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C1 ASSESSMENT OF SHORELINE DYNAMICS

C1.1 Introduction

Since the completion of the original Western Solent and Southampton Water, and East Solent Shoreline Management Plans (SMPs), there is now significant new information resulting from strategic studies, coastal monitoring and coastal defence schemes, aswell as changes in environmental designations and legislation. Furthermore, there have been significant nationally-focused studies such as FutureCOAST, National Flood and Coastal Defence Database (NFCDD), National Coastal Erosion Risk Mapping (NCERM) and new flood zone mapping that need to be taken into consideration. DEFRA have also produced updated guidance on production of SMPs.

It is appropriate therefore that the coastal process information is reviewed and,
where necessary, revised to take account of these intervening studies; this enables the long-term sustainability of the shoreline to be considered and assists in determining clear policies based on both the original data used in developing the first generation SMP and the updated data and scientific knowledge.

This section summarises the historical evolution and present state of knowledge of the geomorphological and ecological systems, and the physical processes in operation across the North Solent. It also predicts future response of the geomorphological and ecological systems in the face of climate change. A number of previous studies were reviewed, including:

- FutureCOAST
- Western Solent and Southampton Water Shoreline Management Plan
- East Solent Shoreline Management Plan
- Coastal Defence Strategy (CDS) Studies
    - West Solent (not concluded)
    - River Itchen, Western Shore, Netley and Hamble (draft)
    - Portchester Castle to Hoeford Lake (completed, not approved)
    - Falkland Gardens and Esplanade Seawall (completed)
    - Portsea Island (approved)
    - Portchester to Emsworth (draft)
    - Hayling Island North (not concluded)
    - Eastoke Point (completed)
    - Pagham to East Head (approved)
- SCOPAC Sediment Transport Study
- Channel Coastal Observatory Annual Reports
- Pagham Harbour to River Hamble Study (HR Wallingford, 1995a&b)
- Other relevant studies such as the Solent Coastal Habitat Management Plan (CHaMP, 2003), Solent Dynamic Coast Project (SDCP, 2008) and SCOPAC Barriers and Spits research (*in progress*).

This section draws upon the recommendations from the DEFRA SMP guidance (DEFRA 2006), which suggests considering large-scale/long-term shoreline changes and local-scale/short-term shoreline changes. In order to predict future response of a geomorphological or ecological system, the historical evolution and interaction with the forcing physical processes must be understood. A brief description of the study area is provided in terms of its geology and Holocene evolution, followed by a summary of the natural forces and geomorphology. The main sediment sources, stores and sinks are then described for three large scale units across the North Solent. The study area is then broken down further into smaller, local geographical units, where historical and future shoreline evolution is investigated in more detail.

C1.2 SMP Overview

The FutureCOAST study (FutureCOAST, 2002) considered that the North Solent region was located within a behavioural coastal system that extended from Selsey Bill, West Sussex to Durlston, Dorset, including the Isle of Wight, Hampshire. The North Solent is a highly complex region, comprising open coast and harbours that are partially sheltered by the Isle of Wight. Beaches, vegetated shingle, low lying cliffs, sand dunes, inter-tidal habitats, lagoons and coastal grazing marsh comprise the geomorphological and ecological systems located on the open coast and in the harbours, the majority of which are designated for their nature conservation value. There are great variations in coastal morphology and processes operating over short distances due to changes in coastal orientation, exposure/sheltering, elevation and geology. Figure C1.1 presents the geomorphological forms across the North Solent, whilst Figure C1.2 presents the ecological systems.

Aswell as being rich in biodiversity, the North Solent is highly developed and has a thriving tourist industry. Competition for space has resulted in market values of land for potential habitat re-creation selling for three times the rate of agricultural land (SDCP, 2008). Because the North Solent is highly developed, 80% of its shoreline is protected from flooding and erosion (Figure C1.3). The geomorphological and ecological systems are heavily managed and engineered and do not always behave in a natural manner.

The past, present and future forms of the North Solent shoreline are shaped by anthropogenic constraints, the antecedent geology, natural forces and coastal vegetation (East Solent SMP, 1997). The natural forces operating in the North Solent include locally generated waves and swell waves in the East Solent, tidal and meteorologically induced water levels, tidal currents, winds, and fresh water flows.

These forces act on the mobile surface material or solid geology causing physical processes such as, erosion, accretion and flooding. These physical processes have been influenced by man’s activities since Roman times (East Solent SMP, 1997). The majority of sediment input into the North Solent system is either locked up in rivers behind toll gates, behind coastal protection and flood defence works or has been reclaimed over the years (Figure C1.4).

Some sediment sinks of the North Solent have undergone aggregate dredging for construction works. In the past, spoil from maintenance dredging would be dumped at the Nab Tower. These activities have contributed to a depleted sediment budget on the whole. Therefore beach renourishment and recycling are central to management on a number of beaches throughout the region to offset losses. Beach Management Plan sites within the North Solent SMP area include Hurst Spit and North Point, Lee-on-the-Solent, Hayling Island, Witterings and Selsey.

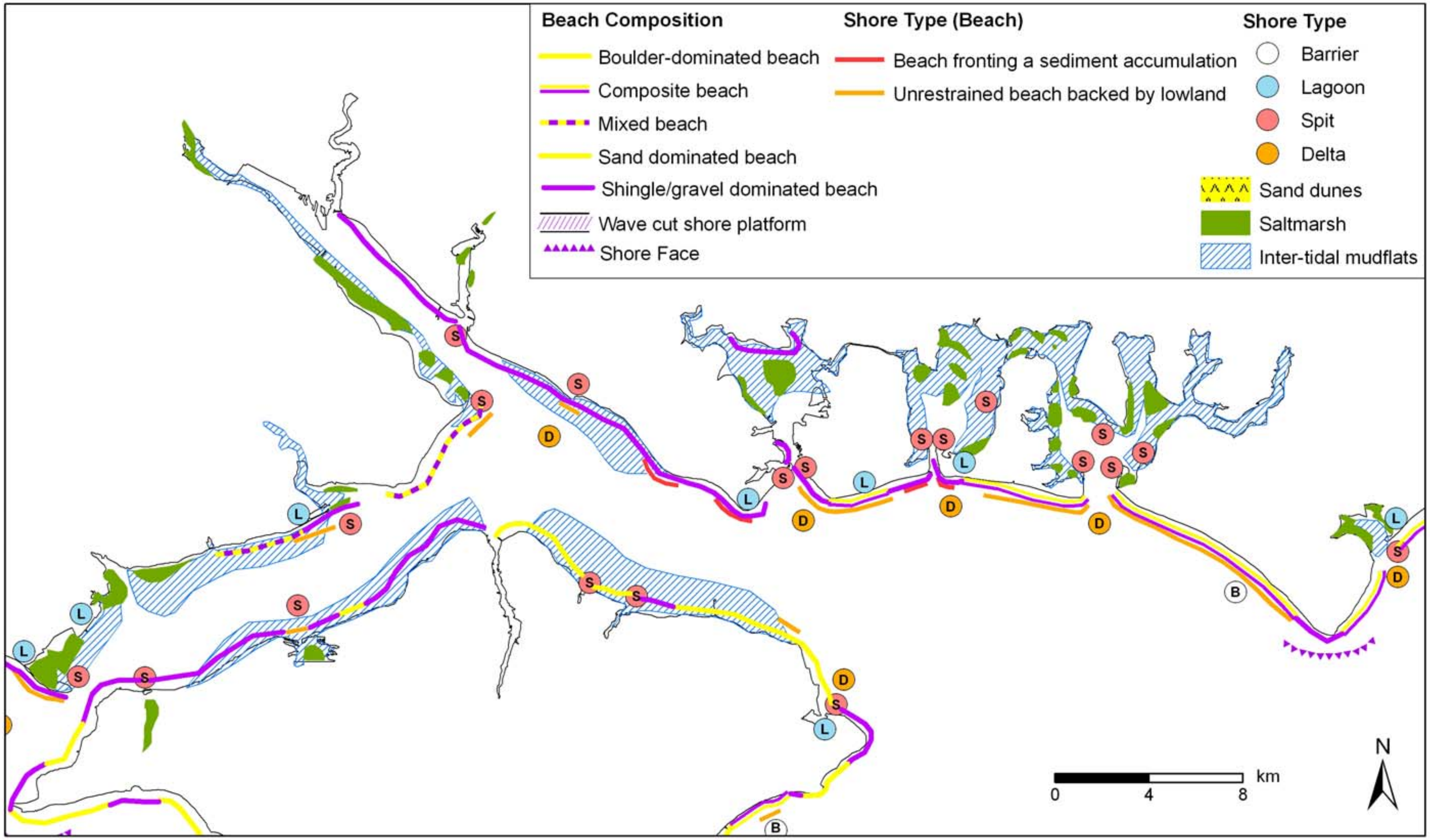

Figure C1.1: Geomorphological forms across the North Solent, taken from the RESPONSE project (2006)

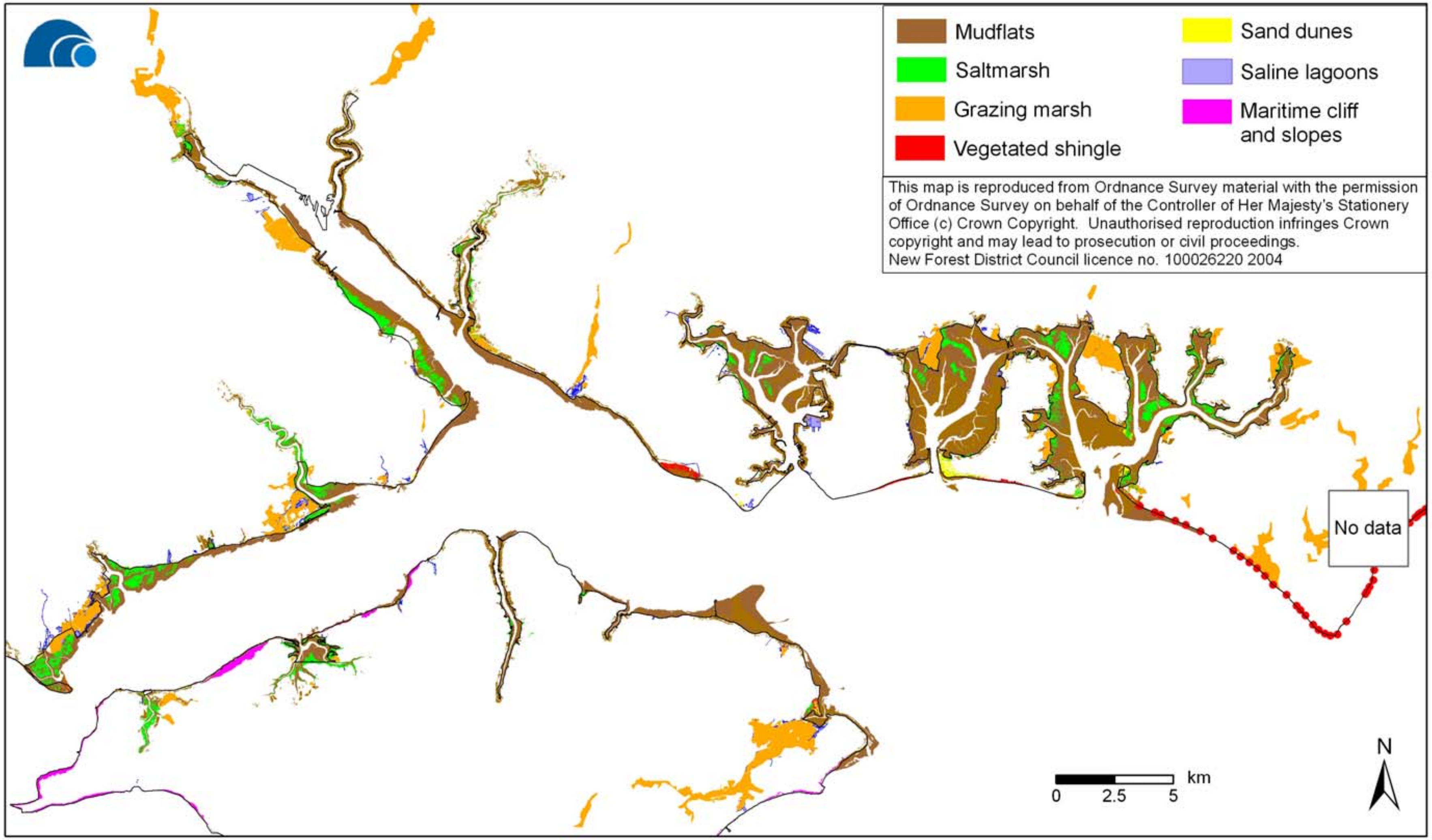

Figure C1.2: Coastal Biodiversity Action Plan habitats across the North Solent (SDCP, 2008)

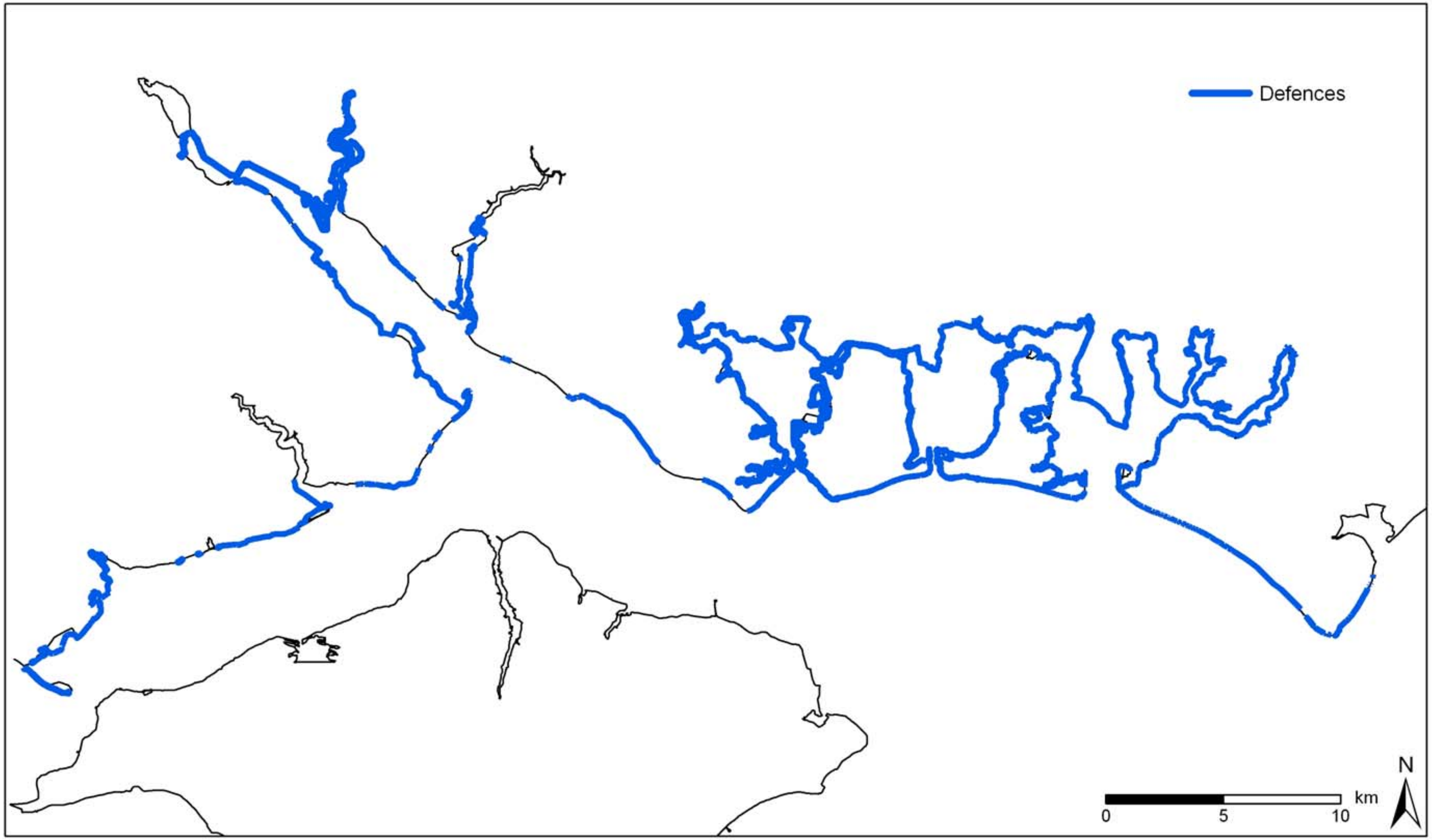

Figure C1.3: Existing shoreline defences across the North Solent

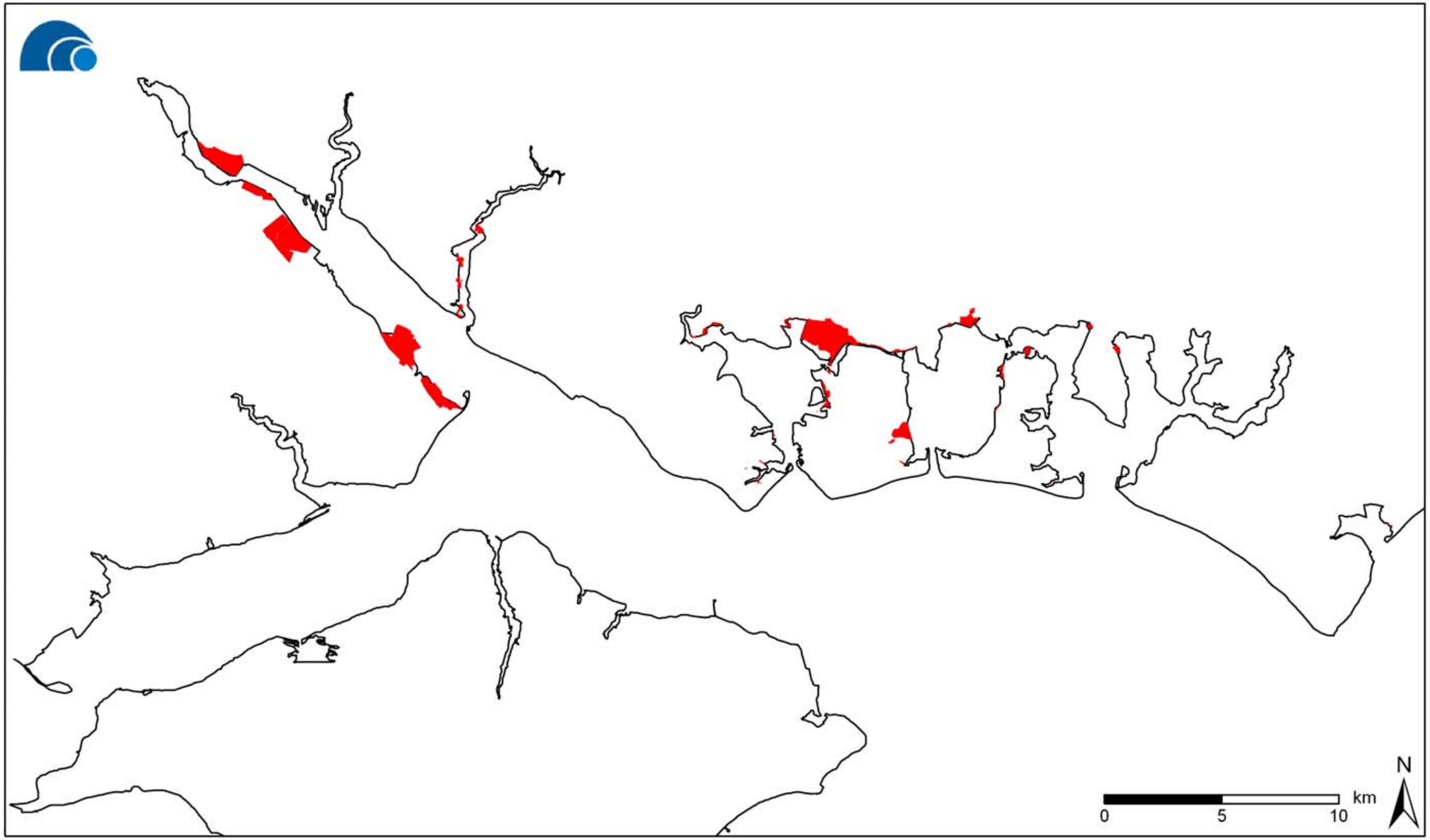

Figure C1.4: Reclaimed areas across the North Solent since 1940 (SDCP, 2008)

The East Solent SMP (1997) notes that the physical processes 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.

C1.2.1 Geology

The following information has been taken from the British Geological Survey, East Solent SMP (1997) and Western Solent and Southampton Water SMP (1998).

The underlying bedrock of the North Solent comprises Barton, Bracklesham and Bagshot beds, chalk, Hampstead beds and Bembridge marls, London clay, Lower greensand and Oldhaven, Blackheath, Woolwich and Reading and Thanet beds (Figure C1.5). These are overlain with alluvium, brickearth, sand and gravel of uncertain age and origin, blown sand and soft clay from the Caenozoic[*] era (see Figure C1.6 for example of the east Solent).

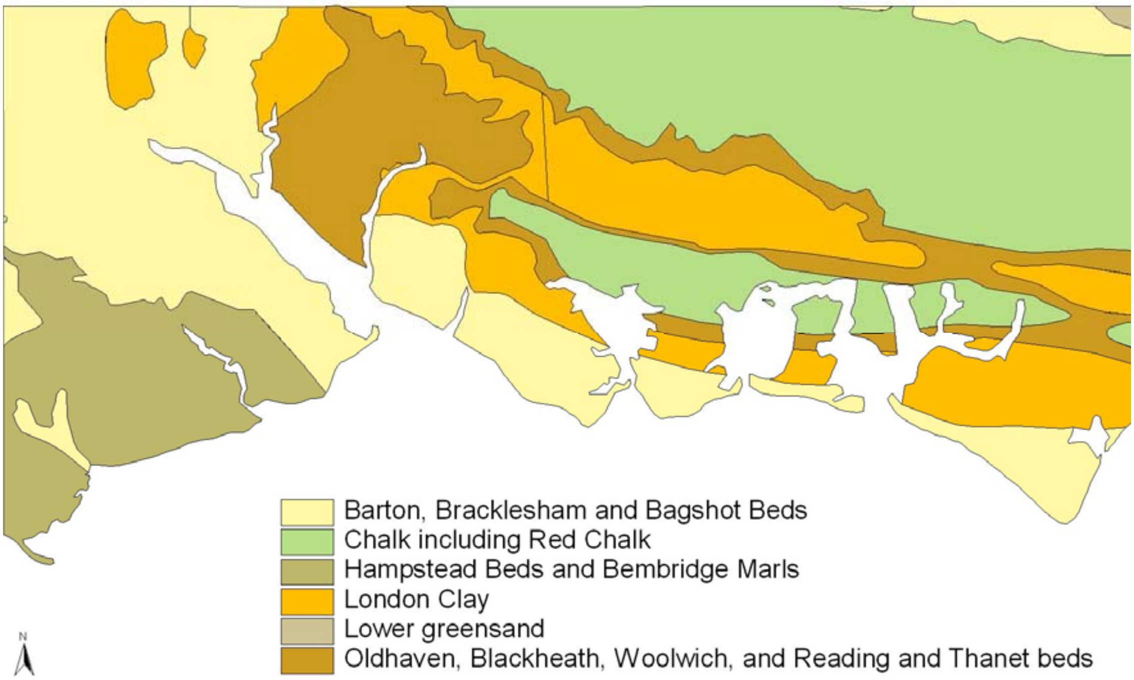

Figure C1.5: Solid geology of the North Solent

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[*] Otherwise known as the "Tertiary" epoch (65 and 2 million years old). The term "Tertiary" is no longer recognized as a chronological term.

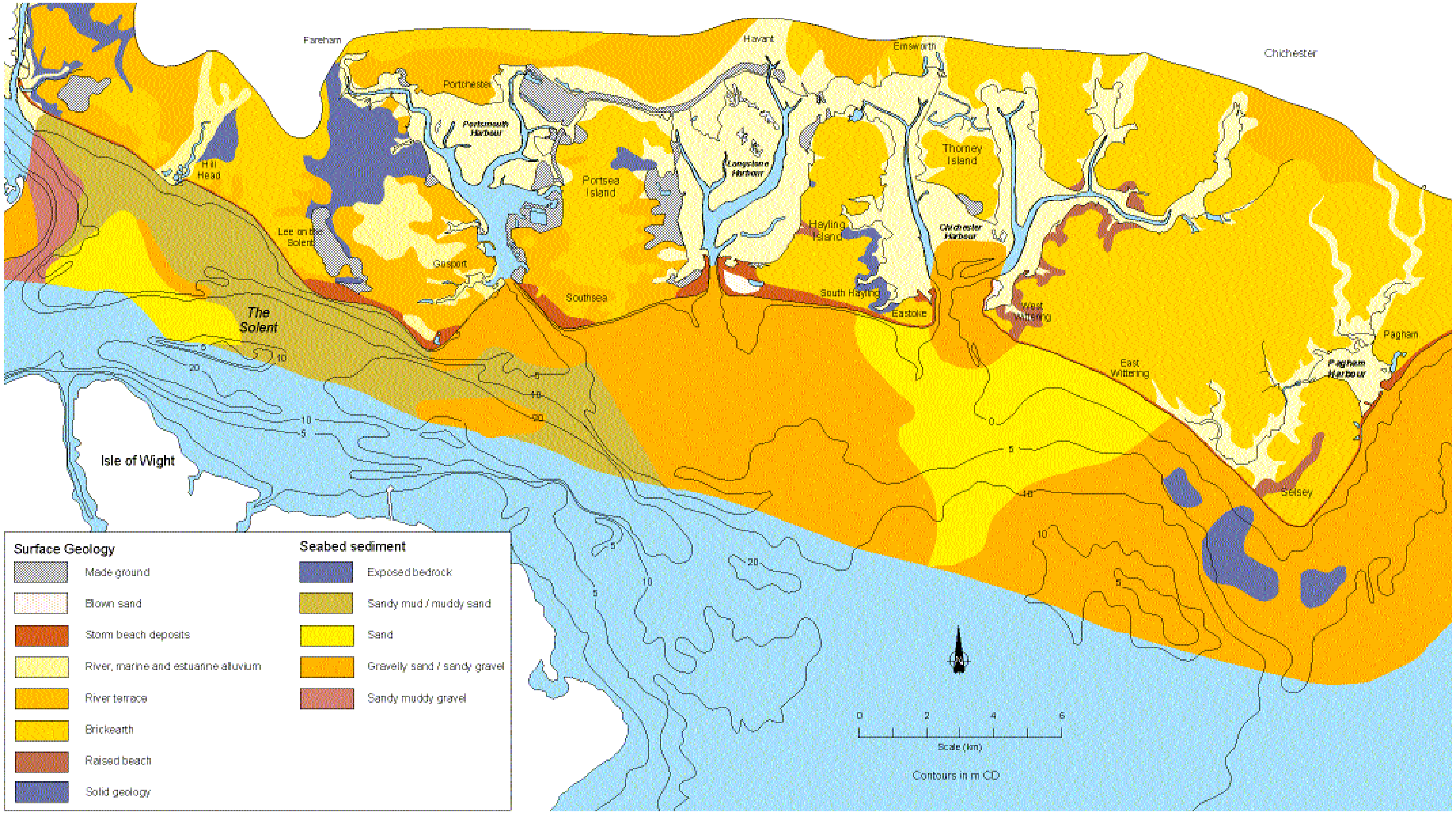


Figure C1.6: Surface geology and nearshore sea bed sediments

C1.2.2 Holocene evolution

Evidence suggests that the Solent was an ancient River that flowed across south east Dorset and southern Hampshire into a major "English Channel" river (Figure C1.7). The Solent River developed during the late Devensian glaciation when sea levels were as much as 120m below the present level (East Solent SMP, 1997); Table C1.1 summarises the archaeological periods and associated estimated sea levels.

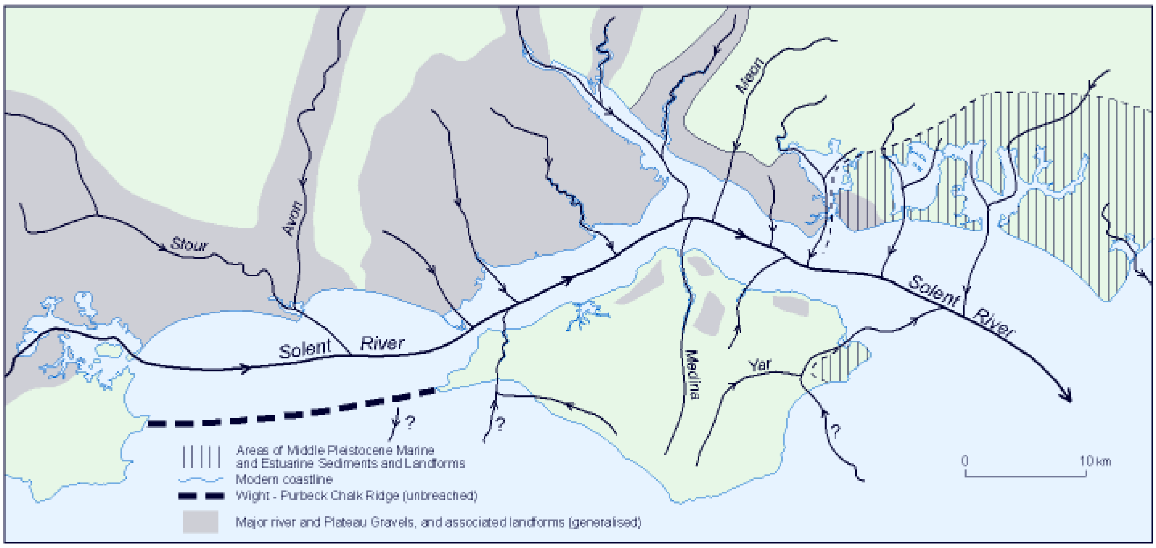


Figure C1.7: The Solent River, Early – to Mid Quaternary (SCOPAC Sediment Transport Study, 2004).

Archaeological Period		**Year**	**Geological Epoch**	**Approximate Sea level**
Prehistoric	Palaeolithic	450,000-1,000BC	Pleistocene (1.65M to 10,000BP)	-130m OD (16,000BC)
			Holocene (10,000BP to present)	-30m OD (8,000BC)
				-15m OD (6,500BC)
	Mesolithic	1,000–4,000 BC		
	Neolithic	4,000-2,000BC		-6m OD (4,000BC)
	Bronze Age	2,000-600BC		-2m OD (500BC)
	Iron Age	600BC-AD43		
Roman		AD43-410		
Medieval		AD410-1485		
Post Medieval		AD1485-1900		
Modern		AD1900-present		

Table C1.1: Summary of Archaeological time periods

The following has been taken from the East Solent SMP (1997) and the SCOPAC Sediment Transport Study (Bray, Carter and Hooke, 2004).

15,000 years BP to 5000 years BP

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 dredging industry. Rising sea levels caused the proto-Test Valley (lower Southampton Water) to be flooded by approximately 7000 years BP.

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 in the East Solent and protecting marshy lowlands. Relict beach deposits have been identified on the sea-bed in Bracklesham and Hayling Bays.

8600 years BP to 6800 years BP

Between 8600 and 6800 years BP the Purbeck chalk ridge (Figure C1.7) connecting the present day north-west Isle of Wight and Hampshire mainland was breached, creating a connection with the shallow but rapidly expanding Christchurch Bay. Sea-level at this time would have been -16 to -18mOD. Subsequently, tidal currents and wave action widened and deepened Hurst Narrows, introducing large quantities of gravel into the West Solent. The latter was rapidly widened, and the former channel of the Solent River deepened, in less than 2000 years (Momber, 2000; 2002).

6000 years BP to 3600 years BP

Between 6000 and 3600 years BP sea-level rise was interrupted by an apparent regression phase, with freshwater replacing saltmarsh at Hythe (Southampton Water) at circa 5500 years BP. Terrestrial peat also accumulated at Stansore Point (Western Solent) between 5320 (+/-200) and 3750 (+/-105) years BP, possibly in a lagoon site. Several other Sub-Boreal organic sediment horizons have been described from the Solent. These include (i) peats at -2 to -3.6mOD below Pennington Marshes, which may have accumulated below a seepage line at the base of a Solent River gravel terrace; (ii) buried peats in front of Hurst Spit, which must have originally formed behind it, thus demonstrating that it has migrated at least 400m during the past 4500 years; (iii) peats, with frequent fossil tree remains ("submerged forests") on the contemporary inter-tidal shorefaces of Stokes Bay (Gosport), Hill Head, Southsea and several locations on the Isle of Wight; and (iv) freshwater peat at -2.8mOD at Dibden Bay (Southampton Water), dated at 5040 (+/-60) years BP.

Although much of the above evidence points towards a Sub-boreal regression, it is possible that sea-level was stationary or slowly rising during this period. The buried peats detailed above may reflect the ability of estuarine sedimentation to keep pace with submergence.

3600-3300 years BP

Although the evidence is not secure, there is a possibility of sea-level stillstand or major reduction in rate of rise between 3600-3300 years BP.

3300 years BP to present day

Commencing at approximately 3500 to 3300 years BP in the eastern and western Solent, and 3000 BP in lower Southampton Water, minerogenic mudflat and saltmarsh sediments overlying late Sub-Boreal buried peats indicate a period of relative sea-level rise. There was probably some acceleration of sediment input associated with human deforestation of catchments drained by river systems tributary to the Solent.

Gravel barrier beaches would have initially migrated landwards with rising sea-level, but might have been segmented and eventually submerged during one or more excursions of accelerated sea-level rise. Some occur at depths of nearly -20mOD, and several would appear to have come to rest on submerged eroded platforms between -10 and -5mOD (e.g. Pullar Bank and Horse Sand Fort – see Figure C1.8). These either represent ancestral abandoned multiple barriers of earlier Holocene age or involve modern redistribution of Solent River terrace deposits. Variations in sediment supply may also have contributed to episodes of barrier building and breakdown.

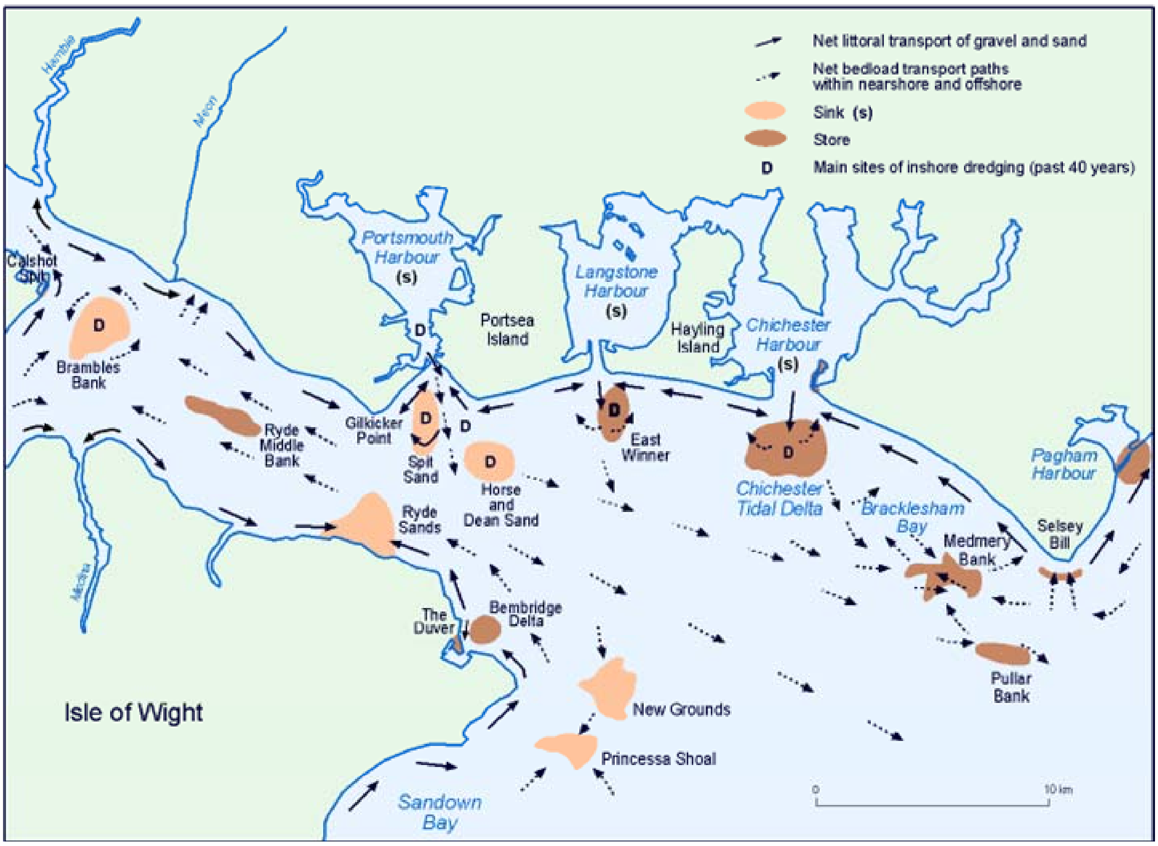


Figure C1.8: East and Central Solent: sediment transport, stores and sinks (SCOPAC Sediment Transport Study, 2004)

Evidence from Langstone Harbour reveals late Neolithic (mid Sub-Boreal) terrestrial peats at between -1 to -0.5mOD. Contemporary organic sediments from the Quarr-Wootton (Isle of Wight) foreshore and lower Southampton Water are between -2.5 and -3mOD, thus suggesting that brackish conditions did not occupy much of the Langstone shallow tidal basin until approximately 2000 years BP. Perhaps barrier breakdown had to occur before Langstone Harbour could be invaded by late Holocene sea-level rise; and this observation may also apply to other harbours in the eastern Solent, notably Portsmouth, Chichester and Pagham. However, a series of incised channels within the main Langstone Channel, cut to a maximum depth of -8.75mOD, suggests the possibility of one, or several, earlier events of barrier breaching and reformation at the basin entrance.

Extensive flooding of the lowland margins of the eastern and western Solent is well documented for the tenth and fourteenth centuries AD, as a result of barrier destruction. However, these relatively catastrophic coastline changes may have been the product of a series of very high magnitude storms superimposed on a background rate of sea-level rise of approximately 1-1.5mma-1. This rate has prevailed for much of the last 3,000 years, until the acceleration of recent decades (extracted from the SCOPAC Sediment Transport Study).

C1.2.3 Wave climate

Waves within the Solent are controlled by local fetches and exposure to waves penetrating from the eastern and western Solent entrances (FutureCOAST, 2002). The dominant direction of wave approach in the Solent is from the south-west, although a significant amount of wave energy can also approach from the south and south-east. Typically, higher waves reaching the North Solent coast are generated locally under winds from the southwest through to the east; swell waves generated further offshore also penetrate the area.

Due to the presence of the Isle of Wight and Hurst Spit, significant wave heights are considerably higher, and wave climate more severe in the eastern parts of Christchurch Bay, and offshore of Hayling and Medmery than within the relatively sheltered Solent, Southampton Water and the harbours. Wave conditions at Selsey Bill and along Selsey East Beach are more severe as they are exposed directly to waves from the south and east and to some extent from the waves generated by southwesterly winds in the English Channel. Further west in the Solent, the exposure to waves generated outside the Solent decreases. Between Southsea Castle and Solent Breezes wave energy increases slightly and the dominant direction changes due to the increased southwesterly fetch up the West Solent.

Within the Solent region, the longest record of wave measurements is from a Waverider buoy deployed in Christchurch Bay, off Milford-on-Sea in 1996. Since 2003, the Strategic Regional Coastal Monitoring Programme has deployed Waverider buoys off Hayling Island and in Sandown Bay, a step gauge on Lymington Starting Platform (referred to hereafter as Lymington SP), and a Wave radar on Sandown Pier. There is a wave gauge at Chichester Bar operated by Chimet. Table C1.2 details the type of ongoing wave measurements in the Solent region.

A 12 year time series of modelled waves was derived for a number of locations within the Solent, based on long term wind data measured at Lymington. Wave heights were hindcast from the measured winds to 8 wave prediction points (HR1-11) (locations shown in Figure C1.9). It should be noted that nearshore wave transformations are complex due to the variable bathymetry and the presence of strong ebb and flood tidal currents within the Solent and near the harbour entrance channels.

Wave roses for wave height and wave period for the Directional Waveriders are shown in Figures C1.10 and C1.11, which essentially provide wave boundary conditions for the Solent.

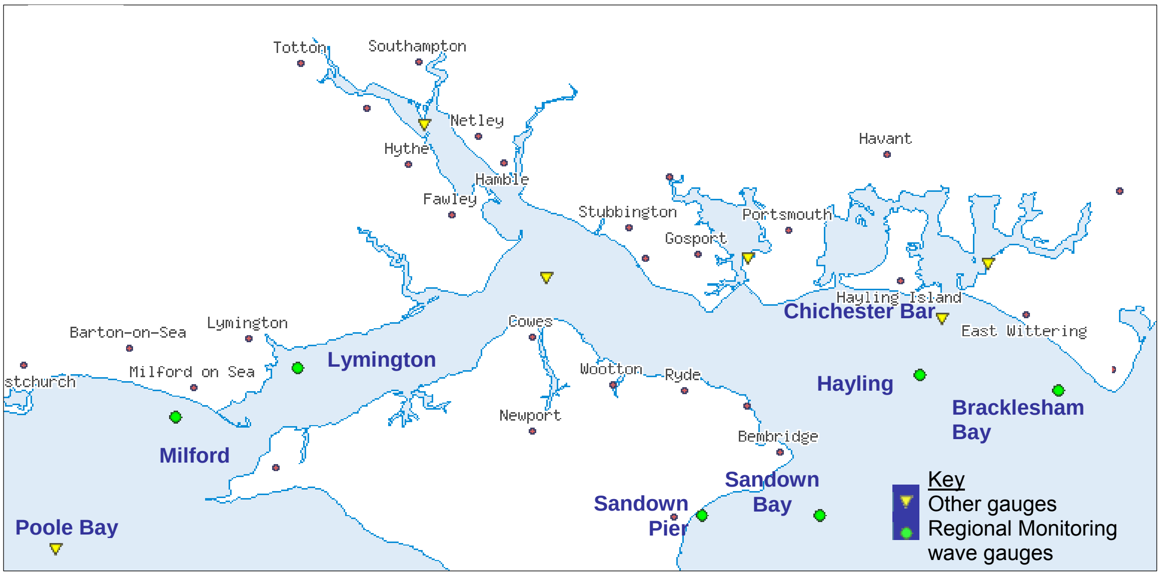


Figure C1.9: Location of long-term wave instrumentation in Solent region. (Source: Channel Coastal Observatory)

Programme	**Location**	**Type**	**Measurements**		
			Wave Height	Wave Period	Wave Direction
Regional Coastal Monitoring Programme (1)	Milford-on-Sea (since 1996)	Directional Waverider Buoy	Yes	Yes	Yes
	Lymington SP (4) (since 08/2003)	Step gauge	Yes	Yes	No
	Hayling Island (since 07/2003)	Directional Waverider Buoy	Yes	Yes	Yes
	Sandown Bay (since 07/2003)	Directional Waverider Buoy	Yes	Yes	Yes
	Sandown Pier (since 05/2003)	Wave Radar	Yes	Yes	No
	Bracklesham Bay since 08/2008)	Directional Waverider Buoy	Yes	Yes	Yes
WaveNet (2)	Poole Bay	Directional Waverider Buoy	Yes	Yes	Yes
Chimet (3)	Chichester Harbour	Pressure transducer	Yes	Yes	No

Table C1.2: Solent region wave measurement sites

1 www.channelcoast.org/data_management/real_time_data/charts/
2 www.cefas.co.uk/data/wavenet.aspx
3 www.chimet.co.uk
4 SP - Starting Platform, located at mouth of Lymington River

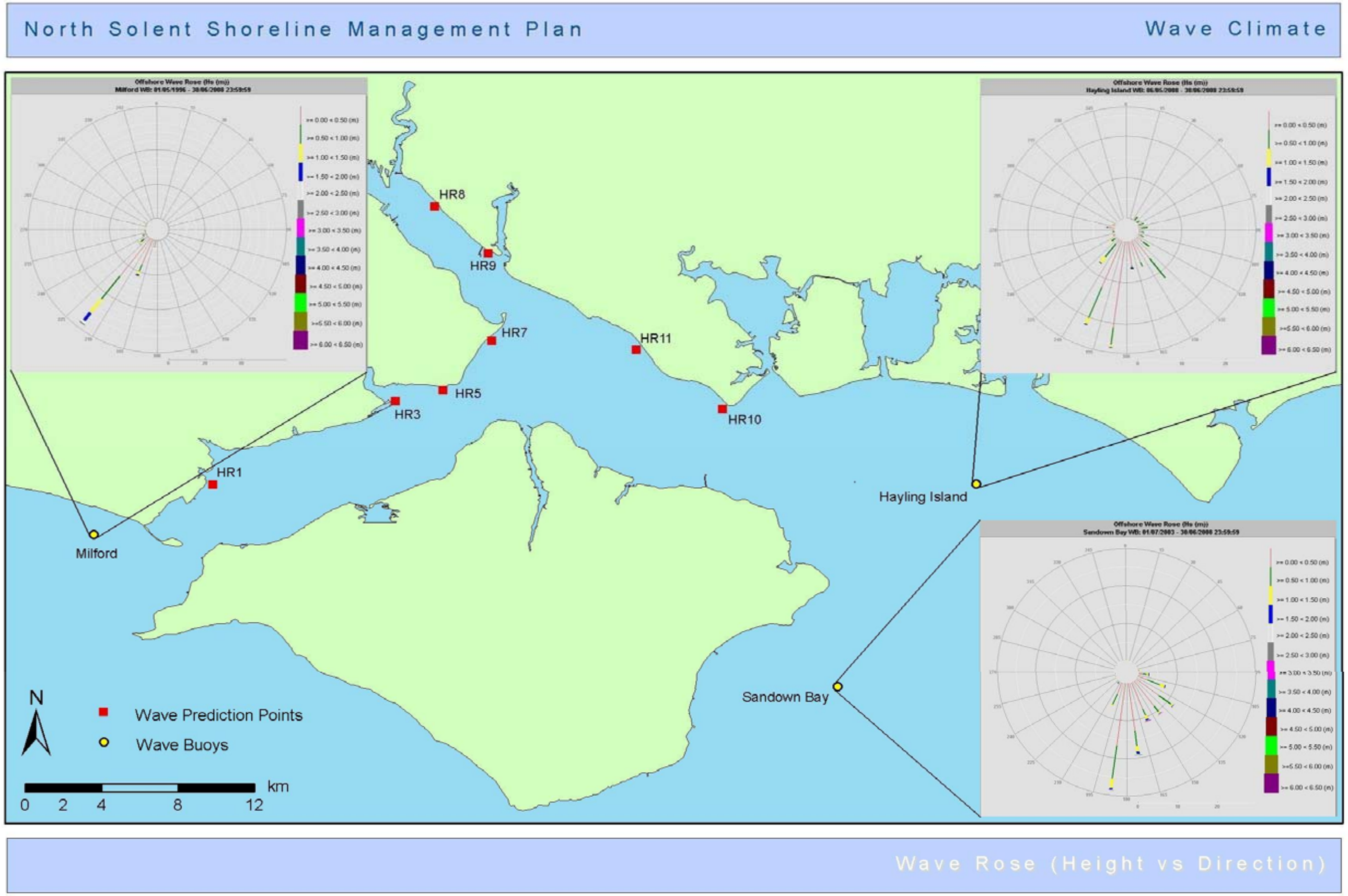


Figure C1.10: Percentage occurrence of wave height and direction

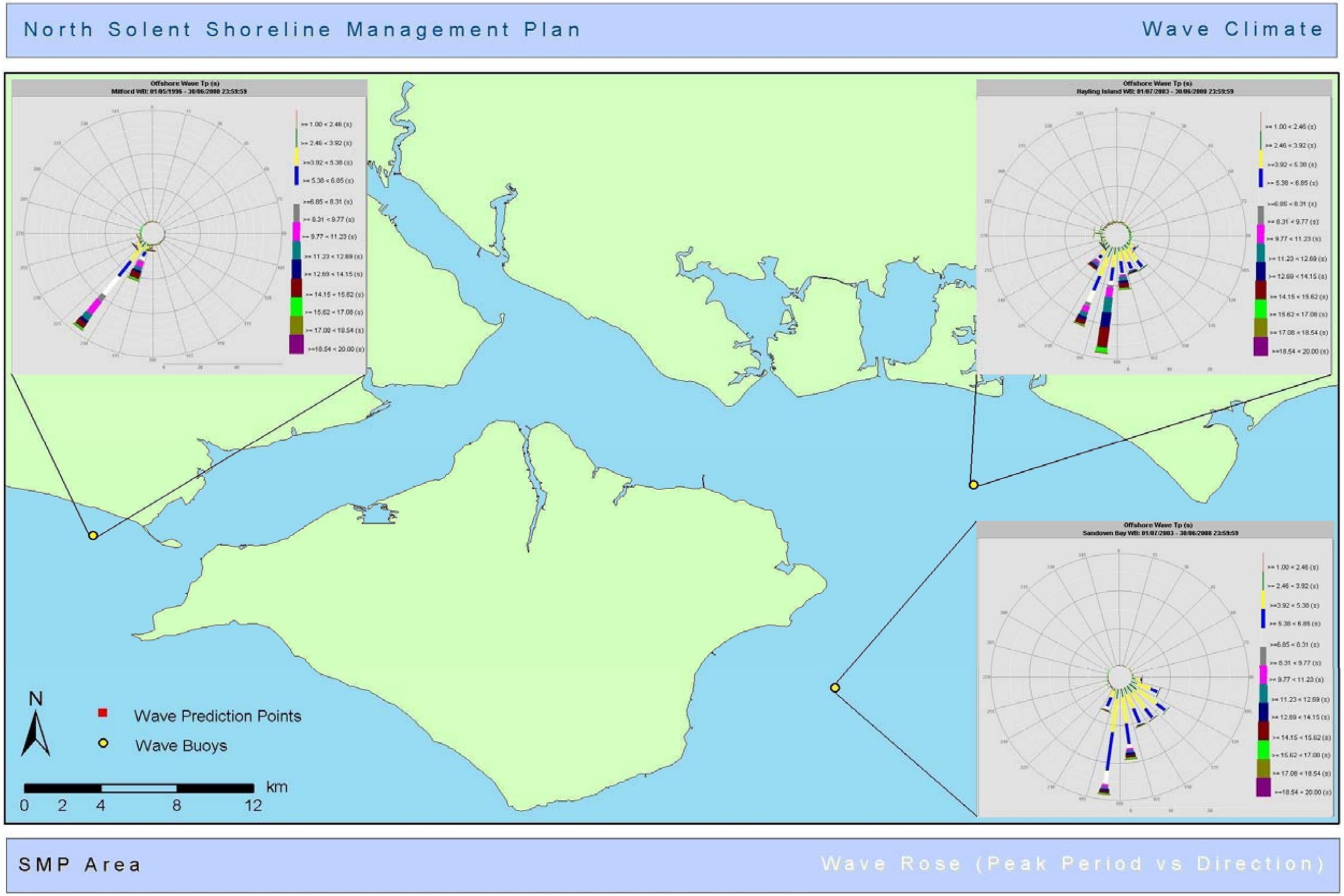


Figure C1.11: Percentage occurrence of peak wave period (T_p) and direction

An indication of the variation of wave climate in the Solent can be obtained from calculations of the wave height exceedence at each location. Wave height exceedence values for measured and modelled sites are given in Table C1.3. For example, 5% of waves at Milford were higher than 1.65m and 95% of waves were 1.65m or lower.

The same values are shown in Figure C1.12, for the sites from west to east, and shows clearly the lower wave heights experienced within the Solent, compared to the more exposed sites beyond the western boundary and towards the eastern boundary of the North Solent SMP study area (note that the exceedance lines have been joined for clarity, it is not intended that values should be interpolated for other locations in between the sites shown in the Figure) . The broad similarity of measured and modelled wave heights at Lymington gives confidence in the wave heights derived from modelling. As expected, Lymington, Calshot and Gilkicker experience higher significant wave heights due to the increased fetch and exposure to wind waves from easterlies, south-easterlies and south-westerlies, respectively.

		Hs exceedance (m)							
		From	**To**	**0.05%**	**0.50%**	**1%**	**2%**	**5%**	**10%**
Milford	Measured	1996	2007	3.30	2.48	2.25	2.00	1.65	1.34
Lymington	Measured	2003	2006	1.12	0.91	0.82	0.72	0.56	0.43
HR01 (Lymington)	Modelled	1991	2002	0.97	0.75	0.70	0.62	0.52	0.45
HR03 (Gull Island)	Modelled	1991	2002	1.07	0.87	0.79	0.76	0.63	0.53
HR05 (Lepe)	Modelled	1991	2002	1.08	0.87	0.84	0.76	0.66	0.56
HR07 (Calshot)	Modelled	1991	2002	1.13	0.82	0.74	0.64	0.54	0.46
HR08 (Netley)	Modelled	1991	2002	0.72	0.57	0.53	0.49	0.42	0.36
HR09 (Hamble)	Modelled	1991	2002	0.71	0.56	0.51	0.46	0.40	0.34
HR10 (Gilkicker)	Modelled	1991	2002	1.67	1.19	0.99	0.85	0.72	0.62
HR11 (Lee-on-the-Solent)	Modelled	1991	2002	1.12	0.92	0.85	0.79	0.70	0.61
Sandown Pier	Measured	2006	2007	1.77	1.33	1.19	1.02	0.78	0.60
Sandown Bay	Measured	2003	2007	2.92	2.07	1.78	1.55	1.25	1.00
Hayling Island	Measured	2003	2007	3.16	2.46	2.22	1.97	1.61	1.28

Table C1.3: Occurrence of wave height exceedance

The wave heights modelled for Lee-on-the-Solent indicate that this location is relatively sheltered by the adjacent coastline. Southampton Water has the lowest significant wave heights, reflecting its sheltered location, and the narrow angle of exposure to waves approaching from the south-east.

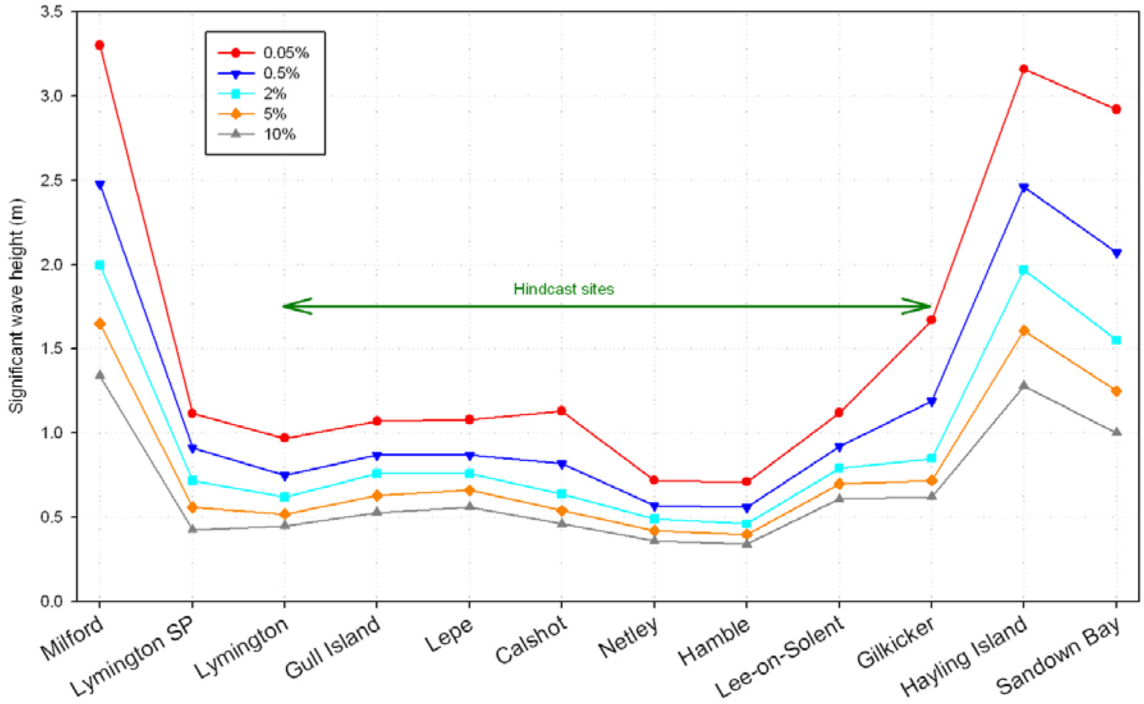


Figure C1.12: Wave height exceedance at the measured and modelled sites

The seasonality, number, frequency and severity of measured storms since July 2003 are presented in Figure C1.13 (note that although Milford Waverider was deployed in 1996, only storms since 2003 are shown to enable comparison across the North Solent SMP region). The record of storm events at both Milford and Hayling indicate the prevailing wave climate for the central south coast, as these sites are not significantly affected by the sheltering affects of the Isle of Wight. The storm event signature measured at Hayling is similar to that recorded at Milford, with the highest waves in the region occurring, as expected, during the winter months.

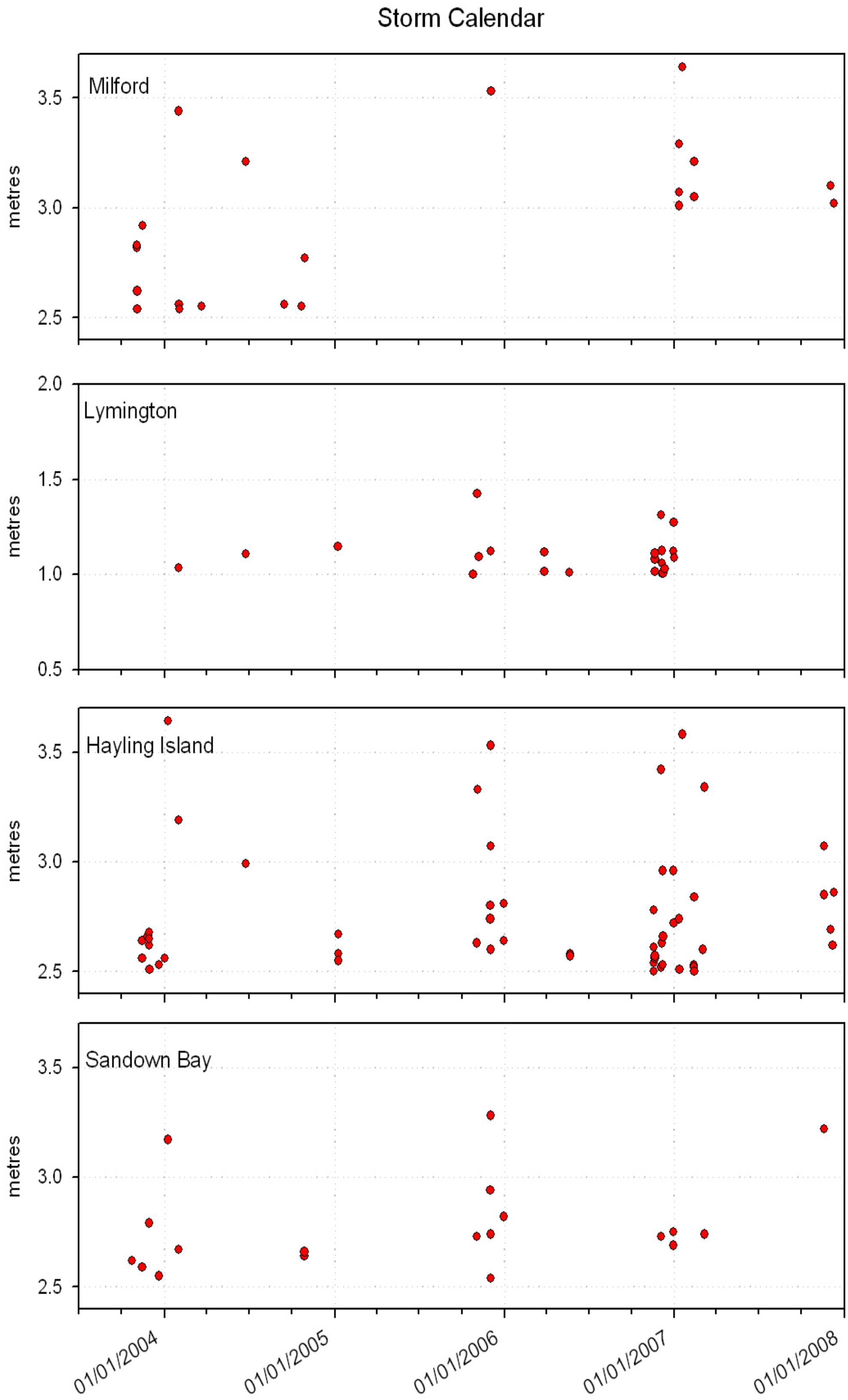


Figure C1.13: Measured storm events from July 2003 to January 2008

From analysis of the measured and modelled wave data, it is possible to calculate estimates of wave heights for different wave return period events. In general, return periods can be estimated for 10-20 times the measured record length. Significant wave heights for given return periods have been derived as shown in Table C1.4, together with the maximum wave height measured to date, in order to provide confidence in the values. From these results, it is clear that the wave climate either side of the Solent is substantially more severe than within the Solent.

The extremes analysis used hourly data, based on the highest 50 measurements, giving reasonable confidence in the results obtained where records exist for 10 years, but less confidence in results obtained from shorter time periods. Similarly, the level of confidence in the predicted wave heights of longer return periods, for example a 1:200yr event, is increased with a longer record of measured data. The highest wave heights measured to date indicate that these levels equate to approximately the proposed yearly wave return period.

		Return Period (years)					**Highest measured to date**			**Years of data**
		1	**10**	**50**	**100**	**200**	**Hs (m)**	**Date**	**Time (GMT)**	
Milford	Measured	3.90	4.56	4.99	5.17	5.34	4.09	31-Dec-2000	19:00	12
Lymington SP	Measured	1.44	1.65	1.79	-	-	1.43	03-Nov-2005	06:00	4
Lymington	Hindcast HR01	1.09	1.20	1.28	1.31	1.34	modelled			12
Gull Island	Hindcast HR03	1.24	1.36	1.44	1.47	1.50				12
Lepe	Hindcast HR05	1.29	1.45	1.56	1.60	1.64				12
Calshot	Hindcast HR07	1.61	1.98	2.23	2.34	2.45				12
Netley	Hindcast HR08	0.92	1.06	1.15	1.19	1.23				12
Hamble	Hindcast HR09	0.84	0.94	1.00	1.02	1.04				12
Lee-on-Solent	Hindcast HR11	1.32	1.51	1.64	1.69	1.74				12
Gilkicker	Hindcast HR10	2.06	2.54	2.87	3.02	3.16				12
Hayling Island	Measured	3.59	3.91	4.10	-	-	3.64	08-Jan-2004	10:30	5
Sandown Bay	Measured	3.48	4.02	4.37	-	-	3.79	02-Dec-2005	18:00	5

Table C1.4: Extremes Analysis. Significant wave height return periods from modelled and measured data - Weibull predictions (where measured dataset is of sufficient duration to calculate wave height return period values)

Figure C1.14 illustrates the calculated wave height return periods for the sites listed from west to east. This indicates that Calshot experiences higher wave height return period levels than other sites within the Solent, since it is exposed to waves from the south-easterly direction. The increased return period levels at Milford and Hayling may indicate that the 1:200 year wave heights may be approaching their limiting height due to bathymetric and fetch conditions. Within the Solent, there is minimal variation in wave heights over the range of return periods, mainly as a consequence of their sheltered locations.

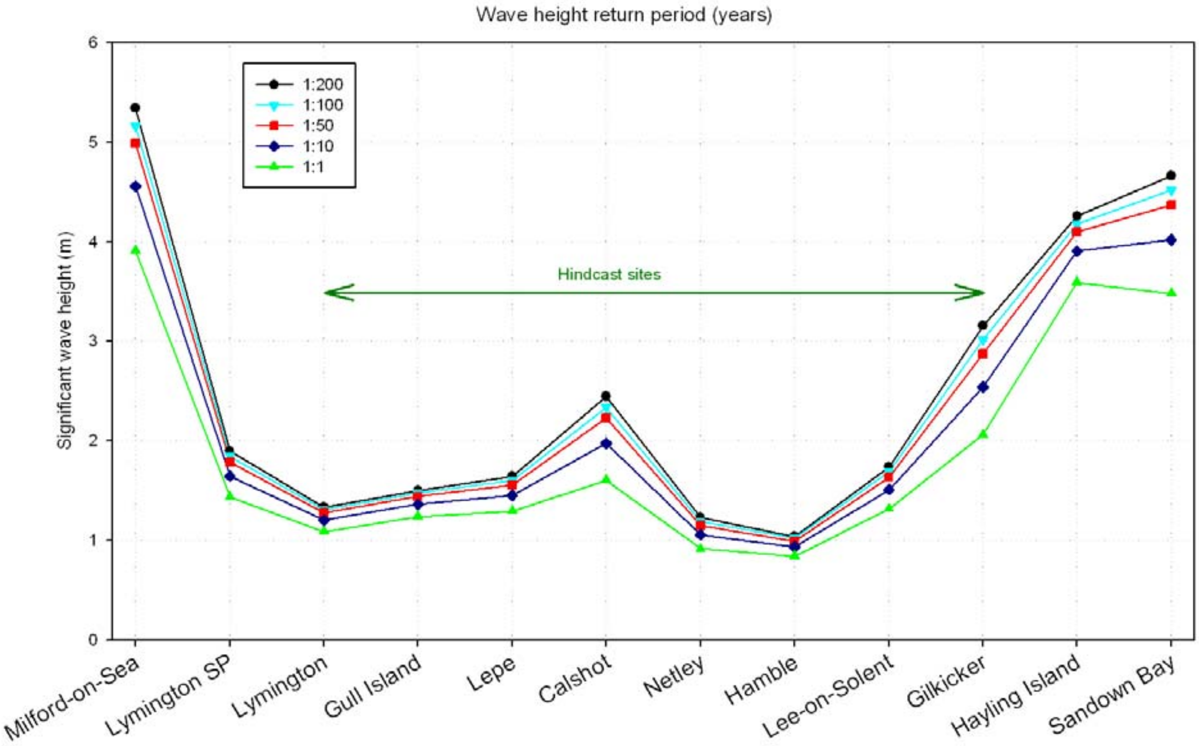


Figure C1.14: Wave height return periods (years) at the measured and modelled sites

Long-term monitoring and analysis of waves along the south coast and Solent region will enable changes in the wave climate, frequency, intensity and trajectories of storms to be determined. The 11 year time series at Milford-on-Sea has not indicated a trend of increased storminess (as shown by the exceedence statistics) but, ideally, over 30 years of measured data at one site is required to identify changes in the wave climate linked to climate change. Furthermore, continuous long-term data sets will provide confidence in the longer term estimates of wave height return periods (100 years +). It is therefore increasingly important that monitoring and analysis of the Regional Monitoring Programme wave gauge network is continued, as the dataset provides increasing value and benefit in the long term, particularly in relation to sea defence design and coastal management (Bradbury *et al.,* 2006).

C1.2.4 Tidal currents

Tidal regime

Tidal currents in the Solent are some of the most complex in the British Isles, with notable differences between the western and eastern Solent. The tidal regime is further complicated by double high waters, which are best known at Southampton. A detailed explanation for the tidal regime at Southampton can be found in Pugh (1989) but, summarising, during spring tides, the tide rises following Low Water but the tidal stream slackens some 2 hours before HW leading to a stand for up to 2 hours (known as the young flood stand) prior to a rapid rise to HW. In total, the flood and double HW can last up to 9 hours, leaving only 3 hours for the tidal ebb. The ebb tide is therefore associated with very strong ebb currents. This ebb tide dominance is reflected throughout the whole of the Solent; Chichester Harbour entrance, for example, experiences a 7 hour flood and 5½ ebb.

In the western Solent, tidal range (spring tides) varies from 2.0m at Hurst Point to around 3.9m at Calshot, producing a significant hydraulic gradient. In the eastern Solent, tidal ranges are around 4m for most of the coastline between Southampton and Chichester Harbour entrance and, therefore, the hydraulic gradient observed in the eastern Solent is less pronounced. As a result, tidal currents in the eastern Solent, whilst still considerable, are less strong than in the western Solent. Tables C1.5 and C1.6 show the tidal streams information extracted from Admiralty Charts 2036 and 2037 to illustrate the strength and asymmetry of the currents.

	Admiralty tidal diamond	Position	Approx. water depth (CD)
Western Solent	A	50° 44.53'N 1° 24.79'W	15 m
	D	50° 47.21'N 1° 19.28'W	8 m
	F	50° 48.43'N 1° 17.59'W	13 m
Eastern Solent	M	50° 47.43'N 1° 13.39'W	5 m
	V	50° 45.13'N 1° 06.29'W	25 m
	P	50° 45.98'N 1° 04.14'W	4 m

Table C1.5: Location of tidal diamonds

Hrs re: HW	Tidal stream (knots)					
	Western Solent			Eastern Solent		
	A	D	F	M	V	P
-6	2.5	1.1	1.8	1.2	0.7	0.4
-5	3.0	1.0	1.0	1.6	1.1	1.2
-4	2.9	1.1	0.4	1.2	1.4	0.8
-3	2.2	1.3	0.4	0.2	0.8	0.2
-2	1.2	0.7	1.4	0.5	0.3	0.6
-1	0	0.8	0.5	1.0	0.4	1.0
0	1.4	2.1	1.0	1.5	1.2	1.1
+1	2.5	1.8	1.1	1.9	1.8	0.7
+2	3.2	1.7	1.2	1.1	1.5	0.2
+3	3.1	1.4	1.4	0.4	0.4	0.5
+4	1.6	0.9	2.4	0.7	0.5	0.6
+5	0.3	0	0.2	0.8	0.4	0
+6	2.2	1.1	1.6	1.0	0.6	0.2

Table C1.6: Tidal streams relative to High Water Portsmouth

Western Solent

Strong tidal currents are experienced along the entire western Solent coastline. Ebb tide currents are stronger but of shorter duration than flood tide currents. Peak surface current velocities of up to 3ms^{-1} have been recorded during the ebb tide at Hurst Narrows, although 1.7 to 2.0ms^{-1} are more characteristic (Heathershaw and Langhorne, 1988). Currents up to 1.8 ms^{-1} were measured at Solent Bank in mid-channel (Hydraulics Research, 1981). Inshore, peak ebb velocities are typically 0.35 ms^{-1}, reducing to 0.14 ms^{-1} in the inner Lymington estuary (ERM, 1998).

Eastern Solent

Again, ebb tide currents are stronger but of shorter duration than flood tide currents. The strongest currents are found off East Beach, Selsey Bill, Gilkicker Point and within the harbour entrance channels (SCOPAC Sediment Transport Study, 2004). Tidal currents nearshore are typically less than 0.5ms-1 during spring tides. Further offshore, current velocities of over 1.25ms-1 in water depths exceeding 5m are experienced, which are sufficient to mobilise non-consolidated fine gravel, as well as sand. (Hydraulics Research, 1992; HR Wallingford, 1995). 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.

C1.2.5 Sea level rise

The first round of Shoreline Management Plans considered the impacts of future climate change and sea level rise by applying the precautionary MAFF guidance of 6mm per annum. DEFRA have subsequently modified these sea level rise allowances in 2006, in response to research and improved predictive climate modelling, and advice from the Intergovernmental Panel on Climate Change (IPCC) and UK Climate Impacts Programme (UKCIP) (FCDPAG, 2006). Global mean sea level rise projections for the 2110s were extrapolated from the 2020s, 2050s and 2080s. The baseline for calculating sea level rise for a given year was taken from 1990. The latest guidance takes into account land movement and the effects of thermo-expansion of the sea, up to the year 2115. Additional contributions from tidal surge and waves are not included. The new allowances are shown in Table C1.7.

Figure C1.15 shows the latest, exponential DEFRA predicted sea level rise compared with the old 6mm per annum guide. The DEFRA guidance of 4mm per annum sea level rise until 2025 is actually a lower rate than was previously applied. From 2025 onwards, the new predicted rate rises steeply, eventually resulting in mean sea level being 0.4m higher than the previous 6mm per annum guide. This has serious implications when planning for future sea defences.

Administrative Region	**Assumed Vertical Land Movement (mm/yr)**	**Net Sea Level Rise (mm/yr)**				**Previous allowances**
		1990-2025	2025-2055	2055-2085	2085-2115	
Eastern England, East Midlands, London, South East England	-0.8	4.0	8.5	12.0	15.0	6mm/yr
South West and Wales	-0.5	3.5	8.0	11.5	14.5	5mm/yr
North West and North East England, Scotland	+0.8	2.5	7.0	10.0	13.0	4mm/yr

Table C1.7: Regional net sea level rise allowances (FCDPAG, 2006)

The Solent region, responding to isostatic readjustment, is experiencing a fall in land levels of an estimated 0.5mm/yr; UKCIP (2002) quote a 0.9mm decrease in land levels for the South East region.

Rising sea levels will increase the probability of flooding for low lying areas protected by a hard defence or barrier beach/spit, through reduction of the crest freeboard thereby allowing shallow water waves to break further inshore. The tidal prism of estuaries and tidal rivers will also increase, which may impact on urbanized residential and industrial areas and the extent of environmentally sensitive habitats.

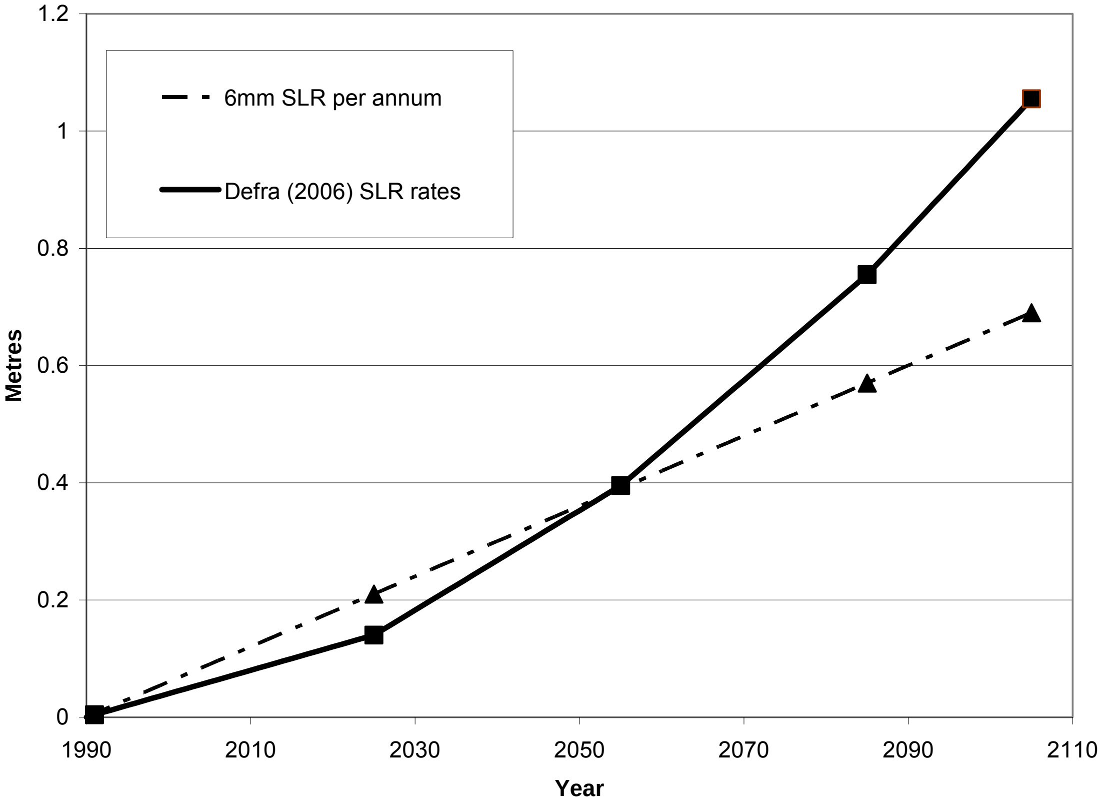


Figure C1.15: Comparison of current Defra sea level rise allowances with previous guidance of 6mm per annum for South East England region

Following discussions and consultation, the North Solent SMP has been advised by the EA and DEFRA to note that the existing sea level rise rates are currently being revised (UKCIP08) and may be available in December 2008 or during 2009; and that the North Solent SMP's Action Plan should note that an Interim Review of the SMP should consider and take account of the revised sea level rise allowances.

C1.2.6 Extreme 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).

Through such projects as the Partnership for Urban South Hampshire (PUSH), and the Strategic Flood Risk Assessments (SFRA) for the PUSH and New Forest District Council and National Park Authority areas, along with Coastal Defence Strategy studies, there had been agreement from all operating authorities within the North Solent SMP area, on the baseline levels (1990) and the subsequent extreme water levels for various return period events.

In order to calculate future sea levels and extreme water levels, an agreed water level measured in 1990 was used as base level, and the DEFRA sea level rise allowances were then applied (see Table C1.7). The increases in level, contributed by the sea level rise rates are shown in Table C1.8.

Year	1990	2000	2010	2025	2055	2085	2115
Extreme Water Level	baseline	1990 + 40mm	1990 + 80mm	1990 + 140mm	2025 + 255mm	2055 + 360mm	2085 + 450mm

Table C1.8: Determination of future sea and extreme water levels

The JBA Report (2003), commissioned by the Environment Agency, Southern Region, aimed to produce extreme sea levels up to a 200 year return period for use in planning and flood risk assessments, and to interpolate between analysed sites to provide estimates of extreme sea levels at any point along the coastline. However, at a number of locations the extreme water levels derived for different return periods were significantly higher than the Environment Agency's currently adopted levels; additional surveys were commissioned, to specifically determine extreme sea levels, for example for Lymington.

The annual maximum water levels for Lymington suggests a one year return period level of 1.6mOD, which correlates well with the one year return period water level provided. However, over the 15 year period of monitoring (but excluding the 1993 data) there have only been 3 occurrences that the water level has exceeded 1.82mOD, and a single occurrence that the water level has exceeded 1.92mOD (21/10/91). This suggests that the one year return period water level of 1.92mOD does not occur annually, and perhaps fits better as a one in ten year return period water level.

The recorded water levels correlate well with the maintenance records that no damaging overtopping of the seawall has occurred since construction. High water levels with waves have not produced the conditions necessary to cause damaging overtopping.

Figure C1.16 presents an estimation of the different zones of extreme water levels for the North Solent SMP area. Zones 5-15 originate from the EA (Hampshire Area team), which sub-divides the Solent (within Hampshire) into compartments delineated through linear interpolation of extreme water level values; zones A to I derive from the Pagham to East Head CDS, and complete the coverage for the North Solent SMP study area. Table C1.9 details the extreme water levels for the different zones for a return period 1:200 year event. These extreme water levels account for still water levels, and storm surges. Tables C1.10 to 21 detail the extreme water levels for a range of return periods at key locations around the North Solent.

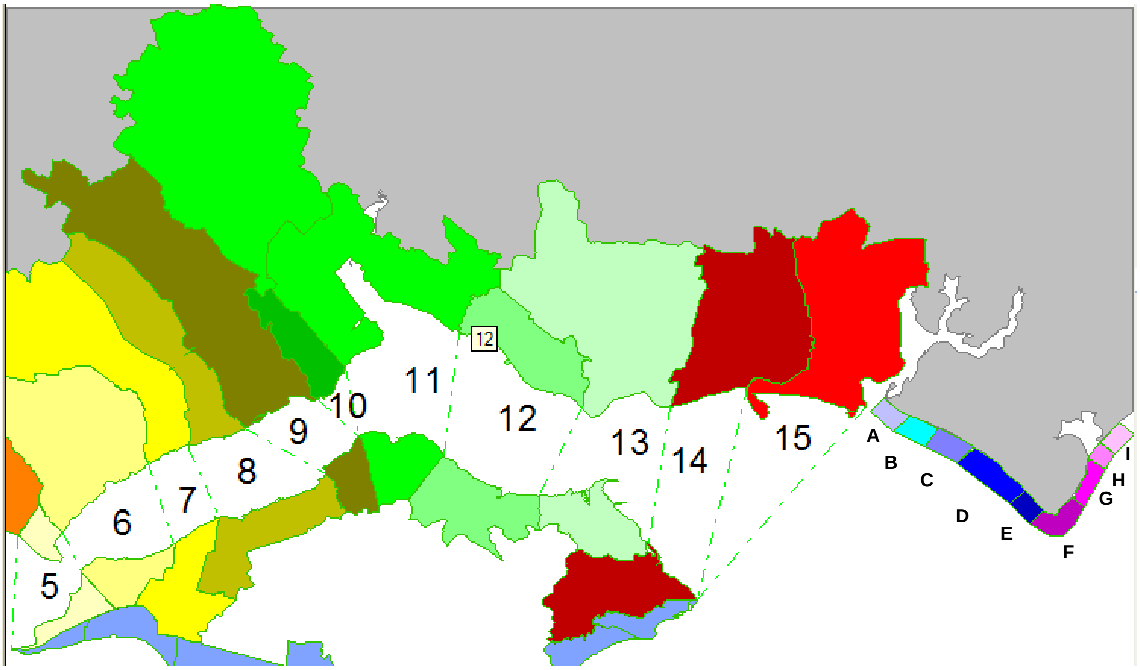


Figure C1.16: Extreme Water Level zones in the North Solent SMP area

Tidal zone	From	To	Extreme water levels (mOD) for a return period 1:200 year event							
			1990	2000	2010	2025	2055	2085	2108	2115
4	Hants boundary	Milford	2.2		2.3	2.3	2.6	3		3.4
5	Hurst	Keyhaven	2.3		2.4	2.4	2.7	3.1		3.5
6	Keyhaven	Tanners Lane	2.4		2.5	2.5	2.8	3.2		3.6
7	Tanners Lane	House-on-the-Shore	2.5		2.6	2.6	2.9	3.3		3.7
8	House-on-the-Shore	Beaulieu Beach Cottage	2.6		2.7	2.7	3	3.4		3.8
9	Beaulieu Beach Cottage	Lepe Country Park	2.7		2.8	2.8	3.1	3.5		3.9
10	Lepe Country Park	Stanswood Valley, Cadland	2.8		2.9	2.9	3.2	3.6		4
11	Stanswood Valley, Cadland to Hythe MOD	RVCP to Titchfield Haven	2.9		3	3	3.3	3.7		4.1
12	Titchfield Haven	Gilkicker Point	3		3.1	3.1	3.4	3.8		4.2
13	Gilkicker Point	Southsea Pier	3.1		3.2	3.2	3.5	3.9		4.3
14	Southsea Pier	Hayling Island west	3.2		3.3	3.3	3.6	4		4.4
15	Hayling Island west	Hants boundary	3.3		3.4	3.4	3.7	4.1		4.5
A	East Head	West Wittering		3.5		3.6	3.9	4.2	4.6	4.7
B	West Wittering	Cakeham		3.5		3.6	3.9	4.2	4.6	4.7
C	Cakeham	East Wittering		3.5		3.6	3.9	4.2	4.6	4.7
D	East Wittering	Medmerry		3.6		3.7	4	4.3	4.7	4.8
E	Medmerry	Selsey West Beach		3.7		3.8	4.1	4.4	4.8	4.9
F	Selsey West Beach	Selsey Bill		3.7		3.8	4.1	4.4	4.8	4.9
G	Selsey Bill	Selsey East Beach		3.7		3.8	4.1	4.4	4.8	4.9
H	Selsey East Beach	Pagham Harbour and Church Norton		3.9		4	4.3	4.6	5	5.1
I	Pagham Harbour and Church Norton	Pagham Beach		3.9		4	4.3	4.6	5	5.1

Table C1.9: Summary of extreme water levels zones for a return period 1:200 year event

Sources of data presented in the following tables are:

🟪 UK Hydrographic Office (as published in 2007)
🟩 PUSH and NFDC/NFNPA Strategic Flood Risk Assessment
🟧 Pagham to East Head Coastal Defence Strategy
🟨 Interpolated
⬜ Not applicable

	Water elevation mOD								
Year	**1990**	**2000**	**2007**	**2010**	**2025**	**2055**	**2085**	**2107**	**2115**
Mean Low Water Springs			-1.28	-1.27	-1.21	-0.95	-0.59	-0.26	-0.14
Mean Low Water Neaps			-0.58	-0.57	-0.51	-0.25	0.11	0.44	0.56
Mean Sea Level			0.02	0.03	0.09	0.35	0.71	1.04	1.16
Mean High Water Neaps			0.62	0.63	0.69	0.95	1.31	1.64	1.76
Mean High Water Springs			1.02	1.03	1.09	1.35	1.71	2.04	2.16
1 in 20 yr	2.32	2.36	2.39	2.70	2.70	3.00	3.40	3.73	3.80
1 in 50 yr	2.38	2.42	2.45	2.80	2.80	3.10	3.50	3.83	3.90
1 in 100 yr	2.44	2.48	2.51	2.90	2.90	3.20	3.60	3.93	4.00
1 in 200 yr	2.52	2.56	2.59	2.60	2.66	2.92	3.28	3.61	3.73
1 in 1000 yr	2.63	2.67	2.70	3.20	3.20	3.50	3.90	4.23	4.30

Table C1.10: Extreme Water Levels Lymington

	Water elevation mOD								
Year	**1990**	**2000**	**2007**	**2010**	**2025**	**2055**	**2085**	**2107**	**2115**
Mean Low Water Springs			-1.94	-1.93	-1.87	-1.61	-1.25	-0.92	-0.80
Mean Low Water Neaps			-0.74	-0.73	-0.67	-0.41	-0.05	0.28	0.40
Mean Sea Level			0.16	0.17	0.23	0.49	0.85	1.18	1.30
Mean High Water Neaps			0.96	0.97	1.03	1.29	1.65	1.98	2.10
Mean High Water Springs			1.76	1.77	1.83	2.09	2.45	2.78	2.90
1 in 20 yr	2.60	2.64	2.67	2.70	2.70	3.00	3.40	3.73	3.80
1 in 50 yr	2.70	2.74	2.77	2.80	2.80	3.10	3.50	3.83	3.90
1 in 100 yr	2.80	2.84	2.87	2.90	2.90	3.20	3.60	3.93	4.00
1 in 200 yr	2.90	2.94	2.97	2.98	3.04	3.30	3.66	3.99	4.11
1 in 1000 yr	3.10	3.14	3.17	3.20	3.20	3.50	3.90	4.23	4.30

Table C1.11: Extreme Water Levels Calshot

	Water elevation mOD								
Year	**1990**	**2000**	**2007**	**2010**	**2025**	**2055**	**2085**	**2107**	**2115**
Mean Low Water Springs			-2.24	-2.23	-2.17	-1.91	-1.55	-1.22	-1.10
Mean Low Water Neaps			-0.94	-0.93	-0.87	-0.61	-0.25	0.08	0.20
Mean Sea Level			0.16	0.17	0.23	0.49	0.85	1.18	1.30
Mean High Water Neaps			0.96	0.97	1.03	1.29	1.65	1.98	2.10
Mean High Water Springs			1.76	1.77	1.83	2.09	2.45	2.78	2.90
1 in 20 yr	2.70	2.74	2.77	2.80	2.80	3.10	3.50	3.83	3.90
1 in 50 yr	2.80	2.84	2.87	2.90	2.90	3.20	3.60	3.93	4.00
1 in 100 yr	2.90	2.94	2.97	3.00	3.00	3.30	3.70	4.03	4.10
1 in 200 yr	3.00	3.04	3.07	3.08	3.14	3.40	3.76	4.09	4.21
1 in 1000 yr	3.20	3.24	3.27	3.30	3.30	3.60	4.00	4.33	4.40

Table C1.12: Extreme Water Levels Southampton

	Water elevation mOD								
Year	**1990**	**2000**	**2007**	**2010**	**2025**	**2055**	**2085**	**2107**	**2115**
Mean Low Water Springs			-1.74	-1.73	-1.67	-1.41	-1.05	-0.72	-0.60
Mean Low Water Neaps			-0.74	-0.73	-0.67	-0.41	-0.05	0.28	0.40
Mean Sea Level			0.01	0.02	0.08	0.34	0.70	1.03	1.15
Mean High Water Neaps			0.96	0.97	1.03	1.29	1.65	1.98	2.10
Mean High Water Springs			1.76	1.77	1.83	2.09	2.45	2.78	2.90
1 in 20 yr	2.70	2.74	2.77	2.80	2.80	3.10	3.50	3.83	3.90
1 in 50 yr	2.80	2.84	2.87	2.90	2.90	3.20	3.60	3.93	4.00
1 in 100 yr	2.90	2.94	2.97	3.00	3.00	3.30	3.70	4.03	4.10
1 in 200 yr	3.00	3.04	3.07	3.08	3.14	3.40	3.76	4.09	4.21
1 in 1000 yr	3.20	3.24	3.27	3.30	3.30	3.60	4.00	4.33	4.40

Table C1.13: Extreme Water Levels Lee-on-the-Solent

	Water elevation mOD								
Year	**1990**	**2000**	**2007**	**2010**	**2025**	**2055**	**2085**	**2107**	**2115**
Mean Low Water Springs			-1.93	-1.92	-1.86	-1.60	-1.24	-0.91	-0.79
Mean Low Water Neaps			-0.83	-0.82	-0.76	-0.50	-0.14	0.19	0.31
Mean Sea Level			0.17	0.18	0.24	0.50	0.86	1.19	1.31
Mean High Water Neaps			1.07	1.08	1.14	1.40	1.76	2.09	2.21
Mean High Water Springs			1.97	1.98	2.04	2.30	2.66	2.99	3.11
1 in 20 yr	2.80	2.84	2.87	2.90	2.90	3.20	3.60	3.93	4.00
1 in 50 yr	2.90	2.94	2.97	3.00	3.00	3.30	3.70	4.03	4.10
1 in 100 yr	3.00	3.04	3.07	3.10	3.10	3.40	3.80	4.13	4.20
1 in 200 yr	3.10	3.14	3.17	3.18	3.24	3.50	3.86	4.19	4.31
1 in 1000 yr	3.30	3.34	3.37	3.40	3.40	3.70	4.10	4.43	4.50

Table C1.14: Extreme Water Levels Portsmouth

	Water elevation mOD								
Year	**1990**	**2000**	**2007**	**2010**	**2025**	**2055**	**2085**	**2107**	**2115**
Mean Low Water Springs			-1.93	-1.92	-1.86	-1.60	-1.24	-0.91	-0.79
Mean Low Water Neaps			-0.83	-0.82	-0.76	-0.50	-0.14	0.19	0.31
Mean Sea Level			0.20	0.21	0.27	0.53	0.89	1.22	1.34
Mean High Water Neaps			1.17	1.18	1.24	1.50	1.86	2.19	2.31
Mean High Water Springs			2.07	2.08	2.14	2.40	2.76	3.09	3.21
1 in 20 yr	2.90	2.94	2.97	3.00	3.00	3.30	3.70	4.03	4.10
1 in 50 yr	3.00	3.04	3.07	3.10	3.10	3.40	3.80	4.13	4.20
1 in 100 yr	3.10	3.14	3.17	3.20	3.20	3.50	3.80	4.13	4.30
1 in 200 yr	3.20	3.24	3.27	3.28	3.34	3.60	3.96	4.29	4.41
1 in 1000 yr	3.40	3.44	3.47	3.50	3.50	3.80	4.20	4.53	4.60

Table C1.15: Extreme Water Levels Langstone Harbour

	Water elevation mOD								
Year	**1990**	**2000**	**2007**	**2010**	**2025**	**2055**	**2085**	**2107**	**2115**
Mean Low Water Springs			-1.84	-1.83	-1.77	-1.51	-1.15	-0.82	-0.70
Mean Low Water Neaps			-0.84	-0.83	-0.77	-0.51	-0.15	0.18	0.30
Mean Sea Level			0.16	0.17	0.23	0.49	0.85	1.18	1.30
Mean High Water Neaps			1.26	1.27	1.33	1.59	1.95	2.28	2.40
Mean High Water Springs			2.16	2.17	2.23	2.49	2.85	3.18	3.30
1 in 20 yr	3.00	3.04	3.07	3.10	3.10	3.40	3.80	4.13	4.20
1 in 50 yr	3.10	3.14	3.17	3.20	3.20	3.50	3.90	4.23	4.30
1 in 100 yr	3.20	3.24	3.27	3.30	3.30	3.60	3.90	4.23	4.40
1 in 200 yr	3.30	3.34	3.37	3.38	3.44	3.70	4.06	4.39	4.51
1 in 1000 yr	3.50	3.54	3.57	3.60	3.60	3.90	4.30	4.63	4.70

Table C1.16: Extreme Water Levels Chichester Harbour

	Water elevation mOD								
Year	**1990**	**2000**	**2007**	**2010**	**2025**	**2055**	**2085**	**2107**	**2115**
Mean Low Water Springs	-2.21	-2.17	-2.10	-2.09	-2.03	-1.77	-1.41	-1.08	-0.96
Mean Low Water Neaps									
Mean Sea Level									
Mean High Water Neaps									
Mean High Water Springs									
1 in 20 yr									
1 in 50 yr	3.26	3.30	3.33	3.39	3.40	3.66	4.02	4.35	4.47
1 in 100 yr	3.36	3.40	3.43	3.49	3.50	3.76	4.12	4.45	4.57
1 in 200 yr	3.46	3.50	3.53	3.59	3.60	3.86	4.22	4.55	4.67
1 in 1000 yr									

Table C1.17: Extreme Water Levels West Wittering

	Water elevation mOD								
Year	**1990**	**2000**	**2007**	**2010**	**2025**	**2055**	**2085**	**2107**	**2115**
Mean Low Water Springs	-1.95	-1.91	-1.84	-1.83	-1.77	-1.51	-1.15	-0.82	-0.70
Mean Low Water Neaps									
Mean Sea Level									
Mean High Water Neaps									
Mean High Water Springs									
1 in 20 yr									
1 in 50 yr	3.26	3.30	3.33	3.39	3.40	3.66	4.02	4.35	4.47
1 in 100 yr	3.36	3.40	3.43	3.49	3.50	3.76	4.12	4.45	4.57
1 in 200 yr	3.46	3.50	3.53	3.59	3.60	3.86	4.22	4.55	4.67
1 in 1000 yr									

Table C1.18: Extreme Water Levels Cakeham

	Water elevation mOD								
Year	**1990**	**2000**	**2007**	**2010**	**2025**	**2055**	**2085**	**2107**	**2115**
Mean Low Water Springs	-1.95	-1.91	-1.84	-1.83	-1.77	-1.51	-1.15	-0.82	-0.70
Mean Low Water Neaps									
Mean Sea Level									
Mean High Water Neaps									
Mean High Water Springs									
1 in 20 yr									
1 in 50 yr	3.26	3.30	3.33	3.39	3.40	3.66	4.02	4.35	4.47
1 in 100 yr	3.36	3.40	3.43	3.49	3.50	3.76	4.12	4.45	4.57
1 in 200 yr	3.46	3.50	3.53	3.59	3.60	3.86	4.22	4.55	4.67
1 in 1000 yr									

Table C1.19: Extreme Water Levels East Wittering

	Water elevation mOD								
Year	**1990**	**2000**	**2007**	**2010**	**2025**	**2055**	**2085**	**2107**	**2115**
Mean Low Water Springs	-2.21	-2.17	-2.10	-2.09	-2.03	-1.77	-1.41	-1.08	-0.96
Mean Low Water Neaps									
Mean Sea Level									
Mean High Water Neaps									
Mean High Water Springs									
1 in 20 yr									
1 in 50 yr	3.36	3.40	3.43	3.49	3.50	3.76	4.12	4.45	4.57
1 in 100 yr	3.46	3.50	3.53	3.59	3.60	3.86	4.22	4.55	4.67
1 in 200 yr	3.56	3.60	3.63	3.69	3.70	3.96	4.32	4.65	4.77
1 in 1000 yr									

Table C1.20: Extreme Water Levels Medmerry

	Water elevation mOD								
Year	**1990**	**2000**	**2007**	**2010**	**2025**	**2055**	**2085**	**2107**	**2115**
Mean Low Water Springs	-2.21	-2.17	-2.10	-2.09	-2.03	-1.77	-1.41	-1.08	-0.96
Mean Low Water Neaps									
Mean Sea Level									
Mean High Water Neaps									
Mean High Water Springs									
1 in 20 yr									
1 in 50 yr	3.46	3.50	3.53	3.59	3.60	3.86	4.22	4.55	4.67
1 in 100 yr	3.56	3.60	3.63	3.69	3.70	3.96	4.32	4.65	4.77
1 in 200 yr	3.66	3.70	3.73	3.79	3.80	4.06	4.42	4.75	4.87
1 in 1000 yr									

Table C1.21: Extreme Water Levels Selsey West Beach

C1.2.7 Inter-tidal habitats

The North Solent is floristically diverse in coastal habitats (Figure C1.2). The area supports important ecological systems, which are protected by multiple international, European and national nature conservation designations. Due to the sheltering effect of the Isle of Wight, coupled with spit confined estuaries and harbours, low levels of wave energy have allowed the deposition of fine material and colonisation by halophytic (salt tolerant) vegetation across the Solent. Much of the Solent shoreline receives natural coast and flood protection from severe wave attack, by the presence of the saltmarshes and extensive inter-tidal mudflats, which act as a coupled system; the wave energy is initially reduced by the wide, shallow inter-tidal foreshores, with the majority of the energy being absorbed by the saltmarsh.

The saltmarshes across the Solent underwent rapid growth in area and elevation between the 1880s and late 1920s due to the invasion of the fertile hybrid cord grass *Spartina anglica*. The fully fertile *S. anglica* was rapid at colonising low level mud and quickly invaded every estuary in the Solent, reaching its maximum extent in the 1920s, since then there has been continuous and substantial mudflat and saltmarsh erosion. Mudflat and saltmarsh habitats still form the largest expanse of coastal habitats across the north Solent that are immediately under threat from climate change and coastal management decisions.

Under rising sea levels, saltmarshes would naturally migrate landward assuming low-lying, gently sloping land inshore. This is often prevented due to the presence and maintenance of defence structures, such as sea walls and revetments, and the proximity of urban and coastal developments. This process termed coastal squeeze, results in the rapid erosion and degradation of these natural flood defences with the complete loss of saltmarsh habitat, and increases the risk of flooding and coastal erosion.

The following is taken from the Solent Dynamic Coast Project (SDCP, 2008) and builds upon the Solent CHaMP (2003) and change detection mapping undertaken by Bailey and Pearson (2007). Figures C1.17 and C1.18 show the saltmarsh extent derived from historical photography interpretation (HPI) for areas in the West and East Solent, respectively.

A continuing broadly linear trend of saltmarsh loss is experienced in the West Solent (Figure C1.18), which has implications from an environmental point of view, and on performance and standard of protection of sea defences.

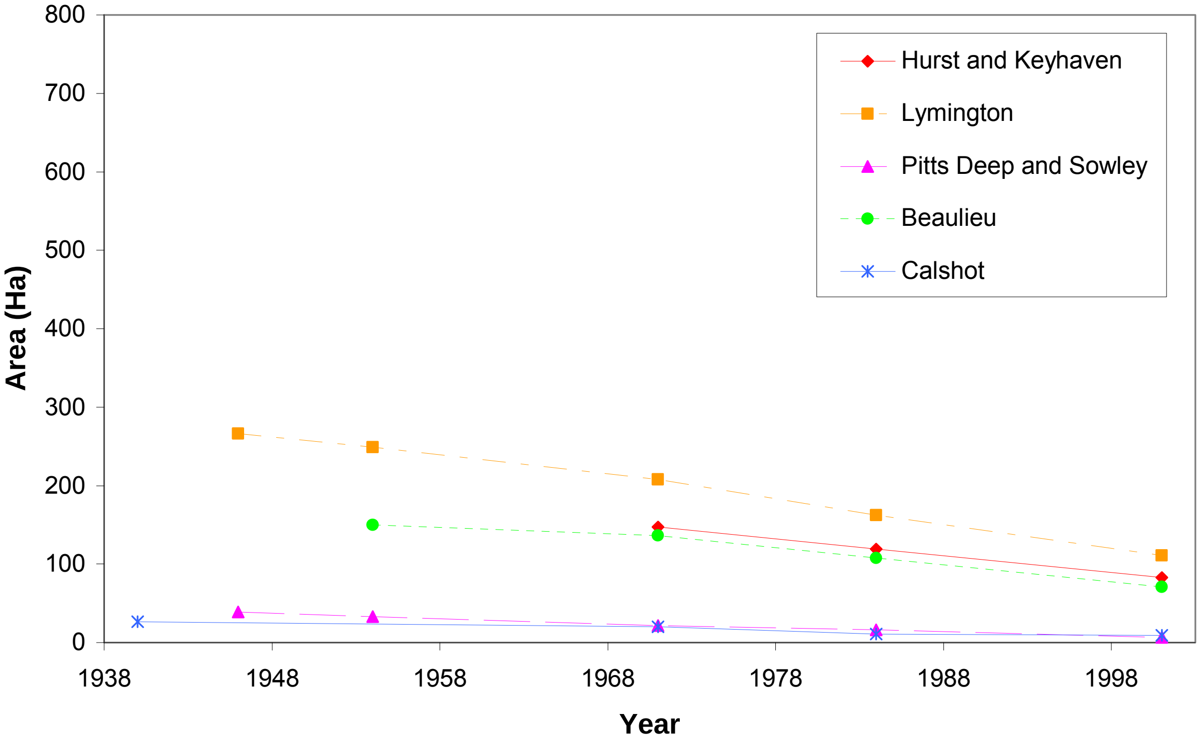


Figure C1.17: Historical change in saltmarsh extent; West Solent (HPI)

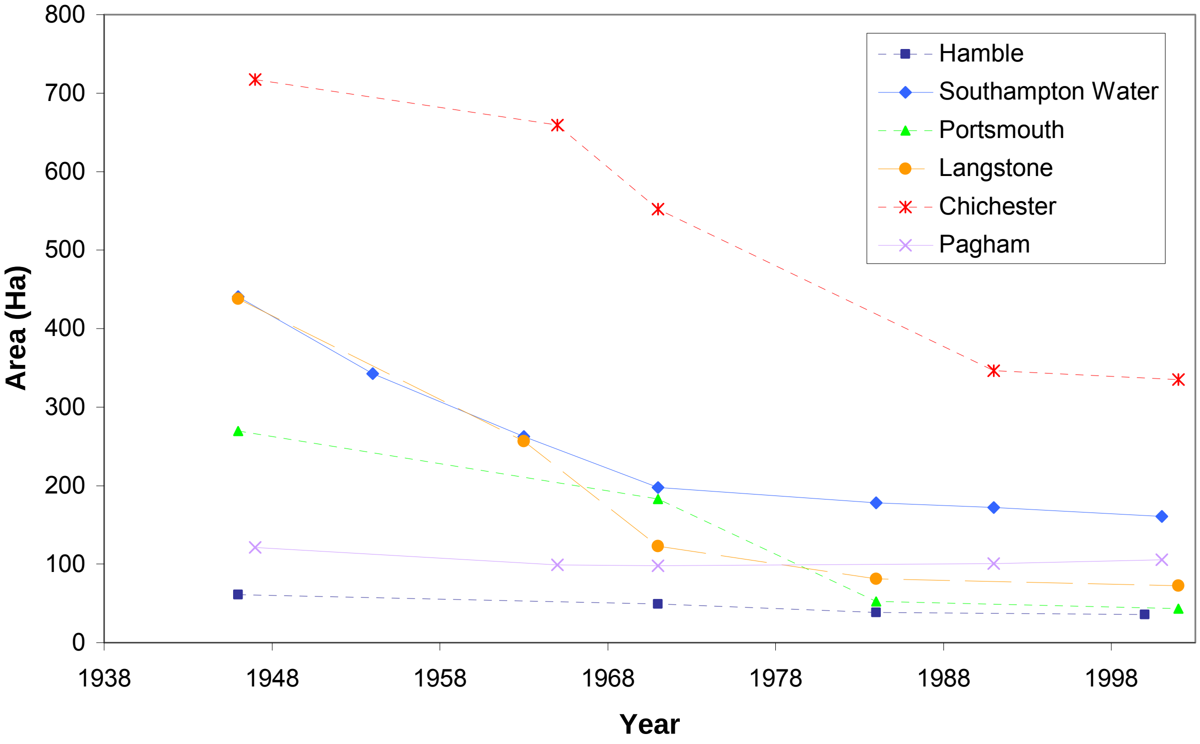


Figure C1.18: Historical change in saltmarsh extent; East Solent (HPI)

The area of loss in the east Solent, excluding the River Hamble and Pagham Harbour, have historically been much higher than those in the west Solent but appear to be slowing down since approximately 1984 (Figure C1.18). Future monitoring is required to confirm this. Pagham Harbour is an exception to all other geographical units in the north Solent, since it underwent a net loss of 12.9% between 1946 and 2001, but the saltmarsh area has been increasing from 1971.

The causes of the rapid decline in spatial extent of saltmarshes and mudflats are uncertain, but may be attributed to a combination of probably inter-related factors, presented in Table C1.22. These include an absolute shortage of sediment (Geodata Unit 1987), on-going relative sea-level rise; land claim, coastal defences, channel dredging, shipping movements and the failure of some intertidal marshes and mudflats to store sediment released by co-adjacent erosion (SCOPAC Sediment Transport Study, 2004).

The greatest percentage of saltmarsh lost across the north Solent since the first date analysed was at Pitts Deep/Sowley and Portsmouth and Langstone Harbours. These areas underwent approximately 83% loss since 1946, which averaged 1.5% loss per annum. For comparison, it should be noted that Portsmouth Harbour underwent the greatest loss since 1946 (the tidal elevation in the 1946 aerial photography limited saltmarsh digitizing). In terms of the “worst bi-decadal period”, Portsmouth Harbour suffered 4.8% annual loss between 1971-1984, whilst Pitts Deep/Sowley and Calshot underwent 3.5% annual loss between 1984-2001 and 1971-1984 respectively (Cope *et al.,* 2007 a).

Factor	Comment
Wave action	Increases in significant wave heights and frequency of storm surges may produce stressed vegetation on the seaward edges of the saltmarshes, clifflets, erosion stacks and hollows, abrasion platforms, and fragmented saltmarsh islands.
Sea level rise and climate change	Rising sea levels and increased storminess would produce higher water levels resulting in the saltmarshes being inundated for longer durations more frequently.
Water logging of estuarine soils	Poorly drained sediments would result in water-logging of the marsh soil causing the development of anaerobic conditions in the mud surrounding the root system.
Vegetation dieback	Concentrations of plant toxins increase as a result of organic matter building up and reduced flushing. This reduces ability of the saltmarsh to bind the sediment through the root network and to trap sediment through the vegetation. This causes slumping and erosion, and the conversion of vegetated saltmarsh to tidal flats/pans or open water.
Lack of sediment supply	A lack of fine-grained sediment supply, either through the retention of eroded sediments or from other sources, would prevent the saltmarshes from accreting vertically to keep pace with rising sea-levels.
Tidal currents	Velocity, duration and direction, ebb dominant in Western Solent.
Bathymetric changes	Sub-tidal erosion and northward migration of palaeolandscape cliffs in the main Western Solent Channel (pers comm. HWTMA)
Human impacts	Growth and decline of the salt working industry; changes in land use management within river catchments; building of hard sea defences causing coastal squeeze; ship-generated waves; dredging and construction of marinas and berths.
Natural loss	Decline in vigour and adaptivity of the vegetation.
Coastal squeeze	Under rising sea levels, saltmarshes and other estuarine habitats and ecosystems would naturally migrate landward. This is often prevented however due to the presence of static coastal and flood defence works (such as sea walls and embankments), and the proximity of urban and coastal developments. This restriction on habitat migration results in the erosion and degradation of these natural flood defences. The loss of saltmarsh area fronting the sea defences allows greater wave action on the shoreline and sea defences and increases the risk of flooding and coastal erosion.

Table C1.22: Potential factors in saltmarsh decline

The west Solent experienced high saltmarsh losses because of exposure to wave attack and *Spartina* dieback, which caused severe edge erosion. Further analysis revealed that both edge erosion and internal dissection were the important processes causing saltmarsh loss in Portsmouth and Langstone harbours. Edge erosion may be surprising given the sheltered nature of the harbours, but the local fetch has increased as the saltmarshes have eroded. In addition, the location of the depleting hybrid cordgrass (*Spartina anglica),* low in the tidal frame, also played a role. All of these factors have contributed to saltmarsh loss since 1946.

In terms of future response to sea level rise, the SDCP predicted saltmarsh loss using two techniques; Historical Photography Interpretation (HPI) and LiDAR and tidal elevation interpretation (LTEI). Table C1.23 presents a comparison of methods showing when the saltmarsh may cease to exist. The HPI extrapolation is based on the last epoch of data (i.e. 1991–2002 for Chichester Harbour – Figure C1.18), whilst the LTEI is based on the relationship between topography and tide and a sea level rise of 6mm per annum with no sediment accretion.

	Year of possible saltmarsh extinction HPI	**Year of possible saltmarsh extinction LTEI**
Hurst	2040	2105
Keyhaven	2040	2105
Lymington	2040	2105
Pitts Deep and Sowley	2015	2105
Beaulieu	2033	Extinction not predicted. Instead, 18 ha remaining
Calshot	2105	2105
Southampton Water	Extinction not predicted. Instead, 89 ha remaining	Extinction not predicted. Instead, 54 ha remaining
Hamble	Extinction not predicted. Instead, 17 ha remaining	Extinction not predicted. Instead, 19 ha remaining
Portsmouth	2093	Extinction not predicted. Instead, 9 ha remaining
Langstone	Extinction not predicted. Instead, 23 ha remaining	Extinction not predicted. Instead, 37 ha remaining
Chichester	Extinction not predicted. Instead, 226 ha remaining	Extinction not predicted. Instead, 103 ha remaining
Pagham	Prediction not possible	

Table C1.23: Comparison of HPI and LTEI as methods for predicting saltmarsh extinction.

The reason for the discrepancy in the prediction of life expectancy of the saltmarshes is down to the method employed. The HPI accounts for all local factors operating at a site such as *Spartina* dieback, wave attack, sea level rise, dredging and pollution etc. The prediction is a simple extrapolation of past losses. The only factors the LTEI takes into account is sea level rise and sediment accretion. If there were no local factors operating at a site then this prediction would be the most reliable. However, in the West Solent in particular, there are discrepancies between the two methods because wave attack is a major local factor and the LTEI prediction does not take this into account (Cope and Bradbury, *in progress*). The HPI and LTEI predictions in the harbours are more uniform given that there are not so many local factors in operation. Topography and tide are the dominating factors.

It is important to establish an estimate of how long the saltmarshes will be present for, in order to realize and assess the implications of losing these natural flood defences. The West Solent Coastal Defence Strategy Study established that with existing saltmarshes, the chances of overtopping of the Keyhaven seawall at MHWS is minimal but if these natural defences no longer exist then there could be overtopping under a 1 in 1 year storm event. In addition, determining such indicative time periods (i.e. short/medium/long-term) associated with the implications of saltmarsh loss is necessary to quantify the requirements for habitat creation and to secure compensatory measures.

C1.2.8 Vegetated Shingle and Sand Dune

The following has been extracted from the SCOPAC Sediment Transport Study (2004).

In a fully natural condition this coastline would provide a wide range of mobile and partly mobile vegetated shingle habitats, however, practices of coastal defence together with a historical trend of natural recession, narrowing and steepening of some gravel beaches, have had some negative impacts on habitat survival and development. The key contemporary habitats are vegetated shingle (Gunner Point, Eastney Beach, Browndown, Hurst Spit, Warren Spit, Gull Island), sand dunes at Gunner Point, Eastoke Point and East Head spit and major intertidal sandbanks exposed at the West Winner.

C1.2.9 Cliffs

Approximately 3% of the north Solent coastline is comprised of low cliffs. There are low cliffs along the Pitts Deep frontage in the West Solent (up to 3m height) that have undergone rapid erosion (up to 0.8m per annum according to historical aerial photography) since inter-tidal loss in the 1980’s left the frontage more exposed to wave attack. This rate is expected to reduce as the coastline reaches equilibrium. Cliffs of approximately 6m in height can also be found along the West Solent at Bourne Gap; again, bi-annual cliff surveys show that these are eroding but at a much lower rate (approximately 0.3m per annum). Low cliffs are located in the east Solent at Solent Breezes and Selsey Bill. The 6m cliffs at Solent Breezes are sand, topped by plateau gravels; these are unprotected and are undergoing erosion (approximately 0.5m per annum according to FutureCOAST). The cliffs at Selsey Bill are up to 8m in height and mostly defended. Use of historical aerial photography has shown that the undefended section to the west of the Bill has been undergoing approximately 1.3m erosion per annum. This rate of erosion is supported by the Pagham to East Head CDS.

C1.2.10 Beaches

The beaches across the North Solent are mainly composed of shingle with a lower sandy foreshore as a result of their geological evolution. Construction of seawalls and groynes, and the placing of recharge have influenced natural beach evolution.

Figure C1.19 demonstrates short to medium term changes in beach cross-sectional area between 2003 and 2008 as noted by the South-east Regional Monitoring Programme (CCO West Solent and CCO East Solent Annual Reports, 2008). These changes include beach extraction and deposition events. Results indicate notable losses at the centre of Hurst Spit and the proximal end of North Point (greater than 30%), Park Shore, Lepe (greater than 30%) and a short section at Bourne Gap in the West Solent, at Solent Breezes in Southampton Water, either side of Gilkicker Point, along the open coast of Hayling Island, The Hinge at East Head and greater than 30% erosion west of Selsey Bill, thereby feeding downdrift accretional features.

Since 2003 there has been accretion in areas to be expected such as cuspate forelands (Browndown in Southampton Water and Sinah Warren at the entrance to Langstone Harbour), promontories (Stansore Point in the West Solent which underwent a 30% increase), the distal ends of spits (Hurst Spit, Warren Farm Spit and Calshot Spit in the West Solent) and spits at the entrances to the East Solent harbour mouths (Eastney Spit at the entrance to Langstone Harbour, Eastoke and Black Point Spit at the entrance to Chichester Harbour which all underwent a 30% increase and the tip of East Head Spit). Eastney Spit and Eastoke undergo annual beach extraction, thereby recycling material back into the system further updrift. In addition, North Point in the West Solent undergoes annual accretion (1,600 m^3 per annum) but this is not highlighted in Figure C1.19 as there was an extraction in December 2004 (CCO West Solent Annual Report, 2008).

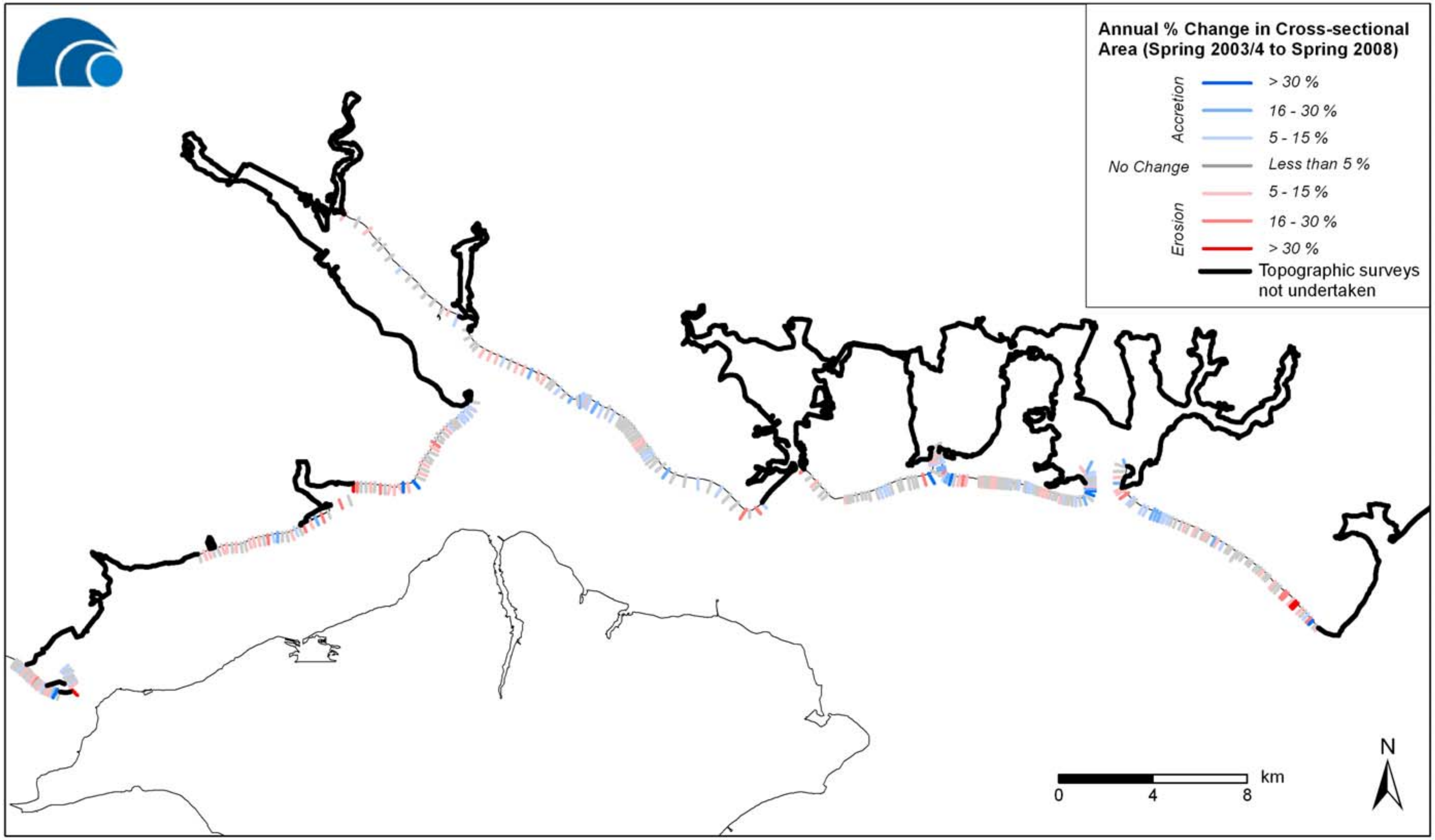


Figure C1.19: Change in cross-sectional area (Spring 2003/4 to Spring 2008) (CCO West Solent and East Solent Annual Reports, 2008)

C1.3 Large/Regional Scale

The North Solent can be split into three regional scale units;

- West Solent (Hurst Spit to Calshot Spit)
- Southampton Water (Calshot Spit to the River Hamble, including the Lower Test)
- East Solent (River Hamble to Portsmouth Harbour entrance to Selsey Bill)

The broad sediment transport patterns are outlined. These are explained in more detail in the Local Scale section (C1.4).

C1.3.1 West Solent

Sediment sources

Natural sediment sources in the West Solent are:

- Gravel inputs from a relict portion of the Beaulieu River ebb tidal delta and swash bars off of Calshot Spit
- Minor input from the cliffs in Stanswood Bay
- Net suspended sediment transport on the flood tide at Hurst Narrows
- Suspended sediment release from mudflat and saltmarsh erosion

Both the major and minor rivers have historically inputted fine sediment but now possess major impediments to sediment transport, such as dams and weirs. The same applies to the defended low cliffs at Inchmery.

Littoral drift

Littoral drift along the West Solent frontage is limited due to the protection afforded by Hurst Spit and the Isle of Wight from south-westerly waves; rates are below 1,000 m^3 per annum along the majority of the coastline and reach a maximum of 2,000 m^3 per annum along North Point. The low rate of sediment transport is from southwest to northeast.

Sediment stores and sinks

The main sediment stores and sinks in the West Solent are:

- Low volume gravel beaches
- Spit features
- Mudflats and saltmarshes
- Low cliffs
- Shingles Bank and other banks and shoals

C1.3.2 Southampton Water

Sediment sources

Natural sediment sources in Southampton Water are:

- Minor input from cliffs at Solent Breezes
- Suspended sediment release from mudflat and saltmarsh erosion
- Net suspended sediment transport on the flood tide but limited entry of course sediments
- Limited river input

Littoral drift

Littoral drift along the east side of Southampton Water is limited due to the sheltered nature of the estuary. Sediment transport is predominantly by tidal currents in a north-west to south-east direction. Where there is a drift divide at Victoria Park on the Netley frontage, material is transported in a south-east direction (see Section C1.4.2).

Sediment stores and sinks

The main sediment stores and sinks in Southampton Water are:

- Low volume gravel beaches
- Spit features
- Mudflats and saltmarshes
- Low cliffs

C1.3.3 East Solent

Sediment sources

Natural sediment sources in the East Solent are (East Solent SMP, 1997):

- Relict nearshore deposits of post-glacial sand and gravel
- 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
- Suspended sediment released from saltmarsh erosion in the harbours

Present day sources are limited by the protection of formerly eroding cliffs and by the dredging of the ebb tide deltas. A major source of sediment is now the recharge material placed at Medmerry and Eastoke through beach management practices.

Littoral drift

Littoral drift along the open coast is dominated by breaking wave processes; rates vary from 5000 m^3 per annum along the Medmerry frontage to about 15,000m^3 per annum around the entrance to Chichester Harbour (East Solent SMP, 1997). The dominant drift direction is from north-west to south-east between the River Hamble to Gilkicker Point and in an anti-clockwise direction between Selsey Bill and Portsmouth Harbour. There are drift divides however, at Eastney in Portsmouth, and Gunner Point and Eastoke on Hayling Island (SCOPAC Sediment Transport Study). In addition, sediment transport around the harbour mouths is cyclical and complex due to tidal currents and ebb tidal deltas (see Section C1.4.4a and C1.4.4b). Tidal currents also have a strong influence around the headlands of Selsey Bill and Gilkicker Point (East Solent SMP, 1997).

Sediment stores and sinks

The main sediment stores and sinks in the East Solent are:

- Gravel beaches
- Spit features
- Mudflats and saltmarshes
- Low cliffs
- Mudflats and saltmarshes in the harbours
- Ebb tidal deltas at the entrances to the harbours

C1.4 Local scale

The North Solent can be split into the following geographical units for discussion.

- Hurst Spit to Calshot Spit
- Southampton Water (Calshot Spit to the River Hamble, including the Lower Test)
- River Hamble to Portsmouth Harbour entrance
- Portsmouth Harbour entrance to the Witterings (open coast)
- Harbours (Portsmouth, Langstone and Chichester Harbours)
- West Wittering to Selsey Bill

The sediment budget, historical and present shoreline trends and predicted future evolution are discussed for each geographical unit. The majority of units follow the Shoreline Behaviour Statements in the FutureCOAST study. The text for this section (C.1.4) has predominantly been extracted from the SCOPAC Sediment Transport Study (Bray, Carter and Hooke, 2004) and the FutureCOAST study (Halcrow, 2002) aswell as more recent supporting research.

C1.4.1 Local scale – Hurst Spit to Calshot Spit

This section of coastline is characterized by shingle spit features at Hurst, Sowley, Needs Ore Point (Beaulieu) and Calshot (Figure C1.20). Mudflat and saltmarsh habitats and coastal grazing marsh are located between Hurst and Pitts Deep and at Beaulieu and Calshot (Figure C1.2). Low cliffs are found between Stone Point and Calshot. The section of coastline between Hurst Spit and the Lymington River is defended by a seawall, with intermittent timber groyne fields and revetments along the remainder of the shoreline, travelling east to Calshot Spit.

Interaction

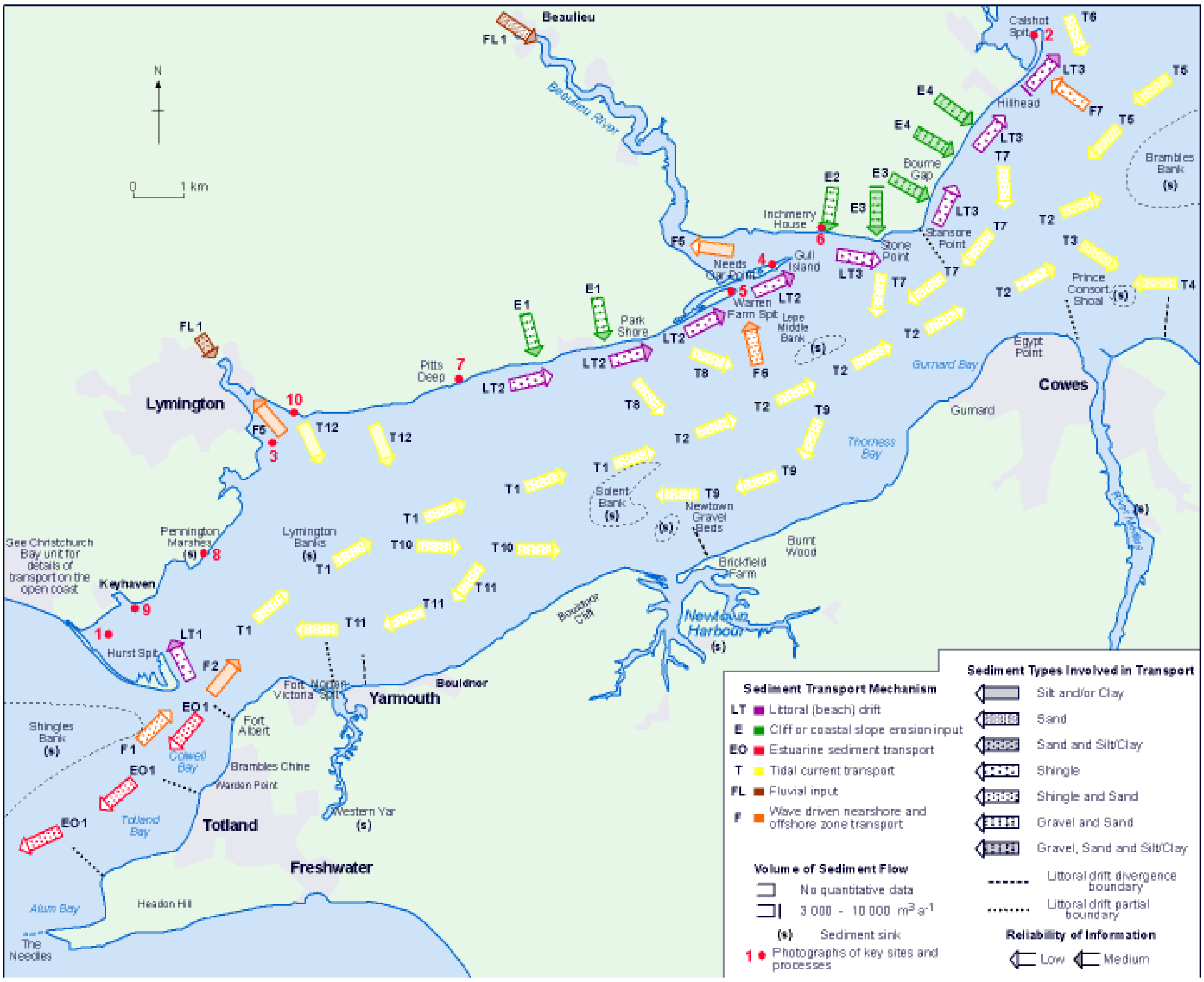


Figure C1.20: Sediment transport between Hurst Spit and Calshot Spit (SCOPAC Sediment Transport Study, 2004).

The prevailing sediment transport direction is from southwest to northeast in the Western Solent. Observations from beach surveys and condition assessment inspections of the groynes and revetments indicates that there is minimal alongshore transport and minimal sediment input from the soft cliffs

(CCO West Solent annual report, 2007). Littoral drift is not a major process in the West Solent because of the shelter to wave action provided by Hurst Spit and the Isle of Wight. Waves from the East Solent may penetrate to Stansore Point. Locally generated waves from south-westerly winds in the Western Solent become significant for the shoreline east of Lymington. Waves are therefore fetch limited and being of low height and short period they do not have much influence on the main channel bed (Langhorne, Heathershaw and Read, 1982). Littoral drift of coarse sediments is consequently restricted to more exposed parts of the upper shoreline from Pitts Deep to the Beaulieu River and eastwards from Lepe, where it is supplied by erosion of gravel and gravel-sand formations exposed in the low cliffs at Cadland. Sediment transport modelling for the Lymington to Calshot frontage indicated that sediment transport volumes involved are relatively very low, with a drift potential of less than 1,000m^3 per year. Alongshore sediment transport appears to be weak; the dominant direction appears to be on/off-shore rather than along-shore for most sections (West Solent Strategy, *in progress*).

Tidal currents are generally weak to moderate along the shoreline, but more rapid currents (up to 2-3 m/sec) are associated with the central and southern portions of the channel, especially at Hurst Narrows. These powerful tidal currents operating within the central parts of the channel have eroded and reworked much of the bed of the Solent River valley. Other gravels appear to have entered the Western Solent from Christchurch Bay. Large quantities of released materials have been deposited within Solent Bank in the centre of the channel (Figure C1.20). This bank, and other irregularities of the bed, affected the tidal flows to create several complex systems of re-circulating tidal eddies that direct strong currents primarily towards the Isle of Wight shore (extracted from FutureCOAST, 2002).

- Sediment inputs (F1 F2 F5 F6 F7 and FL1) (extracted from SCOPAC Sediment Transport Study, 2004).

Entry of coarse sediments (sand and gravel) into the West Solent from Christchurch Bay is normally restricted by tidal conditions at Hurst Narrows because the stronger ebb flow flushes sediment out of the system (F1). Net suspended sediment transport on the other hand, is likely to be into the West Solent at Hurst Narrows due to the greater duration of the flood current (F2 on Figure C1.20). Suspended sediment input to the Lymington and Beaulieu Estuaries (F5 on Figure C1.20), is thought to be of marine, rather than fluvial sources (Codd, 1972), via tidal currents (Posford Duvivier, 1994). Rendel Geotechnics and the University of Portsmouth (1996) calculate that both rivers, together with Bartley Water, Dark Water and Avon Water, contribute approximately 785 tonnes a^{-1} of suspended load to the West Solent (FL1). Both the major and minor rivers, notably the Lymington, possess major impediments to sediment transport, such as dams and weirs.

Gravel input to Warren Farm Spit (F6 on Figure C1.20) appears to be derived from the sub-tidal bed and channel (possibly a relic portion of the Beaulieu River ebb tidal delta) and driven ashore by storms. Gravel input to Calshot

Spit (F7 on Figure C1.20) appears to be from swash bars and other gravel features.

Eroding cliffs along the northern Isle of Wight shore contribute a fresh supply of fine sediments to the Western Solent, but it is uncertain how much crosses the channel to contribute to local saltmarshes as opposed to becoming transported north-eastwards by the residual tidal flow.

See E2, E3 and E4 in "*Shoreline Movement*" for sediment input from eroding low cliffs.

- Longshore drift (LT1, LT2 and LT3) (extracted from SCOPAC Sediment Transport Study, 2004).

Hurst Spit is dependent on an updrift supply of shingle from Christchurch Bay from which littoral drift can reach a maximum of 7,500 – 18,300 m^3/yr at Hurst Castle (Nicholls and Webber, 1987). Most of the sand that is eroded from the cliffs to the west does not reach the spit, indicating that it is carried offshore (Nicholls and Webber, 1987). Detailed studies of littoral drift on Hurst Spit have indicated a long-term west to east supply from Christchurch Bay and transport to the distal end of the spit (Hurst Point). At Hurst Point, a divergence of transport was recognised with some material being supplied to the Hurst Narrows tidal channel, thereby feeding the Shingles Bank and the remainder drifting northwards to build recurves on the spit at North Point (Nicholls and Webber, 1987). Material from North Point is recycled approximately every five years with the material taken to the western side of the spit (Colenutt, 2002) (LT1 on Figure C1.20). The last recycling event was Winter 2006/2007 (CCO West Solent Annual Report, 2007). Reliable rates of accumulation of 1,600 m^3 per annum have been measured over a number of years (New Forest District Council).

The shallow inter-tidal zone and mudflats and saltmarshes between Hurst Spit and Lymington provide some dissipation of wave energy. Cheniers (shell ridges) have been deposited on the southeastern facing seaward edge of the mudflats which afford local protection against wave attack. However, these inter-tidal systems are eroding, thereby releasing fine sediments back into the system as suspended load (Section C1.2.9). Some sediments are re-deposited on marsh and mudflat surfaces, but the majority become distributed throughout the Solent system, or lost into the English Channel. In addition, the tidal cycle is characterised by a 'stand' at high water that provides opportunity for upper foreshore erosion when waves are least depth-limited.

The shoreline between Lymington and Pitts Deep is sheltered from wave action by eroding mudflats and saltmarshes so that there has been little beach development or effective drift (LT2 on Figure C1.20). Exposure is greater along low-lying shores to the east of Pitts Deep where a transgressive upper gravel beach is controlled by a variety of groynes and other coastal defence constructed piecemeal along numerous small private frontages (Venner, 1986a; 1993). A long-term trend for west to east littoral drift is recognised from the historical eastward deflection of the mouth of the Beaulieu River and from the distribution of gravel against groynes and other structures.

Analysis of aerial photography from 1954 to 2001 indicates that the small ness-like gravel feature in front of Inchmery House (northern bank of Beaulieu River mouth) has continually accreted westwards over this period, whilst the beach has narrowed and migrated north, as indicated in Figure C1.21. This reversal in longshore drift can be explained as this shoreline is afforded a degree of protection from south-westerly wave attack by the tip of Gull Island to the south and from easterlies/south-easterlies by Stansore Point to the east. It is estimated from historical photography analysis that the ness feature has prograded approximately 60m west, and accreted by approximately 35m south and 50m south-west.

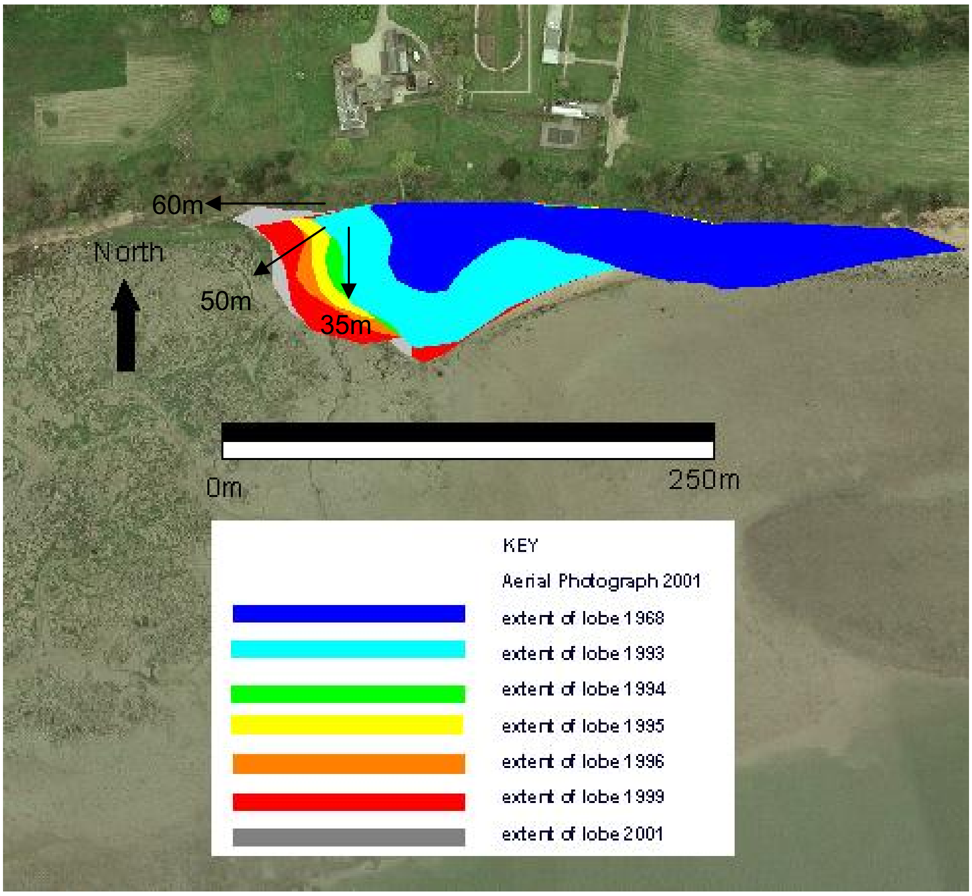


Figure C1.21: Evolution of Inchmery lobe feature

Little specific information relating to littoral drift between Inchmery House and Calshot is available (LT3 on Figure C1.20). The very small quantity of gravel moving from Stansore Point to Bourne Gap is probably due to storage occurring on the foreshore to the north east of Stansore Point, where the upper gravel beach has accreted to a width of 50m. It has also been suggested that sediments may move offshore at Stansore Point before arriving in Stanswood Bay (Dyer, 1980; Lobeck, 1995). Discussions with land and estate owners, and results from beach profile analysis indicate that severe storm wave events mobilises sand and shingle from the submerged offshore banks and are transported directly on/off shore, rather than alongshore. Stansore Point might, therefore, act as a weak sub-cell boundary. There appears to be little change in beach volumes between Stansore Point and Bourne Gap (CCO West Solent Annual Report, 2007). Eastward drift is indicated at Hillhead and along Calshot Spit by the distribution of gravel against groynes and other structures. BEACHPLAN analysis estimated less than 1,000m^3a^{-1} drift rate along the Calshot frontage (West Solent Strategy, *in progress*). Historically, rates have been low because gravel was stored on Warren Farm Spit, and could not by-pass the mouth of Beaulieu River. Lobeck (1995) reports a modest increase in drift rates since 1986, suggesting a weakening of the Beaulieu River mouth as a partial drift discontinuity (Bray *et al,* 1995).

The alignment of Calshot Spit is generally taken to indicate north-eastward drift (Dyer, 1980; Hydraulics Research, 1987; Hinsley, 1990). There is evidence of offshore to onshore feed directly to the spit (see F7 on Figure C1.20). If the erosion yield of the updrift cliffline between Lepe and Hillhead to the littoral drift pathway is in the order of 2,000m^3a^{-1} (Lock, 1999; Bray, *et al.,* 1998), some 220,000m^3 of gravel has been input into Calshot spit since approximately 1870 (date of earliest large scale Ordnance Survey plan). A modest renourishment of Calshot beach adjacent to the proximal part of the spit was undertaken in 1994/5, but there has been no artificial feed of the updrift inter-groyne compartments created in 1991.

- Dredging and reclamation impacts (extracted from SCOPAC Sediment Transport Study, 2004).

Recycling from North Point to replenish Hurst Spit is undertaken every five years to replenish the main section of the spit, and dredging at the tip of Calshot Spit is undertaken when required. The Solent Bank, a major gravel and sand accumulation within the West Solent (Figure C1.20), has been denuded of sediment by aggregate dredging over the period 1950-1990 that has resulted in removal of around 10 million m^3 of material, with consequent lowering of the bank by over three metres. Dredging was also undertaken in the Lymington River until the 1970's, to create navigable channels to maintain berths at the Town Quay, and to create marina basins. Such an activity removes sediments from the coastal system.

Much of the low-lying belt of grazing land between Keyhaven and Lymington was reclaimed in the 18th (used as salterns or salt-pans) and 19th centuries (conversion to grazing meadows). The corner of land forming the western margin of the Beaulieu River mouth around Warren Farm and Needs Ore Point was reclaimed in the 15th Century. Reclamation has impounded sediments, steepened the shore profile and has reduced the effective tidal prism of the estuaries. More recently, Tom Tiddlers ground at Calshot was reclaimed in 1965.

Shoreline movement

This frontage comprises the northern flank of the ancient Solent River valley that became inundated by rising sea-levels some 7,000 to 8,000 years ago.

Initially, the West Solent would have been a low energy estuarine backwater dominated by sedimentation. However, this was transformed between 6,000 and 8,000 years ago by the breaching of a barrier beach, or narrow isthmus of land, at the eastern end of Christchurch Bay connecting the mainland and the Isle of Wight. This led to formation of a permanent tidal channel at Hurst Narrows, linking the West Solent to Christchurch Bay, generating powerful tidal currents and allowing some wave penetration in extreme western parts. It also enabled supply of sediments (clays, sands and gravels) into the Western Solent from Christchurch Bay (extracted from FutureCOAST, 2002).

Two southward flowing tributaries of the Solent River (Lymington and Beaulieu Rivers) were also inundated to form small estuaries. Due to the sheltering effect of the Isle of Wight and Hurst Spit, the western parts of the mainland coast were relatively sheltered against direct wave and tidal action and became characterised by the sedimentation of fine sediments and the growth of tidal flats and fringing saltmarshes (FutureCOAST, 2002).

Gravels released through erosion of the Solent River valley and swept up from the sea bed by rising sea-levels formed small beaches that transgressed over the low-lying mainland shore. Further gravels would have been released as erosion cut into the Solent valley sides creating low cliffs at Stansore Point and within Stanswood Bay. Drift was predominantly eastward and was sufficient to feed the growth of Calshot Spit at the point of change in coastal orientation at the entrance to Southampton Water. The spit formed at a relatively early stage in the inundation of the Solent, around 6,300 years ago, and created sheltered conditions for the deposition of muds and the growth of saltmarshes immediately to the north east. The spit has transgressed slowly across these deposits (extracted from FutureCOAST, 2002).

In terms of more contemporary shoreline trends;

- Hurst Spit

Sediment supply has declined and erosion has increased along Hurst Spit since the 1940's due to construction of coastal defences further west in Christchurch Bay (New Forest District Council, 1997). The rate of landward rollover was 1.5 m per year in 1867 – 1968 and increased to 3.5 m per year in 1968 – 1982 due to a reduced sediment supply (Nicholls, 1985; Nicholls and Webber, 1987). In 1969, massive rock armour was placed along a 600 m frontage of Hurst Spit. Still, repeated overwashing occurred during the winters of 1981/82 and 1984/85 and on occasions there was breaching (Mackintosh and Rainbow, 1995; Bradbury, 1998). The storm of 1989 flattened the spit, with more than 100,000 tonnes of shingle lost overnight (Mackintosh and Rainbow, 1995; Bradbury, 1998). Bradbury (1998) calculated that at this time, the spit was prone to breaching under a 1:1 year storm event, during a south-westerly storm and tidal surge of 0.5 m above mean high water springs. Defence works were undertaken in 1996 to reduce the risk of breaching. The Hurst Spit Stabilisation Scheme included the construction of a rock revetment and offshore breakwater comprising 125,000 tonnes of Norwegian Larvik rock, and 300,000 m^3 of dredged material from the Shingles Bank successfully renourished the beach (New Forest District Council, 2001) (extracted from SCOPAC Barriers and Spits, *in progress*). The area around Hurst Castle continues to suffer loss of material, recorded since 1990 (CCO West Solent Annual Report, 2007).

- Inter-tidal areas

See C1.2.7.

- Pitts Deep and Sowley

Analysis of historical aerial photography shows that the shoreline to the east of Pitts Deep and at Sowley became more exposed to south-westerly wave attack by the 1950's as the fronting saltmarshes eroded. As a consequence, the beach at Sowley was permanently breached during a storm in 1955. The small lagoon which then formed was at a sufficient elevation in relation to tidal inundation to permit saltmarshes colonization. At the same time, erosion of the Pitts Deep frontage released sediment into the system which was transported eastwards, feeding the western Sowley spit. The spit has been accreting eastwards ever since and in October 2008 the two Sowley spits healed, thereby forming a continuous beach once more and sealing the lagoon off from tidal fluctuations (CCO West Solent Annual Report, 2008). The shoreline between Sowley and Park Shore is stable with very low rates of erosion, if any (CCO West Solent Annual Report, 2007).

- Warren Farm Spit

Studies of the episodic development of the sinuous plan-shape form of the gravel shoreline between Parkshore and the tip of Gull Island, revealed intermittent growth in an eastward direction between 1898 and 1976 (Human, 1961; Dobson, 1964; Sawyer, 1978; Clark and Gurnell, 1987; Hooke and Riley, 1987; Hydraulics Research, 1987; Williams, 1988; Lobeck, 1995). This spit is dynamically realigning in response to negligible sediment supply and longshore transport, and south-westerly and south-easterly wave attack.

Occasional storms appear to have been very influential in providing sediment promoting rapid short-term growth, e.g. some 100m of distal extension across former mudflats in 1952/3, (Halcrow, 1998). The same event resulted in breaching of the spit (Hydraulics Research, 1987). In 1986, a tidal channel (Bulls Gap) separating Needs Ore Point and Warren Farm Spit from Gull Island, was closed by importing 13,000 tonnes of gravel recharge (Clark and Gurnell, 1987; Venner, 1986b; Lobeck, 1995) (extracted from SCOPAC Sediment Transport Study , 2004). Since 2000, topographic surveys of the cross-sectional area of the spit reveal erosion at the proximal end (neck) and accretion at the distal end (tip) (CCO West Solent Annual Report, 2007). Analysis of aerial photography since 2001 supports this finding.

MLW has moved seawards some 270m between Needs Ore Point and Gull Island, and 600m at the distal tip of Gull Island, since 1975 (SCOPAC Sediment Transport Study , 2004). In addition, mudflat growth in a seaward direction has occurred in front of Gull Island since 1986, partly as a result of the eastwards extension of this longshore transport pathway (Halcrow, 1998).

- Inchmery House to Lepe (E2) (extracted from SCOPAC Sediment Transport Study, 2004)

Active erosion along a 600m long section of coastline between Inchmery House and Lepe has formed a distinctive series of retreating cliffs up to 6m high cut into Tertiary sands capped by Pleistocene river terrace gravels. The eroding cliffs formerly extended further eastward to Stone Point, but a series of timber and rock revetments in combination with groynes have protected their bases so that the cliffs are now inactive and vegetated (Hampshire County Council, 2003). Posford Duvivier (1994) suggest recession of the High Water Mark between 1868 to 1977 to be 0.4ma^{-1}. Current erosion yield is calculated at 2,000m^{3} a^{-1}, half of which is coarse (gravel) sediment. Analysis since 2000 shows continued reduction in beach cross-sectional area in front of Inchmery House (CCO West Solent Annual Report, 2007).

- Stone Point to Bourne Gap (E3) (extracted from SCOPAC Sediment Transport Study, 2004)

Erosion along this segment has formed low, discontinuous cliffs at Stone Point and to the east of Stansore Point extending to Bourne Gap (E3 on Figure C1.20). Although they extend to no more than 7m, historical cliff toe recession and mass movement has produced a locally important sediment supply to beaches due to their dominant gravel composition. Map comparisons covering the period 1868-1994 reveal cliffline retreat of between 0.20 and 0.27ma^{-1} (Halcrow, 1998) although cliff recession would have ceased well before 1994, due to an increased width of beach. Since 2001, the cross-section of the fronting beach has fluctuated (CCO West Solent Annual Report, 2007), in response to episodic storm events.

- Bourne Gap to Hill Head and Calshot Spit (E4) (extracted from SCOPAC Sediment Transport Study, 2004)

The privately owned coastline in the central section of Stanswood Bay comprises a narrow shingle beach at the toe of a soft sand cliff, some 5-10m in height (E4 on Figure C1.20). Monitoring of the cliffs indicates that the rate of cliff recession is very low, although episodic falls have occurred, principally as a result of southerly or south-easterly storm wave action. Coastline recession of 1.5ma^{-1} over the period 1967-87 (Hydraulics Research, 1987) and 0.2 to 2.0ma^{-1} (Oranjewoud, 1988, 1990; Posford Duvivier, 1999) are reported. Posford Duvivier (1997) give a mean of 0.5m^{3}a^{-1} for the period 1898-1976. Still, the beach between Hill Head and Calshot Spit has been in a healthy state of growth since 1989 (CCO West Solent Annual Report, 2007).

- Calshot Spit (extracted from SCOPAC Sediment Transport Study, 2004)

Calshot Spit has been relatively stable over the past 6300 years (Hodson and West, 1972). The stability of shape and position of Calshot Spit since the construction of the Castle in the 1530s suggests that gains and losses balance in the long term.

Lobeck (1995) was able to demonstrate that sets of groynes constructed during the period 1868-1971, between Stansore Point and Calshot, were the direct cause of HWM recession, especially the proximal sector of Calshot Spit between 1910 and 1931. Stability returned between 1935 and 1971 and thereafter, when most groynes had virtually ceased to function due to neglect. There has been a notable pattern of foreshore accretion along the Calshot Activities Centre frontage since 1971, apparently involving the onshore migration, and accretion, of at least two inter-tidal banks (Halcrow, 1998). Accretion is sufficient that material is recycled and used to recharge beaches along the updrift frontage to the west (Colenutt, 2002; Hampshire County Council, 2003). Since 1989, Calshot Spit has undergone an overall accumulation of beach material (CCO West Solent Annual Report, 2007).

Predictions of shoreline evolution

This frontage is characterised by marine inundation and erosion, of the Solent River valley soft Tertiary and Pleistocene materials. Its shoreline is therefore inherently sensitive to inundation and erosion, even when the driving forces are relatively weak (FutureCOAST, 2002).

- Hurst Spit

The process of overwashing, which is a precursor to breaching, is predicted in Figure C1.22 under MHWS, MHWS+0.5m surge, MHWS+1.0m surge and MHWS+1.5m surge scenarios (SCOPAC Barriers and Spits, *in progress*). Under the MHWS scenario, the spit is predicted to be stable apart from one profile at the castle end which is predicted to overwash under a 1:100 yr storm wave event. As the surge height increases, the spit becomes increasingly vulnerable to overwashing under shorter return period storm events. Under a 1.5m storm surge, the majority of the eastern end of the spit is prone to overwash under a 1:1 year storm wave event (Bradbury and Cope, 2005). It is important to note that Bradbury's (1998) overwashing model was developed for storm waves and not bi-modal seas. The model may therefore underpredict breaching for swell dominated wave conditions (Cope, 2005).

There is a potential for breaching and breakdown of Hurst Spit over the next century. The overall changes are likely to be complex with implications for the evolution of Hurst Narrows and Shingles Bank. In terms of the Western Solent, the main effects would be likely to involve strong tidal currents operating much closer to the mainland shore and increased wave penetration from Christchurch Bay. Such effects would greatly accelerate losses of mudflats and saltmarshes in the lee of the spit. Over time, the majority of saltmarshes occurring between Hurst Spit and Lymington could become eroded and replaced by a much narrower muddy and sandy foreshore. The massive quantities of fine sediment released could significantly increase sedimentation rates throughout other parts of the Solent or be transported out of the Solent system on the ebb tide. Under this scenario it is likely that the reclaimed land between Hurst and Lymington would be inundated more rapidly, although new saltmarsh would only be likely to regenerate where shelter was available (extracted from FutureCOAST, 2002).

If future tidal channels from breaching of Hurst Spit were to ‘capture’ some of the Hurst Narrows tidal flow it could reduce currents at the north Isle of Wight shore and result in a shift of tidal currents towards the mainland shore, with significant implications for the regimes of the respective shorelines (FutureCOAST, 2002).

Potential exists for enlargement of the western Solent channel since this has continued from the late Holocene period to the present day. However, it would appear that enlargement has occurred primarily by recession of the north Isle of Wight shore and deepening of the channel itself. Erosion has operated only to a modest extent on the mainland shore, primarily in areas to the east of Lymington (extracted from FutureCOAST, 2002).

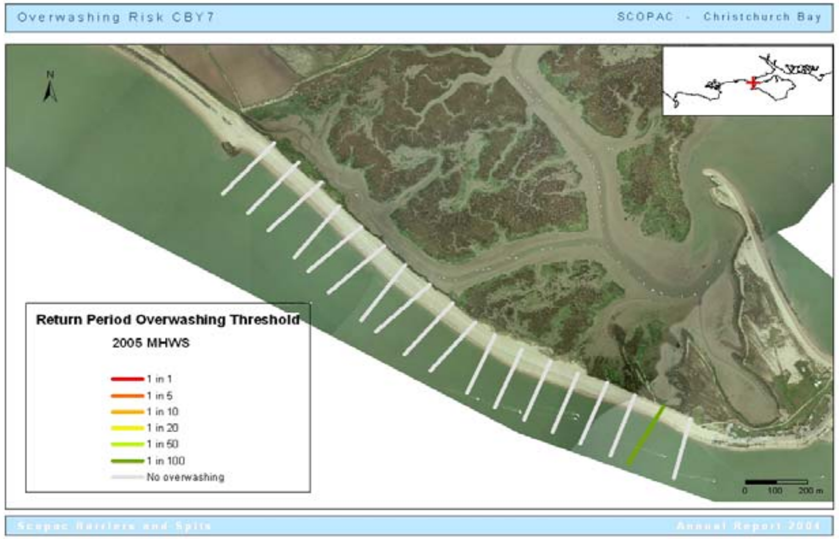


Figure C1.22a: MHWS

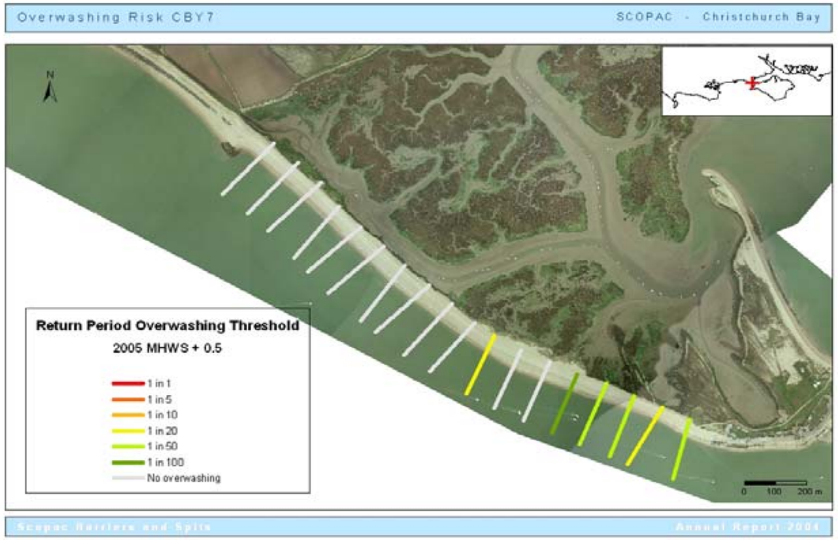


Figure C1.22b: MHWS + 0.5

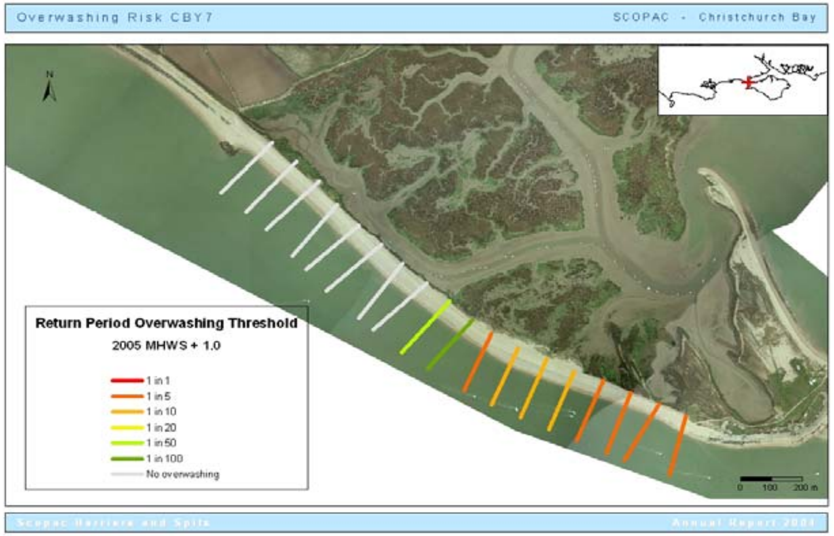


Figure C1.22c: MHWS + 1.0

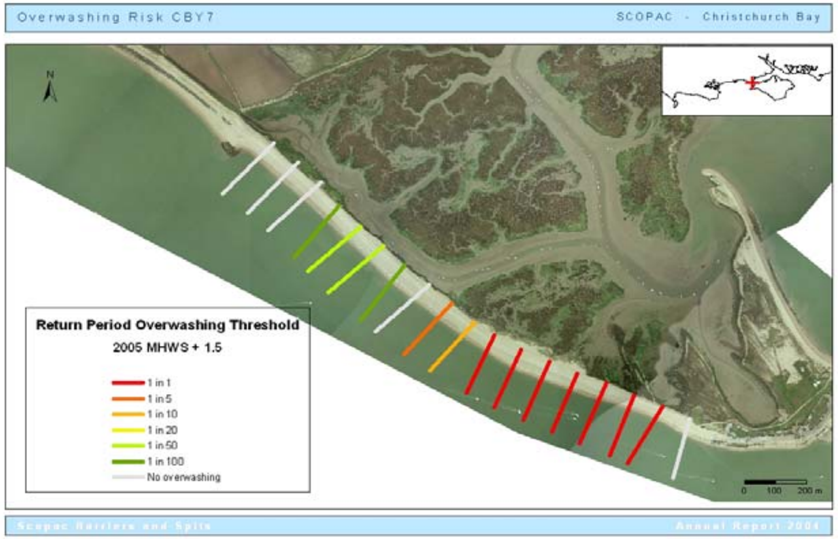


Figure C1.22d: MHWS + 1.5

(SCOPAC Barriers and Spits, *in progress*)

- Inter-tidal areas

Coastal saltmarshes and inter-tidal foreshores are recognised as vitally important ecosystems with multiple values and functions.

Rates of saltmarsh erosion and inter-tidal narrowing are likely to increase due to sea-level rise and increased wave energy associated with climate change. It is uncertain how long narrow fringes or pockets of marsh could remain in more sheltered places, although total losses should be anticipated in the medium to long term on the exposed frontages. Complete loss of saltmarsh at Keyhaven and Lymington is estimated approximately 2040-50 (See C1.2.7); their effectiveness as a natural flood defence will be seriously reduced prior to this. Narrowing of intertidal foreshores and marshes would expose the upper foreshore to increased erosion and increase the likelihood of inundation of low-lying backshores, especially between Keyhaven and Lymington (extracted from Solent CHAMP, 2003). If this process were to continue, many of the reclaimed areas could become inundated and revert to inter-tidal saltmarsh and/or mudflats. Indeed, such newly created areas, together with the mid and inner estuaries of the Lymington and Beaulieu Rivers, could in future become the most resilient remaining areas of saltmarsh along this frontage. This process would be likely to occur more quickly in event of a breach or breakdown of Hurst Spit (extracted from FutureCOAST, 2002). This is supported by the Solent CHaMP (2003).

- Sowley

Now the spits at Sowley have re-sealed, there is a chance the beach could breach again in the future under a comparable 1955 storm, especially if the updrift sediment supply from Pitts Deep reduces.

- Warren Farm Spit

The process of overwashing, which is a precursor to breaching, is predicted in Figure C1.23 below under a MHWS, MHWS+0.5m surge, MHWS+1.0m surge and MHWS+1.5m surge scenario (Bradbury *et al.,* 2005). Under the MHWS scenario, the spit is predicted to be stable. As the surge increases to 0.5m above MHWS, the spit is suddenly vulnerable to overwashing along select profiles under a 1:1 yr event (Figure C1.23 b). This is because wave height and period are fetch limited in the West Solent. Water level is the major factor in determining overwashing therefore. The majority of the spit is prone to overwashing under a 1:1 year storm wave event with a 1.0m surge on top of MHWS. The whole of the spit would be flattened in a 1.1 year storm wave event with a storm surge of 1.5m on top of MHWS (Bradbury *et al.,* 2005*)*.

- Darkwater and Mopley Stream

Increasing upper-shore erosion could also lead to breaching and inundation of a series of some seven narrow infilled southward trending valleys from Keyhaven in the west to Cadland in the east. A similar event occurred in 1955 when the Sowley beach was breached by a storm, inundating the hinterland

and forming two spits, and allowing saltmarshes to establish. This breach has proved to be ephemeral, as this has now recently been sealed naturally by longshore drift. Breaches would generate small tidal inlets that could interfere with the drift of gravel along the upper foreshore potentially resulting in interruptions of inputs to Warren Farm and Calshot Spits (extracted from FutureCOAST, 2002).

- Bourne Gap cliffs

Erosion of the low cliffs between the Beaulieu River and Calshot Spit would increase slightly to moderate rates as foreshore sediments are re-distributed alongshore, leaving the cliff base increasingly exposed. Gravels yielded would be transported towards Calshot and potentially reinforce the stability of the spit (FutureCOAST, 2002). This is supported by the Solent CHaMP (2003) also.

- Stanswood barrier and Calshot Spit

The process of overwashing, which is a precursor to breaching, is predicted in Figure C1.24 below under MHWS, MHWS+0.5m surge, MHWS+1.0m surge and MHWS+1.5m surge scenarios (SCOPAC Barriers and Spits, *in progress*). Under the MHWS scenario, both the Stanswood barrier and Calshot Spit are not predicted to overwash under any storm return period. Under a 0.5m surge, Calshot Spit remains stable but the Stanswood barrier is prone to overwashing at two vulnerable locations under a 1:20 and 1:10 yr return period (Figure C1.24 b). Under a 1m surge, Calshot Spit suddenly becomes vulnerable to overwashing under a 1:1yr storm return period aswell as the two vulnerable locations at the Stanswood barrier. Both the Stanswood barrier and Calshot Spit would be flattened under a 1.5m surge (SCOPAC Barriers and Spits, *in progress*).

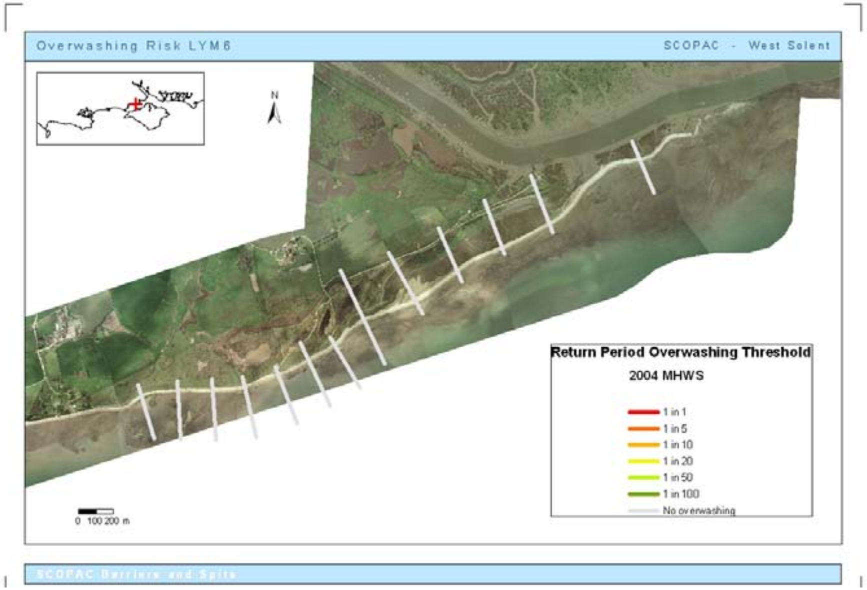


Figure C1.23a: MHWS

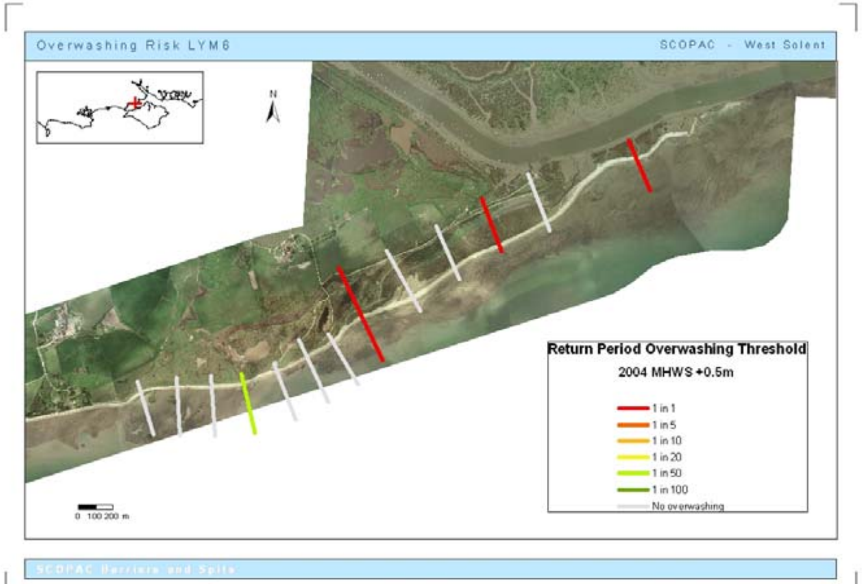


Figure C1.23b: MHWS + 0.5

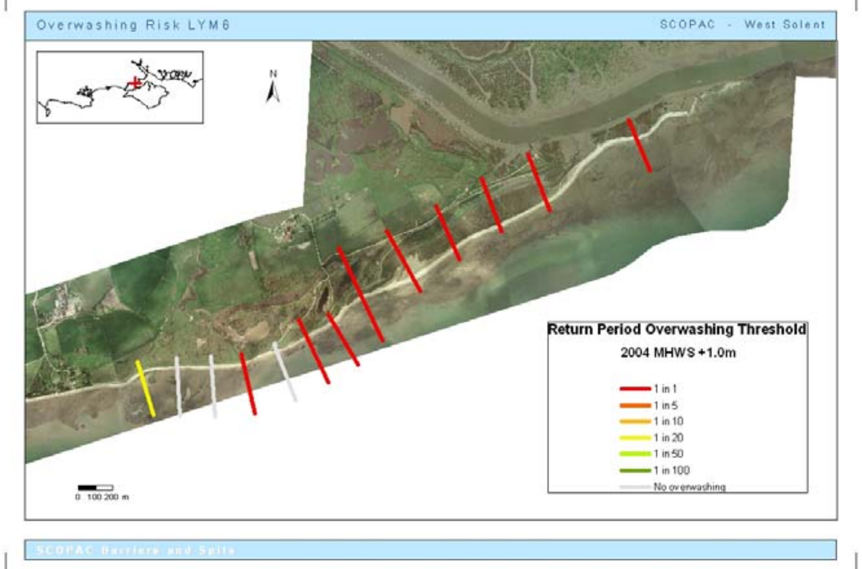


Figure C1.23c: MHWS + 1.0

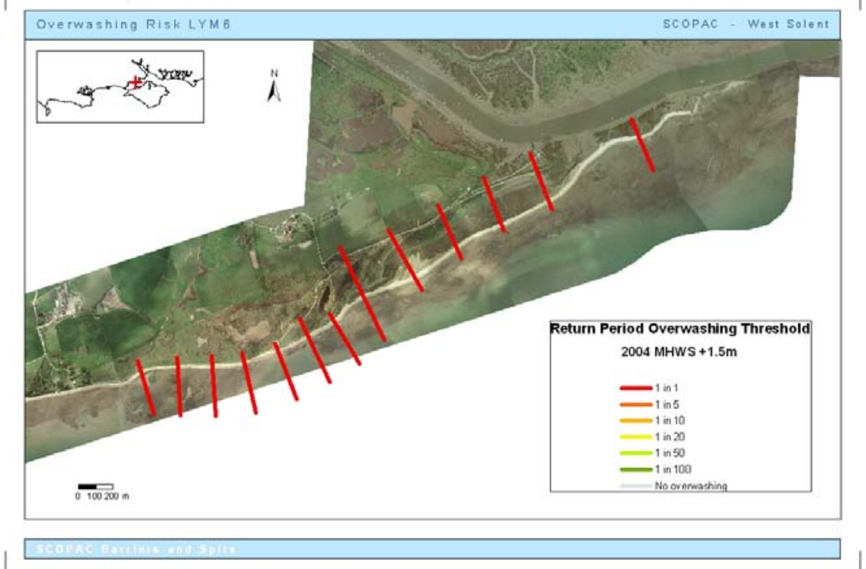


Figure C1.23d: MHWS + 1.5

(SCOPAC Barriers and Spits, *in progress*)

Figure C1.24a: MHWS

Figure C1.24b: MHWS + 0.5

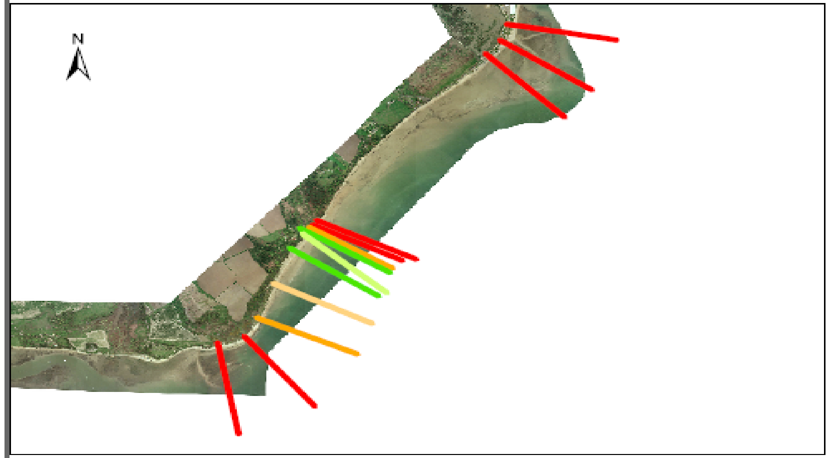
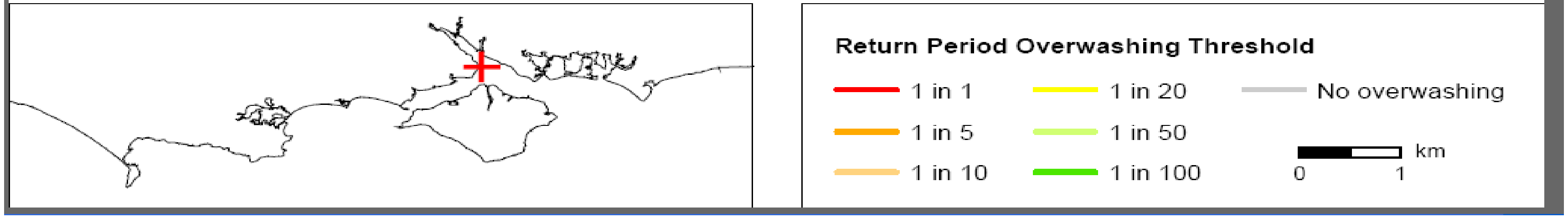


Figure C1.24c: MHWS + 1.0

Figure C1.24d: MHWS + 1.5



(SCOPAC Barriers and Spits, *in progress*)

C1.4.2 Local scale - Southampton Water (Calshot Spit to River Hamble, including the Lower Test, River Itchen and River Hamble)

This section of coastline is characterized by a large tidal estuary (Southampton Water) which the River Test, River Itchen and River Hamble drain into (Figure C1.25). The north-eastern coast, between the River Hamble and Itchen, is most exposed to wave action and is fringed by beaches of varying width and stability, composed of materials from the adjacent eroding cliffs. Much of the low energy northern and western margins of the estuary are either reclaimed and protected by embankments, or are fronted by saltmarsh and mudflats (SCOPAC Sediment Transport Study, 2004). The shoreline around Souhampton city, Marchwood, Fawley and the Rivers Itchen and Hamble are defended. The dominant geomorphological features are mudflats and saltmarshes located on the western coast, at the mouth of the Test (aswell as reedbeds) and the River Hamble estuary.

Interaction

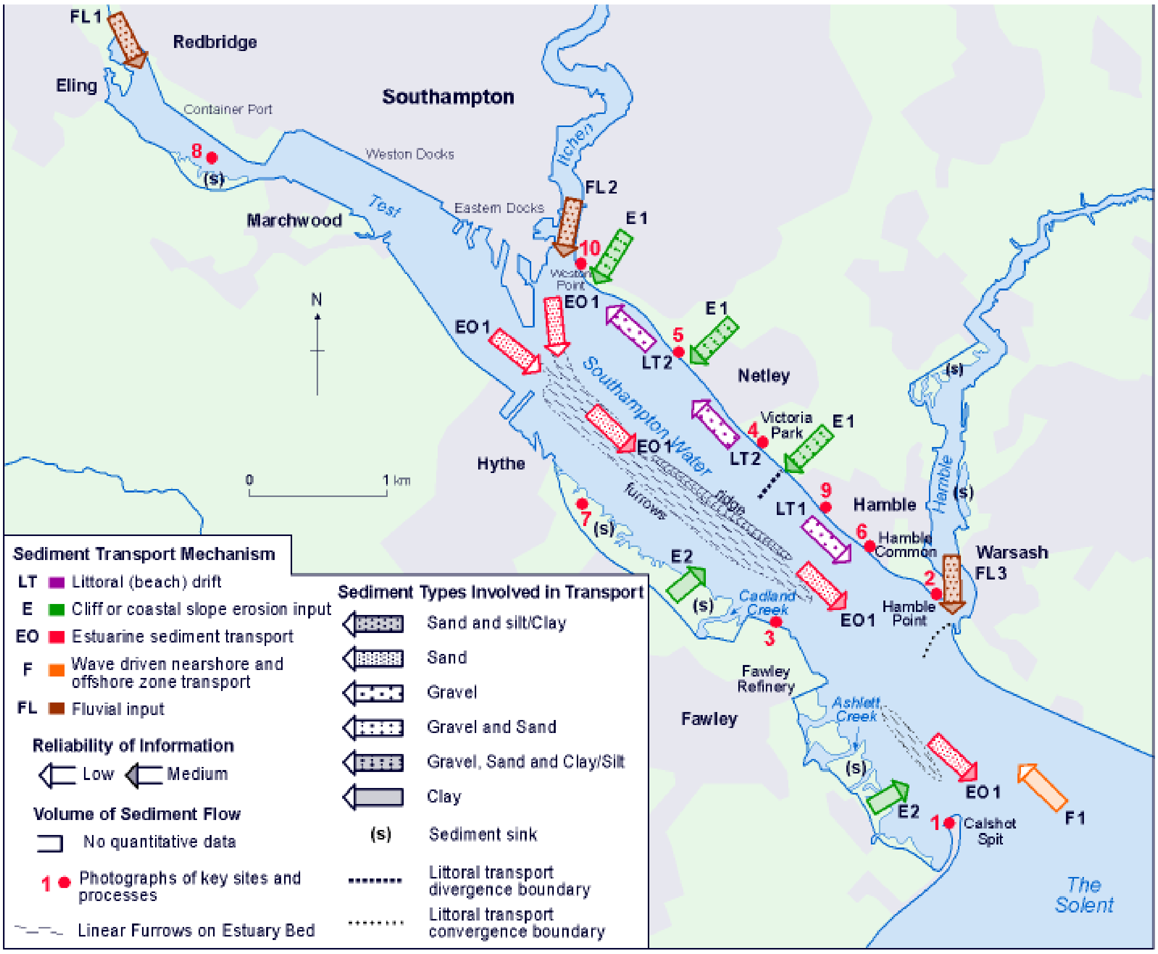


Figure C1.25: Sediment transport between Calshot Spit and the River Hamble (SCOPAC Sediment Transport Study, 2004).

Maximum significant wave heights generated by the longest available fetch are between 0.57 and 1.02m, although in reality waves from this narrow window are infrequent and prevailing wave heights are significantly lower (extracted from SCOPAC Sediment Transport Study, 2004).

Sediment transport is predominantly by tidal currents because wave generation is limited by the narrow and sheltered nature of the estuary.

- Sediment Inputs (F1, FL1, FL2, FL3, E1 and E2) (extracted from SCOPAC Sediment Transport Study, 2004)

Marine sources are likely to be the most significant, however, analysis of tidal conditions indicates that net input comprises suspended rather than bedload sediments. The quanities of inputs involved have yet to be measured although they have been inferred by sediment budget analysis. Littoral drift is a negligible input because most material transported towards Southampton Water is retained on Calshot and Hook spits or entrained and flushed back into the Solent. Fluvial input is considered small because river discharge is limited and low in suspended sediment concentrations by comparison to tidal.

Erosion of cliffs between the Itchen and Hamble river mouths supply gravel to local beaches, but the quantity is small due to slow rate of retreat and low cliff height. In addition, a significant trend for erosion of *Spartina* marsh margins and narrowing of the intertidal zone has been identified, (ABP Research and Consultancy, Ltd., 2000c; Solent CHAMP, 2003; SDCP, 2008). Whilst this process undoubtedly releases significant quantities of predominantly fine sediments, it does not comprise much input of new sediments but, rather, re-distribution of the existing estuarine sediment store.

- Longshore drift between Hamble/Netley to Weston Point (LT1 and LT2) (extracted from SCOPAC Sediment Transport Study, 2004)

Limited littoral drift is reported on beaches between the rivers Hamble and Itchen, with a drift divergence between Royal Victoria Country Park and Hamble Common. Both north-westward and south-eastward drift is indicated for this section of coastline (Hydraulics Research 1987) with minimal change (CCO East Solent Annual Report, 2007).

Although the Brambles Bank, in the central Solent could be thought of as the ebb tidal delta of Southampton Water it is unlikely to actually receive much contemporary material flushed out of Southampton Water. Instead, it is either a relic feature, or has formed from sediment movements within the Solent that are influenced by ebb tidal flows emerging from Southampton Water. The intertidal and subtidal portions of Hamble Spit, approximately 1000m south of Hamble Common could be considered as being derived from the ebb tide delta of the Hamble, composed of coarse silt, sand and fine gravel.

- Estuarine sediment transport (EO1) (extracted from SCOPAC Sediment Transport Study, 2004)

Bedload and suspended load transport along the axis of the main channel are in opposite directions, with the former travelling southwards, because of higher velocity but shorter duration ebb currents (Webber, 1980). Suspended sediments such as fine silts and clays undergo net transport up the estuary and into various creeks, channels and saltmarshes. Channels are relatively stable with low natural siltation and stable bedforms (Flood, 1981; Ziedler, 1990; ABP Research and Consultancy, 1993, 2000c). Thus, it is generally the view that sediment transport rates are low within the estuary.

There is no evidence for longshore transport along the western shore of Southampton Water because the shoreline is sheltered from prevailing southwesterly waves. Sedimentation in Southampton Water is generally restricted to the western side of the main channel where rates of $0.12m.a^{-1}$ are characteristic for limited areas (Halcrow, 1998). Overall vertical sedimentation rates over the past 6500 years are estimated at 2mm - $10mma^{-1}$ (Dyer, 1980) and 1mm - $2mma^{-1}$ (Hodson and West, 1972). These authors therefore suggest that sedimentation has kept pace with sea-level rise over recent millennia. More rapid 20th Century rates of $4\text{-}8mma^{-1}$ have been recorded from the Hythe and Hamble saltmarshes (Cundy and Croudace, 1995; 1996).

- Dredging and reclamation impacts (extracted from SCOPAC Sediment Transport Study, 2004)

Dredging and land claim are both sediment outputs from the system. Historically, sediment inputs to Southampton Water, mostly comprising silts and clays, have exceeded outputs with consequent sedimentation over the past 6500 years (Hodson and West, 1972). It is possible that this balance has been upset by recent reclamation and dredging so that these practices may be contributory factors in the widely reported erosion of saltmarsh and intertidal areas. Both capital and maintenance dredging of the main channel, dock approaches and berths have been undertaken within Southampton Water for over two centuries. A total of over 11 million m^3 of sediment has been removed from Southampton Water during these operations (Webber 1980). Routine maintenance dredging of berths and channels is also conducted and mean estimates of material removed are in the order of $90,000m^3a^{-1}$ (Robinson 1963) to $100,000m^3a^{-1}$ (Webber 1980). Removal of this sediment represents a significant proportion of the total sediment losses from the system.

Significant areas of Southampton Water have been reclaimed beginning in 1836 (Eastern Docks, Southampton) and extending up to the 1980s (Dibden Bay). See Figure C1.4 for inter-tidal areas that have been reclaimed since the 1940's. ABP Research and Consultancy (1995b; 2000c) provide a comprehensive documentation, with total land claim amounting to over 500 hectares.

Both dredging and reclamation practices have resulted in localised variation in tidal velocities, but with net reduction of the tidal prism and enlargement of the submerged profile of the channel (Associated British Ports Research and Consultancy, Ltd., 1989, 2000c). These changes suggest possible reduction of output by bedload transport with potential reduction in marine inputs due to the reduced tidal exchange.

Movement

The two distinct geomorphological systems that undergo erosion are the low cliffs and beaches between the Hamble and Itchen rivers, and the mudflat and saltmarsh areas.

- Hamble and Netley to Weston Point (E1) (extracted from SCOPAC Sediment Transport Study, 2004)

The coast between the Hamble and Itchen rivers comprises low cliffs up to 9m height. Historically, erosion was probably continuous, but over the past 100 years there has been piecemeal construction of defences and significant lengths are now protected to differing standards. At present, unprotected cliffs are actively eroding through basal undercutting and slab failure.

Cliff retreat is generally slow and concentrated at Weston Point, and from Netley Castle to Netley Hard (Hydraulics Research, 1987; Posford Duvivier, 1994; 1997). The narrow gravel upper beach has been characterised by falling levels causing undermining and the erosion of sea walls recently at the Royal Victoria Country Park.

South of Royal Victoria Country Park (Figure C1.25), the cliff line is vegetated and partly wooded, thus suppressing potential erosion. Map comparisons over the period 1870-1965 have revealed retreat at a rate of 0.1 to $0.5m.a^{-1}$, (Posford Duvivier, 1994; 1997; 1999) with some coastal advance by land claim at Hamble Point (Hooke and Riley, 1987). Highest recession rates ($0.5ma^{-1}$) appear to be at Hamble Common and between Netley Abbey and the Royal Victoria Country Park. Approximately 20-25% of the eroded sand and gravel released by cliff erosion (constituting approximately 50-100 m^3a^{-1}) is retained on local beaches, with the remainder (about 400 m^3a^{-1}) removed as suspended load (Posford Duvivier, 1997). Although the yield is very low it appears to have been sufficient in the past to supply the bulk of sand and gravel on the adjacent narrow beaches (Hydraulics Research, 1987). Since 2004, there has been minimal change in this region (CCO East Solent Annual Report, 2007).

- Mudflat and Saltmarsh Erosion in Southampton Water (E2) (extracted from SCOPAC Sediment Transport Study, 2004)

See Section C1.2.7.

The Lower Test is the only recorded site in the North Solent to be undergoing recent saltmarsh expansion. There was a notable expansion of Festuca between ground surveys in 1996 and 2003 (Sanderson, 2003). Overall saltmarsh directly to the north of the Redbridge Causeway has migrated inland (north) by approximately 80m between 1996 and 2003 and has increased in area from 8.9ha in 1996 to 11.2ha in 2003 (26% area increase).

- Southampton Water Estuary (extracted from SCOPAC Sediment Transport Study, 2004)

Examination of the Southampton Water estuary regime reveals that its cross section area at the mouth (and also at intervals further upstream) is larger than the equilibrium value that might be expected for its tidal prism (ABP Research and Consultancy Ltd. 2000c; Solent CHAMP, 2003). The non-equilibrium regime appears to have been inherited from the Test/Itchen valley that was inundated by rising sea-levels some 6,000 years ago. Sediment transport and deposition should normally act to reduce the inlet cross section towards its equilibrium value. However, infilling appears to have operated slowly within most Solent estuaries due to a limited sediment supply and shelter from wave action at their entrances.

Predictions of shoreline evolution

- Hamble and Netley to Weston Point

With increased sea level rise, beach profile narrowing and steepening may increase, resulting in transportation of beach sediment to near or offshore storage. This, in turn, will increase basal cliff abrasion and profile steepening, leading to a faster rate of shoreline retreat. This will have the advantage of increasing the input of both coarse and fine sediments to local beaches, littoral drift pathways and possibly nearshore/offshore sinks. Increased incidence of storm waves and the amount/intensity of winter rainfall would enhance both effects. The apex of Hamble Common is a particularly vulnerable location. In addition, vegetated shingle communities may have problems adapting (extracted from Solent CHAMP, 2003).

- Mudflat and saltmarsh erosion

Projected and predicted rates of sea-level rise over the medium to longer timescale have the potential to accelerate mudflat and saltmarsh submergence and inter-tidal foreshore narrowing. This may increase prevailing rates of marsh erosion if sediment accretion does not keep pace with sea level rise, with significant losses in the short-term in the lower estuaries of the Hamble, Test and Itchen (see Section C1.2.7). Coastal squeeze will be intensified if backing defences are not modified or re-aligned (extracted from Solent CHAMP, 2003).

- Southampton Water Estuary (extracted from Solent CHAMP, 2003).

With sea level rise, the width and volume of Southampton Water would increase, expanding the tidal prism and initially increasing both flood and ebb velocities. This would tend to increase erosion of the channel margins and the overall sediment flux so that output of both fine suspended and coarse bedload sediments would be greater than at present, thus enlarging the current overall negative sediment budget.

C1.4.3 Local scale – River Hamble to Portsmouth Harbour entrance

This section of coastline is characterized by a recurved spit (Hook Spit) at the entrance to the River Hamble, low cliffs at Solent Breezes, a defended section from Brownwich Stream to Browndown which is characteristic of a historic barrier beach, a shingle cuspate foreland at Browndown and another defended section around the Gilkicker peninsula, again characteristic of a historic barrier beach (Figure C1.26).

Interactions

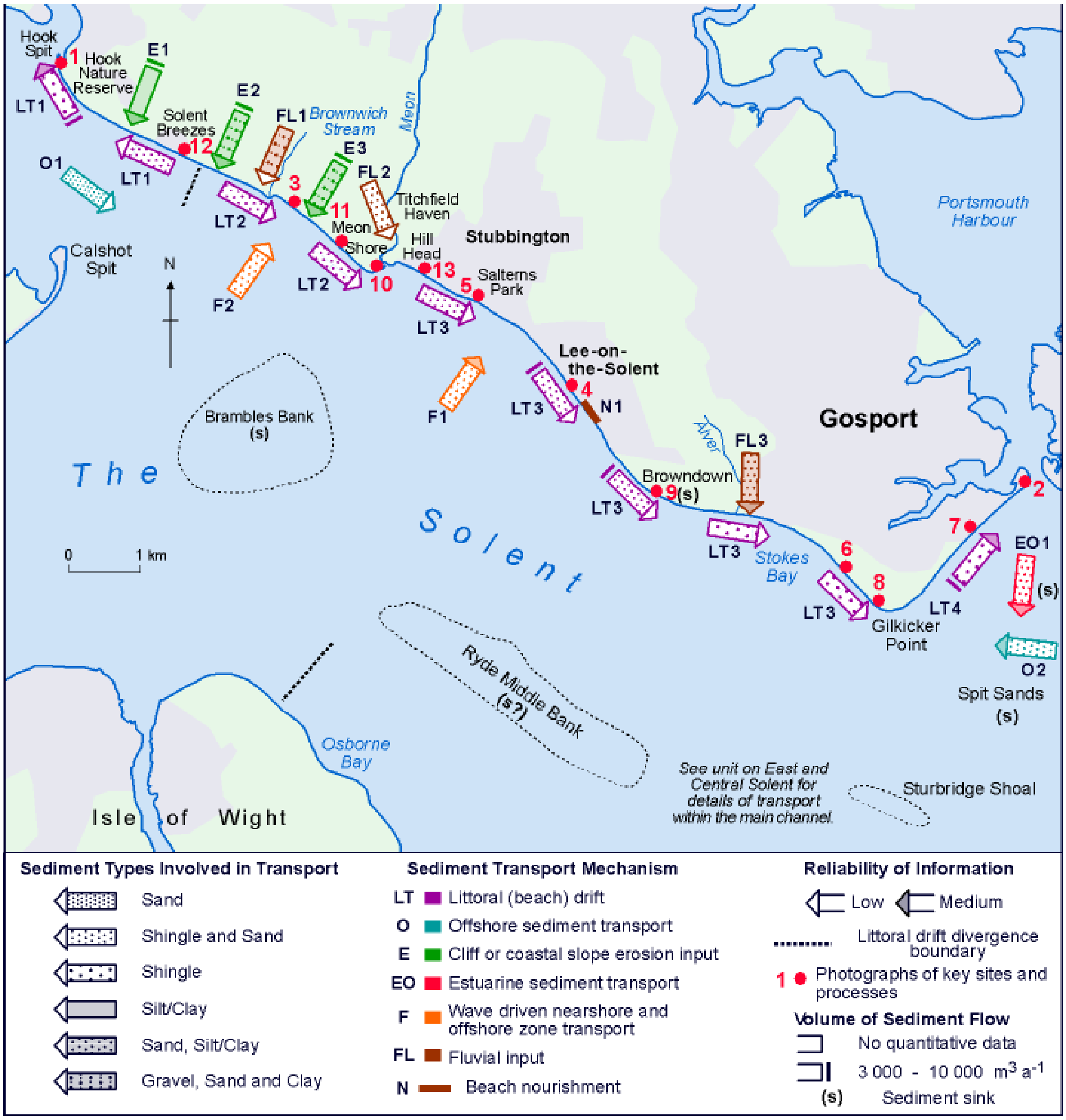


Figure C1.26: Sediment transport between the River Hamble and Portsmouth Harbour entrance (SCOPAC Sediment Transport Study, 2004).

This frontage is influenced primarily by waves. The Isle of Wight provides shelter against swell from the Atlantic and waves generated within the English Channel, but some waves from the east may be refracted and diffracted around Gilkicker Point to affect Stokes Bay. Local waves generated by south-westerly, westerly and north-westerly winds in the Western Solent and Southampton Water are also significant. The shoreline between Hill Head and Gilkicker Point is most exposed (extracted from FutureCOAST, 2002).

Tidal exchange at the entrance to Southampton Water and between the East and West Solent has generated an ebb tidal delta comprising the shoals known as Brambles Bank that lie 1-2 km offshore from Hill Head and Lee-on-the-Solent. They dissipate waves approaching from the south-west at low water. Tidal currents are generally weak in the nearshore and are only significant at the entrance to the Hamble estuary and at Gilkicker Point (extracted from FutureCOAST, 2002).

- Sediment inputs (F1, F2, FL1, FL2 and FL3) (extracted from SCOPAC Sediment Transport Study, 2004)

The beach at Salterns Park is unusual in that it is a gravel barrier composed of onshore migrating swash bars (F1 on Figure C1.26). The same applies at the Meon Shore where it is postulated that the sediment source maybe an abandoned ebb tidal delta on the foreshore that would have been active when Titchfield Haven was an estuary (F2). There is a deposit of gravel at the mouth of the Brownwich Stream (FL1) and River Alver (FL3), however it is unclear whether this is a relic deposition from the stream or interruption of littoral drift. It is estimated that the Meon and Hamble both supply a suspended load of 2,500 tonnes a^{-1} and a bedload input in excess of 700 tonnes a^{-1} (FL2).

- Longshore drift (LT1, LT2, LT3 and LT4) (extracted from SCOPAC Sediment Transport Study, 2004)

The form of Hook Spit, which displays a well developed distal recurve, is clearly the product of wave and tidal current induced north westwards drift, which extends eastwards from an inferred partial, probably transient, littoral transport divergence at Solent Breezes (LT1 on Figure C1.26). The seaward portion of Hook Spit at the mouth of the River Hamble has been stabilised so that it can no longer migrate landward. Evidence of progressive increases in beach levels east and west of this location is provided by Wheeler (1979). HR Wallingford (1995), have modelled drift based on a hindcast wave climate covering the period 1971-1991. For Hook Spit they determined a potential net westwards drift of around 300 m^3a^{-1}, with mean annual variations from 200 m^3a^{-1} to the east to 600 m^3a^{-1} to the west. For Solent Breezes, they determined a potential net westwards drift of around 500 m^3a^{-1}, with mean annual variations from 800 m^3a^{-1} to the east to 1,400 m^3a^{-1} to the west. However, the actual drift rate between Solent Breezes and Hook Spit is probably low, owing to very modest input from cliff erosion along this sector. Posford Duvivier (1999) suggest that lower foreshore abrasion along this, and the adjacent sector to the east, removes approximately 900-6,000 m^3a^{-1}, but most of this material is as suspended sediment.

At Solent Breezes, beach levels are characteristically low, despite the availability of potential input of gravel and sand from actively eroding cliffs. The increase in beach widths to the east of the inferred drift divergence indicates both greater sediment supply from cliff toe and cliff face erosion, and some acceleration of the net eastwards drift rate (LT2 on Figure C1.26). Gravel accretion has occurred to the west of the culverted sewage/storm water outfall at Brownwich, and some scour and set back of the position of mean high water has occurred to the east (Lewis and Duvivier, 1948, 1954; Wheeler, 1979; Webber, 1979; Brian Colquhoun and Partners, 1992).

Supply to the drift pathway is likely to increase downdrift to the mouth of the Meon because of cumulative input from cliff degradation. Posford Duvivier (1997) suggest that a transient drift boundary may exist at the mouth of the Meon. The wide inter-tidal shore profile is stable but there maybe a moderate increase in cliff recession due to future sea-level rise. A combined wave and hydrodynamic model study of this shoreline (Price and Townend, 2000) revealed that strong northwest to southeast drift is driven by storm waves generated in the western Solent. HR Wallingford (1995), have modelled drift based on a hindcast wave climate covering the period 1971-1991. At Hill Head, they determined a potential net eastwards drift of around 1,200 m^3a^{-1}, with mean annual variations from 1,700 m^3a^{-1} to the east to 500 m^3a^{-1} to the west. Further evidence of net eastwards drift is apparent from the deflection of the mouth of the River Meon in this same direction. This process, of marginal lateral spit growth, is confirmed by historical map analysis (Lewis and Duvivier, 1954; Wheeler, 1979) back to the mid-nineteenth century.

Littoral drift is southeastwards in direction between Hill Head and Gilkicker Point (Lewis and Duvivier, 1954; Hydraulics Research, 1987; Korab, 1990) (LT3 on Figure C1.26). The River Meon outfall appears to have an intercepting effect on the drift of coarse sediment (Lewis and Duvivier, 1954, 1962; HR Wallingford, 1995; Posford Duvivier, 1997). Material moving alongshore may be deflected offshore and may return onshore in the vicinity of Salterns Park as the beaches to the east generally show net accretion (Lewis and Duvivier, 1954; Korab, 1990; HR Wallingford, 1995). A drift estimate of 3,000 m^3a^{-1} at Hill Head (Halcrow and Partners, 1993). The resultant south-eastward net drift predicted at Browndown was 4,000 m^3a^{-1}, implying a tendency for net erosion along the intervening coastline. At Lee-on-the-Solent, they determined a potential net eastwards drift of around 3,400 m^3a-1, with mean annual variations from 4,200 m^3a^{-1} to the east to 900 m^3a^{-1} to the west. Shoreline stabilisation by groynes and seawalls was completed in the 1950s and 1960s between Hill Head and Browndown, thereby restricting littoral drift (Hydraulics Research, 1987; HR Wallingford, 1995; Oranjewould 1988, 1991).

The upper gravel and lower sand-gravel beach at Lee-on-the-Solent has a history of depletion (Bray, 1993), with eastward drift more rapid than updrift supply from Salterns Park (Lewis and Duvivier, 1957; Hydraulics Research, 1987; Halcrow, 1993). In 1996, Lee-on-the-Solent beach was substantially renourished (300,000m^3) (Fowler, 1998; Banyard and Fowler, 2000) with gravel derived from dredging of Southampton Water. Monitoring of subsequent volume changes has continued and suggests beach stability with a continuing net eastward drift across the rock groyne field (Bradbury *et al.,* 2007).

There are limited details of littoral drift between Browndown and Gilkicker Point (LT3 on Figure C1.26), although generalised sediment transport maps indicate a net eastward drift (Lonsdale, 1969; Dyer, 1980; Hydraulics Research, 1987 Bray, 1993). At Stokes Bay there appears to be potential net eastwards drift of around 3,000 m>^{3}a^{-1}, with gross annual variations from 3,700 m^{3}a^{-1} to the east to 700 m^{3}a^{-1} to the west (HR Wallingford, 1995), feeding Gilkicker Point. Shoreface erosion of fine-grained sediment, which is probably removed as suspended load, was estimated at approximately 5,000m^{3}a^{-1} by Posford Duvivier (1999).

The section between Gilkicker Point to Portsmouth Harbour Entrance (LT4 on Figure C1.26) is protected by continuous sea walls and intermittent groynes (Dobbie and Partners 1987). Net eastward littoral drift was determined by Harlow (1980) to be approximately 2,000m^{3}a between 1863-1972, and revealed significant erosion of the lower beach. Posford Duvivier (1999) calculate a shoreface erosion yield of some 2,500m^{3}a^{-1} of fine sediment, removed as suspended output.

- Dredging and reclamation impacts

Dredging to enlarge navigable channels has been undertaken on Brambles Bank in the 1950s and 1960s. It is uncertain whether it has lowered the bank sufficiently to affect the shoreline (FutureCOAST, 2002).

Movement

Rising sea levels of the mid to late Holocene around 7,000 to 8,000 years ago inundated the East Solent, West Solent and Southampton Water which exposed this frontage to locally generated wind-waves and tidal currents. As sea levels rose, the shoreline eroded the old valley floor and combed up gravels and coarse sands and transported them landwards to form barrier type beaches and spits. The north-eastward trending valleys of the Hamble and Meon rivers became inundated forming long narrow estuaries (extracted from FutureCOAST, 2002).

- Hook Spit

Map analysis reveals that the beach frontage of Hook Local Nature Reserve has accreted a series of gravel ridges since at least 1910 (Wheeler, 1979; Hooke and Riley, 1987; Korab, 1990), and Hook Spit has extended slightly into the Hamble River estuary mouth (SCOPAC Sediment Transport Study, 2004).

- Meon River Valley

Inundation of the Meon River valley formed an estuary at least as far inland as Titchfield. Tidal exchange at its inlet would have intercepted drifting sediments and generated an ebb tidal delta. However, with reclamation of the whole of the estuary in the 17th century, this delta became relict and has supplied its sediments onshore in the form of swash bars that migrate landward over the foreshore. This process continues to the present day and appears focussed on the Hill Head and Salterns Park frontage where there is much shingle spread across the foreshore. The low-lying shoreline frontage of Titchfield Haven is now protected against flooding by a seawall (extracted from FutureCOAST, 2002).

- River Hamble to Gilkicker Point

Between the River Hamble and Gilkicker Point, prevailing westerly waves generated a net south-east drift that tended to remove much of the beach material in this direction. Over time, the drift resulted in the formation of two distinctly different regimes within this frontage. Beach sediment removal in north-western parts resulted in continued cliff erosion and sediment supply. Delivery of beach sediments to south-eastern parts resulted in progradation of foreland type shingle and sand features at Browndown and Gilkicker Point and abandonment of the former cliffs up to 500m inland. It is probable that sediment supply has diminished over time so that the zone of active eroding cliffs has migrated south-eastwards at the expense of the prograded shingle features (extracted from FutureCOAST, 2002). Between Hook Spit and Gilkicker Point, there has been relatively little change in beach cross-sectional area since 2004 (CCO East Solent Annual Report, 2007). Small pockets of erosion and accretion have occurred in the vicinity of Lee-on-the-Solent and Hill Head respectively. Just to the east of Gilkicker Point there has been accretion since 2004 (CCO East Solent Annual Report, 2007).

- Gilkicker to Portsmouth inlet

The Gilkicker to Portsmouth inlet frontage has been denuded of most of its beach material and is dependent on defences, some of which were constructed directly on top of its beaches and spit, impounding their sediments. A similar situation occurs between the Portsmouth inlet and Southsea Castle. Along each frontage there are losses from beaches to the tidal inlet, but there are no obvious mechanisms for natural replacement of sediments. These low-lying frontages are therefore dependent upon their defences to maintain their shoreline positions (extracted from FutureCOAST, 2002).

Predictions of shoreline evolution

- Hook Spit

The process of overwashing, which is a precursor to breaching, is predicted in Figure C1.27 below under MHWS, MHWS+0.5m surge, MHWS+1.0m surge and MHWS+1.5m surge scenarios (SCOPAC Barriers and Spits, *in progress*). Under the MHWS and MHWS+0.5m surge scenarios, the spit is predicted to be stable. As the surge increases to 1.0m above MHWS, the spit is suddenly vulnerable to overwashing along half of the selected profiles under a 1:1 yr event (Figure C1.27 b). This is because wave height and period are fetch limited; therefore water level is the major factor in determining overwashing. Under a 1.5m surge, the whole of the spit would be flattened for a 1.1 year storm wave event (SCOPAC Barriers and Spits, *in progress*).

The Solent Breezes development could emerge increasingly as a minor headland as erosion to either side outflanks its defences. In the long-term this would interfere with the north-western directed drift pathway that supplies sediments to Hook spit, potentially leading to destabilisation of the spit. Titchfield Haven would be maintained as a freshwater marsh (extracted from FutureCOAST, 2002).

Under current management, with sea level rise, presently active cliffs are likely to erode slightly more rapidly and contribute additional sediments that would drift towards the south-east. Groyne fields at Hill Head would probably intercept the majority of these materials leading to some beach accretion. Further downdrift at Lee-on-the-Solent, drift inputs would be negligible, but losses would continue to occur to Browndown so that the newly replenished beach would tend to narrow, albeit at slow rates due to its large volume and controlling groynes (extracted from FutureCOAST, 2002).

Drift outputs to the Browndown frontage would be lower than with the unconstrained scenario, but could be sustained in the long term if it is assumed that management would involve repetitive cycles of re-charge at Lee-on-the-Solent (FutureCOAST, 2002).

Figure C1.27a: MHWS

Figure C1.27b: MHWS + 0.5

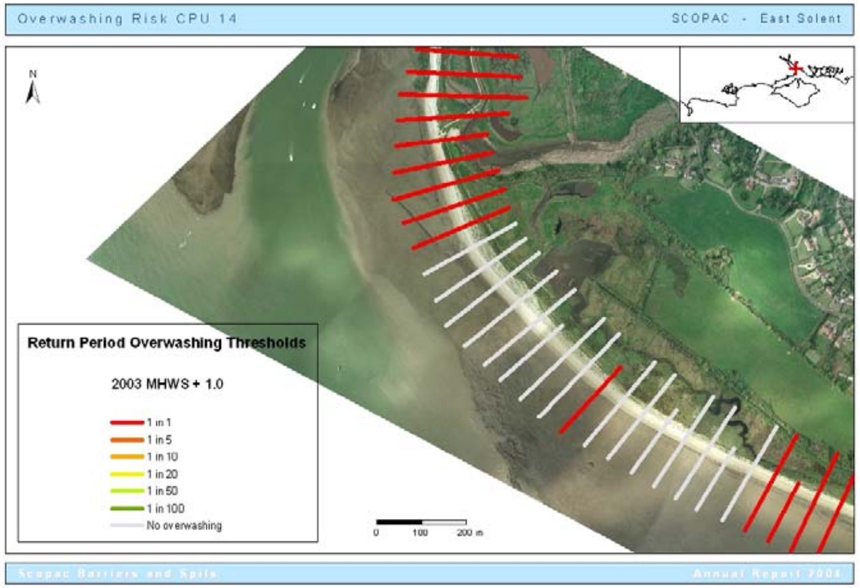


Figure C1.27c: MHWS + 1.0

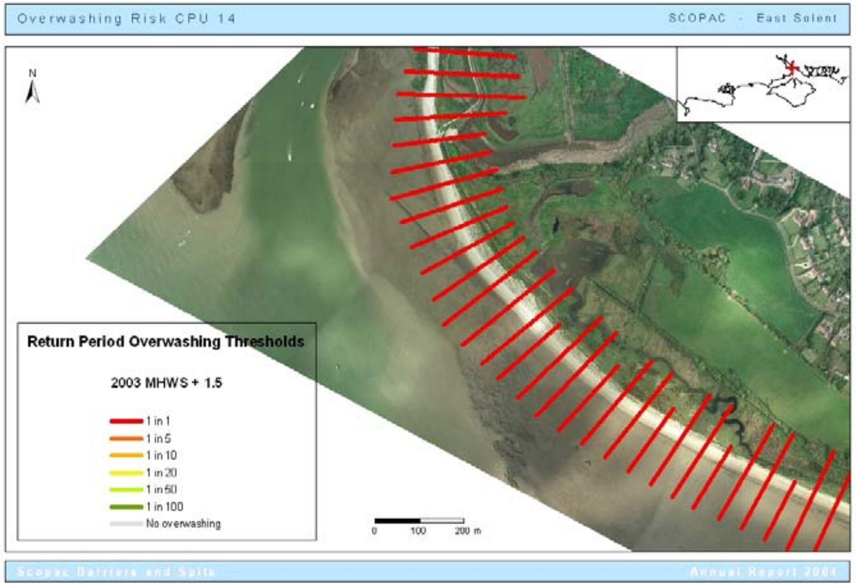


Figure C1.27d: MHWS + 1.5

(SCOPAC Barriers and Spits, *in progress*)

C1.4.4a Local Scale – Portsmouth Harbour entrance to West Wittering (Portsmouth, Langstone and Chichester Harbours)

Open coast

This coastline is characterized by three distinct harbours, namely Portsmouth, Langstone and Chichester (see section C1.4.4b for harbours), and transgressive barrier beaches that are fronted by low gradient sandy foreshores (Figure C1.28). The gravel beaches are relatively starved of sediment. Much of the potential beach-building sediment is stored offshore within relic channel, or bed deposits, or within present day ebb tide deltas (FutureCOAST, 2002). The open coast beaches at Portsmouth and Hayling Island are predominantly backed by seawalls or timber breastworks with additional groyne structures and recycling operations at Hayling Island compared with Portsmouth.

Interactions

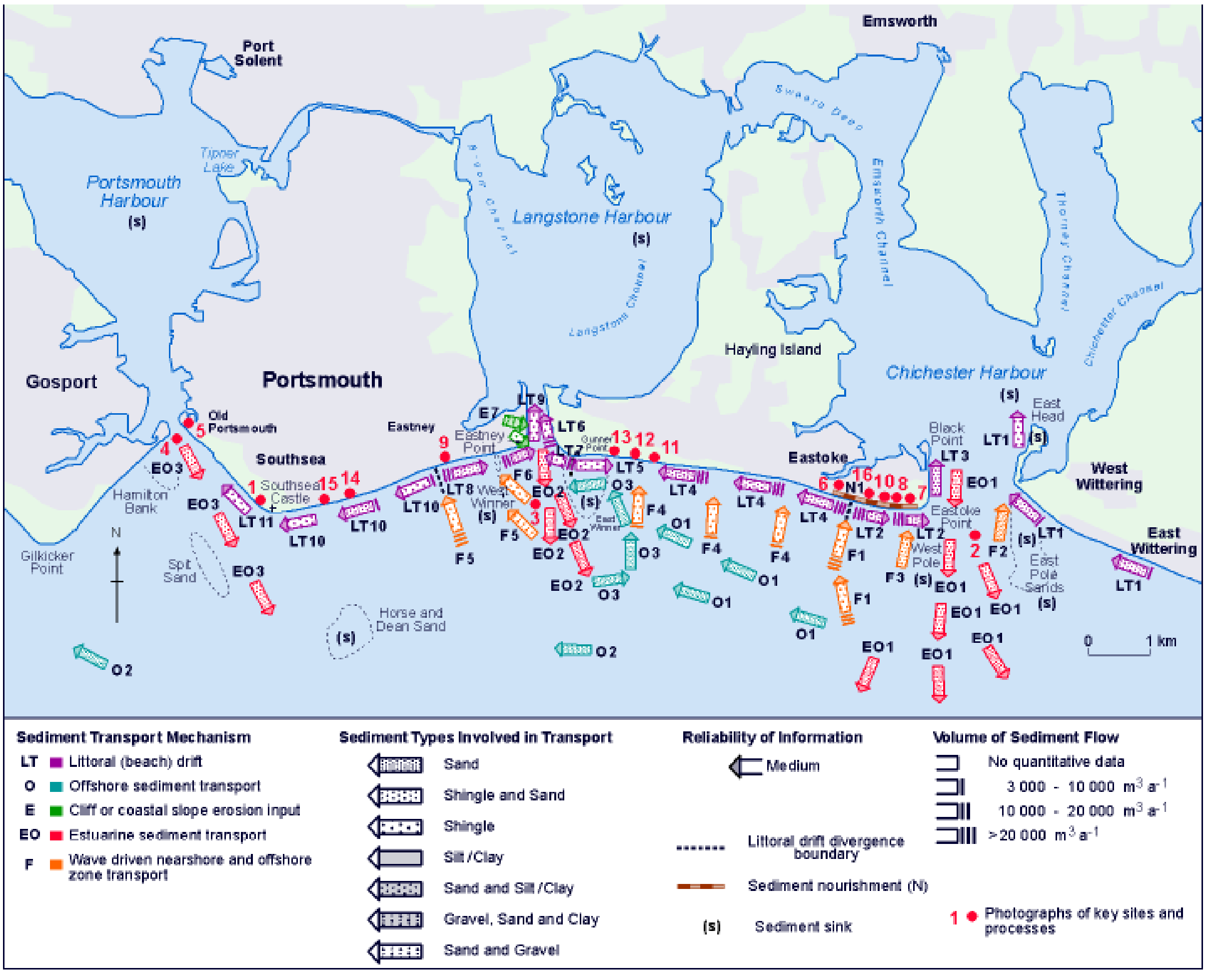


Figure C1.28: Sediment transport between Portsmouth Harbour and Chichester Harbour entrances (SCOPAC Sediment Transport Study, 2004).

The present shoreline exhibits the characteristics of a swash-aligned barrier attempting to continue to roll landwards with rising sea levels, but being partly constrained from doing so by: (i) the shelter afforded to western parts by the

Isle of Wight; (ii) the anchoring effect in the east of Selsey Bill; and (iii) the local stabilising influences of the ebb tidal deltas formed at tidal inlets. Within this constrained response there are coastal sub-systems developed of intense cycling of shoreline sediments between beaches, tidal inlets and tidal deltas with most materials being stored within the deltas. Spits have grown under the control of the inlet regime and local sustaining drift pathways.

Wave energy is lower along the Portsmouth to Chichester Harbour frontage, compared with the River Hamble to Gilkicker Point (C1.4.3), as the south-westerly fetch is shorter. Modified swell waves do not contribute to the wave climate west of Eastney as the Isle of Wight offers protection (Hydraulics Research, 1984). The coastline between Eastney and Southsea is exposed to a larger local fetch from the southeast than it is to the west, due to a change in orientation, but the offshore presence of Horse and Dean Sands (Figure C1.28) reduces incident wave heights along the central and eastern Portsea Island coastline. Ship-generated waves are normally less than 0.40m height, but may be an important local component. 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 (East Solent SMP, 1997).

- Sediment inputs

With regards to sediment input, coast erosion has been prevented by extensive coast protection structures therefore the maintenance of beaches relies upon supply from co-adjacent sediment transport systems. However, significant longshore supply by littoral drift is prevented by the deep water channels at Chichester, Langstone and Portsmouth Harbour entrances. The most effective potential sediment supplies to the Portsea and Hayling beaches (excluding re-nourishment shemes) are via onshore feed, mostly from sediment stores associated with the harbour entrances; supply directly from the Eastern Solent is comparatively small, and may not operate under low to "average" wave conditions (extracted from SCOPAC Sediment Transport Study, 2004).

Due to the complexity of the system, the various sediment inputs will be discussed individually (see Figure C1.28).

- Gravel feed from the Chichester Tidal Delta (F1) (extracted from SCOPAC Sediment Transport Study, 2004)

The Chichester tidal delta sediment volume is estimated at 25 million cubic metres by Webber (1979) and water depths over the delta are relatively shallow (Webber, 1979; Harlow, 1980; Wallace, 1988). Onshore gravel feed to east Hayling Island between 6 to 13,000m^3a^{-1} is postulated by Harlow (1980). Hayling Island receives considerably less material than it did in the past when Chichester Bar was a more effective bypassing mechanism. Onshore movement can still be observed to be taking place via the West Pole but the volumes are believed to be diminishing. Hayling Island does not have any fresh source of material produced by coastal erosion therefore the coastal sediment budget, as on the Selsey peninsula, is negative making beach recharge an important management requirement.

- Sand feed from the Chichester Tidal Delta to East Head (F2) (extracted from SCOPAC Sediment Transport Study, 2004)

Sand deposited on the outer bar and East Pole Sands can be transported onshore by wave action to supply East Head (Webber, 1979; ABP Research and Consultancy Ltd, 2000; HR Wallingford, 2000). East Pole Sands has exhibited net erosional lowering since the late 1920s (ABP Research and Consultancy Ltd, 2000).

- Feed from West Pole Sands (F3) (extracted from SCOPAC Sediment Transport Study, 2004)

Onshore movement of gravel to the beach immediately takes place by periodic migration of bars during storm conditions (Harlow, 1980; 1983).

- Feed to Eastney from Langstone Harbour entrance tidal delta (F5) (extracted from SCOPAC Sediment Transport Study, 2004)

Beach volume analysis reveals that littoral drift is weak and site observations have indicated that a transient littoral transport divide exists at Eastney. Beach accretion is therefore explained by onshore gravel feed in the vicinity of this divide (Webber, 1979; Harlow, 1980; Halcrow Maritime, 2000), originating from the Langstone Harbour tidal delta. Independent analysis of beach profiles covering the period 1970 to 1981 concluded onshore gravel feed to be 13,000-14,000m^3a^{-1} (Webber, 1979, 1982).

- Feed to West Winner from Langstone Tidal Delta (F6) (extracted from SCOPAC Sediment Transport Study, 2004)

Although no quantitative evidence has been presented, the development of the West Winner spit during the twentieth century suggests maintenance of supply from the Langstone bar. The presence of numerous sub-parallel, low gravel ridges that make up the cuspate foreland (or ness) behind Gunner Point indicates that onshore transport also occurs from the East Winner Sands, perhaps commencing in the sixteenth century (Tubbs, 1999).

- Longshore drift

Due to the complexity of the system, the longshore drift and linkages will be discussed individually, starting in the east (see Figure C1.28).

- Chichester Harbour Entrance (E01) (extracted from SCOPAC Sediment Transport Study, 2004)

Prior to protection of the shoreline of Bracklesham Bay since 1874 (Harlow, 1980) and an upgrading of the groynes at West Wittering in the mid 1980s, sediment supply to the main tidal channel was in the region of 70,000m^{3}a^{-1} from East Head via the Winner or directly from the distal end of the spit (Webber, 1979; ABP Research and Consultancy Ltd, 2000). This supply has probably now virtually ceased. Eastward littoral drift at Eastoke Point (LT2) supplies sediment to the tidal channel at a minimum rate of 5000m^{3}a^{-1} (Harlow, 1980). The result of this offshore flushing of sediments (mostly now from Eastoke Point) has been the accumulation of some 25 million cubic metres of sediment within a major ebb tidal delta (Webber, 1979). Harlow (1980) suggests that wave action can mobilise sediments on the tidal delta and drive them back shoreward towards Eastoke, Hayling and West Wittering. The net result of these processes appears to be an anticlockwise circulation in the east of Chichester entrance as reported by ABP Research and Consultancy (2000).

Not only have inputs to the delta reduced, but losses due to dredging of Chichester bar have increased since 1973. Analyses of bathymetric data have suggested that the ebb tidal delta suffered a net loss of 1.4 million cubic metres from 1974 to 2000 (see *Dredging and Reclamation Impacts in the Harbours section*).

- Eastward Drift to Eastoke Point (LT2) (extracted from SCOPAC Sediment Transport Study, 2004)

Analysis indicated a transient littoral drift divide approximately 100m west of the Beach Club (Harlow, 1980). The 1985 beach replenishment scheme has had a significant effect on littoral drift (see *historical and present shoreline trends* section). The most recent estimation of eastward drift is 11,500 m^{3}a^{-1} between 1990 and 1991 (Whitcombe, 1995).

- Eastoke Point to Black Point (Sandy Point Spit) (LT3) (extracted from SCOPAC Sediment Transport Study, 2004)

Site observations indicate northward drift from Eastoke Point to Black Point (Harlow, 1980). It appears that potential littoral drift may be between 1000 and 8000 m^{3}a^{-1}, although transport may be effectively prevented by coast protection structures when beaches are depleted. In addition, the coastal protection structures prevent Eastoke Point from re-aligning landwards by holding the beach in place. Quinquennial dredging of the approach channel to Chichester Harbour provides a small quantity of sediment for periodic replenishment, if required (Havant Borough Council, 1999).

- Westward drift to Gunner Point (LT4) (extracted from SCOPAC Sediment Transport Study, 2004)

The presence of the East Winner banks, eastward of the Langstone Harbour Channel, is evidence of the long-term operation of westwards drift (Harlow, 1980). Havant Borough Council (1999) estimate that net westwards drift along this entire sector is approximately 20,000 m^{3}a^{-1}.

- Reverse drift at Gunner Point (LT5) (extracted from SCOPAC Sediment Transport Study, 2004)

A local reversal of littoral drift between Gunner Point and Beachcot is implied (Hydraulics Research, 1988; H R Wallingford 1995; W.S. Atkins, 1998). As it was identified for a relatively short time period (5 years), the longevity of this phenomenon is uncertain.

- Northward drift from Gunner Point along Langstone Harbour Entrance Channel (LT6) and Eastward Drift to Langstone Channel (LT7) (extracted from SCOPAC Sediment Transport Study, 2004)

Analysis by Harlow (1980) indicated a long-term mean westward drift of 15,000m^{3}a^{-1} to Gunner Point where mean accretion of 5000m^{3}a^{-1}, primarily gravel, was recorded. Much of the remaining 10,000m^{3}a^{-1} of sediment was transported into the Langstone tidal channel and then flushed seaward to accumulate on the bar or on East Winner (LT7). No major gravel accumulations exist in the Langstone Entrance Channel so it is postulated that gravel is progressively lost to seaward transport as it moves northward towards the recurved distal point of the Hayling ferry spit (LT6).

- Langstone Harbour Entrance (E02) (extracted from SCOPAC Sediment Transport Study, 2004)

Tidal currents at the Langstone entrance have a similar effect to those at Chichester in causing net offshore transport of sediments entering the channel by littoral drift. The Langstone tidal delta may therefore also be a finite sediment store resulting from reduced littoral drift feed to the tidal channel. Whitcombe (1995) has analysed changes in the plan shape and volume of the East Winner, 1976-1992. This reveals fluctuating accretion and erosion of an average of 50,000m^{3}a^{-1}.

- Eastward Drift at Eastney (LT8) and drift from Eastney Point to Eastney Spit (LT9) (extracted from SCOPAC Sediment Transport Study, 2004)

Beach volume analysis using map comparisons over the period 1868-1967 indicated a littoral drift divide at Eastney (Harlow, 1980). An estimated 6,800m^{3}a^{-}of eastward littoral drift to Eastney Point was calculated with some net accretion in front of Fort Cumberland (LT8) (HR Wallingford, 1995).

Limited northward littoral drift from Eastney Point to the end of Eastney Spit has been indicated from site observations including sediment distribution in groyne compartments (LT9) (Webber, 1974). It would appear that Fort Cumberland outfall now acts as a terminal sink to sediment transport. This could lead to beach starvation and lowering of beach levels at Eastney Spit (Moon, 2008, *pers comm.*)

- Westward Drift, Eastney to Southsea Castle (LT10) (extracted from SCOPAC Sediment Transport Study, 2004)

There is some uncertainty over longshore drift rates west of the Eastney drift divide, ranging from 2,000m^{3}a^{-1}, (Harlow 1980), 3-4,000m^{3}a^{-1}.(HR Wallingford 1997) and 6,000m^{3}a^{-1} (Webber, 1974). All are agreed that rates decline rapidly westwards, to no more than 300m^{3}a^{-1} between South Parade Pier and the coastal salient of Southsea Castle.

The beaches between the drift divide and Southsea Castle reduce drastically in volume compared with Eastney Beach and have not changed substantially over the past 40-50 years; this is confirmed by Regional Monitoring data (CCO East Solent Annual Report, 2007). Moon (2008, pers comm.), however, notes that if sediment feed from the West Winner to Eastney Beach is reducing, then longshore drift in a westerly direction from Eastney to Portsmouth may also reduce.

- North-westward drift, Southsea Castle to Portsmouth Harbour entrance (LT11) (extracted from SCOPAC Sediment Transport Study, 2004)

Evidence suggests that the historical direction of net littoral drift between Southsea Castle and Clarence Pier is north-westward, which corresponds with present day observations (Atkinson, 2000). Littoral transport is probably not in excess of 300m^{3}a^{-1} (HR Wallingford, 1995); this material is transferred to the harbour entrance channel and moved seawards by the ebb current forming a well defined transport cell boundary (EO3) (Bray et al., 1995). In view of the lack of bypassing at Southsea Castle, much of the gravel supply to this beach must derive from onshore movement. In recent years, modest quantities (<1000m^{3}a^{-1}) of sediment have been periodically added to replenish winter losses.

- Portsmouth Harbour Entrance (E03) (extracted from SCOPAC Sediment Transport Study, 2004)

The Portsmouth Harbour entrance is the most sheltered of the inlets thus littoral drift input to the tidal channel is very low (Halcrow Maritime, 2000). Although its tidal prism is smaller than for the other harbours the Portsmouth entrance is considered extremely stable and easily capable of flushing out any arriving littoral drift as both spits either side of the harbour entrance have been stabilized (Harlow, 1980; Halcrow Maritime, 1999; Universities of Newcastle and Portsmouth, 2000).

Due to diminished wave energy, the ebb tidal current transports material further offshore than at Chichester or Langstone. Supply from the Gosport frontage is transported offshore to Spit Sand and supply from the Southsea frontage is transported to Horse and Dean Sand (Harlow, 1980; HR Wallingford, 1997) (See Figure C1.28).

- Dredging and reclamation impacts

See *Dredging and Reclamation Impacts* in the Harbours section for detail.

Over the past 20 years the sediment budget of this cell has been dominated by artificial inputs and outputs of sediment. Output by dredging was over 3 million cubic metres, whilst input by beach replenishment was approximately 550,000m^3. Ignoring the 2.3 million cubic metres extracted from the Horse and Dean Sand sediment sink in the early 1970s, the dredged output from the active sediment circulation system remained over six times the input by replenishment. If this situation continues, a sediment shortage may develop leading to reduced beach levels and erosion of sediments from onshore stores, e.g. Gunner Point.

- Vegetated shingle and sand dune

Some 93 ha of sand dunes have developed on the shingle foreland of Gunner Point/Sinah Warren, including foredune, mobile dune and dune grassland. A large part of the site is managed as a golf course that has reduced the areas of remaining natural dune grassland. The sand dune habitat here is likely to be maintained or increase slightly in area due to continuing accretion of shingle ridges that act as a substrate upon which dune formation occurs. A relatively mature vegetated dune system of 14 ha also occurs at Eastoke (Sandy) Point. It is low-lying and protected by defences such that periodic tidal inundations could occur if defences were not maintained and upgraded (Solent CHAMP, 2003).

A major area of vegetated shingle occurs at Gunner Point thinning eastward towards Eastoke. Successive gravel ridges have accreted, as the shoreline has grown seaward by up to 600m over the past 400 years. Much of the area has since become covered by sand and succeeded to dune grassland with a large area converted to a golf course. The shingle habitats are restricted to a variable discontinuous strip along the back of the beach some 10-50m wide along the majority of the frontage, but increasing to 150m at Gunner Point amounting in total to around 30 ha. Beach ridge accumulation has been sustained in recent years by “spillage” westward by drift of sediments from the beach replenishment operations at Eastoke. A smaller area of accreting vegetated shingle is present along Eastney Beach from Fort Cumberland westward to Lumps Fort.

The area of vegetated shingle is likely to experience a modest expansion due to continued deposition of shingle ridges at Gunner Point (Solent CHAMP 2003). Disturbance and recreational pressure are intense and these areas may require zoning of activities in future to reduce impacts.

Movement

The area is characterized by a flat, low-lying coastal plain extending inland to the toe of the South Downs Chalk escarpment upon which transgressive gravel barrier beaches and three major tidal inlets have developed as sea-levels have risen. These inlets define Portsea and Hayling Islands comprising slightly elevated areas on the coastal plain to which the transgressive barrier beaches have become attached (extracted from FutureCOAST, 2002).

As sea levels have risen, this shoreline has followed a classic transgression model of a coastal barrier migrating across a low-lying hinterland. Up until the early nineteenth century, (1820-1830) much of the backshore area of Portsea Island was a swampy or marshy residue of former lagoonal conditions (The Great and Little Morass). This suggests that the tendency along this coastline since the mid-Holocene has been for the development of a shorewards migrating barrier beach, cutting off former shallow tidal embayments and creeks (Wallace, 1988, 1990). The harbour entrance spits may post-date the breaching and breakdown of an offshore barrier, as recently as the late seventeenth century (Wallace, 1990) (extracted from SCOPAC Sediment Transport Study, 2004).

Sediment supply has been historically maintained by the progressive erosion and recession of this coastline, considered by Wallace (1990) to be in the order of 2 km since the 13th century. This view is based on diving inspections of archaeological sites in Hayling Bay and apparent submerged relict barrier beaches. In terms of more contemporary processes, beaches have generally declined in front of defences over the past 100 years, a process that has been attributed to defences that have slowed or halted barrier transgression preventing reworking of gravel deposits of the coastal plain and reduced landward inputs from ebb tidal deltas potentially related to major dredging activities. Shoreline stability has been achieved only by continued management of coastal defences and beach recharge (extracted from FutureCOAST, 2002).

- Chichester Harbour entrance (extracted from SCOPAC Sediment Transport Study, 2004)

There has been a rather variable pattern of channel narrowing and deepening; widening and shallowing since the mid-nineteenth century (ABP Research and Consultancy, 2000; HR Wallingford, 1998). The channel initially decreased in size, as the Winner bank accreted, 1887-1923; but overall, given the rotation and retreat of East Head and subsequent lowering of the Winner, the cross-sectional area of the channel has increased over the last 150 years. This suggests that it is adjusting towards a new equilibrium condition, but is below its optimum cross-sectional area given the tidal prism of Chichester Harbour. It stimulates the suggestion (ABP Research and Consultancy, 2000) that the harbour mouth has adjusted, or is adjusting, to a change from a wave-dominated littoral transport fed sediment budget to one which is controlled more strongly by tidal currents.

- Black Point Spit (extracted from SCOPAC Sediment Transport Study, 2004)

A study of Langstone and Chichester Harbour entrances by Hooke and Riley (1987) revealed erosion of the proximal point of Black Point, Hayling to be in the order of 0.32 ma^{-1} between 1910 and 1968 (E7).

- Eastoke Point (extracted from SCOPAC Sediment Transport Study, 2004)

Prior to the 1985 beach replenishment scheme, net potential eastward littoral drift varied between 2,000 and 12,000m^3a^{-1} over the study period (1842-1972) (Harlow, 1980). Mean drift increased at Eastoke Point to 10,000m^3a^{-1} (Hydraulics Research, 1980). Post-replenishment analysis demonstrates that the littoral drift divide remained in approximately the same position as before replenishment (Whitcombe, 1995). Eastward drift increased to 53,000m^3 between February 1986 and February 1987 (Hydraulics Research 1987 and 1988). It then decreased to approximately 30,000 m^3a^{-1} over the period 1986-1990 (Havant Borough Council, 1992b) and reduced further to 11,500 m^3a^{-1} between 1990 and 1991 (Whitcombe, 1995).

The result of rapid eastward drift since replenishment has been significant accretion at Eastoke Point. Material has been artificially recycled from this accumulation area and replaced on the replenished beach. In 1991 and 1992, a terminal rock reinforced groyne was completed at Eastoke Point, designed to restrict littoral drift into the Chichester Harbour entrance channel and a rock revetment was added to the frontage of Eastoke Point to provide further beach stability.

The south-western sector of Eastoke Point has continued to lose material after approximately 1988 (Whitcombe, 1995). The beach crest at the Eastoke frontage has a mean retreat rate of 1ma^{-1} since 1986.

- East Hayling (extracted from SCOPAC Sediment Transport Study, 2004)

The historical trend has been for beach erosion (Harlow, 1980). Regular profile measurement of the east Hayling replenished beach have revealed that net erosion has continued, particularly at the littoral drift divide and at its extremities (Harlow, 1985; Whitcombe, 1995; W.S. Atkins, 1998). Losses have been calculated at 30,000 $m.a^{-1}$, 1985 -1994 (Whitcombe, 1995).

Prior to the Eastoke replenishment, long term mean drift rates west from the drift divide (LT4 on Figure C1.28) were between 13,000m^3a^{-1} - 20,000m^3a^{-1} (1842 – 1976). Post-replenishment, volumetric analysis using measured beach profile data revealed that drift was 37,000m^3a^{-1} (February 1986 to February 1987) and between 6,000 and 13,000m^3a^{-1} (1987-97) immediately westward of the Beach Club on the replenished beach (Hydraulics Research, 1987, 1988; HR Wallingford, Whitcombe, 1995). Since 1990, the beach westwards to the Fun Fair and Norfolk Crescent has shown net accretion (W.S. Atkins, 1998), thus representing a potential source for future re-cycling operations to maintain the Eastoke replenished beach.

- Gunner Point, Hayling Ferry Spit and East Winner (extracted from SCOPAC Sediment Transport Study, 2004)

Historical accretion has been well documented for this site and began at least 400 years ago. Accretion has been variable and reduced to a mean of 5,600m^3a^{-1} during the period 1842-1977 (Harlow, 1980). Beach profile analysis over the period 1975-1987 revealed a fluctuating pattern with net accretion up to 1982 and significant erosion and recession of the beach crest thereafter (Hydraulics Research, 1988, HR Wallingford; 1995; Havant Borough Council, 1999). Whitecombe (1995) also notes accretion at East Winner and in the western part of Hayling Bay between 1842-1976.

The growth of the Hayling Ferry Spit on the east side of Langstone Harbour, between the late seventeenth and mid-nineteenth centuries, together with the more recent expansion of Gunner Point, accounts for the historical narrowing of the entrance channel to Langstone Harbour (Tubbs, 1999). Geo-rectification and analysis of historical aerial photography between 1946 and 2002 reveals pulses of sediment moving around Gunner Point along the entrance channel (Cope *et al.,* 2005). Reduction in the elevation of the Langstone Bar (up to 4m in places over last 36 years) may also control wave climate reaching Gunner Point as well as increase in size of East Winner (growing to south and east) (Moon, 2008, *pers comm*.).

- Eastney and Southsea Castle

Significant accretion, fed by inputs from the Langstone delta (F5 on Figure C1.28), has been determined at Eastney from map comparisons since 1842 (Harlow, 1980, Grontmij, 1973 and Halcrow Maritime, 2000). The accretion rate averaged 10,000-12,000m^3a^{-1} for the beach as a whole, but since 1966 accretion at 4,000m^3a^{-1} has been recorded behind Fort Cumberland sewage outfall (Webber, 1982). During this time, onshore feed was approximately 15,000-16,000m^3a^{-1} (extracted from SCOPAC Sediment Transport Study, 2004). Aerial photography from 1994 shows that the West Winner Spit still exists, aswell as large volumes of shingle upper beach around Fort Cumberland (Moon, 2008, *pers comm*.). Analysis of 1994, 2001 and 2005 aerial photography shows movement of a ‘pulse’ of material up into the harbour (Moon, 2008, pers comm.). Fort Cumberland outfall now appears to act as a complete terminal barrier to transport into the harbour (LT9) (Webber, 1974, 1982; Moon, 2008, pers comm.). Harlow (1980) and Webber (1974; 1982) suggested in the late 1970’s that bypassing was beginning to shut down. If this is the case then the feedback sediment to the West Winner will fail (E02) and there could be lowering of beach levels at Eastney Spit (Moon, 2008, *pers comm*.). A study of Langstone and Chichester Harbour entrances by Hooke and Riley (1987) revealed significant erosion at Eastney outfall (0.48 ma^{-1} 1870-1932), together with a shortening and thickening of Eastney Spit (E7).

The build up of material from the west part of Fort Cumberland since at least the 1940s, has shifted westward to opposite Eastney Barracks by 2001 (LT2). Beach profiles at Eastney and Southsea measured by Portsmouth City Council over the periods 1935-1958, 1970-1972 and since 1983 have revealed up to 1.5m variation in beach level. Analysis of beach cross-sectional area since 2004 between Eastney and Southsea Castle suggest recent stability (CCO East Solent Annual Report, 2007).

- Southsea/Old Portsmouth (extracted from SCOPAC Sediment Transport Study, 2004)

It was reported by Hydraulics Research (1987b) that the beach between Eastney Barracks and Southsea Castle was relatively stable. Between Southsea Castle and Old Portsmouth beach levels tend to fluctuate, with a small net loss of sediment since approximately 1980. Recent topgraphic data confirms this (CCO East Solent Annual Report, 2007). This area is heavily protected by sea-walls and concrete slopes (Hydraulics Research, 1987b; Halcrow Maritime, 2000).

Predictions of shoreline evolution

The following has been extracted from FutureCOAST, 2002.

The present shoreline exhibits the characteristics of a swash-aligned barrier attempting to continue to roll landwards with rising sea levels, but being partly constrained from doing so. This frontage has been managed and in places heavily constrained in its natural evolution for several hundred years and has been subject to non-typical changes such as foreshore steepening due to the effects of defences. It could mean that much of the recent historical behaviour upon which our understanding is so largely based is not a true analogue for the types of change that may occur in future under an unconstrained management regime. For example, it is difficult to estimate the distance landward that unconstrained barrier beaches with depleted foreshores may need to migrate before they can achieve a degree of ‘natural’ stability. Certainly the response would initially be more rapid and greater in magnitude than might be expected of a natural beach.

The overall behaviour of this shoreline is extremely complex due to the number of system inter-linkages operating at different spatial and temporal scales. Any further sub-division of this frontage therefore represents a compromise between the needs to identify characteristic behaviour at manageable local scales and the requirement not to totally separate the inter-dependent coastal frontages.

Beaches are likely to continue to deplete in front of defences unless countered by continuing beach management programmes. Continuing natural sediment starvation and difficulties in preventing losses to tidal inlets will mean that in-situ beach maintenance is likely to become increasingly difficult to sustain in areas such as Eastoke. As beaches erode and foreshores narrow in front of defences, greater wave energy will impact upon the upper beach or the defences themselves leading to increased overtopping and probability of structural damage unless defences are periodically improved to maintain standards of protection. Without protective beaches, future defences would have to become increasingly substantial to provide standards of protection comparable to those achieved today. Impacts of this type are likely in the short to medium term (20 to 50 years).

Accretion is likely to be maintained within limited areas such as Eastney Beach, Gunner Point and the ebb tidal deltas, but could become sustained increasingly by ‘spillage’ from artificial re-charge and re-cycling operations if these are continued in future. Without these artificial additions to the shoreline sediment budget, it is likely that accretion could slow significantly at the aforementioned sites and sediments could become increasingly scarce on many of the exposed foreshores. Due to the effects of buffering sediments already within the coastal sediment circulation systems the impacts could be progressive, beginning within 10 years, but becoming increasingly evident over the medium to long term (50 to 100 years).

The duration and extent of human interference are such that total relaxation of management could trigger major readjustments involving a variety of shoreline changes, both spatially (hundreds to thousands of metres) and temporally (decades to centuries) before new equilibrium configurations are achieved. The beaches are under increasing pressure to migrate landward and are held in their present positions only by defences. Unconstrained, drift would transport sediments more rapidly towards inlets and depleting beaches would quickly suffer overwashing and breaching, especially where the hinterland is low-lying, within the next 10 years. Permanent breaches are most likely where barriers roll back over low-lying soft compressible and erodible deposits, especially if the low-lying hinterland is sufficiently large to generate a significant tidal prism. These conditions occur at Eastoke (Hayling) and along the Southsea Common frontage of Portsea Island and initial breaching could occur within 10 to 20 years. Under natural conditions Eastoke would behave in a similar manner to East Head Spit by migrating into the harbour. At other locations, especially where beach sediments are available and hinterlands are not below high tidal levels, breaches are likely to be temporary and become re-sealed by drift.

A consequence of permanent breaches would be the development over the forthcoming 20 to 50 years of new tidal inlets with associated spits and tidal deltas. The shoreline sediment transport systems would become increasingly segmented and complex. New tidal connections could occur with existing estuaries/harbours and the prisms of the existing harbours could potentially be captured by the new inlets causing major changes in regime on the coast and within the harbours.

The spits at the mouths of Portsmouth, Langstone and Chichester Harbours would continue to roll back ashore with rising sea levels, or alternatively would breakdown and disperse. This may in part be due to continued mouth widening as a consequence of continuing sea level rise.

C1.4.4b Local scale – Portsmouth Harbour entrance to West Wittering (Portsmouth, Langstone and Chichester Harbours)

Harbours

Portsmouth, Langstone and Chichester Harbour are characterized by mudflat and saltmarsh habitats, with grazing marsh habitats situated on the fringes of Langstone and Chichester Harbours (Figure C1.2). Intermittent beaches are dispersed around the harbour perimeters. Langstone Harbour has low cliffs running along the western side of Hayling Island. All three harbours are heavily defended (Figure C1.3). The tidal inlets of Langstone and Chichester Harbour have strongly recurved spits, composed of sand and gravel whilst the spits at Portsmouth Harbour have been fixed in their current position.

Interactions

Considerable tidal exchange occurs at each inlet and the local tidal regime is ebb dominant. Tidal currents are the major mechanism for sediment transport as wave action is relatively insignificant due to limited fetch. It results in each harbour being a sink for fine suspended sediments, although coarser sands and gravels entering the inlet are preferentially flushed seaward to form large ebb tidal inlets (corresponding smaller flood tidal deltas can be identified landwards of the inlets) (FutureCOAST, 2002). This output may amount to little more than 1,000m^{3}a^{-1} (Harlow, 1980) (see Section C.1.4.5a for more information on tidal outputs). Although the inlets intercept drift, wave action drives sediments back ashore from tidal deltas allowing bypassing to occur. Each of the harbours behave as relatively self-contained units despite being connected by shallow channels at their northern limits. The sediment transport between and within the harbours is presented in Figure C1.29.

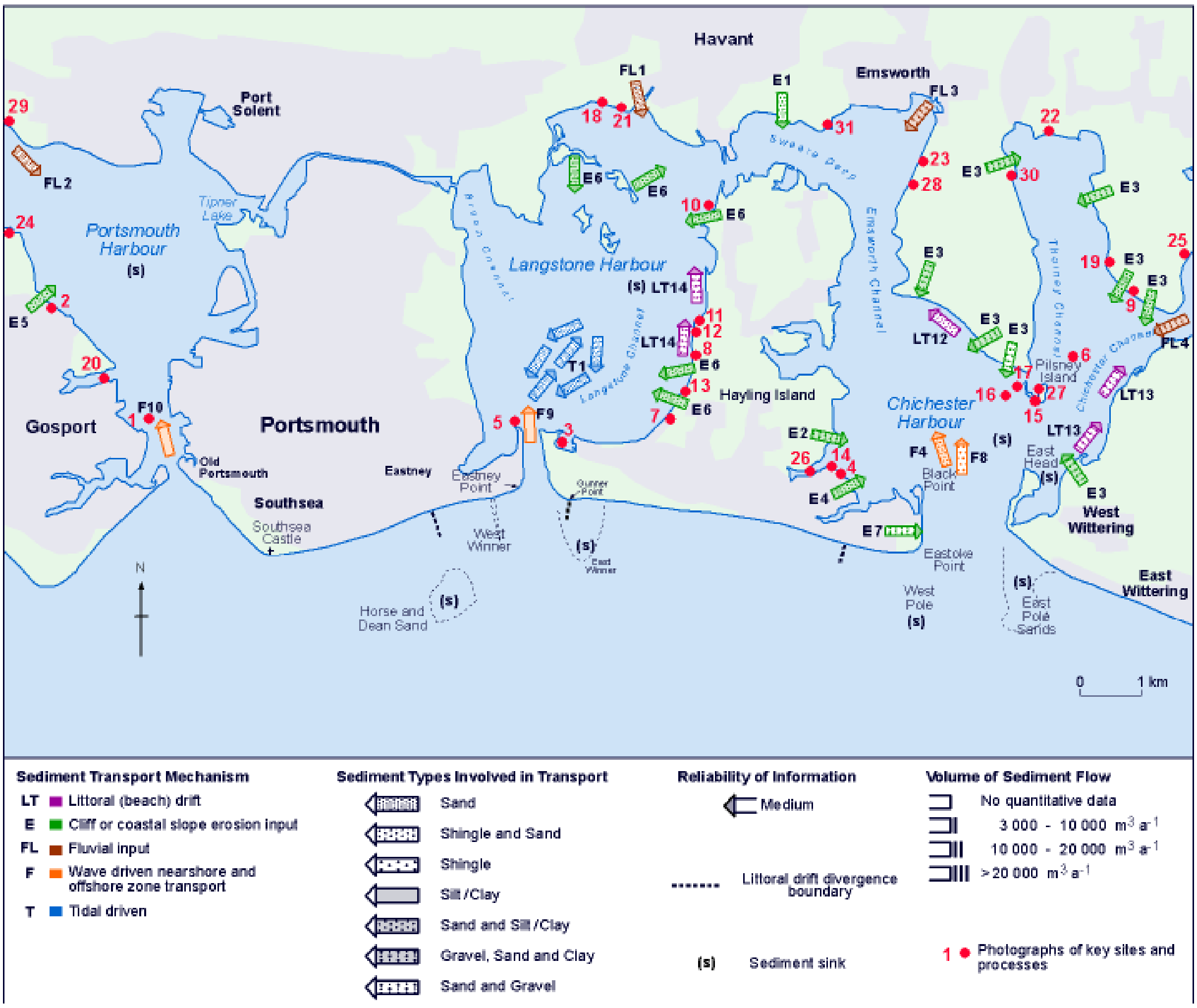


Figure C1.29: Sediment transport in Portsmouth, Langstone and Chichester Harbours (SCOPAC Sediment Transport Study, 2004).

- Sediment input - Marine sources (F4, F8, F9 and F10) (extracted from SCOPAC Sediment Transport Study, 2004)

Sediment is transported into the harbours from the Eastern Solent via tidal currents. The mean ebb current is of shorter duration but significantly greater velocity than the flood current (Hydraulics Research, 1959; Portsmouth Polytechnic, 1976; Harlow, 1980 and Wallace, 1988). Thus, net bedload transport of coarse sands and gravels is dominantly seaward at each harbour entrance, forming extensive part-submerged coarse sand and gravel delta deposits immediately offshore. Input of coarse material is limited (Gao and Collins, 1994) but enough to form flood banks in each of the harbours.

The flood tidal stream is of lower velocity but longer duration than the ebb tidal stream, thus net transport of suspended sediments (fine sands, silts, clays and organic particles) is probably into the harbours (Harlow, 1980; Wallace, 1988; HR Wallingford, 1997) although this has not been substantiated (HR Wallingford, 1994). All three harbours may be regarded as sediment sinks (HR Wallingford, 1997), where the rate of sedimentation has kept pace with post mid- to late-Holocene sea-level rise.

- Sediment input - Fluvial (FL1, FL2, FL3 and FL4) (extracted from SCOPAC Sediment Transport Study, 2004)

The volume of freshwater flowing into the harbours is small, (including artesian spring resurgences), carrying relatively little suspended sediment (Harlow, 1980). It would appear that Chichester Harbour receives the most suspended sediment load, being 1,450 tonnes/km^2/yr from the River Ems (FL3) and 2,100 to 2.400 tonnes/km^2/yr from the River Lavant (FL4) (Rendel Geotechnics and the University of Portsmouth, 1996).

- Littoral transport (LT12, LT13 and LT14) (extracted from SCOPAC Sediment Transport Study, 2004)

Harlow (1980) suggested that littoral drift in all of the harbours was possible in some of the wider embayments, but does not give any specific locations. LT12, LT13 and LT14 are transport pathways, producing beaches and spit features.

- Tidal sediment transport

The harbours are connected via single tidal channels at their northern extremities. Portsmouth Polytechnic (1976) and Gao (1993), showed that currents were principally westward at the northern connections between harbours so that a small quantity of net suspended sediment transport might be expected from Chichester to Langstone and from Langstone to Portsmouth Harbours. However, most research indicates that sediment transport is mostly confined to a closed circulation within the harbour system (Portsmouth Polytechnic, 1976) (extracted from SCOPAC Sediment Transport Study, 2004).

In terms of sediment stores, gravel and sand beaches exist around parts of each of the harbour perimeters. However, the main sediment store and sink constitutes fine sediment. The three harbours are characterized by mudflat and saltmarsh habitats (Figure C1.2). Saltmarsh loss (*Spartina anglica*) has been of major concern in the harbours. Where the saltmarsh has disappeared, mudflat remains. Stable tidal creeks confirm that the mudflat has not undergone much lateral erosion since the 1940's. There is no topographic baseline data from the 1940's to compare with recent datasets to demonstrate whether the mudflats have reduced in height over the years.

- Coastal erosion in the harbours (E1, E2, E3, E4, E5, E6 and E7) (extracted from SCOPAC Sediment Transport Study, 2004)

Sediment can be supplied to the harbours from erosion of both drift and substrate materials discontinuously exposed around their perimeters. Examination of maps indicates that much of the shoreline environment comprises reclaimed land at or below Mean High Water level, with erosion prevented by protective artificial bunds, earth banks or sea walls. Failure of these structures would result in flooding rather than any significant erosion and sediment supply (HR Wallingford 1994). Exceptions occur along the western shore of Hayling Island, the south eastern shore of Chichester Harbour and the four major islands in Langstone Harbour that are not protected and for which there is evidence of erosion since the late eighteenth century (Allen, 2000a). No parts of the perimeter rise more than a few metres above mean high water level so erosion forms low cliffs which can only supply limited sediment volumes even when retreating (Clare, 1996).

- Dredging and reclamation impacts (extracted from SCOPAC Sediment Transport Study, 2004)

Several main channels in Portsmouth, Langstone and Chichester harbours are dredged for navigational purposes and parts of their tidal deltas are also dredged for the same reason, and previously for aggregates. These practices are permanent actual outputs from the harbour sediment systems, although aggregate removal from these sites has now been discontinued.

Licensed (FEPA) maintenance dredging of navigation channels between 1987 and 1997 removed 237,000 tonnes from within Portsmouth Harbour and 333,000 tonnes from Hamilton Bank and Spit Sand immediately south of the harbour entrance. The latter figure may, however, underestimate the actual total (Universities of Portsmouth and Newcastle, 2000). Capital dredging for the same period was confined to the harbour, and accounted for 1,530,000 tonnes. All dredged material was deposited at the Nab Tower disposal site.

Langstone was a port until 1914 and approach channels within the harbour were dredged over the period 1882-1914 (Portsmouth Polytechnic, 1976). Quantitative information relating to dredging activity in Langstone Harbour reported by the Universities of Portsmouth and Newcastle (2000), based on FEPA licence data, indicate that a total of 143,190 tonnes of sediment was dredged from Langstone Harbour and its approaches between 1987 and

1997. Small quantities (less than 1,000m^3a^{-1}) are periodically used to replenish Southsea Beach, west of Southsea Castle.

Routine maintenance dredging is undertaken in Chichester Harbour for navigational purposes on the ebb tidal delta outside the harbour, with part of the spoil used to maintain the replenished beach in south-east Hayling, according to availability (Havant Borough Council, 1999). Quinquennial recharge will be undertaken at Eastoke, using material obtained by dredging the approach channel to Chichester Harbour. The initial quantity will be 50,000m^3, followed thereafter by inputs of approximately 25,000m^3. Dredging of the Chichester Bar began, on a significant scale, in 1973 (Shaw 1974). Some 600,000m^3 was removed between 1974 and 1982. Between 1988 and 2000 the average annual quantity of dredging has not exceeded 20,000m^3.

From bathymetric information (Posford Duvivier, 2001) it can be concluded that the Chichester tidal delta has lost material more recently due to reduction of littoral supply from Bracklesham Bay in combination with outputs by dredging. This can be estimated at 1.4 million cubic metres for the period 1974 to 2000. This quantity is quite significant in comparison to the total estimated volume of the delta.

Universities of Portsmouth and Newcastle (2000) calculate that just over 9% of the pre-1770 area of Langstone Harbour has been reclaimed, all of it by localised enclosures such as for grazing meadows and salterns. In the case of Portsmouth Harbour, the figure is much larger, approximately 35%. Figure C1.4 maps areas of reclamation between 1940 and 2002 (SDCP, 2008).

Movement

Portsmouth, Langstone and Chichester Harbour are shallow tidal basins, created after sea levels approached their present levels approximately 5 to 5,500 years BP, flooding a sequence of low relief valleys draining the coastal plain. This coastal plain was trimmed by at least one previous marine transgression during a Quaternary interglacial period creating a flat coastal plain extending inland to the toe of the South Downs Chalk escarpment. Raised beach deposits at Bembridge, Selsey and to the north-east of Chichester provide evidence of such past activity. The extensive mudflats and saltmarshes indicate that sedimentation of fine-grained material has kept pace with the inundation of the harbours over recent millennia (Cundy and Croudace, 1996).

The plan-form of this frontage is believed to be dependent partly on the presence of Selsey Bill and partly on the local presence of ebb tidal deltas as ‘anchoring points’ that control landward transgression. An additional major control is the shelter afforded by the eastern part of the Isle of Wight (FutureCOAST, 2002).

The geometries of tidal inlets and their associated ebb tidal deltas are sensitive to the tidal prisms of the harbours that can be affected by reclamation, realignments of harbour defences or by sea level rise. The tidal prism controls inlet cross-section area and the capacity of the ebb tidal delta to store sediment with a larger prism enlarging the inlet and increasing the delta storage capacity (extracted from FutureCOAST, 2002).

Contemporary shoreline trends are discussed below,

- Warblington Castle (E1) (extracted from SCOPAC Sediment Transport Study, 2004)

Harlow (1980) reported that low cliffs of Brickearth, 300m in length were eroding near Warblington Castle. The cliff exposure is now largely protected by an embankment, upgraded in 1989 and subsequently maintained to prevent breaching.

- Tournerbury (E2) (extracted from SCOPAC Sediment Transport Study, 2004)

Hydraulics Research (1987) reported that the earth embankment between Tournerbury and Pound Marsh on Hayling Island was rapidly eroding; it has recently been partially upgraded.

- Chichester Harbour (E3) – (extracted from SCOPAC Sediment Transport Study, 2004)

Deterioration of sea defences west of Longmere Point, Thorney Island has allowed localised erosion of the earth banks and low cliffs behind, causing development of several scour holes (Calderwood 1986). These 2-4m high cliffs are cut into the underlying Eocene substrate, and various overlying drift sediments. Cliffs of up to 5m in height along the south-facing coastlines of both the Bosham and Chidham peninsulas occur where there are no protection measures, or where the latter have failed. At both sites, there is clear evidence for small scale slumping, basal notching and platform abrasion in Eocene clays, overlying Quaternary drifts, particularly Brickearth, which have been undermined and have left coarse materials on the adjacent beach.

- Creek Point (E4) (extracted from SCOPAC Sediment Transport Study, 2004)

Erosion of low cliffs, 1.5 to 3.0m in height, along the Mengham to Selsmore frontage is encountered where former saltmarsh has been converted into mudflats (W.S. Atkins, 2000).

- Portsmouth Harbour (E5) (extracted from SCOPAC Sediment Transport Study, 2004)

A small outcrop of London Clay is subject to erosion at Hardway, Gosport.

- Langstone Harbour (E6) (extracted from SCOPAC Sediment Transport Study, 2004)

Clare (1996) suggests a rate of 0.8ma^{-} for the period 1967-1995 affecting London Clay cliffs in the south-east of Langstone Harbour. Cope and Webbon (2005) note a 0.3ma^{-} for the period 1946-2002. This rate may increase if the fronting mudflat volume decreases. Hooke and Riley (1987) plotted the position of Mean High Water Mark between 1870 and 1965 for Langstone Harbour using successive Ordnance Survey maps. They found that the harbour had changed very little since the sixteenth century, except in areas of land claim and oyster bed construction. This conclusion is supported by other analyses, e.g. Tubbs (1999), Gao and Collins (1994) and Allen and Gardiner (2000) for Langstone, and W.S. Atkins (2000b) for Chichester Harbour.

Erosion monitoring by the RSPB, 1988-1996, at six sites on North Binness and Long Islands revealed active wave abrasion of shore platforms; cliff retreat at a mean rate of 0.34ma^{-1} and the creation of "furrows" and "spurs" at the edge of low cliffs delimiting areas of saltmarsh.

- Inter-tidal areas

The saltmarshes have reduced in extent by 84% in Portsmouth Harbour, 83% in Langstone Harbour and 53% in Chichester Harbour since 1946 (see Section C1.2.7 and Figure C1.18 SDCP, 2008).

Predictions of shoreline evolution

It is difficult to draw boundaries within this frontage due to the highly interconnected nature of the beach, inlet and nearshore sub-features. It means that changes in one area could result in impacts elsewhere at differing spatial and temporal scales. For example, the management of the harbour margins controls the inlet tidal prisms, which control inlet geometry and tidal deltas; these in turn affect the drift and storage of shoreline sediments, in turn affecting barrier beach volumes and stability against transgression and/or breaching. New breaches will affect tidal prisms, inlets and tidal deltas. For this reason, prediction of future evolution is contingent on a web of direct and indirect factors and is inherently difficult on this frontage (extracted from FutureCOAST, 2002).

Under an “unconstrained” scenario, major inundation would occur around the reclaimed harbour margins especially at Farlington marshes, East Hayling and along the Thorney peninsular to re-establish Thorney Island. Fetches would increase within the harbours allowing larger, more energetic waves to be generated within the harbours. New mudflats and saltmarshes may form within the inundated areas. Existing freshwater habitats would tend to narrow and migrate inland with significant losses where this response was constrained by rising topography. The increased tidal prism would generate powerful currents that would quite rapidly erode and widen the main channels and inlets, potentially allowing greater wave penetration from the open coast. The ebb tidal deltas would enlarge potentially storing shoreline sediments, creating shortages in the long term in downdrift areas such as Eaststoke and Eastney Beaches (extracted from Solent CHAMP, 2003).

If new breaches were to form, particularly at Eastoke and along the Southsea Common frontage of Portsea Island, and were to inter-connect with the existing harbours, the tidal prisms would be enlarged, as would the inlet cross-sectional area, tidal currents and tidal deltas (FutureCOAST, 2002).

It should be noted that whilst the statements above assume an ‘unconstrained’ open coast response, it is understood that the perimeter defences of the Harbours would remain intact. Due to this, there will be a slow increase in the tidal prisms of the Harbours due to continuing sea level rise, increasing slightly the potential for available sediment to be stored within the tidal deltas and for widening and/or deepening of the Harbour mouths (extracted from FutureCOAST, 2002).

- Inter-tidal areas

Many upper and mid saltmarshes are confined at their landward margins by defences and are consequently sensitive to coastal squeeze as sea-level rises. Areas of *Spartina anglica* lower marsh are extremely sensitive to wave erosion at exposed locations. It remains uncertain whether wave erosion induces die-back, or whether die-back occurs first causing the marsh then to become susceptible to wave erosion. As *Spartina anglica* dies-back and becomes eroded so harbour shorelines are becoming exposed to greater wave energy increasing the likelihood of erosion or overtopping or damage to defences. Increasing erosion of harbour margins in some areas would release additional gravels from raised beach deposits that could support accretion of protective spits and beaches. All reclaimed lands, including former and current landfill sites, are susceptible to rapid inundation or erosion in the future (extracted from Solent CHAMP, 2003).

Predicted future inter-tidal evolution is explained in section C1.2.7. Because of Portsmouth Harbour’s rapid decline in saltmarsh extent, future predictions indicate complete saltmarsh loss by 2093, with the area of saltmarsh loss replaced by mudflat. In addition, with sea level rise, the seaward edge of the mudflat will be lost. Langstone Harbour predictions indicate that saltmarsh loss may level off, leaving an area of 23-37ha remaining by 2105. There is a large discrepancy in figures for Chichester Harbour. However, like Langstone Harbour, it would appear that saltmarsh loss will level off by 2105, with 103-226ha remaining. Future saltmarsh extent greatly depends on the relationship between sea level rise and fine sediment accretion. If fine sediment accretion can keep pace with sea level rise then there is every chance that the existing saltmarsh will survive. Where there is a seawall preventing inter-tidal migration inland, the fronting inter-tidal area will undergo loss through coastal squeeze.

C1.4.5 Local scale - West Wittering to Selsey Bill (including Pagham Harbour)

The coastline between East Head and Pagham Harbour is characterized by a sand spit at the eastern side of the entrance to Chichester Harbour (East Head); a barrier beach (Medmerry) extending from West Wittering to Selsey, backed by low lying land at the Medmerry section; low cliffs (3-4m in height) comprising raised beach deposits and sand around the Selsey Peninsula and a drift-aligned shingle spit extending north-eastward across Pagham Harbour. Pagham Harbour is characterized by mudflat and saltmarsh habitats, with grazing marsh on the fringes (Figure C1.2). A groyne system lines the majority of the frontage, with hard defences at the neck of East Head Spit, annual recycling and renourishment at Medmerry, hard defences at Selsey Bill and a training wall on the east side of Pagham Harbour.

Interactions

The coastal zone of the Selsey peninsula is an exceptionally complex environment, not least because the well-defined headland of Selsey Bill separates shorelines with different orientations. Because of spatial variation in wave climate, and the effects of both planshape and submerged relief on the local tidal current system, the apex of the peninsula functions as a regionally significant boundary between adjacent sediment transport cells, as presented in Figure C1.30. The presence of offshore and nearshore banks, bars, shoals and reefs adds unusual complications to the sediment budgets of each of the several distinct littoral transport sub-systems (extracted from SCOPAC Sediment Transport Study, 2004)

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 (East Solent SMP, 1997).

The following section identifies potential sources of sediment are identified for this coastline, although they have been supplemented in recent decades by beach replenishment at several sites. Due to the complexity of the system, the various sediment inputs will be discussed individually with reference to Figure C1.30.

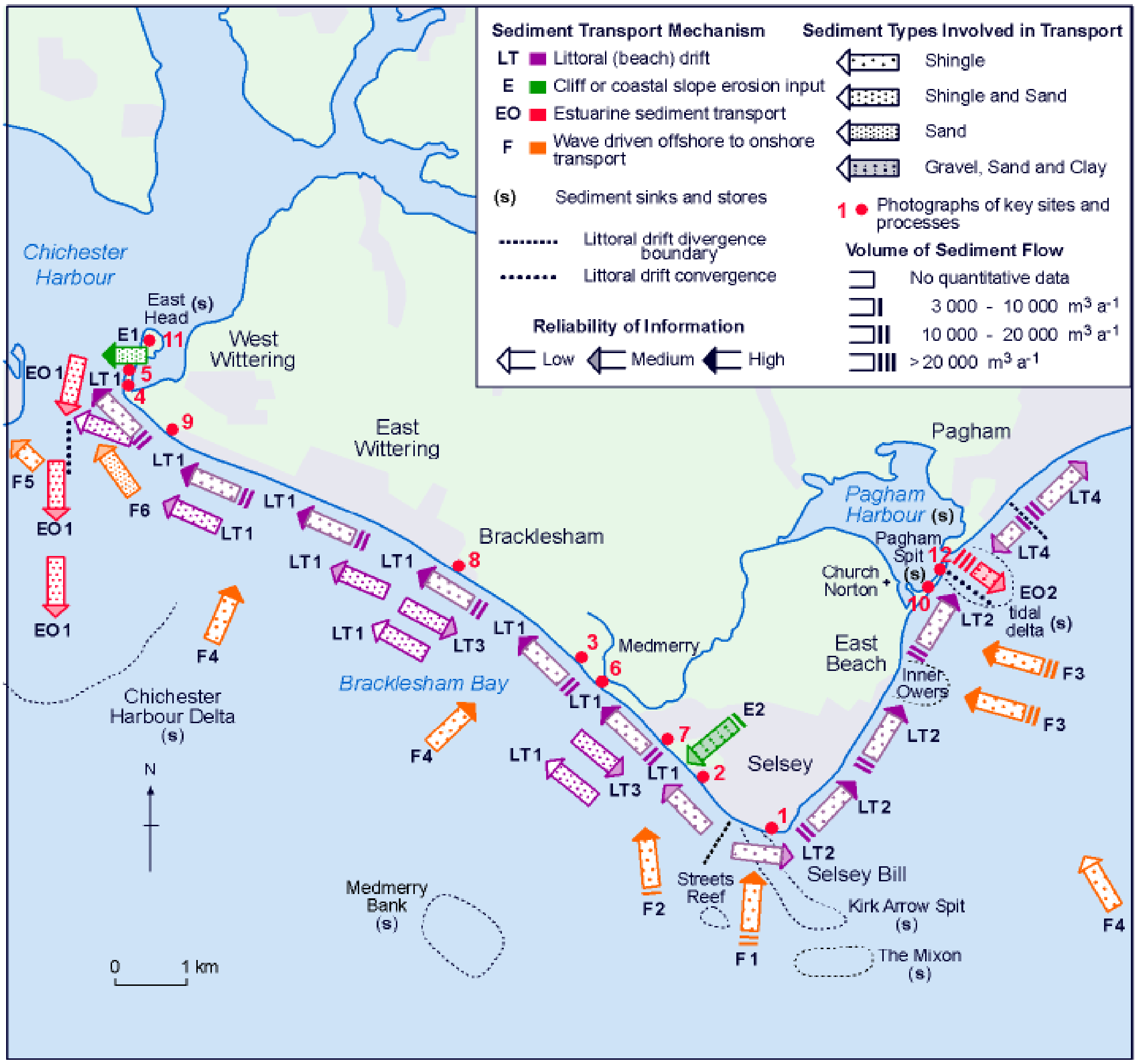


Figure C1.30: Sediment transport between West Wittering to Selsey Bill (including Pagham Harbour) (SCOPAC Sediment Transport Study, 2004).

- Onshore gravel feed from the Kirk Arrow Spit (F1)

The low soft headland of Selsey Bill itself is partially protected from direct wave action by the presence of limestone reefs 2 to 3 km offshore and the variable presence of the Kirk Arrow shingle spit within the nearshore. Collectively, these features play an important role in dissipating wave energy before it reaches the shoreline, constraining tidal flows and generating rapid currents (FutureCOAST, 2002). The Kirk Arrow Spit is a mobile gravel bank with a mean volume of 20-40,000m^3 exposed at low water some 300-500 m offshore from Selsey Bill. It is believed that shingle is periodically transported onshore from the spit to feed adjacent beaches when waves approach from the south or south-west (Lewis and Duvivier 1977; Wallace 1990; Posford Duvivier, 2001). An "outer circulation" of kelp-dragged shingle is believed to be vital in replenishing the Kirk Arrow spit (extracted from SCOPAC Sediment Transport Study, 2004).

Wallace (1990) examined accretion behind groynes constructed in 1989 at Selsey Bill and estimated 15,300m^3 of gravel to have accumulated over a four month period (46,000 m^{3}a^{-1} if maintained over a year; depending on season of four month survey period). Wallace (1990) also calculated that 5 million cubic metres of shingle have accumulated south of the entrance to Pagham Harbour since 1866, giving a mean rate of 41,700 m^{3}a^{-1}, The major sources are regarded as net onshore supply from both the Kirk Arrow Spit and from the nearshore Inner Owers bank (extracted from SCOPAC Sediment Transport Study, 2004). This onshore feed has increased since 2002, building up the Church Norton Spit on the south side of the harbour (see LT2).

- Onshore feed from the Streets and Malt Owers Reefs (F2) (extracted from SCOPAC Sediment Transport Study, 2004)

The Streets Reef and Malt Owers interact with waves and a local tidal current gyre, causing turbulence, which can result in deposition of kelp-rafted gravel (Jolliffe and Wallace, 1973) estimated at 1,000 m^3 annually (Harlow, 1980; Wallace, 1990).

- Onshore feed from the Inner Owers (F3) (extracted from SCOPAC Sediment Transport Study, 2004)

The Inner Owers are a series of mobile nearshore gravel banks, situated between East Beach, Selsey and Pagham Harbour inlet, which periodically migrate onshore. Gravel is supplied to the local beaches in wave-driven pulses. A long term average input of 3,000-5,000 m^{3}a^{-1} is quoted by Lewis and Duvivier (1977).

- Input from the Chichester Tidal Delta (F5) (extracted from SCOPAC Sediment Transport Study, 2004)

The sediment volume of the ebb tidal delta at Chichester Harbour was estimated as being 25 million cubic metres by Webber (1979). Sedimentological analysis of the delta deposits indicate that net transport of gravel from the tidal delta is westward resulting in accumulation in banks seaward of West Pole, Hayling Island (Harlow, 1980; GeoSea Consulting, 2000). It is uncertain whether a corresponding north-eastward pathway operates to deliver gravel from the delta back to the shore at West Wittering.

- Sand feed from the Chichester Tidal Delta to East Head (F6) (extracted from SCOPAC Sediment Transport Study, 2004)

Sand deposited on the outer Bar and East Pole Sands has the potential to be transported onshore by wave action to East Head (Webber, 1979; Harlow, 1980). Hydrographic chart evidence has shown up to 3m of vertical erosion on the western margins of East Pole Sands, and 2-3m of accretion further east since 1923 (ABP Research and Consultancy, 2000).

- Longshore drift

Due to the complexity of the system, the various longshore drift pathways will be discussed individually.

- Bracklesham Bay (Selsey to West Wittering) (LT1) (extracted from SCOPAC Sediment Transport Study, 2004)

Net drift of gravel is westward from West Street, Selsey to East Head. However, sensitivity to wave approach direction and the capacity for drift reversals are high because Bracklesham Bay is a swash-aligned shoreline (FutureCOAST, 2002). A present day net, mean drift volume of between 2,800 and 7,000 m^3a^{-1} is suggested for this unit as a whole (Posford Duvivier, 2001; ABP Research and Consultancy, 2000). The potential drift rate at West Beach, Selsey is 15,000-16,000 m^3a^{-1}, declining to 2-6,000 m^3a^{-1} at Bracklesham, because of the reduction in wave approach angle north-westwards (HR Wallingford, 1995, 1997). It should be noted that the lower rates of drift associated with more recent decades mostly reflect the role of defence structures in reducing fresh sediment inputs and intercepting transport.

Erosion of the proximal end of East Head spit since the mid 1990s suggests that the input of sediment via littoral drift updrift of the terminal groyne is virtually zero, although a net westwards drift here of $2{,}600m^3a^{-1}$ is suggested by HR Wallingford (1995). The downdrift benefits of the substantial gravel recharges on Medmerry beach have been surprisingly modest because of sediment interruption at outfall sites. Net cross-shore fluctuations have been dominant at Medmerry, varying between annual gains of up to $40{,}000m^3$ to annual losses of over $60{,}000m^3$ (net loss of $17{,}000m^3a^{-1}$ since 1974).

Reduction of this sediment supply has halted the exchange of sediment onto East Pole Sands and final transportation to Chichester Harbour ebb tidal delta (EO1).

- Selsey Bill to Pagham Harbour (LT2) (extracted from SCOPAC Sediment Transport Study, 2004)

Littoral drift pathways diverge in the vicinity of Selsey Bill (Lewis and Duvivier, 1976; Harlow, 1980; HR Wallingford, 1995, 1997 and Posford Duvivier, 2001). At this point, groynes and a seawall have been constructed, either side of which erosion has occurred, thus forming an artificial headland. Littoral drift of gravel is from Selsey Bill north-eastwards to the entrance to Pagham Harbour.

Approximately $20{,}000\text{-}40{,}000m^3$/year of material is supplied from the west/south-west (HR Wallingford, 2002). Actual rates are considered to be in the range 7,000 to 1,000 m^3a^{-1}, being controlled by groynes (Posford Duvivier, 2001). The Church Norton Spit on the southern side, that helps to define the entrance to Pagham Harbour, has a history of fluctuation, thus indicating temporal variation in littoral and offshore drift supply (SCOPAC Sediment Transport Study, 2004). However, recent build up and elongation of the spit since 2003, across the mouth of the harbour, is causing erosion on the downdrift side through sediment starvation and wave refraction. The spit has accreted eastwards by 400m between 2003 and 2008 which equates to 100,800 m^3 (approximately 20,000 m^3 per annum) (Amos, 2008, *pers comm*.).

- Reversed littoral drift of sand in Bracklesham Bay (LT3) (extracted from SCOPAC Sediment Transport Study , 2004)

Experiments employing fluorescent sand and shingle tracers at Medmerry (Hydraulics Research, 1974) over a 6 month period indicated that sand transport may be reversed on the lower foreshore, seaward of groynes, due to strong eastward residual tidal currents up to East Wittering. It is possible the experiments were not representative of typical conditions.

- LT4 drift divergence north of Pagham Harbour Entrance (extracted from SCOPAC Sediment Transport Study, 2004)

The northern (Pagham) spit is the product of a local 'counter' drift, resulting from a transport divide some 2000m north-east of the harbour entrance. This itself is the outcome of interaction between tidal currents generated by the inlet and complex wave refraction over the Pagham tidal delta (Geodata Institute, 1994). With a maximum southwest drift throughput of 5,000m^3a^{-1} (Barcock and Collins, 1991; Collins, *et al.*, 1995), this northern spit has had less capacity for growth and change than its southern counterpart.

- Chichester Harbour entrance (EO1) (extracted from SCOPAC Sediment Transport Study, 2004)

See C1.4.5a.

- Pagham Harbour entrance (EO2)

Pagham Harbour and Church Norton Spit on the southern side of the harbour, act as a sediment sink. Coarse material, including gravels and sands that are flushed from the harbour are deposited at the harbour entrance to form a tidal delta in the order of 16,000m^3a^{-1}. Sediment has a short residence time within the delta and is liable to being driven back ashore within swash bars to the west and east of the inlet. Fine sediments are transported in suspension into the harbour where they may be deposited to form mudflats and saltmarsh (English Nature, 2003) (extracted from Beachy Head to Selsey Bill, SMP).

The principal stores are the spits at either side of the entrance to Pagham Harbour; East Head Spit, the ebb tidal delta offshore of Pagham Harbour, and the estuarine sediments within Pagham Harbour (SCOPAC Sediment Transport Study, 2004).

- Dredging and reclamation impacts

The Pagham channel was dredged circa 1937 when a new entrance was cut. Land claim around Pagham Harbour is documented in 1876 (Environment Agency, 1998b). Analysis of aerial photography since the 1940’s does not show any new land claim (SDCP, 2008).

Movement

The East Head to Pagham areas is characterized by a flat, low-lying coastal plain extending inland to the toe of the South Downs Chalk escarpment upon which a controlling headland, transgressive gravel barrier beaches and a major tidal inlet have developed as sea levels have risen (FutureCOAST, 2002). It is thought that, as sea levels rose throughout the Holocene transgression, large quantities of sand and shingle were combed up to form a super barrier that migrated onshore forming massive shingle spits, barrier beaches, offshore shoals and forelands, several kilometres seaward of the present coastline (Hydraulics Research, 1996). In the latter 5,000 yrs this rise would have led to the drowning of former tributary systems, thereby forming tidal inlets such as Pagham and Chichester (ABP, 2000). Coastal erosion over this period must have occurred at a rate at least as fast as that recorded for the nineteenth and first half of the twentieth centuries (May, 1966). Throughout the previous 2,000 to 3,000 years, these barrier and spit forms have migrated landward. There is evidence of relict barrier islands named the Mixon Shoal and Owers, situated offshore from Selsey Bill, to support this hypothesis (Wallace, 1996; Posford Duvivier, 1999). These barriers would have protected the coastline 2,000 yrs B.P. when Selsey was part of an island, separated from the mainland by a tidal channel running from Pagham Harbour to the Medmerry frontage (Posford Duvivier, 1999). Pagham and Chichester Harbour would have been open to the sea, as they are today (extracted from Cope, 2005).

- East Head

East Head spit re-orientated itself from a swash alignment (parallel to the Bracklesham Bay shore) to a drift alignment trending at a right angle into the Chichester Harbour inlet from the late-19th Century to the 1940s (FutureCOAST, 2002). Studies have reported a clockwise rotation of the spit accomplished by very rapid recession of its seaward face, at 6.8 ma^{-1} during the period 1875-1896, and 2.3 ma^{-1} during the period 1896-1909 (Searle, 1975; May, 1975; Lewis and Duvivier, 1977; Harlow, 1980; ABP Research and Consultancy, 2000 and Baily *et al.,* 2002). It comprises a classic landform response to sediment starvation from updrift, although other factors such as sea-level rise and increasing storminess are also implicated. Exploratory coring surveys of the marshes behind the spit have revealed at least two old overwash deposits dating circa 1790 and 1890 (Bray and Teasdale, 2007). By 1963 the spit was in approximately its present position and had accreted significantly at its distal (north) end and eroded at its landward attachment. Although East Head as a whole has retreated very little since 1963 it cannot be regarded as stable for it was breached along its neck immediately north of "The Hinge" by a storm in 1963, was overtopped in 1987 and has experienced rapid thinning since the early 1990s. Bray (2007) noted that, “further thinning led to overwashing of a 100m long segment of the neck beginning on 28th October 2004 and continuing throughout the winter of 2004/05. A permanent breach appeared to be averted by a hitherto buried boulder revetment and the accretion of a substantial washover fan of sand that extended over saltmarsh and mudflat deposits behind the line of the neck (Baily and Bray, 2005).”

Its current, apparent stability has only been achieved by extensive use of brushwood fencing to stimulate dune growth (Searle, 1975; Baily et al. 2002). Most authorities agree that a combination of a spring tide and a severe storm could again breach the neck of the spit resulting in further recession and possibly its permanent breaching and ultimate destruction. Analysis of beach profile data between 2003 and 2008, shows a 5-30% reduction in cross-sectional area around The Hinge (CCO East Solent Annual Report, 2008). The exact cause of the current phase of erosion is uncertain, but involves reductions in natural sand supply from updrift longshore and nearshore sources. An additional factor may be a continuing adjustment of cross-section of the Chichester inlet mouth to the tidal prism of the harbour (ABP Research and Consultancy, 2000). It has involved lowering since 1923 of the Winner sand and gravel bank by up to three metres allowing increased wave exposure and reducing the intertidal foreshore width in front of East Head (extracted from SCOPAC Sediment Transport Study, 2004).

- Medmerry

Throughout the previous 2,000 to 3,000 years, Medmerry barrier is believed to have reformed and breached several times; at times isolating the Selsey peninsula as an island. With time, the rifes occupying the tidal channel between Pagham Harbour and Medmerry were reclaimed (Geodata Institute, 1994) and Broadrife slowly filled with alluvium, thereby forming the low-lying hinterland that we see today. Hydraulics Research (1996) note that Medmerry was breached in 1910 (along with Pagham spit barrier), temporarily reverting Selsey into an island. Following from this, groynes were implemented along the Medmerry barrier and West Wittering frontage (Hydraulics Research, 1996). At present there is greater potential for shingle transport than can be met by natural supply along the Medmerry frontage. Net drift is north-westerly; Harlow (1980) calculated a drift rate (all sediment grades) of 35-40,000 m^3a^{-1} for the period 1965-1973 but only 1,000-8,000 m^3a^{-1} for the period 1973-77. This rate has not changed substantially. However, since 1974, the main source of sediment supply has been from nourishment schemes (Hydraulics Research, 1996; Posford Duvivier, 1999). Between 1975 and 1980 some 200,000m^3 of gravels were recharged onto the beach with frequent emergency top-ups throughout the 1980s, 1990s and in recent years (Cope, 2004). In spite of these efforts, the barrier beach volume has remained insufficient to provide assurance against overwashing or breaching, which occurs on an annual basis, so that frequent beach scraping and re-profiling has been required to maintain a substantial beach crest. Some secondary embankments have been constructed in places to contain inundation during overwashing of the main barrier (FutureCOAST, 2002).

- Selsey Bill (extracted from SCOPAC Sediment Transport Study, 2004)

Prior to the construction of comprehensive 'hard' sea defences between 1962 and 1969, much of the tip of the Selsey peninsula provided inputs of easily eroded sediment from wave-induced cliff and shoreface erosion. This has been the case for over 1300 years, thus accounting for over 2 km of coastline retreat since the second or third centuries AD (Ballard, 1910; Heron-Allen, 1911; White, 1934; Aldsworth, 1987; Wallace, 1990 and 1996; Castleden, 1996; Bone 1996; Thomas, 1998;). Shoreface erosion has accelerated over this period due to ongoing sea level rise and the lowering of protective off-shore rock outcrops. SCOPAC Sediment Transport Study (2004) estimated the long term average rate of retreat either side of Selsey Bill to be in the region of 350-400m since the 1800's. Estimates of historical beach erosion around Selsey Bill vary, ranging from approximately 1m/year (Futurecoast, 2002) and 2-3m/year (Wallace, 1990a). Unpublished local authority records (Lewis and Duvivier, 1950) report that between 1930 and 1952 annual rates of erosion between Medmerry and East Beach were as high as 8m. This was the highest rate recorded for any location in England during the twentieth century. Seawall and embankments have fixed the landward limits of the beaches east of Selsey Bill, at East Beach. This has since resulted in a long term trend of profile steepening and a reduction in foreshore width of over 650m in the last 125 years. Posford Duvivier (2001) calculated that approximately 150m of recession of mean low water occurred at East Beach between 1900 and 1950, with substantial beach drawdown and erosional loss along this south-east orientated shoreline.

- Pagham Harbour (extracted from SCOPAC Sediment Transport Study, 2004)

Pagham Harbour (2.83km^2) is a product of Holocene sea-level submergence of the former mouth of the river Lavant prior to its diversion in Roman times (Wallace, 1990). The convergent gravel spits that define the Pagham Harbour entrance channel have behaved in a highly dynamic fashion over at least the past seven centuries (Robinson, 1955; Robinson and Williams, 1983; Barcock and Collins, 1991; Geodata Institute, 1994; Gifford Associated Consultants, 1997; Environment Agency, 1998b; Posford Duvivier, 2001). The earliest reasonably reliable map evidence (1587) suggests that the southern (Church Norton) spit had a configuration similar to the present, possibly in response to one or more breaches dating back to 1340-1410. Since this time, the spit has undergone rapid extension and breaching episodes, depending on sediment feed. Its present form is the result of storm surge inundation on 6th December 1910 following complete enclosure and land claim in 1876 (Environment Agency, 1998b). Since the breach in 1910, erosion occurred on the east Pagham beach following the interruption of longshore drift, accompanied by a shift to the north of the Church Norton Spit over the following 27 years (Geodata Institute, 1994). By 1937 the spits had re-sealed as a result of a small tidal prism compared to volume of longshore drift, therefore a new entrance was cut close to the original 1910 breach.

Analysis of aerial photography shows that between 1946–1965, the Church Norton Spit on the southern side of the harbour accreted 700m in a north-easterly direction. The beach fronting Church Norton Spit has been replenished (averaging 15,000m^{3}a^{-1}) by routine artificial recycling of gravel taken from the adjacent nearshore banks since the early 1990s. The Church Norton Spit was relatively stable until 2001, but since 2002 has elongated a further 300 m across the mouth of the harbour, is building seaward and with easterly migration of the ebb tidal delta is causing increased erosion downdrift on east Pagham beach due to wave refraction. From monitoring data and physical inspections, it can be shown that the beach fronting parts of east Pagham beach has retreated (through scour and erosion) by up 30 metres since 2003 and as much as 5 metres in the 6 months between September ’06 and March ’07 (Arun District Council, 2007).

See Section C1.2.7 for historical inter-tidal changes.

Predictions of shoreline evolution

- East Head

The Chichester inlet and East Head spit are likely to be sensitive to the tidal prism of the harbour that is presently maintained by relatively stable by defences. It has been observed that the Chichester Harbour inlet is narrower than might be expected considering its tidal prism. This suggests that the spit rotation is a response to the inlet hydrodynamic regime, however sediment starvation remains critical as the spit would probably be maintained in a shore parallel alignment by longshore drift where unhindered erosion/drift possible. The future of East Head Spit is dependent on sediment input. With a reduction in sediment feed to East Head Spit, there is an increased chance of permanent breaching at the hinge over the next 10 years (FutureCOAST, 2002) particularly if the Winner Bank continues to reduce in volume, thereby not dissipating onshore waves as effectively (Bray, 2007).

- Medmerry

Narrowing and rollback of the shingle barrier is predicted to continue, increasing the risk and frequency of breaching. As noted in the Pagham to East Head Strategy Study (2008), should a permanent breach occur, either through natural or managed means, it is likely that a stable inlet would form. This would result in tidal inundation of the low lying hinterland. The Strategy notes that in the short to medium term, littoral drift maybe interrupted but in the longer term as the flood and ebb deltas evolve, natural sediment bypassing would be established, thereby reinstating a sediment feed to downdrift frontages. Under a natural breaching scenario, with no management, Selsey would become an island as the new estuary would adjoin Pagham Harbour. Selsey Bill would continue to act as a control to the coastline in the east (Beachy Head to Selsey Bill SMP).

- Selsey Bill

In the next 100 years the rate at which Selsey Bill retreats will be influenced by the continued presence of Mixon Reef, sea level rise and sediment supply. Over time, the Mixon Reef will exert less protective influence on Selsey Bill as sea levels rise and create deeper waters and continued erosion of Selsey Bill effectively increases the distance of the reef from the shoreline. Futurecoast (2002) estimated that the shoreline along the eastern flank of Selsey Bill would retreat by up to 200m or more over the next 100 years if there were no defences. For the future we must assume that the rapid supply of material from Kirk Arrow Spit, typical of the past 50-100 years will continue. At some point however, it is likely that the nearshore gravel stores that sustain this onshore feed will become exhausted (extracted from Beachy Head to Selsey Bill SMP).

- Pagham Harbour (extracted from Solent CHAMP, 2003).

As noted in the Pagham to East Head Strategy Study (2008), if an un-managed breach were to occur at Medmerry, tidal waters would connect up with Pagham Harbour, having major implications on the tidal prism and drainage of the harbour.

The Church Norton Spit, on the southern side of the harbour entrance, is sensitive to variations in the rate of sediment drift from the south-west. If sediment supply were reduced, the spit would eventually become sensitive to overwashing, landward recession and breaching in the 20-50 and 50-100 year epochs. The northern spit is sensitive to the sediment supply that it receives from the ebb-tidal delta and to wave attack. These factors control the position of the drift divide and the relative quantities of material drifting to the tip of the spit as opposed to continuing eastward towards Bognor.

The ebb-tidal delta is sensitive to the tidal prism of the Harbour. It has been estimated that sea-level rise could increase the tidal prism by 13% by 2070 assuming that the Harbour area remains confined by defences. Such an increase in the flushing power of currents at the inlet would tend to improve the stability of the inlet and also increase the storage potential of the ebb-tidal delta.

Future response of inter-tidal areas in Pagham Harbour is difficult to predict given that saltmarsh underwent loss between 1946-1971 and then expansion from 1971 to present day (See Section C1.2.7).

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