spring tide cycle. These residuals are important in driving sediment transport in areas outside the breaker zone. The model can also be used to predict: flows at any state of the tide; the interaction between waves and currents, and their combined effect on sediment transport; and to predict the impact of surges, future sea level rise and changes to the shoreline or nearshore bathymetry.

The model shows that:

- ebb currents (westward) are generally stronger than flood (eastward)
- the strongest currents are found off East Beach, Selsey Bill, Gilkicker Point, and within the harbour entrance channels
- residual currents are an important component of the transport regime off Selsey Bill where they oppose the dominant wave induced currents, and in the harbour entrances where they give rise to ebb tide deltas
- currents are unlikely to change significantly if sea level rises, and currents during storm surge conditions are not significantly stronger than existing spring tide currents.

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 summarises 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 (MoD)

Point	LAT	MLWS	MHWS	HAT	Return Period (years)					Estimated 50 year rise (m)
					1	5	10	50	200	
A			2.48	2.85	2.99	3.31	3.38	3.53	3.69	0.3
1		-2.55	2.55	2.92	3.06	3.38	3.45	3.60	-	0.3
2		-2.3	2.48	2.89	3.03	3.35	3.42	3.57	-	0.3
3		-2.10	2.40	2.78	2.91	3.21	3.28	3.43	-	0.3
4		-1.98	2.28	2.69	2.82	3.11	3.18	3.32	-	0.3
5		-1.84	2.16	2.57	2.70	2.98	3.05	3.18	-	0.3
6		-1.84`	2.16	2.57	2.70	2.98	3.05	3.18	-	0.3
10	-2.73	-1.93	1.97	2.37	2.46	2.72	2.78	2.90	-	0.5
11		-1.93	1.97	2.37	2.46	2.72	2.78	2.90	3.05	0.3
12		-1.88	1.92	2.28	2.40	2.65	2.71	2.83	2.97	0.3
13		-1.88	1.82	2.16	2.27	2.51	2.57	2.68	2.82	0.3
14		-1.94	1.76	2.10	2.21	2.44	2.50	2.61	2.74	0.3

Figure 8 Tidal current residuals for a spring tide cycle

Figure 9 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 Isle of Wight offers protection from the most severe waves in the Channel, but the level of this protection varies greatly along the frontage. Wave conditions at Selsey Bill and along East Beach are severe as these areas are exposed directly to waves from the south and east and to diffracted waves generated by southwesterly winds in the Channel. Further west the exposure to waves generated outside the Solent decreases. West of Southsea Castle up to Solent Breezes wave energy increases slightly and the dominant direction changes due to the increased southwesterly fetch up the West Solent. Waves in Pagham Harbour are generated locally and are only of significance at higher water levels.

Nearshore wave transformations are complex due to the variable bathymetry and the presence of strong tidal currents. At Selsey Bill the shoreline is offered protection by the nearshore limestone scarps and shingle banks. Further west the wide lower beaches and submerged banks also offer protection, while the strong ebb and flood currents around the harbour entrance channels have a variable impact on waves as they move inshore. These influences vary according to water level and the neap-spring cycle of tidal currents.

The wave climate for the area is considered in detail in HR Wallingford 1995 (a & b). The HINDWAVE and TELURAY models were used to predict inshore wave conditions at a number of nearshore points. These models take account of refraction, diffraction and shoaling due to the bathymetry, the presence of tidal currents and the tidal cycle of water levels. Work is also presented on swell waves, the effect of climate change and extreme wave conditions based on a Weibull distribution.

Table 4 Extreme wave heights (non-directional)

Point	Depth (m OD)	Significant wave heights (m) for given return periods				
		1 year	10 year	50 year	100 year	200 year
A	*	0.37	0.44	0.48		
1	-4.7	3.94	4.72 +	5.24 +		
2	-4.7	4.60 +	5.53 +	6.10 +		
3	-4.7	3.87	4.58 +	5.04 +		
4	-4.7	4.32	5.20 +	5.79 +		
5	-0.2	1.44	1.67	1.82		
6	-12.1	2.82	3.42	3.84		
8	-12.7	2.10	2.42	2.62		
9	-4.7	1.22	1.37	1.46		
10	-12.3	1.20	1.34	1.43		
11	-4.7	1.39	1.58	1.71	1.76	1.81
12	-4.7	1.24	1.41	1.52	1.57	1.61
13	-4.7	1.27	1.47	1.60	1.65	1.70
14	-4.7	0.97	1.14	1.26	1.31	1.36

* Treated as deep water. Waves too small to be breaking.
+ Unbroken wave heights. Actual wave heights will be depth limited to about 4.5m

Table 4 presents the predicted wave conditions at the points indicated by Figure 9. The figure presents directional wave roses for each of the points to indicate dominant directions.

Analysis of the local wave conditions over the past 20 years suggests that changes in the wave climate have already occurred, with far reaching implications for shoreline management of erosion, accretion and flood risks. Figure 10 presents variations over 20 years in three categories of wave height (waves exceeded 50%, 10% and 1% of the time) and in mean wave directions. The locations selected are representative of conditions throughout the area. The plots also show linear regression lines.

Figure 10 Trends in wave heights and wave directions from 1971 to 1991

Figure 11 Transport path for sand and shingle (Inset: mean annual nett potential shingle drift rates)

Wave modelling of the East Solent also suggests that changes in offshore wave heights due to increased storminess and/or rising sea levels will cause a near linear change in inshore wave heights. However, a shift in wave direction due to a shift in the North Atlantic weather patterns, will cause a more complicated change inshore: a clockwise shift in offshore wave direction will cause a clockwise shift in nearshore waves from Selsey Bill to Pagham, but an anti-clockwise shift to nearshore waves further west due to the protection afforded by the Isle of Wight. The opposite will occur if there is an anti-clockwise shift offshore.

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 transformation 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.

3.7 Sediment transport

Sediment transport along the East Solent open coastline has been discussed in detail in the previous study (HR Wallingford 1995a & b). The study utilised advanced numerical models and related the results to geomorphological studies and field observations (Dyer, 1976; Wallace, 1984, 1990 & 1994; Sudo, 1991) and the South Coast Seabed Mobility Study (HR Wallingford, 1993).

It should be noted that transport predictions are subject to the limitations of theoretical understanding of processes, algorithm development and the availability of high quality field data, particularly regarding wave forces within the intertidal zone. Areas with complex wave and tidal regimes, such as the East Solent, are difficult to simulate and model predictions can be misleading. The following discussion and figures attempt to summarise the important aspects of the sediment transport regime that are relevant to the area planning requirements of the SMP. Detailed information required for specific scheme designs can be obtained from the earlier HR Wallingford study. Repetition of the results of that study in isolation from the background information on modelling approaches and input information is considered unnecessary and potentially misleading.

Figure 11 indicates the dominant drift directions and presents an inset showing the mean annual *potential* shingle drift rates calculated using derived nearshore wave conditions for the period from 1971 to 1991. Figure 12 indicates the annual variability in gross and nett drift rate at Eastoke and serves as a warning of the potential misunderstanding of the complexity of predicted drift rates. These figures are discussed further below.

Sediment sources

Natural sediment sources for the Plan area beaches were:

- relict nearshore deposits of post-glacial sand and gravel (Figure 3)
- eroded material from the low soft cliffs along the shoreline at Selsey Bill, East Wittering and from Lee-on-the-Solent to beyond Solent Breezes
- eroded material from exposed nearshore outcrops of bed rock
- material lost to ebb tide deltas at the entrance channels to the four harbours and subsequently returned under favourable conditions.

Present day sources are limited by the protection of formerly eroding cliffs and by the dredging of the ebb tide deltas. A major source is now the recharge material placed at East Beach, Bracklesham Bay and Eastoke. Further information on nearshore sediment movement can be found in the South Coast Seabed Mobility Study (HR Wallingford, 1993).

Littoral drift

Littoral drift along the open coast is dominated by breaking wave processes. Tidal currents have a strong influence around the headlands of Selsey Bill and Gilkicker Point, and around the harbour entrance channels, through direct transport and through their effect on shallow water wave transformation. Drift rates have been calculated or estimated by various studies. Some have considered total transport of sand and shingle while others have separated the two components. The recent HR Wallingford study calculated potential drift rates at a number of points along the frontage (potential rates assume that there is no restriction on the supply of material); most of the points considered shingle transport only. These rates and directions are indicated in Figure 11. Other studies have used beach volume changes to estimate actual drift.

Potential drift rates vary with wave energy and wave direction. The mean wave direction, weighted for swell and wind sea energy from each direction sector, was used in HR Wallingford (1995 a & b) to determine long term shingle drift rates as well as changes in annual drift rates over the past twenty years. The highest potential rates were calculated for East Beach, Selsey at around 30,000m^3/year. High rates of about 15,000m^3/year were also found around the entrance to Chichester Harbour and along West Beach, Selsey. The Selsey area is affected by high wave energy as it benefits least from the protection offered by the Isle of Wight. Further west wave energy reduces due to increasing protection from waves generated in the English Channel. Mean wave directions also change as waves from the eastern approaches to the Solent become dominated by waves generated locally in the Western Solent. Potential nett transport rates along Bracklesham Bay and west of Chichester Harbour are low at less than 5000m^3/year. Actual rates are even lower due to the influence of groynes and the lack of available material.

Gross rates in either direction may be much higher than the predicted nett rates, making beach management difficult; single storm events can have a marked effect on the annual rates, causing beaches to be very volatile. Beach monitoring is thus particularly important in this area as transport models are indicative only and cannot provide absolute drift rates in an area of variable sediments, variable wave climate and strong tidal currents. Figure 12 presents gross and nett rates at Eastoke over a 20 year period and indicates the level of annual variability that can occur in a complex area such as the East Solent.

Beach transport is predominantly north-eastwards from Selsey Bill towards Pagham and north-westwards from Selsey Bill towards Portsmouth. The beach at Selsey is fed by intermittent onshore transport from nearshore banks formed of relict deposits and renewed by tidal current dominated nearshore transport. The majority of this material is believed to feed East Beach rather than West Beach. Reports by Wallace (1988 and 1994) and Southampton University (SUDO 1991) provide details of transport processes around Selsey Bill inferred from geomorphological studies and field research.

The high northwards potential drift rate along East Beach reduces along the Pagham Harbour Spit due to the impact of the nearshore Inner Owers Bank and the ebb tide delta off the harbour mouth. Studies by Southampton University (SUDO, 1991) have shown that the Pagham Harbour ebb delta is sufficiently prominent to dampen waves and to refract them round so that there is a local drift reversal from Pagham Beach Estate towards the harbour entrance. This counter-drift means that, from the viewpoint of coastal management, the Pagham Beach Estate forms a sensible eastern boundary to the SMP area, albeit not a closed boundary.

From the Bill towards Portsmouth Harbour the shelter against south-westerly waves gradually increases and drift becomes increasingly dominated by southerly and south-easterly waves. These waves, in combination with strong currents in the Chichester Harbour Channel, promote a transfer of material from the Selsey peninsula to Hayling Island.

Hayling Island receives considerably less material than it did in the past when Chichester Bar was a more effective bypassing mechanism. In recent years the bar has diminished in size (Webber, 1979) and the entrance has deepened, making it more difficult for material, particularly shingle to be transferred to the Island from the Selsey peninsula. Onshore movement can still be observed to be taking place via the West Pole but the volumes are believed to be diminishing. The Island does not have any significant input of supply from the seaward nor is there any fresh source of material produced by coastal erosion. The coastal sediment budget, as on the Selsey peninsula, is therefore negative making recharge an important management requirement.

At the western end of Hayling the increased shelter against easterly wave action reduces the bypassing capacity of Langstone Harbour channel, hence the long term accretion at Gunner Point. On the west side of the inlet, drift along the Portsmouth frontage is very low and this promotes conditions for long term beach accretion at Eastney, encouraged by the sheltering effect of Horse and Dean Sand.

Little drift passes the Southsea Castle headland and littoral drift along the western end of the Portsmouth frontage at Southsea is low. The coastal defences which have been in place for many years at the mouth of Portsmouth Harbour have fixed the high water line resulting in a very narrow foreshore due to the long term tendency for beach erosion. This, coupled with low energy wave conditions, means that littoral drift and the supply of material to the entrance is now very small indeed. Some sand and shingle is swept onto the banks on either side of the approach channel to Portsmouth Harbour.

Sand transport paths along the lower beaches are less clearly understood than the shingle transport of the upper beaches. Beaches to the east of the Bill are characterised by a steep shingle foreshore with a tidal channel close inshore. There is little evidence of sand deposits except at the Bill itself and an admixture of sand at the Pagham Harbour entrance. By contrast there is a wide sand foreshore at low tide immediately west of the Bill. The presence of sand at the Bill suggests a possible throughflow of fine sediment from the east linked to a back eddy on the eastern flank of the Bill (Wallace, 1994). Due to a lack of contemporary sediment supply, sand beach levels at the Bill have been falling in recent years, resulting in the frequent exposure of Bracklesham Clays. Further west at West Wittering/East Head beach profile analysis indicates that sand levels are stable or accreting.

The coastline from the River Hamble to Portsmouth is dominated by southwesterly waves, causing southeasterly drift except for the frontage north of Solent Breezes, where the northwesterly drift has given rise to Hook Spit. Erosion of the soft cliffs and nearshore seabed around the drift divide at Solent Breezes provides shingle and sand to the sediment budget. Cliff erosion rates reduce to the southeast and shingle accretion occurs updrift of Hill Head harbour. Erosion begins again at Hill Head, but shoreline protection in the form of groynes and seawalls hold the high water line as far as the south end of Lee-on-the-Solent. Onshore migrating shingle bars are believed to feed the beach south of Hill Head. Drift continues southwards to feed the shingle forelands at Browndown and along Stokes Bay. Shingle tends to accumulate around the River Alver outfall, causing maintenance problems. Some drift passes Gilkicker Point and enters the ebb tide dominated processes of the Portsmouth Harbour entrance channel, though the volume is considered to be low.

Nearshore and offshore transport

Bedform surveys (Dyer, 1972), diver observations (Wallace, 1984, 1990, 1994), analysis of dredging operations (Fishbourne, 1977) and numerical modelling (HR Wallingford 1993 and 1995a&b) have been considered in determining transport pathways below low water and out to the deep channels of the Solent. The dominant processes in this area are tidal currents. Nett transport rates in the deep channels are low and generally run south-eastwards out of the Solent. To the south and east of Selsey Bill the nett transport is southwestwards for suspended load, including kelp rafted shingle which has been observed to form an important part of the total drift in this area. From the Portsmouth Harbour entrance channel to Selsey Bill there is believed to be a nett movement southeastwards in the broad nearshore zone, driven by the dominant ebb tidal flows; this general pattern is complicated by the channels and ebb tide deltas of the harbours, and by onshore transport driven by wave action.

From the Portsmouth Harbour entrance channel to the River Hamble the nearshore and channel transport paths are even more complex. There is an anticlockwise circulation around Brambles Bank, giving a nett northwesterly movement from Lee-on-the-Solent to the River Hamble and an easterly movement in the deeper channel to the south. Within Stokes Bay there is little nett movement. East of Gilkicker Point sand and shingle is carried towards Portsmouth entrance, but is flushed back by the strong ebb flows feeding the sediment sinks at Spit Sands and Horse and Dean Sand.

Future drift

3.8 Joint probability conditions and existing defence standards

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

Figure 12 Nett and gross annual drift rates near Eastoke, 1971 - 1991

Future patterns of sediment transport can not be predicted with any certainty as they will depend on management operations and changes in the wave climate, tidal regime and water levels. Best estimates can be made based on recent trends in wave climates, which in general are becoming more energetic and are shifting clockwise (HR Wallingford, 1995a & b).

These wave climate changes suggest that the high north easterly drift to the east of Selsey will increase, while the much lower north westerly drift west of Selsey will decrease still further and may even reverse direction. The low nett drift westward from Eastoke may also decrease, causing further complexity in this area of annual variations (Figure 12).

Low southeasterly drift from Solent Breezes towards Gilkicker Point may increase resulting in accelerating erosion of the unprotected cliffs northwest of Hill Head and further deposition around Stokes Bay. Drift north from Solent Breezes to Hook Spit may decrease, improving the stability of the cliffs, but causing starvation of the Spit.

It must be noted that the wave climate trends may not continue, and will, in any case, not be sufficiently constant to allow great confidence to be placed on predictions of the future.

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 localised damage to a section of promenade, while a major breach of a shingle ridge may cause extensive flooding of hundreds of hectares of farmland or damage to major holiday facilities.

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 joint probability values set out for the SMP are for guidance only as they are based on the worst case conditions for specific overtopping or beach erosion tests. More rigorous definition is required for detailed design of coastal structures or management operations, particularly in areas of high risk.

Most of the shoreline 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 of the two. Table 5 sets out the extreme conditions for return periods of 5, 50 and 200 years for the points shown in Figure 9. These conditions are all based on the -4.7m OD contour unless marked otherwise. They also assume present day water levels.. Actual conditions at the toe of the beach or seawall will depend on wave transformation inshore from the prediction contour.

Table 5 Worst case joint probabilities conditions

Point	Return period (years)	SWL (m ODN)	Storm waves	
			H_s (m)	T_m (s)
1	5	3.19	2.50	5.40
1	50	3.53	2.85	5.76
1	200	3.60	3.18	6.09
2	5	3.16	2.90	5.35
2	50	3.50	3.32	5.72
2	200	3.57	3.70	6.04
3	5	3.03	2.53	5.24
3	50	3.36	2.87	5.58
3	200	3.43	3.18	5.88
4	5	2.93	2.69	5.87
4	50	3.25	3.09	6.29
4	200	3.32	3.46	6.66
5[1]	5	2.81	0.95	3.49
5	50	3.11	1.08	3.72
5	200	3.18	1.20	3.92
6[2]	5	2.81	1.74	2.82
6	50	3.11	2.00	3.02
6	200	3.18	2.25	3.21
8[3]	5	2.69	1.47	3.97
8	50	2.98	1.63	4.18
8	200	3.04	1.78	4.36
9	5	2.61	0.91	3.12
9	50	2.88	0.99	3.26
9	200	2.94	1.06	3.37
10[4]	5	2.57	0.88	2.50
10	50	2.83	0.97	2.63
10	200	2.90	1.04	2.72
11	5	2.72	0.99	3.25
11	50	2.90	1.11	3.44
11	200	3.05	1.11	3.44
12	5	2.65	0.96	3.20
12	50	2.83	1.08	3.40
12	200	2.97	1.08	3.40
13	5	2.27	1.13	3.47
13	50	2.27	1.44	3.92
13	200	2.27	1.54	4.05
14	5	2.31	0.68	2.69
14	50	2.61	0.68	2.69
14	200	2.74	0.68	2.69

[1] Point 5 - Depth = -0.2m OD

[2] Point 6 - Depth = -12.1m OD

[3] Point 8 - Depth = -12.7m OD

[4] Point 10 - Depth = -12.3m OD

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, MAFF Coast Protection Survey (MAFF, 1994) and NRA (Environment Agency) Sea Defence Survey (NRA, 1991)), 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, 14 and 15 present the potential flood areas, the frontages at risk from erosion and the potential shoreline assuming a “do-nothing” management approach over 50 years. 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. 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 include the very extensive low lying farmland around Pagham Harbour and across to Bracklesham Bay, the residential areas of Eastoke and the environmentally important area around Gilkicker Lagoon.

The erosion risks indicated on the figures 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 four categories from high actual or potential erosion down to no significant erosion. In some area, such as Browndown Ranges or Gunner Point, erosion trends have been variable over long time periods; however in these cases the consequences of short term erosion are minimal so they are classified according to recent trends. Areas of particular erosion concern include the National Grid frontage north of Solent Breezes, Eastoke Beach, the shingle ridge and adjacent unprotected cliffs between Bracklesham and Selsey, the headland at Selsey Bill and East Beach at Selsey. The potential shoreline changes are presented only for areas subject to erosion and not flooding. They are based on a “do nothing” management approach and assume the historical erosion rate, modified for the expected life of the existing defences (MAFF and NRA surveys modified after site observations) and their continued influence after failure. In some areas, such as the Old Portsmouth frontage, continued erosion may not cause failure of the defences but may render them unsafe for their secondary functions of providing public access to the seafront and protection of historic sites.

Seawall overtopping risks are not included in the figures but were calculated for the HR Wallingford study (1995a&b). Overtopping can cause extensive flooding, although volumes of water will be less than result from a breach. Low overtopping rates may not cause flooding, but can cause local damage to structures or may be hazardous to pedestrians or motorists if roads or promenades follow the shoreline.

The seawalls around Selsey are predicted to suffer the greatest overtopping, depending on the level of beach along the frontage. At East Beach peak rates under a 1:5 years event are sufficient to cause damage to shoreline structures and to put the public at risk along the immediate shoreline. Under the 1:200 years event the overtopping rates will cause severe damage and flooding of the low lying ground behind the walls.

At West Beach, Selsey, the rates are lower and there is no low lying land to flood, but property and structures close to the wall will be damaged. Overtopping along East Wittering and at Sandy Point will cause similar localised damage. At Eastoke the predicted overtopping will cause local damage, and will result in flooding of low lying residential areas if the beach levels are not maintained. Frontages along Portsea Island are subject to some overtopping, and low lying areas of Old Portsmouth are liable to some flooding.

The Haslar Seawall suffers minor overtopping along much of its length. At the southwest end of the wall the crest elevation drops to only 3.8m OD and severe overtopping is predicted in the event of beach drawdown. Under the 1:200 years event, damage to shore front structures and extensive flooding of the Gilkicker Lagoon area is likely.

A short length of seawall along the Stokes Bay shoreline protects the coast road along the backshore. Overtopping of this wall under a 1:5 year event is sufficient to make use of the road dangerous. Under more severe events the overtopping could cause localised flooding.

Overtopping rates at Hill Head harbour predict some localised risk of damage. The previous HR study did not examine the possibility of overtopping for the low cliff fronting the National Grid tunnel, but recent minor flooding highlights the future problems likely in this area.

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 over 50 years. 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 and that wave directions may shift.

Given these potential developments, and an ever decreasing natural supply of sediment, then a number of shoreline changes are likely:

1. Increased wave energy and water levels will tend to increase erosion of beaches. Where the beach forms the main existing defence then the potential for major breaches and flooding increases with time. Where the beach is in front of a seawall then erosion will lead to greater overtopping and greater risk of structural damage.

2. Increased water levels will tend to increase tidal flows through the harbour channels, leading to more prominent ebb deltas and greater nearshore wave refraction. Greater refraction at Pagham and Chichester Harbour entrances will enhance the drift separations at Pagham Estate and Eastoke, leading to increased local erosion.

3. Changes in wave directions, even by small amounts will lead to changes in the sediment budget. Decreasing potential drift due to more shore normal waves will lead to reduced erosion; conversely, increasing potential drift will lead to increased erosion. As many areas of the frontage have very low nett drift rates due to their orientation with the dominant wave direction, then a shift in offshore wave direction may cause a reversal in drift. Although different amounts and directions of shift will have different effects, it is possible to say that any changes, whether long or short term, will lead to important changes in the sediment budget.

4.

Figure 13 (section a) Flood and erosion risk – Pagham Harbour to East Head
Ref: V1-Fig13

Figure 13 (section b)

Figure 14 (section a) Flood and erosion risk – Hayling and Portsea Islands
Ref: V1-Fig 14

Figure 14 (section b)

Figure 15 – (section a)Flood and erosion risk- Portsmouth Harbour entrance to River Hamble
Ref: V1-Fig 15

Figure 15 (section b)

Figure 16 Field monitoring sites

3.10 Existing monitoring programmes

A number of monitoring programmes are ongoing in the area and much of this information has been used in HR Wallingford (1995a&b):

- The Environment Agency undertake annual aerial surveys of the whole area within their south coast programme. Photogrammetry is used to produce profile plots, although the quality of the work has been questioned due to insufficient ground control in some areas.

- Tide levels are monitored at the Portsmouth Naval Dockyard and at the Langstone Harbourmaster's landing stage, by Havant Borough Council off Eastoke (since 1995) and by Arun DC at a new installation (1996) in the east of the area off Rustington.

- Wave measurements have been undertaken at a number of sites including the Owers Light Vessel (1968-69) and off Hayling Island (Whitcombe, 1995) but these programmes are not ongoing. Havant Borough Council have installed a pressure sensor to monitor waves off Hayling Island (1996).

- Wind data have been collected at a number of sites suitable for use in wave modelling, including Lee-on-the-Solent and Thorney Island. Havant BC established a permanent Met Station at Eastoke in 1994. Arun DC are collecting meteorological data at their new (1996) permanent installation to the east off Rustington.

- Profile surveys have been undertaken along many parts of the shoreline for specific purposes and as part of co-ordinated, long-term programmes. Portsmouth City, Havant Borough, Fareham Borough and Arun District Councils undertake regular surveys of their open beaches.

- Tidal currents have been measured at a number of sites by the Admiralty, HR Wallingford, Havant Borough Council and others. Coverage is good at the entrances to Chichester and Langstone and further south to the east of the Isle of Wight. No current meters have been deployed around Selsey. Float tracking has been undertaken around Selsey specifically for the TELEMAC model calibration.

- Bathymetric surveys are undertaken by Havant Borough Council and Arun District Council for beach management purposes, and by the harbour authorities for navigation purposes.

- Defence inspections are carried out at regular intervals by each of the Operating Authorities.

Figure 16 indicates the extent of the existing monitoring programmes.