Appendix C
Baseline Processes

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APPENDIX C - CONTENTS

C1 INTRODUCTION

This appendix aims to outline the outcome of Task 2.1a Coastal Processes and Evolution. The aim of Task 2.1a is to provide a review of the dynamic coastal and estuarine behaviour used in the development of the baseline scenarios (Task 2.2, Appendix F). The development of baseline scenarios will also identify risks and test the response of management options over different timescales.

This report covers the assessment of the coastal and estuarine processes and reports on several comprehensive assessments of saltmarsh change in Essex and South Suffolk. The aim of this report is to provide a foundation for understanding the potential impacts of policies on the coastal and estuarine processes along the SMP frontage (and elsewhere), at different temporal and spatial scales, to ensure that the correct policy decisions are made at later stages.

The understanding of the dynamic coastal and estuarine behaviour is constructed using the ‘behavioural systems approach’ detailed in Appendix D of the SMP Guidance (Defra, 2006). There is a focus on identifying and understanding components, interactions and linkages within a coastal system to develop an overall framework of its functioning.

This report starts by identifying the sources of information that constitute the basis of the review, and then gives a general overview of the Essex and South Suffolk coast. The main body of the report focuses on geology and geomorphological developments, present day exterior drivers (tidal regime and wave climate), geomorphology and resultant sediment transport, and coastal change. The report finishes with a discussion on the division of the coast.

C1.1 Review of Information

The initial Shoreline Management Plan (SMP1) was published in 1997, drawing from a large number of studies. Since the development of the SMP1, further work has been undertaken to consider the detailed behaviour of the coast and estuaries. This report has benefited from the following strategic level studies.:

- The Southern North Sea Sediment Transport Study (SNS2) (HR Wallingford et al 2002), developed an understanding of sediment transport pathways, particularly within the nearshore and the offshore areas of the southern North Sea, but also examined alongshore sediment transport including the Essex coast;
- Futurecoast (Halcrow 2003) set a national and regional geomorphological framework for the development of second generation SMPs;
- The Suffolk and the Essex Coastal Habitat Management Plans (CHaMP) (Royal Haskoning et al 2003) provided advice to the SMP2 on management of Natura 2000 sites;
- Essex Coastal Trends Analysis (Anglian Coastal Monitoring Programme 2008). This Environment Agency report contains the findings of the beach monitoring undertaken for the Anglian region, with particular focus on rates of erosion and accretion along coastal frontages. The rationale behind the programme is to assist the implementation of appropriate and sustainable works on the coast;
- The Estuary Flood Risk Management Strategies for Hamford Water, Stour and Orwell, Crouch and Roach, Colne and Blackwater aimed to set out the employment of an integrated portfolio of approaches to manage flood and erosion risks.

Within these projects new data and information was identified; however, they have also collated and re-interpreted previously gathered information. This review draws largely from the above mentioned strategic level reports, but also incorporates analytical reports and other Research and Development (R&D) outputs that have been completed since the original SMP1.

C1.2 General description

The Essex and South Suffolk SMP2 covers a length of approximately 550 km between Felixstowe Port in the north and Southend – Two Tree Island in the south. This coastal frontage comprises the 3d sediment sub-cell (Figure C1.1) with a southwest to northeast orientation.

The Essex and South Suffolk coast forms an unusual shoreline consisting of a series of estuaries - Stour and Orwell, Hamford Water, Colne and Blackwater, Crouch and Roach, and the Thames - interrupted by discrete lengths of open coast – Walton-on-the-Naze to Colne Point, the Dengie Peninsula and the Maplin/Foulness shore.

Much of the estuarine areas are dominated by muddy intertidal flats and salt marshes, whereas in areas of open coast there are a range of coastal features including London Clay sea cliffs and shingle, sandy and muddy beaches. Overall, the shoreline is predominantly low lying and protected by earth clay flood embankments with seaward facing revetment works or seawalls together with groynes.

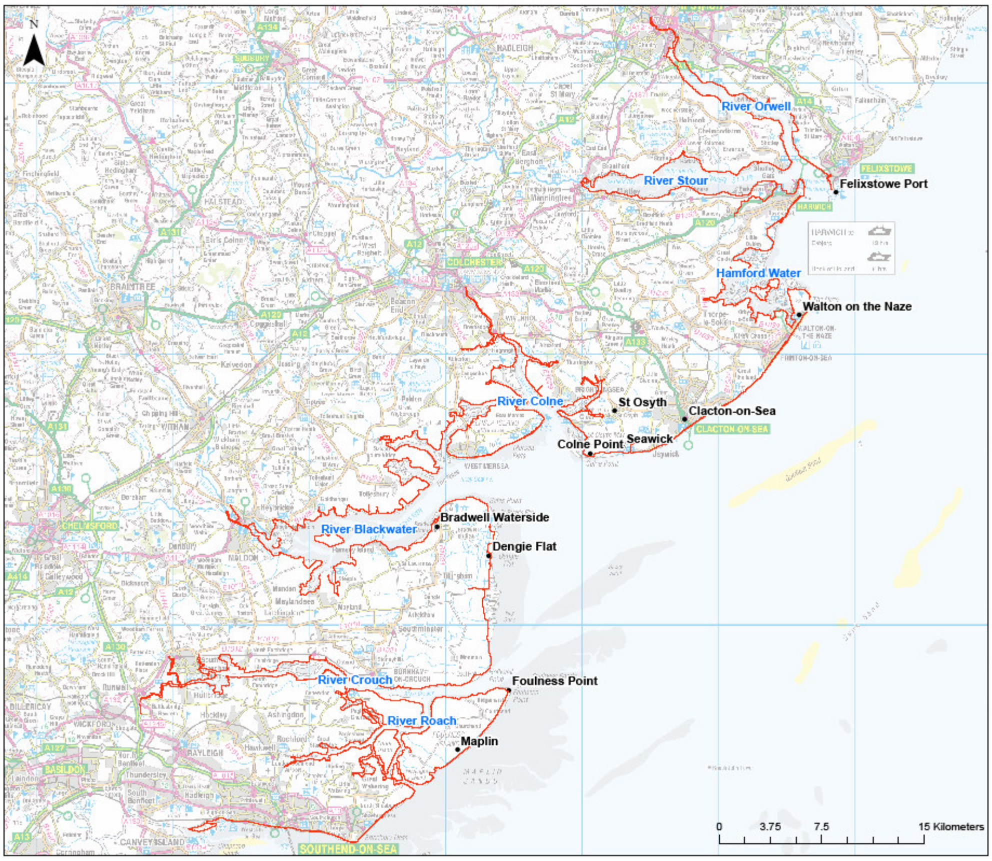

Figure C1.1: Essex and South Suffolk SMP2 area

C2 GEOLOGICAL EVOLUTION

C2.1 Solid geology - Tertiary

The underlying geology of the Essex and South Suffolk coast comprises of Tertiary (Lower Eocene – 56-49 Ma) London Clay. The London Clay is a marine formation of stiff grey-blue clay which is weathered to brown. This formation is exposed at The Naze (Tendring), Cudmore Grove (Mersea Island) and sections of the Stour and Orwell banks. Overlying the London Clay is a sequence of Pleistocene sands and gravels, followed by Holocene sands and muds. The Pleistocene deposits include Crag, characterised by shelly, friable sand, exposed at Walton-on-the-Naze, and the Terrace Gravels, a series of medium to coarse grained flood plain sediments, probably deposited in the early Pleistocene.

C2.2 Drift geology – Pleistocene

The Pleistocene ice advances were responsible for a series of deposits ranging from silts in the west to outwash sands and gravels in the east, covering much of the present-day nearshore zone. The underlying London Clay platform has been dissected by a number of relatively deep channels, probably fluvial in origin, some of which may be associated with the fall in sea level during the glacial periods. For example, sea level during the last glacial period (Devensian) fell to 110 m below its present level. The southern North Sea shelf was exposed and transformed into a fluvial plain. The former estuaries were at this time occupied by small rivers which cut relatively deep channels in their beds.

There is evidence to suggest that the River Thames often switched position during the Pleistocene and may have flowed east and northeast during the late Pleistocene with a mouth at the location of the present Blackwater Estuary, between Bradwell and West Mersea (CHaMPS, 2003). The River Thames formed a series of terraces, covered by alluvial sediments, which now overlie much of the London Clay in Essex. Since most of the estuary channels are large compared to their present-day fluvial inputs it has been postulated that Hamford Water, the Blackwater and the Crouch are all former mouths of the proto-Thames (Balson and D'Olier, 1990).

C2.3 Drift geology - Holocene

The majority of the Holocene sediments around the Essex and South Suffolk coast comprise of subtidal sands, intertidal sands and muds, and freshwater peats overlying the London Clay or the Pleistocene sands and gravels. As a result the Essex and South Suffolk shoreline is prone to erosion as these soft sediments are easily picked up and transported by waves and tides. Another coastal management challenge in Essex and South Suffolk is the freshwater peats as they are prone to consolidation leading to subsidence of the floodplain.

During the rapid sea-level rise after the Devensian ice started to retreat approximately 12,000 years ago, sands and gravels were transported into the newly formed estuarine channels and deposited as linear, subtidal banks, oriented parallel to sub-parallel to the tidal currents. A complex series of banks are situated offshore from the Essex and South Suffolk coast in the outer Thames Estuary and appear to control the in- and outflow of the tidal volume in the estuaries. The shoreline has experienced a series of sea-level changes which are largely responsible for the present-day geomorphology. The rise in sea level relative to the land during the Holocene was not a continuous process. Sea level was marked by a series of transgressive (relative sea-level rise) and regressive (relative sea-level fall) phases reflecting changes in rates of the vertical movements both of the land mass (tectonic changes and local sediment supply) and of global sea level (eustatic changes) itself.

During regressive phases the inner estuaries and upper shore areas would have reverted from saline to freshwater conditions in which peat would have been deposited. Throughout the Essex region a major phase of freshwater conditions is the Tilbury III regression, which can be traced by land surfaces dating *c.* 4400–2500 BC (Wilkinson and Murphy 1986). There is evidence to suggest that this regressive phase is not described in the Holocene stratigraphy of the Stour and Orwell region, which has been attributed to a more rapid tectonic downwarping of this region (Brew, 1990) or low sediment supply (Brew et al. 1992).

In subsequent eras, many changes in sea level have occurred, some of which have had considerable impact on the human use of the coast. In particular, the Thames III marine transgression which took place in around 2400–1100 BC caused widespread flooding of settlements and agricultural lands and led to early attempts to protect land from flooding. From the early medieval period onwards, the protection of land with sea defences became widespread and was particularly associated with the management of grazing marshes (Williams and Brown 1999).

By 200 years ago, an estimated 42% of the total intertidal area was reclaimed land. This reclamation, which had begun slowly in the Roman era, accelerated through the medieval and post-medieval periods to reach a peak during the 18th and 19th Centuries. The removal of almost half of the intertidal area has had huge impacts on coastal processes. The decrease in estuarine channel has led to higher velocities and increased bed-scour. Consequently, the estuaries are deeper than naturally stable channels.

The time interval between 1650 AD and 1850 AD is characterised by a regressive phase known as the Little Ice Age. During this period, reclamation of the saltmarshes was at its height, and was paralleled by natural seaward extension of coastal landforms. The more prominent spits and bars such as Landguard Point, Colne Point and Foulness Point seem to have extended during this period.

C3 HYDRODYNAMIC SETTING

C3.1 Bathymetry

Figure C3.1 shows the bathymetry offshore from the Essex and South Suffolk Coast. The area is characterised by strong tidal currents and seabed sediments are consequently dominated by sands and gravels, sculpted into banks in the Outer Thames Estuary. Areas of mud deposition are restricted to some sheltered areas between the sandbanks and to intertidal areas within the estuaries and along the coast.

The area offshore from the mouth of the Stour and Orwell estuary and Hamford Water is a broad shallow plateau extending approximately 14km from the coast where water depths are typically less than 10m. Cork Sands, which are exposed at low tide, are located on this plateau, approximately 7km southeast of the Stour and Orwell estuary entrance. Water depths for the other estuaries of the Essex coast (excluding the Thames) are also relatively shallow, reaching depths of 10 to 15m.

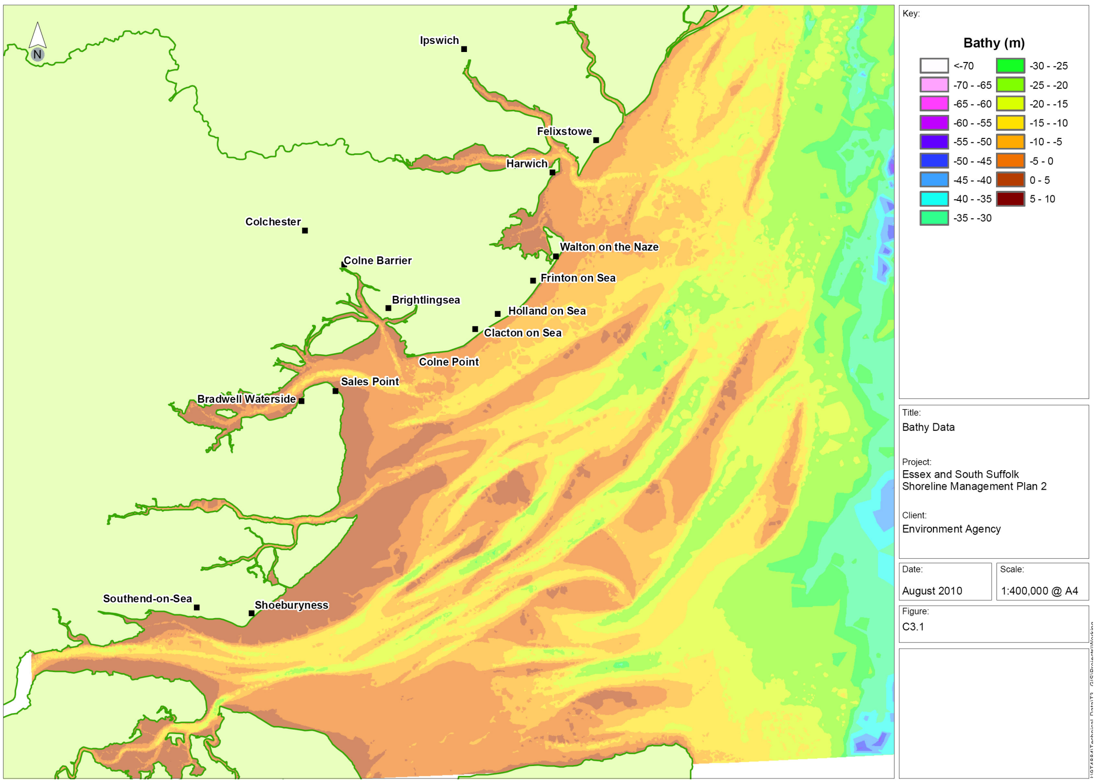

Figure C3.1 Essex and South Suffolk Bathymetry

The offshore area between the Naze and Thames Estuary is characterised by a complex series of sandbanks separated by channels. The major banks in this system include Gunfleet Sand, East and West Barrow Sand, Sunk Sand, and Long Sand. The sand banks are typically exposed during low water. The nearshore areas of the Essex coast are very shallow with extensive intertidal areas along the Dengie Peninsula and Maplin Sands. The low water mark of Maplin Sands is 5 to 11km from the modern coastline.

C3.2 Tide and Water Levels

Water levels along the Essex and South Suffolk coast result from a combination of astronomical tide levels and surge (caused by meteorological effects of wind and pressure).

Astronomical tides

The Essex and South Suffolk tidal environment is affected by the Atlantic tidal wave which enters the region through the Dover Strait, and to a lesser extent via the North Sea (between Scotland and Norway) (Figure C3.2). The tidal range is generally macro (>4m) and increases from north to south, with a mean spring tide range of 3.6m in the Harwich area increasing to 5.9m in the outer Thames. Tidal range also increases locally due to shallow water effects at the mouths of the major estuaries (Orwell/Stour, Blackwater, Crouch and Thames). Tidal range decreases with distance from the coast, although it remains >4m inshore of the 20m bathymetric contour (SMP1, Mouchel 1997).

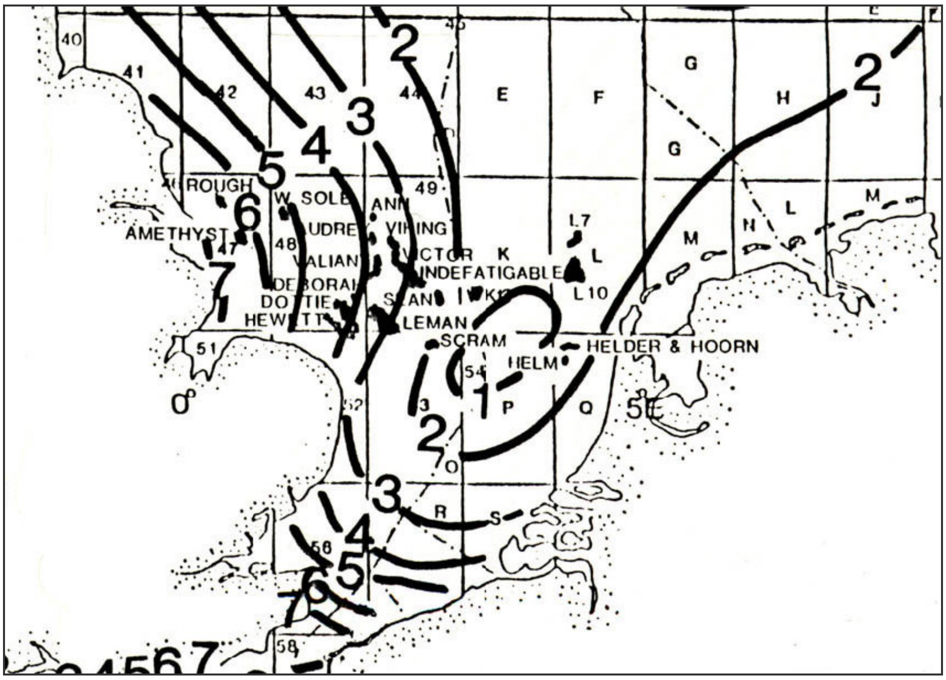

Figure C3.2 Propagation of tides

Predicted water levels for standard and secondary ports along the Essex coast are presented in Table C3.1 (taken from the Astronomical Tide Tables). The variation in the levels of high and low water along the frontage is significant, resulting in a difference in water level across the frontage at both high water and low water. As a consequence, the extents of intertidal areas range considerably between north and south Essex. For areas of comparable topography the intertidal extent would be larger in southern areas compared to the north.

Table C3.1 Tidal levels for stations on Essex and South Suffolk

Location	Tidal Level (mODN)			
	MHWS	MHWN	MLWN	MLWS
Rochford	3.00	1.90	No data	No data
Burnham-on-Crouch	2.85	1.85	-1.35	-2.15
Bradwell Waterside	2.52	1.52	-1.38	-2.28
Osea Island	2.67	1.67	-1.43	-2.23
Brightlingsea	2.56	1.36	-1.24	-2.04
Colchester	2.80	1.70	No data	No data
Clacton-on-Sea	2.21	1.21	-1.19	-1.79
Walton-on-the-Naze	2.04	1.24	-1.06	-1.76
Bramble Creek	2.40	1.60	-0.70	-1.40
Harwich (Landguard Point)	1.98	1.38	-0.92	-1.62

Surge and extreme water levels

In addition to water levels controlled by astronomical parameters, extreme water levels are also affected by meteorological effects such as wind and atmospheric pressure, leading to positive or negative surges. Positive surges (i.e. elevated water levels) can cause negative impacts on flood and erosion risk management. Extreme water levels for each frontage is presented in Table C3.2 and Table C3.3 (from Royal Haskoning, 2007).

Table C3.2 Extreme tidal levels along the Essex coastline (Royal Haskoning, 2007).

Location	Return period extreme tide levels (mODN)*							
	1:1	1:10	1:25	1:50	1:100	1:250	1:500	1:1000
Harwich	2.68	3.21	3.42	3.57	3.73	3.94	4.10	4.26
Walton-on-the-Haze	2.71	3.24	3.45	3.60	3.76	3.97	4.13	4.29
Brinton-on-Sea	2.75	3.28	3.49	3.64	3.80	4.01	4.17	4.33
Holland-on-Sea	2.84	3.36	3.57	3.73	3.88	4.09	4.25	4.40
Clacton-on-Sea	2.87	3.39	3.60	3.75	3.91	4.12	4.27	4.43
Colne Point	2.97	3.48	3.68	3.84	3.99	4.20	4.35	4.51

Location	Return period extreme tide levels (mODN)*							
	1:1	1:10	1:25	1:50	1:100	1:250	1:500	1:1000
Sales Point	3.07	3.58	3.78	3.93	4.08	4.29	4.44	4.59
Holliwell Point	3.17	3.67	3.87	4.02	4.17	4.37	4.52	4.67
Shoeburyness	3.38	3.87	4.06	4.21	4.35	4.55	4.69	4.84
Southend-on-Sea	3.50	4.00	4.22	4.30	4.50	4.66	4.83	5.00

*Confidence level for majority of water levels above have been described as good (Royal Haskoning, 2007).

Table C3.3 Extreme tidal levels in the Essex & South Suffolk rivers and estuaries (Royal Haskoning 2007)

Location	Return period extreme tide levels (mODN)*							
	1:1	1:10	1:25	1:50	1:100	1:250	1:500	1:1000
Rivers Crouch/Roach								
Holliwell Point	3.17	3.67	3.87	4.02	4.17	4.37	4.52	4.67
Burnham-on-Crouch	3.37	3.79	3.97	4.08	4.23	4.40	4.51	4.63
North Fambridge	3.46	3.86	4.02	4.15	4.27	4.43	4.56	4.63
Hulbridge	3.48	3.88	4.04	4.17	4.29	4.45	4.58	4.65
Paglesham Eastend	3.44	3.87	4.06	4.18	4.31	4.44	4.51	4.57
Rochford	3.54	3.87	4.20	4.31	4.42	4.53	4.58	4.61
River Blackwater								
Sales Point	3.07	3.58	3.78	3.93	4.08	4.29	4.44	4.59
Bradwell Waterside	3.07	3.58	3.78	3.93	4.08	4.29	4.44	4.59
Osea Island	3.27	3.78	3.98	4.13	4.28	4.49	4.64	4.79
River Colne								
Colne Point	2.97	3.48	3.68	3.84	3.99	4.20	4.35	4.51
Brightlingsea	3.19	3.45	3.55	3.63	3.71	4.20	4.35	4.51
Colne Barrier	3.55	3.86	3.98	4.07	4.17	4.29	4.38	4.49

Location	Return period extreme tide levels (mODN)*							
	1:1	1:10	1:25	1:50	1:100	1:250	1:500	1:1000
Rivers Stour and Orwell								
Manningtree	2.68	3.21	3.42	3.57	3.73	3.94	4.10	4.26
Ipswich	2.85	3.38	3.59	3.74	3.90	4.11	4.27	4.43

*Confidence level for majority of water levels above have been described as low to medium (Royal Haskoning, 2007).

Figure C3.3 illustrates the distribution of extreme water levels along the Essex and South Suffolk frontage. The distribution of water levels reflects the nature of surge in the North Sea, through the Dover Strait, being generated from the south and progressing as a wave to the north. This propagation of the surge will tend to be elevated as it sets against the southeast coast, lowering to the north.

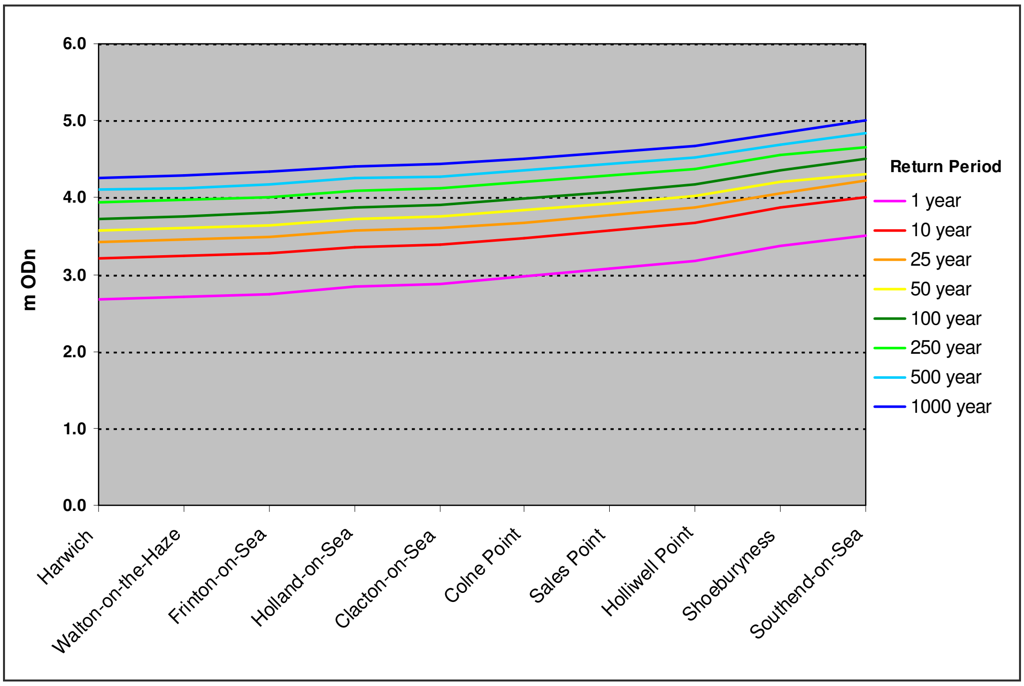

Figure C3.3 Variation of extreme water levels along the Essex frontage

C3.3 Tidal currents

Tidal currents along the Essex and South Suffolk frontages are known to be rectilinear and directed north to south on the flood tide and south to north on the ebb tide. Due to the flood dominance of the tidal system, the residual tidal current is southwards. In the Southern region of the plan areas this is predominantly southwest. (Table 4).

Table C3.4 Tidal current velocities

Location	Current Velocity (m/s)	Comments	Source
Clacton-on-Sea	0.26	Peak flood, spring tide	Admiralty Chart 1183 (G)
	0.10	Peak ebb, spring tide	
	0.15	Peak flood, neap tide	
	0.05	Peak ebb, neap tide	
Knob Channel	0.26	Peak flood, spring tide	Admiralty Chart 1183 (B)
	0.10	Peak ebb, spring tide	
	0.15	Peak flood, neap tide	
	0.1	Peak ebb, neap tide	

The ebbing tide lasts longer than flooding tide hence there is a tidal asymmetry i.e. the tidal flow velocities between the flood and the ebb are different. As the tidal waves moves landwards this asymmetry is exacerbated by the channel morphology particularly in estuaries (Table C3.4).

C3.3.1 Tides in the Estuaries

Stour and Orwell

The tidal range of both estuaries generally increases with distance upstream. The average spring (largest) tidal range is 3.6m at Harwich, increasing to 3.9m at Ipswich in the Orwell, and at Mistley in the Stour. This large tidal range is important for the formation of extensive intertidal habitats within the estuaries.

The influence of the tide extends from the coast to the Horseshoe Weir in Ipswich on the Orwell, and to Cattawade Sluice in the Stour. In both estuaries, the ebbing tide exhibits stronger currents than those of the flooding tide (with the exception of their upper reaches) particularly in the Orwell. Average spring tide currents can reach $1ms^{-1}$ in the Stour, and $0.8ms^{-1}$ in the Orwell, at Shotley. However, at Orwell a flood residual is noted due to dredging modification of the channel, (IECS, 1993).

Hamford Water
The tidal range in Hamford Water is 4.2m. It's short length (7km) means that, compared with the estuaries in Essex, only a relatively small change in the volume of water within the embayment on each tidal cycle. This is termed the tidal prism. This results in low tidal currents at the mouth, allowing the formation of Stone Point Spit. Overall the embayment is ebb dominant.

Colne Estuary
This estuary is macro-tidal, with a tidal range of 5.2m at Brightlingsea and is characterised by ebb dominant currents. The funnel shape of the Colne estuary means that as the tidal wave passes up the estuary its amplitude is increased, giving a greater tidal range. Mersea Island is situated within the common mouth of the Blackwater and Colne Estuaries. As a result it is subjected to the influence of tidal flows from both estuaries respectively.

Blackwater Estuary
The Blackwater estuary is macro-tidal with a tidal range of 5.2-5.8m. The estuary is ebb dominant and this results in a net export of material from the mouth of the estuary. However, some of the sediment is still carried up the estuary by the flood tide and is deposited in the wider and shallower reaches of the upper estuary beyond Osea Island. The constriction in width at the mouth leads to bed scour, so the channel remains extremely deep here.

Crouch and Roach
The Crouch estuary has a macro tidal spring tidal range of 5.7m at Burnham, decreasing inland towards North Fambridge where the maximum range is 5.5m. The shape of the channel results in the flood tide being more dominant than the ebb tide. This leads to a trend for net sediment accumulation at the mouth of the estuary.

C3.4 Fluvial discharge

The only significant fluvial discharge along the Essex and South Suffolk coast is from the River Thames. The freshwater input into the other estuaries is relatively insignificant compared to their respective tidal prism. This suggests that the estuarine channels were not formed by their contemporary rivers.

C3.5 Wave climate

Along the coast, wave energy generally decreases from north to south. This variation results from a number of factors including depth-limitation effects, extreme mean wind speed variation and wave breaking/refraction processes. Departures from this general trend are caused by offshore banks in the north and by shallow water within the estuary mouths.

The dominant wind direction is from the northeast, and wave attack will initiate from this direction, exposing the Tendring peninsula to flood risk and erosion. Although waves from the northeast have the greatest fetch, Essex and South Suffolk are somewhat protected from these waves by the topography of the rest of East Anglia to the north. The shoreline is more vulnerable to storms approaching from the east. Further south, the wave energy is channelled towards the estuaries with some wave energy dissipation by sand banks in the Outer Thames Estuary. The gradual shallowing of the North Sea Basin to the south and the reduction of fetch lengths from all directions except the north-east, leads to a reduction of wave activity in the area (SNS2, 2002). In the Stour and Orwell larger waves generated offshore can regularly affect the Orwell, due to its northwest-southeast orientation. The Stour estuary is sheltered from these but local winds typically produce 0.2-0.3m high waves in the Stour. If strong westerly winds prevail, 1m waves are capable of occurring along the whole of this estuary.

Data from the SMP1 indicated that frictional attenuation of open sea waves means they rarely travel more than 10km into the estuary mouths. The waves in the inner estuaries, are locally generated and are consequently fetch-limited. In addition, the Essex and South Suffolk saltmarshes, sands and mudflats reduce the extremity of incoming wave energy as they decrease as they progress across the intertidal areas.

The frequent occurrences of offshore sandbanks influence the hydrodynamic conditions of the coast, by:

- providing a physical barrier to incoming wave energy, which directly reduces the energy of waves reaching the coast.
- refracting incoming waves to focus wave energy onto the shore, enhancing beach or cliff erosion on short coastal sections. Subsequent changes in sandbank configuration may change the focus of this wave attack.

This review does not include the return period and direction of extreme wave heights. Such information is important for understanding sediment transport and other coastal processes. In October 2006, the Environment Agency's Shoreline Management Group initiated a 3-year monitoring programme with the deployment of 20 nearshore wave buoys and 5 offshore wave riders. Analysis of this information will be undertaken at the end of the programme and will constitute the most up to date wave analysis of the east coast. This information will be considered in the SMP2 review and will be included in the SMP3.

C4 SEDIMENT TRANSPORT PATHWAYS AND SEDIMENT BUDGETS

C4.1 Sediment sources

Coarser sediment along the Essex open coastline derives from sediments deposited during the Holocene transgression. The transgression resulted in the movement of sediment from the central North Sea into the Thames embayment. The majority of the sediment appears to be derived from glacial and fluvio-glacial outwash sands and gravels, which are now being re-worked by present-day wave (beaches) and tidal (sandbank) processes. Finer materials have been winnowed and removed from the coarse deposits by tidal and wave-driven transport and have been deposited from suspension in areas of lower energy (inner estuary channels and quiet open coast areas).

C4.2 Alongshore sediment transport (bedload)

Potential alongshore sediment transport rates around East Anglia were modelled in the pioneering studies by the University of East Anglia in the late 1970s and early 1980s (Vincent 1979; Onyett and Simonds, 1983). They developed a model for alongshore transport that was applied to the northern part of the Essex coast. Many of the regions were not modelled again for several years. However, following the requirement for Shoreline Management Plans, some areas have been modelled in more detail using up-to-date techniques and site specific model settings. These longshore transport rate predictions detailed on SNS2, shown on Figure C4.1 and tabulated in Table C4.1, provide an indication of their magnitude and direction.

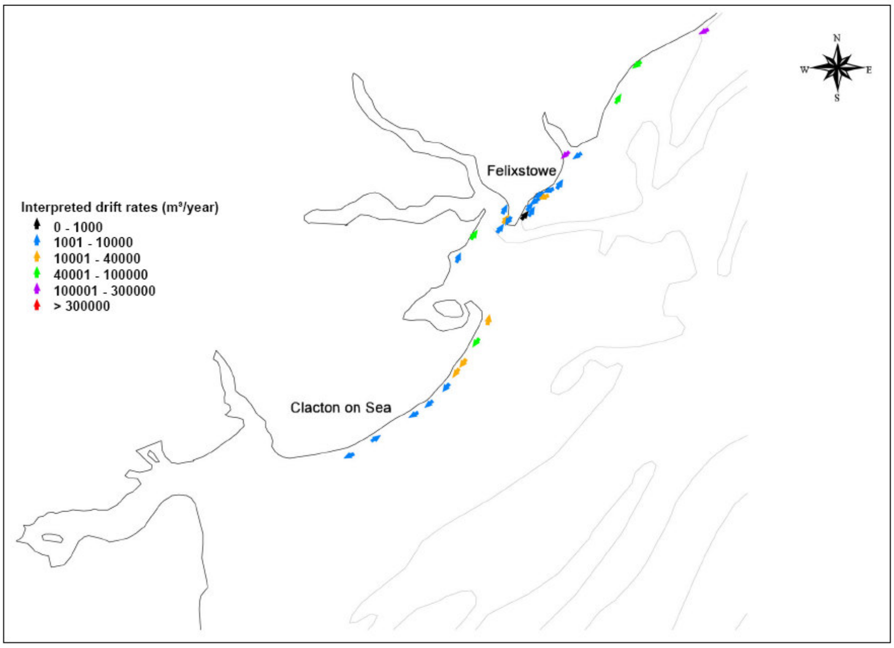

Figure C4.1: Potential alongshore sediment transport based on SNS2 conceptual model (SNS2, 2002 - Appendix 11 – Sutherland et al., 2002).

Table C4.1: Potential Alongshore Sediment Transport Rates in Essex (SNS2)

mE	mN	Location	Net Direction	Potential Q [m3/yr]	Type	Source
621500	216700	Clacton	233	105000	Wave	Vincent (1977)
617770	214480	Clacton	55	4,675	Wave	Posford Duvivier (2001)*
618650	215050	Clacton-On-Sea	231	50000	Wave	Onyett and Simmonds (1983)
625989	230875	Dovercourt	35	49,600	Wave, Sand	HR Wallingford (1997)
624984	228974	Foulton Hall	22	3,400	Wave, Sand	HR Wallingford (1997)
624800	220600	Frinton-On-Sea	215	21000	Wave	Onyett and Simmonds (1983)
624240	219820	Frinton-On-Sea	216	16,350	Wave	Posford Duvivier (2001)
623420	218600	Holland Gap	219	5,450	Wave	Posford Duvivier (2001)
620000	215850	Holland-On-Sea	240	80000	Wave	Onyett and Simmonds (1983)
622040	217260	Holland-On-Sea	228	1,950	Wave	Posford Duvivier (2001)
620800	216380	Holland-On-Sea	238	2,725	Wave	Posford Duvivier (2001)
612500	212400	Jaywick	262	70000	Wave	Onyett and Simmonds (1983)

mE	mN	Location	Net Direction	Potential Q [m3/yr]	Type	Source
615520	213030	Jaywick	244	7,875	Wave	Posford Duvivier (2001)
626800	224200	Naze	0	75000	Wave	Onyett and Simmonds (1983)
625990	225770	Naze (North)	310	254,900	Wave, Sand	HR Wallingford (1997)
627397	223884	Naze (South)	9	26,600	Wave, Sand	HR Wallingford (1997)
626334	221979	Walton	215	45,100	Wave, Sand	HR Wallingford (1997)

* Posford Duvivier is now Royal Haskoning

Potential alongshore transport rates were calculated by HR Wallingford (1997) between Dovercourt and Walton and by Posford Duvivier (2001) between Frinton-on-Sea and Jaywick. The HR Wallingford (1997) results came from the southern part of their Harwich channel study but were for sand, rather than shingle. The Royal Haskoning (2001) study used the coastal profile model UNIBEST-LT, which models tide and wave induced longshore currents, wave set up and set down, and alongshore sediment transport distribution across the beach profile. The model contains various formulae for calculating the potential transport rate of sand or shingle due to predefined wave climate and tidal regime. Summer and winter 2000 beach profiles were used for the analysis. A D_{50} value of 0.4 mm and a D_{90} of 1.0 mm were used as input to the model. Potential gross transport volumes in opposing directions were calculated from which the potential net value was determined.

The information of alongshore sediment transport detailed on SNS2 was based on existing predictions from a variety of sources. They are difficult to compare as the wave climate is highly variable from year to year and models were set to estimate transport of different types of sediment. Predictions made from different periods using different particle sizes may vary by a large amount. The potential transport rates calculated by Vincent (1977) and Onyett and Simmonds (1983) are much larger than the more recent estimates, which were more detailed local studies and probably reflect the present situation more accurately. It should also be noted that SNS2 only provides data for the northern stretch of the Essex coast.

The potential alongshore sediment transport data from SNS2 shows a broad variation in net rates and directions. Overall, this indicates a variable gross alongshore rate with only weak net movement. This movement very sensitive to the relationship between wave direction and coastal orientation. The Naze is seen as a transport divide with a stronger net transport to the south.

The alongshore sediment transport along the Walton to Jaywick frontage is variable but essentially towards the south-southwest (Figure C4.1). The overall net transport rates are weak along the north section of this frontage and increase to the south. There is a limited volume of sediment available supply the north as the erosion of the frontage has been prevented by the construction of erosion protection defences. The groynes along the frontage were designed to trap some of the remaining sediment in place, providing a buffer to waves. Sediment transport continues to the west of Jaywick to Colne Point, which serves as a sediment sink.

C4.3 Sediment Sinks

Accretion of fine to medium sand takes place in the southern region of Essex at the Maplin Sands, the Dengie Flat and in the banks within the estuaries. South of Clacton, there appears to be a closed sediment system. Which implies that the sediment is redistributed within the coastal system instead of a constant input and loss of external (offshore) sediment sources and sinks.

C4.4 Offshore Sediment Transport

Suspended sediment

Suspended sediment concentration in the southern North Sea is between 10-80ppm with the higher concentrations during winter months (SNS2, 2002). The concentration of sediment in the Thames embayment is relatively high; 50ppm. This concentration leads to the deposition of between 0.24 and 0.69 M (million) tonnes per year of fine sediments (Gerritsen et al., 2000, Odd and Murphy, 1992). Suspended sediment concentrations increase nearer the coast and within the estuaries. In addition, areas offshore of the Thames are used for disposal of dredged materials and this is an additional source of 0.3 M tonnes per year of fine sediment (Gerritsen et al., 2000).

The Naze is eroding at a rate of 1.4 m/year providing approximately 0.12 Mt of fine sediment per year to the surrounding system (ABP, 1996). The Naze is the only substantial fine sediment source for the frontage along the coast. Other sources of fine sediment include the relatively large number of rivers that enter the North Sea along the Essex coast which combined provide approximately 3.75 Mt per year of fine sediment (Odd and Murphy, 1992).

Bedload

In the Harwich region, sediment moves from Landguard Point to Cork Sand where it is temporarily stored. The one-year return storm waves move the sediments onshore towards the Naze where they are stored for up to 50 years. Chart and map evidence suggests that up to 70,000m^3/yr is input into the Naze from this store. The majority of the bedload sediment is derived from Cork Sand with a small volume being generated from cliff erosion at the Naze (SNS2, 2002).

Figure C4.2 illustrates the bed load transport pathways (and suspended sediment) from the SNS2 (2002) conceptual model. These pathways are weak and variable but may be reinforced by storm surge conditions. Sea bed indicators show a general clockwise movement of sediment around Gunfleet Sand and a circulation around the Cork Sands. The field measurement work and analysis of sea bed sediment transport indicators provided strong proof of no link between Gunfleet Sand and the shore, and no substantial link between Cork Sands and the Naze. Bedload sediment is seen as feeding in through Knock Deep and Long Sand being moved north to feed Foulness and the Dengie Peninsula. There is no established bedload feed to Sales Point and the accumulation of material at this location is characteristic of migratory chenier (shell deposit) ridges. The various elements of work also show no significant pathways for bedload sediment between the shore and the nearshore at Clacton.

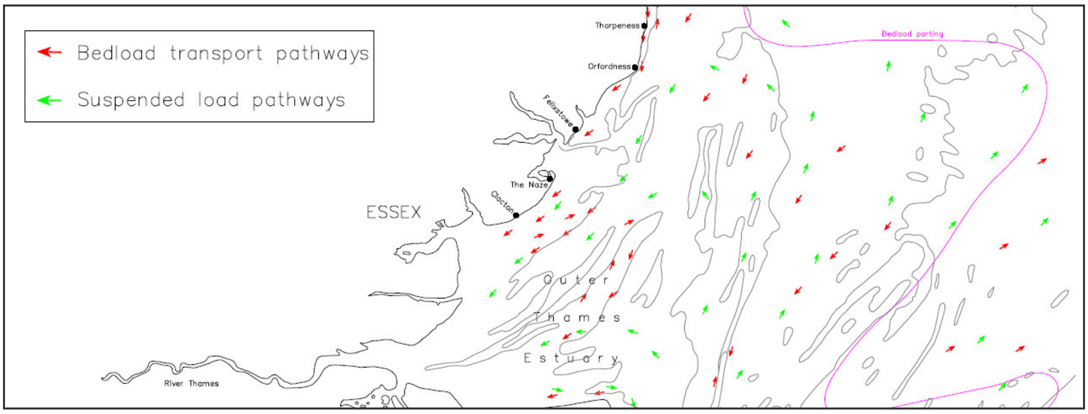

Figure C4.2: Conceptual bed load and suspended sediment transport in Essex (SNS2, 2002)

Dredging areas situated to the northeast of the Thames Estuary lie within the sandy sediment pathways feeding into the banks in the Outer Estuary. However, the licensed dredging in these areas is for gravel, hence the “extra” sand generated as the dredgers “screen” the cargo to obtain the required mix of gravel/sand may be liberated into these sand pathways.

C5 GEOMORPHOLOGY

C5.1 Coastal Setting

The CHaMP (2002) divides the Essex and South Suffolk coast into two open-coast geomorphological sections:

- A northern section between Felixstowe and Clacton is characterised by coarser-grained sediment forming open beaches, with 15m-high cliffs at the Naze. This section is not punctuated by estuary mouths, apart from Hamford Water which forms an integral part of the Orwell/Stour estuary system.
- A southern section between Clacton and Canvey Island forms the northern portion of the Greater Thames embayment, characterised by subtidal and intertidal estuarine mudflat and marshes.

Northern section

Within the Stour and Orwell estuaries, the intertidal areas are mainly muddy and become sandier towards the sea. Hamford Water is comprised of intertidal flats and saltmarshes. Dovercourt Bay, which lies between the Stour Estuary and Hamford Water, is dominated by London Clay cliffs reaching 15m in height, fronted by muddy shores.

The frontage between the Naze and Clacton-on-Sea is dominated by sea cliffs comprised of London Clay intersected by low-lying coastal strips at Walton-on-the-Naze and Holland Gap. There is only a very narrow intertidal zone, containing sand beaches with some shingle along the upper profile. Jaywick and Seawick are both low-lying areas fronted by a sand foreshore that contains localised shingle deposits. Further to the west, Colne Point nature reserve consists of saltmarshes and a series of shingle ridges that extend westwards, then northwards into the Blackwater Estuary. The area between St. Osyth and St. Osyth Stone Point contains a beach ridge composed of shingle that fronts saltmarsh.

Southern section

Mersea Island between the Colne and Blackwater Estuaries is an isolated island of London Clay. The seaward facing side of Mersea Island contains a long section of low cliff and steep natural slope with two localised areas of low-lying backshore. The foreshore comprises the Mersea Flats, a relatively wide area of mud and fine sand forming an intertidal flat. There is very little saltmarsh present along the foreshore.

The frontage from Dengie to Foulness contains wide intertidal flats and saltmarshes that front extensive areas of reclaimed low-lying land. There are chenier (beach ridge of sand – sized material resting on clay or mud) features near Sales Point, Dengie and immediately south of Foulness Point. The Dengie and Bradwell marshes north of the River Crouch are dissected by small creeks but form a single compact area since reclamation. To the south of the Crouch Estuary, tidal channels separate a group of islands all below high water.

The coastal area between Shoeburyness and Leigh-on-Sea is characterised by sea cliffs, comprised of London Clay, intersected by lowland in two areas. The cliffs are fronted by a predominantly mud and fine sand foreshore. There is some coarse sand and shingle trapped within groyne compartments along the eastern Southend-on-Sea frontage.

C5.2 Estuarine Setting

C5.2.1 Stour and Orwell

The valleys occupied by the two estuaries today are considered to have been created by a course incised by a Proto-Thames Estuary, which would have been forced progressively further south to its present day location by the advancing ice sheet of the last glacial maximum. The development of the Orwell Estuary is largely constrained by high ground, with consistently steeply rising banks on the north side of the estuary, and high ground at Bourne Hill and Woolverstone, down to Collimer Point on the southern flank. The Stour, on the other hand, is a “classic” funnel shaped estuary and is fairly long and straight. The channel itself is only guided by steeper land at Sutton Ness, Wrabness, Harkshead Point, Erwarton and Parkeston, with seven sheltered inter-estuarine bays interspersing these. The conditions within these bays are ideal for the mudflat and saltmarsh habitats located here.

At low water, the channel occupied by the Orwell is 500m wide at Shotley, decreasing to 80m at Ipswich. The Stour’s channel is slightly smaller, varying between 120-150m wide as far as Wrabness and decreasing to 30m upstream from here.

The estuaries differ in their sediment composition slightly; the Stour is sandier towards its mouth, whilst the Orwell is characterised by muddy substrates throughout its length. This denotes the biodiversity of the region.

C5.2.2 Hamford Water

The anomalous geomorphology of Hamford Water has more often led it to be called a tidal embayment, rather than an estuary. In the past it was 7km long and 3.5km wide, giving it a the large mouth width to length ratio (0.5). Today the mouth width has reduced to 2.1km by the formation of Stone Point Spit on the southern bank, however its dimensions still remain unique amongst the Essex estuaries.

C5.2.3 Colne Estuary

The Colne estuary is also funnel shaped and its mouth spans between Colne Point and East Mersea. The estuary is approximately 14km in length and consists of five tidal arms branching off of the main river channel of the River Colne. These are; Pyefleet Channel, Geedon Creek, Alresford Creek and Brightlingsea Creek. The estuary channel is particularly deep which suggests it is a relict feature of the Proto-Thames Estuary.

The estuary lies on the limb of the London tectonic basin. It is inferred that the underlying geological structure is partially responsible for the rising land around the Colne estuary. Colne point has formed two shingle spits; the spits are a relict of extensive shingle ridges which up until the 1800's stretched between Walton-on-the-Naze and St Osyth. The bed slope of the estuary gets steeper, particularly at its head and north of the Wivenhoe tidal barrier, the estuary dries at low tide. This results in a rapid decrease in the tidal prism and the inner channel of the estuary.

The Colne estuary system is close to equilibrium and is considered to be geomorphically stable. It does not appear to have been affected by reclamation activities or constraints imposed by the geology of the area. The stability of the estuary is supported by there being no significant change in the intertidal morphology over the past 150-200 years. An explanation for this may be the north-south orientation of the main channel (which contrasts to the other Essex estuaries) and provides it with protection against locally generated waves during periods of dominant south-west winds.

C5.2.4 Blackwater Estuary

The Blackwater estuary is defined as a coastal plain estuary that is enclosed by a shingle spit. The estuary is an exception to typical estuarine morphology, with a wider landward cross section than seaward. This is predominantly owing to the geology of the area and its quaternary history, which results in constrictions at Bradwell and Mersea. The estuary has two major London Clay islands (Osea and Northey) located within its tidal are. The estuary has an over-deepened channel at its mouth which is probably due to the location of the proto-Thames. The depth of the channel can also be attributed to the channel constriction which leads to increased scour and hindered deposition.

The saltmarsh in this estuary has not developed as extensively as the surrounding Essex estuaries. This is owing to a process of natural coastal squeeze where the geology has constrained and limited the transgression of the saltmarsh. The geological constraints of the Islands of Osea and Northey and the valley sides at Steeple and Mundon have caused the estuary to subdivide resulting in a greater proportion of saltmarsh to mudflat.

C5.2.5 Crouch and Roach

The Crouch estuary extends 24km to its tidal extent at Battlesbridge and the Roach is 14km in length to its tidal extent in Rochford; it has numerous tributary creeks along its length. The estuaries are classified as coastal plain estuaries as they deepen and widen at their mouth. The relief produced by the Eocene and quaternary rocks is subdued but has still played an important role in constraining the development of coastal landforms in the area, limiting the transgression of Holocene deposits in the estuary. The estuary floors have a large width to depth ratio and have been infilled with post-glacial sediments sourced by deposits trapped in the southern North Sea.

The ratio of reclaimed inter-tidal area to extant intertidal area (1:7.6) is the largest among the Essex estuaries and demonstrates the extent to which the system has been modified. Owing to reclamation the Crouch has the lowest ratio of intertidal to subtidal areas among the Essex estuaries and the smallest area of saltmarsh.

Most of the intertidal areas of the estuaries have been reclaimed (11600ha) which has resulted in deep, narrow channels with thin intertidal areas. The reclamation has also resulted in a change in the outer sub-tidal channels. In particular the abandoning of the Ray Channel which was formerly the main channel of the estuary.

C5.3 Supratidal areas

Supratidal chenier ridges are located parallel to the marsh edges in a number of areas along the north Thames foreshore; Foulness Point, Colne Point and Sales Point. These ridges are composed of coarse-grained sediment consisting of carbonate shell fragments and silica gravels that have been washed over the saltmarsh edge. It is possible that these chenier ridges previously provided shelter to aid establishment of saltmarsh areas during lower sea levels. As sea levels have risen, the ridges have either been eroded or rolled landwards leaving the saltmarsh to develop on the foreshore.

Colne Point has a range of shingle ridges as part of a spit that extends northwards for 2.5km between Jaywick and Sandy Point. The spit appears to be the remains of a series of shingle ridges that originally extended from Walton to Colne Point but these probably disappeared during the 19th Century (IECS, 1994).

C5.4 Saltmarsh

Erosion of saltmarsh along the Essex coast and estuaries has been a great concern over the past couple of decades. Saltmarsh erosion rates have been recorded by Burd (1992) and Cooper (2000), and were presented in CHaMPs (2002). Table C5.1 and Figure C5.1 present data from these reports.

Table C5.1: Rates of saltmarsh erosion in Essex (CHaMP, 2002).

Area	Monitoring period	Saltmarsh area (ha)*	Average loss per year	
			ha	%
Stour and Orwell	1988-1997	161	6.3	3.9%
Hamford Water	1988-1998	614	14.4	2.3%
Colne	1988-1998	670	5.6	0.8%
Blackwater	1988-1997	670	7.0	1.0%
Dengie	1988-1998	409	2.7	0.7%
River Crouch	1998-2000	276	10.4	3.8%
River Roach	1998-2000	113	0.7	0.6%
Benfleet and Southend	1988-1998	135	1.4	1.0%
Total		**3048**	**48.5**	**1.6%**

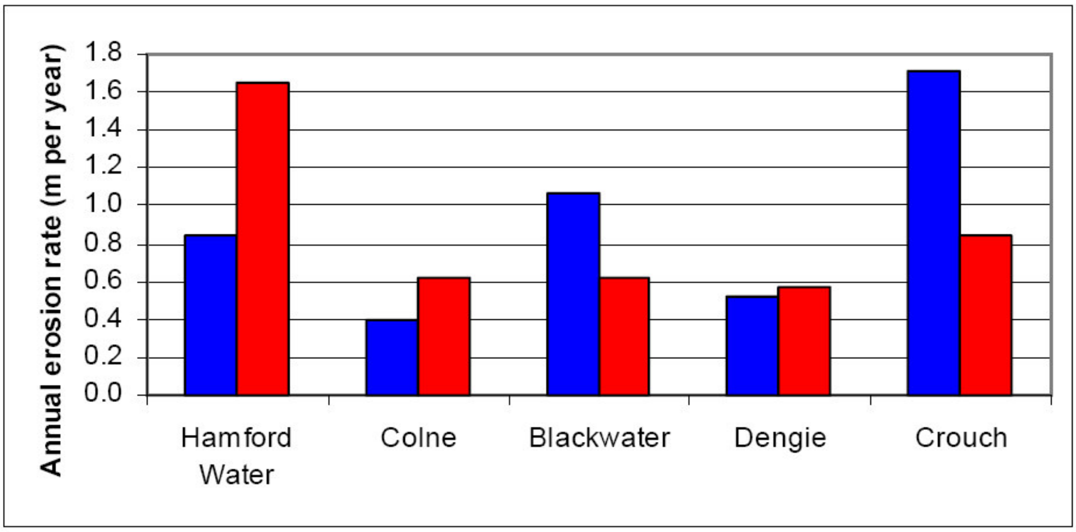

Figure C5.1: Mean annual saltmarsh erosion rates as a percentage of total salt marsh area calculated for two periods: 1973-1988 in blue and 1988-1998 in red (CHaMP, 2002)

The intertidal area is a natural part of estuaries and embayments. It provides natural protection against waves and currents, which means it acts as a natural flood and erosion defence. In addition the intertidal area is an internationally important habitat, which gives it a protected status. The natural response of saltmarsh to sea level rise is to migrate in a landward direction. If this landward migration is blocked by natural high ground or by flood defences, then this is referred to as ‘coastal squeeze’. If saltmarsh is being lost in an area, then a managed realignment of the flood defence can be an appropriate response: this moves the defence away from the natural pressures to a more sustainable location and can lead to re-creation of saltmarsh, with its benefits for habitats and flood defence.

For these reasons, it is important for the development of the SMP to understand the currently ongoing losses and gains of saltmarsh and mudflat. This section sets out our current understanding. Appendix F also contains specific information about the frontages that are under pressure as a result of intertidal developments.

Monitoring of saltmarsh change in the SMP area has taken place since 1973, using a range of techniques including aerial photographs, GIS and field based calibration. For the open coast, the Environment Agency's Coastal Trends Analysis reports are an important source of information; they are based on monitoring since 1991. Appendix C provides more details on these data sources. This shows that calculating and predicting losses and gains of saltmarsh and mudflats is not a straightforward task and the resulting numbers should be used with extreme caution.

A general conclusion is that the Essex and South Suffolk estuaries are generally losing saltmarsh. Data on mudflat losses and gains is inconclusive. However, the Coastal Trends Analysis report suggests that mudflats are accreting at Dengie and Foulness. Table C5.1 lists the average loss of saltmarsh per year based on the most recent monitoring periods. There are important caveats for the use of these rates:

- these are measured rates of saltmarsh loss, which may not have all been caused by coastal squeeze or the presence of defences;
- more recent data shows different trends (but are difficult to quantify); this means there is large uncertainty;
- the data is based on the area within the designated Special Protection Areas (SPAs); there is no quantitative data for Foulness.

Analysis of saltmarsh loss in the SPAs within the SMP study area

A comprehensive assessment of saltmarsh change in Essex was undertaken in 1992 (Burd, 1992) to quantify the rates of erosion and vegetation change of saltmarshes using aerial photographs, a GIS and field-based ground calibration techniques. This analysis of the saltmarsh is referred to in this note as the saltmarsh area from GIS.

This technique was analysed in 2000 (Cooper *et al*, 2000) and discrepancies in the scale and level of detail of the mapping were found to have given rise to considerable ‘apparent losses’ of saltmarsh between 1973 and 1988 which are greater than the ‘actual losses’ (Royal Haskoning, 2004). The recalculation of the saltmarsh loss by Cooper *et al* is referred to in this note as the saltmarsh area from the report. This is also the figure for saltmarsh coverage which has been used to calculate the rate of loss below.

The extrapolation of the extent of continued predicted saltmarsh loss has been calculated using a range of techniques, as described in the Essex CHaMPS (Posford Haskoning, 2002). The methods used in this note to predict the future saltmarsh coverage are:

- Linear extrapolation: direct extrapolation of historic trends.
- Regime theory: application of known relationships between physical attributes of an estuary in order to predict long-term changes.
- Mudpack: prediction of mudflat elevation changes on a specific profile over periods of between 1 and 100 years.

The pink layers on each table represent the predicted saltmarsh area using one of the methods described above.

Stour and Orwell Estuaries SPA

Area of saltmarsh in the Stour and Orwell Estuaries SPA in 1973, 1988 and 1997

Year	Saltmarsh area GIS	Saltmarsh area report	Method used
1973	No data	363.7	
1988	242.3	217.7	
1997	161.1	161.1	
2004		117.1	Linear
2023		0	Linear

Saltmarsh loss in the Stour and Orwell Estuaries SPA between 1988 and 1997

Year	Saltmarsh loss (ha)	Loss rate (hayr^{-1})
1988-1997	56.6	6.29

Hamford Water SPA

Area of saltmarsh in Hamford Water SPA in 1973, 1988 and 1998

Year	Saltmarsh area GIS	Area inside SPA GIS	Saltmarsh area report	Estimated area inside SPA Report	Method used
1973	No data	No data	876.1	No data	
1988	787.1	780.0	765.4	758.5	
1998	622.6	615.8	621.1	614.3	
2004				527.8	Linear
2041				0	Linear

Saltmarsh loss in Hamford Water SPA between 1988 and 1998

Year	Saltmarsh loss (ha)	Loss rate (hayr^{-1})
1988-1998	144.2	14.42

Colne Estuary SPA

Area of saltmarsh in the Colne Estuary SPA in 1973, 1988 and 1998

Year	Saltmarsh area GIS	Area inside SPA GIS	Saltmarsh area report	Estimated area inside SPA Report	Method used
1973	No data	No data	791.5	No data	
1988	748.8	730.3	744.4	726.0	
1998	694.1	668.9	694.9	669.7	
2004				635.9	Linear
2054				354.4 519.9	Linear Regime

Saltmarsh loss in the Colne Estuary SPA between 1988 and 1998

Year	Saltmarsh loss (ha)	Loss rate (hayr^{-1})
1988-1998	56.3	5.63

Blackwater Estuary SPA

Area of saltmarsh in the Blackwater Estuary SPA in 1973, 1988 and 1997

Year	Saltmarsh area GIS	Area inside SPA GIS	Saltmarsh area report	Estimated area inside SPA Report	Method used
1973	No data	No data	880.2	No data	
1988	746.1	740.8	738.5	733.3	
1997	688.6	675.1	683.6	670.2	
2004				621.1	Linear
2054				270.6 Regime 0	Linear

Saltmarsh loss in the Blackwater Estuary SPA between 1988 and 1998

Year	Saltmarsh loss (ha)	Loss rate (hayr^{-1})
1988-1997	63.1	7.01

Dengie SPA

Area of saltmarsh in the Dengie Estuary SPA in 1973, 1988 and 1998

Year	Saltmarsh area GIS	Area inside SPA GIS	Saltmarsh area report	Estimated area inside SPA Report	Method used
1973	No data	No data	473.8	No data	
1988	451.9	451.5	436.5	436.1	
1998	420.2	419.7	409.7	409.2	
2004				393.1	Linear
2054				258.6 Recovery of saltmarsh	Linear Mudpack model:

Saltmarsh loss in the Dengie Estuary SPA between 1988 and 1998

Year	Saltmarsh loss (ha)	Loss rate (hayr^{-1})
1988-1998	26.9	2.69

Crouch and Roach Estuaries SPA

Area of saltmarsh in the Crouch and Roach Estuaries SPA in 1973, 1988 and 1998

Year	Saltmarsh area	Area inside SPA	Method used
Crouch 1998 Roach 1998	303.2 118.7	296.5 114.4	
Crouch/Roach 1998	421.9	410.9	
Crouch 2000 Roach 2000	282.0 116.2	275.7 113.1	
Crouch/Roach 2000	398.2	388.8	
Crouch/Roach 2004		344.6	Linear
Crouch 2054		0	Regime

Saltmarsh loss in the Crouch and Roach Estuaries SPA between 1988 and 1998

Year	Saltmarsh loss (ha)	Loss rate (hayr^{-1})
River Crouch (1998-2000)	20.8	10.40
River Roach (1998-2000)	1.3	0.65
Total (1998-2000)	22.1	11.05

Foulness SPA

No saltmarsh change information is provided due to a paucity of historical change analysis. Aerial photos are available with saltmarsh coverage from 1993 and 1997; however these have not been scanned or analysed currently.

Benfleet and Southend Marshes SPA

Area of saltmarsh in Benfleet and Southend Marshes SPA in 1973, 1988 and 1998

Year	Saltmarsh area	Area inside SPA	Method used
1998	197.0	148.5	
2000	181.0	134.7	
2004		126.4	Linear
2054		57.4	Linear

Saltmarsh loss in Benfleet and Southend Marshes SPA between 1988 and 1998

Year	Saltmarsh loss (ha)	Loss rate (hayr^{-1})
1988-1998	13.8	1.38

C5.5 Mudflats

Two large areas of open coast intertidal flat are present along the Essex coast. There is 2590ha of intertidal mudflats on the Dengie Peninsula reaching 3km in width. Foulness Sands extends south towards the Thames Estuary and forms part of Maplin Sands which is the largest intertidal area in Britain with an area of 8658ha (CHaMPs, 2002). The mudflats have a width of 6km with 88ha of backing saltmarsh, and are sheltered behind a chenier ridge between Northern Corner and Foulness Point.

Changes in mudflat extent along the Essex coast have not been quantified. Variations in the area of mudflat are approximated as the inverse of saltmarsh loss (see Table C5.7 and Figure C5.7). The loss of an area of saltmarsh results in horizontal landward retreat of the salt marsh-mudflat boundary (i.e. an equal amount of mudflat gain is likely to occur). Although this assumption is generally correct, this must be qualified:

- low water marks will vary
- saltmarsh losses may include internal dissection, a process that results in an area of bare mud that may not be recognized as intertidal mudflat.

The intertidal area between Canvey and Southend was over 2243ha in 1988, but this had been reduced by 10% since 1940 (2492ha in 1940). Similarly, Maplin Sands experienced recession of its seaward edge over the same period (IECS, 1992). However, no quantitative data is available.

Shore profiles along the open coast recorded by the EA provide an accurate measurement of the changes in mudflat morphology on the open coast over the past decade (CHaMPs, 2002). The surveys show that the intertidal slope has flattened at profiles across Dengie. Accretion on the lower intertidal flat at the northern and southern extremities of the Dengie Peninsula was responsible for a flatter slope; average accretion rates for these areas range from 0.03 to 0.06 m/yr. In contrast, the central section of the shoreline, at Marsh House, experienced significant erosion on the upper intertidal area at a mean rate of 0.03m/yr. Inspection of bathymetric surveys for the three profiles fails to explain the variation. Overall, these results describe a decrease in the intertidal slope, resulting in a wider foreshore and an increase in the extent of the mudflat habitat.

C5.6 Grazing marsh

Grazing marsh is defined as periodically inundated pasture or meadow with ditches containing standing brackish or fresh water. Freshwater coastal grazing marshes have been created since the Roman times by the enclosure of high saltmarshes. These areas are traditionally used for summer grazing and provide an attractive habitat for breeding and wintering birds (CHaMPs, 2002).

Historically, grazing areas were created initially as pasture for dairying or livestock production, but through changing agricultural practice, have been largely replaced by arable production. In Essex during the 17th century, arable production was limited but increasing demand for arable crops from London encouraged conversion of grazing marshes. By the mid 1850s the majority of northeast Essex and land around the Blackwater Estuary was pasture. Whereas the majority of the Dengie and Crouch marshes had been converted to arable production (Gramolt, 1961). In the 20th century, the loss of pasture increased due to the demand for increased cereal production during wartimes and through agriculture policy in post-war times. It has been calculated that between the 1930s and the 1980s, the coastal grazing marshes in Essex declined by as much as 72% (Williams and Hall, 1987) (Table C5.2).

Table C5.2 Changes in the extent of grazing marsh in Essex (CHaMPS, 2002)

	1930	**1960**	**1970**	**1980**
Area of grazing marsh (ha)	25402	12381	10542	7030
Percent of 1930 total	100	49	42	28

The factors causing loss or decline of grazing marshes over the last 50 years in Essex are two-fold; conversion to arable use and conversion for development and urbanisation. Since the 1930s, nearly 10,000 hectares of grazing marsh have been converted to arable production in Essex. Loss of marshes for urban and industrial development has mainly occurred along the Thames Estuary. It is estimated that between 1970 and 1980 approximately 26% of the marshes were lost in the Essex Greater Thames Estuary area for this reason (Essex County Council, 1999). Other factors contributing to the current loss trend include sea-level rise, drought, mismanagement and pollution.

By the end of the 1990s it was estimated that there were 6,500 hectares of grazing marsh in Essex in all the coastal districts, compared to 7,030 ha in the 1980s and 25,402 ha in the 1930s. Table C5.3 presents the areas of unimproved grassland (freshwater grazing marsh) for the Essex Estuaries (CHaMPS, 2002).

Table C5.3: Areas of freshwater grazing marsh in the Essex estuaries (Natural England)

	Hamford Water	**Colne**	**Crouch/Roach/Foulness**	**Benfleet and Southend**	**Blackwater**
Total area (ha)	67.7	310	321.1	51	458.5

C5.7 Coastal Changes

The Environment Agency (EA) have undertaken regular strategic coastal monitoring of the Anglian coast since 1991 (Coastal Trends Analysis, Essex EA 2008). The results of the most recent analysis of the data generated by the monitoring program are discussed below. The Coastal Trends Analysis uses monitoring data to identify rates of erosion and accretion based on the landward or seaward movement of mean high water neap (MHWN), mean sea level (MSL) and mean low water neap (MLWN).

Of the 78 profiles surveyed along the Essex coastline, almost half (49%) show a general accretion trend over the 16 years between 1991 and 2007 (Table C5.4, Figure C5.2 and Figure C5.3). Significant trends of accretion were apparent along the broad expanses of mudflats at Dengie Flat, Maplin Sands and Shoeburyness. Over a quarter (28%) of the profiles showed an erosional trend. Significant erosion was observed at three main locations

- The Naze, particularly at Stone Point at the tip of the Naze with an erosion trend of 3m/yr
- Jaywick, adjacent to Brooklands where the erosion trend is 4.5m/yr (despite beach nourishment works)

- On the east of Mersea Island with erosion rates between 3.2 and 4.4 m/yr.

The majority of profiles (49%) show a significant flattening trend of the foreshore and around a quarter (26%) show a foreshore steepening trend. Roughly one fifth of profiles have shown no change in the general trend and no change in foreshore gradient. Flattening is often associated with accretion and steepening with erosion.

Table C5.4: Coastal trends analysis summary

Coastal Change		**Number of profiles**	**Percentage (%)**
General Trend	Accretion	38	49
	No Change (+/-0.2m yr)	18	23
	Erosion	22	28
Foreshore Gradient	Flattening	38	49
	Steepening	20	26
	No rotation	15	19
	N/A*	5	6
Defences at profile location	Defences	72	92
	No defences	6	8

** some profiles did not have sufficient MLWN data to determine a reliable FCP score*

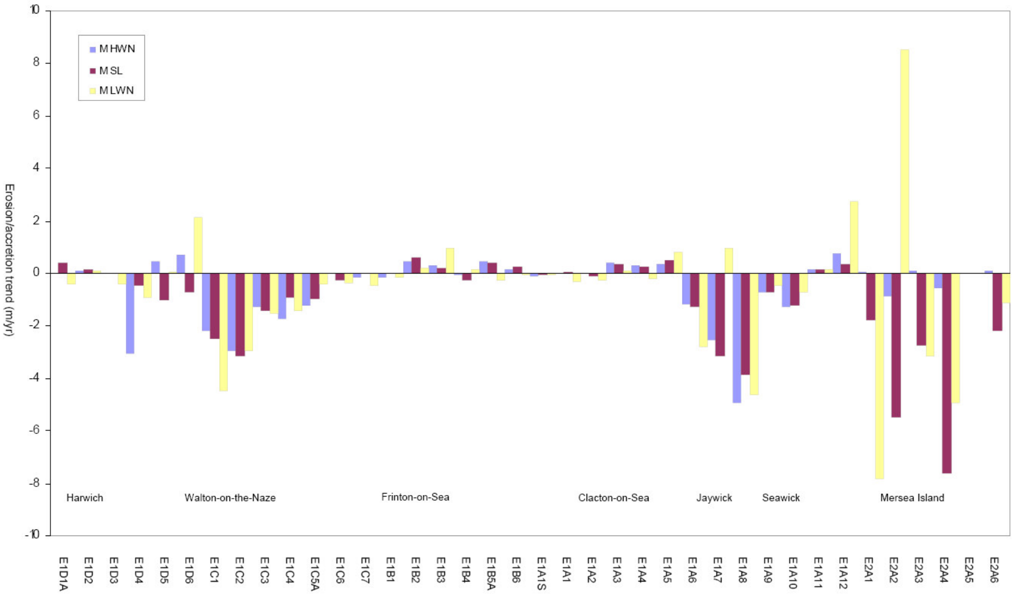

Figure C5.2: Coastal Trends 1991 – 2007, Harwich to Mersea Island, showing the three major areas of erosion at the Naze, Jaywick and Mersea Island (EA, 2008)

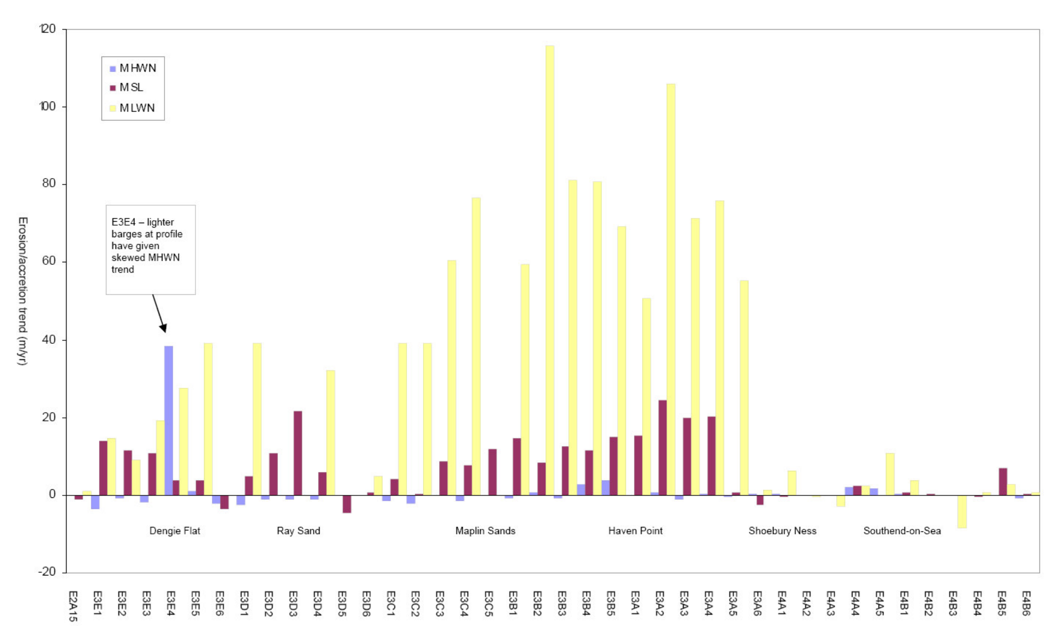

Figure C5.3: Coastal Trends 1991 - 2007, Dengie Flat to Leigh-on-Sea, showing significant accretion (EA, 2008)

C5.8 Estuarine Changes

C5.8.1 Stour and Orwell

The length of both estuaries is largely undefended or altered by human intervention, partly because of the naturally steep land which constrains them. However, human developments such as Felixstowe and Harwich Ports at the estuary’s shared mouth do exert significant control on natural processes. In addition to these developments, channels are periodically dredged to allow access for vessels, which reduces the sediment available for habitat creation upstream.

Figure C5.4: Intertidal habitats of the Stour and Orwell Estuaries, FMU 5: Manningtree. Source: Royal Haskoning, unpublished

Despite the similarities in tidal hydrodynamics in both the estuaries, overall, the Orwell is considered to be flood-dominant. This is associated with a net import of marine-sourced fine sediments. This process promotes the 20,000-30,000m^3 per year of sediment currently being accreted upstream of Levington Creek. The ebb-dominant current speeds of the tide in the Stour act over a larger area of the estuary, causing an overall export of sediments.

Any waves that affect the estuaries act to erode intertidal habitats such as mudflats and saltmarsh, and “stir up” sediments which can either be redistributed inside the estuary, or lost offshore.

C5.8.2 Hamford Water

The Stone Point Spit and the associated Pye Sands in the estuary mouth are formed by sediments that are eroded from the Naze cliffs to the south. In turn, the features provide more shelter from oncoming waves in the estuary, allowing the accumulation of fine muddy sediments and the development of extensive intertidal habitats.

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Figure C5.5: Photograph of Hamford Water.

Today, Hamford Water is ebb dominant, which means that any eroded sediment has a tendency to be exported offshore. This is a large problem within this system, which is currently experiencing the largest losses of saltmarsh habitat in the region (see Section C5.4), due to erosion and coastal squeeze. Waves typically come from the north-northeast and south-southwest, but the former tend to be larger and more influential in moving sediment. As a result, the existence of the protective spits is threatened by coastal erosion.

C5.8.3 Colne Estuary

Owing to the reduced wave climate at the Colne, sediment transport is governed by tidal currents and the estuary. The tidal channels have shown a slight decrease in mean depth mainly owing to an increase in the elevation of the intertidal mudflats.

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Figure C5.6: Brightlingsea Marshes

Considering the equilibrium profile of the estuary, the upper estuary is too narrow and is therefore experiencing erosion. This is supported by higher bed shear stresses in the upper reaches of the estuary downstream of the Roman River and the Colne Barrier. In contrast, the mouth is too wide and is experiencing accretion. This is supported by the supply of surplus sediment to the system brought into suspension by the waves and deposited within areas sheltered from direct wave attack. Shingle enters the Outer Thames Estuary from the north of the Essex Coast, where it is deposited along the shoreline at St Osyth and as spits on the east side of the Colne estuary mouth.

C5.8.4 Blackwater Estuary

The estuary morphology has been significantly modified due to the effects of climate change. The lower intertidal mudflats have experienced recession along with the upper mudflats and saltmarsh. Coastal squeeze is a significant issue in the area and is exacerbated by issues of foreshore steepening and loss of wave attenuation leading to increased erosion.

Figure C5.7: Photograph of Old Hall Marshes in the Blackwater Estuary

The mouth of the estuary is under significant pressure from north-easterly waves and estuary processes. Effectively, the estuary at this section is trying to widen. The widening of the estuary is constrained by existing flood defences. The north bank in this section of the estuary is most affected by waves. whilst the south bank in the mid estuary is under pressure from estuarine processes. Overall there is erosion of saltmarsh at outer and mid sections of the estuary and siltation at inner creeks and the inner estuary. Jet ski and boat wash may cause further erosion. At some locations overtopping is an issue. In the past foreshore recharge has been carried out on the seaward face of the Old Marshes to prevent overtopping. At Mundon Creek and Mayland Creek there is hydrodynamic pressure on the defences due to the natural widening of the estuary meanders.

C5.8.5 Crouch and Roach

Erosion occurs along the Wallasea Island reach but accretion continues further up the estuary. This pattern corresponds with the channel variation within the estuaries and reflects the estuaries attempt to gain equilibrium; that is eroding where the channel is too narrow and accreting where the channel is too wide. This pattern of erosion and accretion supports the ‘rollover’ model for sea level rise and suggests that the sediment budget is in balance.

However, the restriction of the channel width due to the continuous flood embankments along the estuary mean that any deposition that occurs as a result of flood asymmetry leads to a decrease in the channel dimension, an increase in velocity and erosion of deposited material. Consequently the estuaries are experiencing an artificial balance owing to the constraints of the flood defences. As tidal velocities increase erosion will become a dominant feature of the estuary channel, placing considerable stress on existing flood defences. Although the present sediment budget in the Roach/Crouch appears to be balanced, the ultimate sources of sediment is unclear. This may have a significant impact in the future when increased sediment loads will be required to counter sea level rise.

Figure C 5.8: Photograph of Wallasea Island in the Crouch estuary

C6 DIVISION OF THE COAST FOR FURTHER SMP ANALYSIS

This section applies the understanding built up in the preceding sections to determine logical units from a geomorphological point of view.

For the SMP1 the Essex coast was subdivided into 9 coastal (open coast and estuary) units. The SMP1 coastal units (CU) subdivision has been adopted by this SMP2, with the inclusion of the Orwell Estuary into coastal unit 9 of the SMP1 (Table 11). In addition, SMP1 CU 1 (renamed to CU I) will start at Shoeburyness and only cover the Southend-on-Sea frontage. The partial adoption of the SMP1 CUs and the SMP2 adjustments are supported by the updated understanding of geomorphology and coastal processes for this task. It considers aspects of the Essex frontage such as:

- Geomorphological setting – Clacton to Canvey Island (subtidal and intertidal mudflats), CU I to CU D, and Clacton to Felixstowe (coarse grained sediment beach), CU C to CU A;
- Orientation of the coast - northeast to southwest (Tendring Peninsula, CU C, and Foulness, CU F) and north to south (Dengie Peninsula, CU H); and
- The Naze sediment divide, defining the subdivision of CU B and CU C.

It is important to note that this division of the coast will be primarily used for a number of Stage 2 tasks, such as Baseline Scenarios Assessment and Flood Risk. These divisions are not the final frontages for which the SMP will define policies. The SMP Policy Units / Policy Development Zones will be decided during Stage 3 and will be developed together with the CSG and EMF.

Table C 6.1: Divisions of the Essex and South Suffolk coast for the SMP2

Location	SMP1 Management Units	Future Coast	FutureCoast (Local systems)	SNS2 Sediment Transport	SMP2 Local Physical description of frontages
Mardyke to North Shoebury	1	1	1	Essex	J
North Shoebury to Courtsend/Foulness Point	2		2		I
Courtsend/Foulness Point to Holliwell Point (North)	3				H
Holliwell Point (North) to Sales Point	4				G
Sales Point to East Mersea	5		3		E F
East Mersea to Colne Point	6	2	4		D
Colne Point to Walton-on-the-Naze	7	3	5 6		C
Walton-on-the-Naze to Little Oakley	8		7		B
Little Oakley to Lawford	9		8		A
Lawford to Landguard Point					

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