Appendix F
Shoreline Interactions & Responses

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CONTENTS

F1. INTRODUCTION

This Appendix reports on a number of activities carried out in the course of the SMP development to assess the interaction of SMP policy and coastal processes. It builds on the baseline description of the coastal processes described in Appendix C.

The Appendix contains the development of baseline scenarios (Task 2.2), the assessment of coastal and flood defences (Task 2.1b), the Coastal Risk assessment (mapping exercise developed as an addition to Task 2.2), and assessment of the shoreline response to the preferred options (Task 3.2). The Appendix also reports on the additional tasks carried out in order to provide sufficient data to enable preferred policies to be selected following the policy appraisal process.

> It is important to note that this Appendix contains a full record of the assessments undertaken and decisions made along the route to concluding final SMP policies for Essex & South Suffolk. All of this information has been used within the decision making process, but it may not have necessarily been taken forward and reported on within the main SMP document or non-technical summary. In some instances insights have changed over the course of the SMP process, so it is possible that the text in the Appendices seems to contradict the content of the main SMP document or non-technical summary. In such cases, this is highlighted in the introduction to the Appendix section. The main SMP document and the non-technical summary contain the agreed final SMP policies.

F2. DEVELOP BASELINE SCENARIOS

F2.1 Introduction

F2.1.1 Aim

The aim of Task 2.2 as a whole is to provide an appreciation of how the shoreline is behaving and the influence that coastal management has upon this behaviour. This will provide the basis upon which flood and coastal risks are determined. This analysis will then be used to develop and appraise policy scenarios.

Task 2.2 is divided into three explicit tasks:

- A description of the baseline response assessments for the 'No Active Intervention (NAI)' scenario. This assumes that defences are no longer maintained and will fail at the start of epoch 2.
- A description of the baseline response assessment for a 'With Present Management (WPM)' scenario. This assumes that all defences are maintained to provide a similar level of protection to that provided at present.

Both the NAI and WPM scenarios will discuss coastal evolution within 3 epochs: Present day to 2025; 2026 to 2055; and 2056 to 2105.

F2.1.2 Geographical units

To break this task down into manageable sections of work, the Essex and South Suffolk coastline has first been sub-divided into ten frontages. These frontages were derived mainly using the natural geomorphological breaks found along this coastline.

- Frontage A (Stour and Orwell Estuaries) – Little Oakley/Harwich to Felixstowe Port
- Frontage B (Hamford Water) – Walton-on-the-Naze to Little Oakley/Harwich.
- Frontage C (Tendring Peninsula) – Colne Point to Walton-on-the-Naze.
- Frontage D (Colne Estuary) – Colne Point to Old Marshes (Quarter Spit)
- Frontage E (Mersea Island) - all of Mersea Island.
- Frontage F (Blackwater Estuary) – Old Marshes (Quarter Spit) to Sales Point.
- Frontage G (Dengie Flat) – Holliwell Point to Sales Point.
- Frontage H (Roach and Crouch Estuaries) –. Foulness Point to Holliwell Point.
- Frontage I (Foulness Island) – Foulness, Potton and Rushley Islands.
- Frontage J (Southend-on-Sea) - Two Tree Island (most southern extent of the SMP2) to North Shoebury.

F2.1.3 Task methodology

The first stage in completing this task was to collate all relevant baseline information for each frontage. This baseline data was originally collected as part of the assessment of coastal processes. For this report, however, it was necessary to highlight the relevant information for each frontage and assemble it into a useful format. A Table was therefore designed to present this information that included a section for the baseline scenario predictions. This Table is based on the presentation of results suggested for this task in the SMP guidance (Defra 2006). This has effectively allowed a quick reference guide to be created for each frontage.

The Table is divided into four main sections, with the first three summarising the baseline conditions, and the final one outlining the baseline scenario assessment outcomes. The individual sections are:

- Section 1 – **Description**. Includes information on the physical characteristics of the frontage and the existing coastal defences and management practices.

- Section 2 – **Baseline information**. Includes data on water levels, extreme water levels, currents, tides, wave climate, patterns of erosion and accretion, and sediment sources and transport.
- Section 3 – **Geomorphology**. Includes data on processes, patterns of change and geomorphological controls, sensitivities and influences.
- Section 4 – **Baseline management scenarios**. This section describes the results of the scenario assessment for both the WPM and NAI scenarios and outlines the thought process behind the scenario results.

It is useful to mention here that, if the individual sections in the Tables are blank, specific information for the relevant frontage was not available during the completion of this report. In some cases where this information was not available, it was felt there was sufficient information relevant in other sections to provide an accurate assessment of the baseline scenarios. These tables are provided on sections F2.2 and F2.11.

Following completion of the baseline data collation exercise, the actual scenario assessment commenced. The geomorphology of the frontage was studied, leading to an in-depth knowledge of the main processes that occur to shape the frontage and the importance of longshore interactions between the frontages. In some cases there were conflicting ideas about the formation of certain landforms and in these situations expert judgement was needed to choose the most likely mechanism involved. This information was then compared to the future evolution predictions discussed in both the Essex Coastal Habitat Management Plan (CHaMP, 2003) and Futurecoast (Halcrow, 2002). Finally, a description of future evolution was completed using a combination of these sources and geomorphological knowledge gained. This description was also broken down into the three epochs for both scenarios. The results were written up into the table discussed earlier.

Where possible, the rates recorded during the recent Environment Agency monitoring programme were applied to the future prediction of shoreline evolution. In most cases one rate was applied to the entire frontage. This rate was calculated from an average of the rates for each individual profile for that particular frontage. In some cases specific profiles showed highly variable trends and only the rate at high water was available. In these cases, the profile was excluded from calculations of an average rate for the specific frontage. The average rates used are in Table 2-1.

Finally, the technical description of the processes under the baseline scenarios was described in a more accessible format, focusing on an overall understanding of coastal behaviour within the frontages and their interactions. This description is included in Section 3.0 of the Tables. The Tables relating to each frontage are in the relevant section of the report.

Table 2-1 Erosion Rates (Coastal Trend Analysis, 2008)

Frontage	Profile Number	MHWN	MSL	MLWN	Mean Rate
A (Stour and Orwell)- Dovercourt	E1D1A	0.02	0.39	-0.40	0.00
	E1D2	0.10	0.14	0.13	0.12
	E1D3	0.01	0.01	-0.39	-0.12
	E1D4	-3.05	-0.48	-0.91	-1.48
	E1D5	0.47	-1.04	0.07	-0.17
	Average	**-0.49**	**-0.20**	**-0.30**	**-0.33**
B (Hamford Water, Entrance)	E1D6	0.69	-0.72	2.15	0.71
Pye Sand (Hamford Entrance)	E1C1	-2.17	-2.49	-4.46	-3.04
	E1C2	-2.94	-3.16	-2.92	-3.01
	Average	**-2.56**	**-2.83**	**-3.69**	**-3.03**
The Naze	E1C3	-1.29	-1.44	-1.50	-1.41
	E1C4A	-1.70	-0.93	-1.43	-1.35
	E1C5A	-1.24	-0.95	-0.42	-0.87
	Average	**-1.41**	**-1.11**	**-1.12**	**-1.21**
C (Tendring Peninsula)	E1C6	0.00	-0.25	-0.35	-0.20
	E1C7	-0.16	-0.02	-0.47	-0.22
	E1B1	-0.13	-0.01	-0.16	-0.10
	E1B2	0.45	0.59	0.21	0.41
	E1B3	0.28	0.21	0.95	0.48
	E1B4	-0.05	-0.26	0.16	-0.05
	E1B5A	0.44	0.41	-0.23	0.21
	E1B6	0.14	0.28	-0.06	0.12
	E1A1S	-0.09	-0.07	-0.06	-0.07
	E1A1	0.01	0.04	-0.30	-0.08
	E1A2	0.00	-0.12	-0.25	-0.12
	E1A3	0.40	0.38	0.13	0.30
	E1A4	0.31	0.23	-0.19	0.12
	E1A5	0.37	0.49	0.83	0.56
	E1A6	-1.18	-1.24	-2.78	-1.74
	E1A7	-2.53	-3.15	0.98	-1.56
	E1A8	-4.92	-3.87	-4.64	-4.48
	E1A9	-0.71	-0.70	-0.45	-0.62
	E1A10	-1.28	-1.23	-0.70	-1.07
	E1A11	0.15	0.16	0.15	0.15

Frontage	Profile Number	MHWN	MSL	MLWN	Mean Rate
	E1A12	0.77	0.34	2.76	1.29
	Average	**-0.37**	**-0.37**	**-0.21**	**-0.32**
D Mersea Island	E2A1	0.05	-1.79	-7.81	-3.18
	E2A2	-0.89	-5.47	8.51	0.72
	E2A3	0.12	-2.77	-3.14	-1.93
	E2A4	-0.57	-7.60	-4.93	-4.37
	E2A5	0.00	-0.02	-0.01	-0.01
	E2A6	0.11	-2.18	-1.10	-1.06
	Average	**-0.20**	**-3.31**	**-1.41**	**-1.64**
F (Dengie Flat)	E2A15	0.02	-0.96	0.84	-0.03
	E3E1	-3.38	13.80	14.52	8.31
	E3E2	-0.92	11.66	8.98	6.57
	E3E3	-1.72	10.88	19.25	9.47
	E3E4				
	E3E5	0.88	3.66	39.26	14.60
	E3E6	-2.12	-3.52		-2.82
	E3D1	-2.50	4.84	39.06	13.80
	E3D2	-1.19	10.71		4.76
	E3D3	-1.12	21.60		10.24
	E3D4	-1.16	6.00	32.09	12.31
	E3D5		-4.69		-4.69
	E3D6	-0.01	0.71	4.94	1.88
	Average	**-1.20**	**6.22**	**19.87**	**6.20**
H (Foulness Island)	E3C1	-1.59	4.06	39.25	13.90
	E3C2	-2.28	0.22	39.04	12.33
	E3C3	0.09	8.64	60.34	23.02
	E3C4	-1.43	7.50	76.46	27.51
	E3C5	-0.17	11.85		5.84
	E3B1	-0.68	14.56	59.59	24.49
	E3B2	0.72	8.24	115.74	41.57
	E3B3	-0.84	12.58	81.27	31.00
	E3B4	2.63	11.55	80.89	31.69
	E3B5	3.71	15.08	69.30	29.36
	E3A1	0.01	15.46	50.60	22.02
	E3A2	0.80	24.59	106.13	43.84
	E3A3	-1.10	19.75	71.20	29.95
	E3A4	0.17	20.41	75.95	32.18
	E3A5	-0.41	0.52	55.27	18.46
	E3A6	0.18	-2.40	1.29	-0.31
	Average	**-0.01**	**10.79**	**65.49**	**24.18**

Frontage	Profile Number	MHWN	MSL	MLWN	Mean Rate
I (Southend-on-Sea and Shoebury)					
	E4A1	0.39	-0.41	6.40	2.12
	E4A2	-0.06	-0.18	-0.53	-0.26
	E4A3	-0.12	-0.11	-2.89	-1.04
	E4A4	2.02	2.41	2.49	2.31
	E4A5	1.79	0.02	10.96	4.26
	E4B1	0.29	0.60	3.85	1.58
	E4B2	-0.01	0.24	0.04	0.09
	E4B3	-0.01	-0.18	-8.39	-2.86
	E4B4	0.12	-0.26	0.48	0.11
	E4B5	-0.01	6.92	2.68	3.20
	E4B6	-0.89	0.16	0.59	-0.05
	Average	**0.32**	**0.84**	**1.43**	**0.86**

F2.1.4 Sea level rise

For the purpose of the assessment of baseline scenarios, the rate of sea level rise will need to be taken into account. The following summarises the current guidance relating to sea level rise.

Defra's sea level rise guidance for the East of England, East Midlands, London and south-east England (south of Flamborough Head) is summarised in Table 1.2 (FCDPAG3 Economic Appraisal Supplementary Note to Operating Authorities – Climate Change Impacts October 2006). All values are rounded to the nearest 0.5 millimetres per year ($mmyr^{-1}$).

Table 2-2: Sea level rise guidance (Defra 2006)

Time period	Net rate of sea level rise ($mmyr^{-1}$)	Total sea level rise (mm)
1990 – 2025	4.0	140
2025 – 2055	8.5	255
2055 – 2085	12.0	360
2085 – 2115	15.0	450

F2.1.5 Assumptions and general notes

The following assumptions have been applied during the assessment of shoreline evolution for the Essex and South Suffolk frontages:

- The predicted year that a defence is expected to fail in is assumed to signify total defence failure. Therefore it has been assumed that once a defence has "failed", it will have no residual effect as a defence. Since this data was not available at the time of the task completion, it has been assumed that the defences would fail at the start of epoch 2.

- All accretion/erosion rates quoted are an average for the entire frontage length (unless stated) and can mask localised trends of erosion and accretion.
- All rates and predictions of future morphological development in the WPM scenario assume that WPM will continue in the adjoining SMP areas as well as the adjoining lengths of coast.

The following notes summarise sources of individual erosion/accretion rates as well as a number of points that need to be considered when reading the main text:

- Horizontal accretion/erosion rates have been taken from the Coastal Trends Analysis Report (Shoreline Management Group, 2008). In some cases, the SMP has used average rates for entire frontages between 1991 and 2008.
- Although increased storminess is predicted in the future as an effect of climate change, a quantitative assessment of these effects has not been included in any of the scenarios above. Currently there are no long-term data sets available to identify specific trends in the occurrence of storms. However, the coastline development discussed in each scenario may actually occur earlier than predicted if the frequency and strength of storms increases.
- The Defra rates of sea level rise quoted are intended as conservative estimates and therefore the scenarios represent the worst case scenario.

F2.1.6 Tables layout

As discussed above, the tables that follow provide a detailed description of the baseline information and resultant scenario description per management unit. The first section (section two) of the tables will provide a brief overview of the coastal processes and geomorphological interactions along the Essex and South Suffolk coast. This is a summary of the assessment of coastal processes report and provides the underpinning knowledge that was used to assess the baseline scenarios.

Section 3 of the table will discuss the large-scale interactions along the Essex and South Suffolk SMP study frontage. Each section presents an overview of the geomorphological characteristics and predicted shoreline evolution under the two baseline scenarios for each individual frontage.

The final sections of this report will provide a broad summary of the Essex and South Suffolk area as a whole and the main conclusions drawn from the assessment, as well as the references used in the analysis itself.

F2.2 Frontage A - Stour and Orwell Estuaries

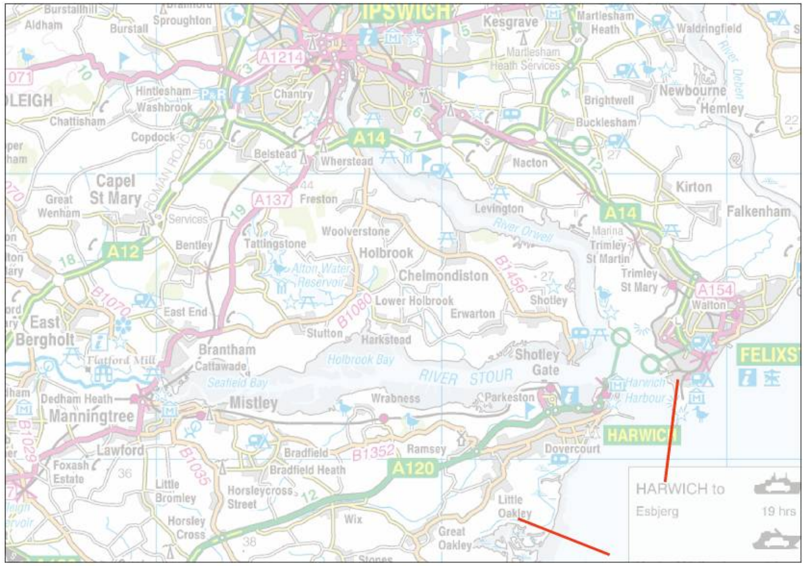
Frontage A – Stour and Orwell Estuaries **Chainage km km**

Section 1 – Description

General: The Stour and Orwell Estuary complex is viewed as an integrated coastal unit. The two rivers share a mouth, located between Landguard Point and Harwich, to the south of Felixstowe. They both contain internationally designated areas of wetland, with SPA and Ramsar status. Outside the SPA is agricultural land which can be viewed as a "support habitat" (CHaMP, 2002). Centres of significant populations are located in the area, and the ports of Harwich, Ipswich and Felixstowe, at the shared mouth are both nationally and internationally important.

To the south of Harwich lies approximately 5km of coastal frontage, extending to the mouth of Hamford Water tidal embayment/estuary in the south. The frontage is heavily developed, more so in the north, where it is backed by Harwich Port and the town of Dovercourt (total population 14,434), and further inland the villages of Little and Great Oakley (population 2306).

Physical: The Stour is a 17km long, straight, coastal plain estuary, orientated west-east, and is the more southerly of the two rivers. At low water the channel is 120-150m wide, as far as Wrabness, decreasing to less than 30m at Mistley. The navigation channel varies from a depth of -9.0m CD up to Harwich International Port, to -0.4m CD at Mistley. The tidal extent is limited by a sluice at Cattawade. The channel itself is strongly influenced by its steeply rising banks, which consist of low boulder cliffs, but are interspersed with fringes of *Spartina* saltmarsh and a total seven shallow bays along its length. Steeper land constraining the estuary is also located at Sutton Ness, Wrabness, Harkshead Point, Erwarton and Parkeston. The estuarine substrates are sandy at its mouth, with some gravel outcrops, becoming progressively finer and muddier towards its upper reaches. The surrounding land is characterised by ancient woodland and agricultural land. It is characterised by a large area (1500ha) of intertidal mudflat, and 130ha saltmarsh, the latter being restricted to the sheltered areas of the inter-estuarine bays (CHaMP, 2002). Holbrook has the largest expanse of intertidal flat, at 1.5km wide and with a slope of 1:500 (excluding the saltmarsh). Seafield Bay and Copperas Bay intertidal areas also have slopes of 1:500, and widths of 1.2km and 800m respectively. Erwarton and Bathside Bay intertidal areas, with slopes of 1:300 have widths of 500m and 750m, respectively (Halcrow, 2005). Saltmarsh widths are typically 50-100m wide, although there are wider portions at Seafield Bay, eastern part of Copperas Bay and west part of Erwarton Bay widths reach 200m, 600m and 300m, respectively. On the south shore east of Mistley there is a 1km stretch of saltmarsh backed by cliffs which reach 18m in height.



The Orwell is a 20km long, northwest-southeast orientated estuary extending from Ipswich to Felixstowe. The tidal extent of the Orwell is limited by Horseshoe Weir in Ipswich, but the Orwell Bridge is considered to be the upper boundary for the SMP. The estuary is linear, and at low water the channel is approx. 500m wide at Shotley, decreasing to 80m at Ipswich. The navigation channel has a depth of around -5.0m CD up to Ipswich Dock. The upper reaches of the Orwell are constrained by a narrow, steep sided valley. On the northern side of the estuary the banks are consistently steep; particularly so at the Ridge to Fagbury cliff, behind Felixstowe Docks, and Sleighton Hill. High ground to the south of the estuary is located at Bourne Hill and Wolverstone, down to Collimore Point. Ridges at Crane's Hill and Shotley Point on the eastern side guide the estuary down to its mouth. Developments such as Felixstowe Port at Fagbury have, however, reduced the relative importance of these natural constraints at the estuary mouth. The substrates of the Orwell are generally muddier than those of the Stour. The surrounding land at the mid-estuary consists of low reaches of farmland and wet meadow. The Orwell contains 500ha of Intertidal Mudflat, 60ha of Saltmarsh and 75ha of Wet Grassland, of which the majority of the latter is located at Shotley and Trimley in the Estuary's southern reaches. Intertidal flats are generally 200-400m on the northern bank and 100-200m on the southern bank, and are typically uniform along its length. Intertidal slopes are between 1:100 to 1:200 in the upper estuary and 1:33-1:50 downstream of Collimer Point. Saltmarsh is only located at Crane's Hill, Levington Creek, Colton Creek (all 250m wide and 500m, 500m and 1.5km long, respectively), and east of Pinmill (50m wide, 1km long).

Therefore, within the Stour/Orwell Estuary complex is 2000ha of mudflats, 190ha of saltmarsh and 75a of coastal grazing marsh (CHaMP, 2002). Both estuaries have a cross sectional area too large for the tidal prism and a width slightly high for the channel length (Halcrow, 2005). possibly a legacy of past geomorphology, prior to the development of sluices along the estuaries.

Harwich is a relatively hard point on the entrance to the Stour/Orwell estuaries and is comprised of limestone, within the wider London Clay bedrock of the region. At Dovercourt, and generally along the whole of the 5km frontage to the south of the estuaries, up to Little Oakley, the soft and easily eroded London Clay is exposed, putting a strong control on the development of this area. This bedrock extends from the sea cliffs, the fronting shore platform and the offshore basement. The cliffs here reach 15m in height in places, fronted by a muddy foreshore with thin and discontinuous, localised shingle deposits. This frontage is strongly influenced by the estuarine processes of the Stour/Orwell in the north.

Frontage A – Stour and Orwell Estuaries

	Chainage km km
Defences[1] and manmade features:	Approximately 43% and 55% of the total length of the Stour and Orwell, respectively, are defended. The defences predominantly consist of embankments and revetments, but also with some stretches of concrete wall, sheet piling and flood gates. Defences on the Orwell are considered to be in balance with the estuarine processes, in general, and those on the Stour are considered to have a minimal impact on estuarine development, overall. The main coastal defences on the Orwell are located between Shotley to just before Colton Creek saltmarsh on the southern shore, and between Fagbury and Trimley on the northern shore. At Shotley, some private effort has been put in place to maintain these defences. A stretch of embankment also protects Yacht Marina and Levington Creek. The port at Felixstowe in the mouth of the Estuaries significantly reduces the natural control exerted on channel development at this location. The navigation channel in both estuaries is dredged to maintain depths. There are beaches backed by numerous groynes between Harwich and Dovercourt. At Dovercourt the sandy beach is also backed by defences made of light Essex block and asphalt. At the southern end of Dovercourt are numerous beach huts, a small car park and a large area of grassland on a raised plateau. Where human developments stop in the south, a clay embankment backs an area comprising saltmarsh and tidal creeks.

[1] A full list of defences is provided in the ‘ Assessment of Coastal Defences’ report

Frontage A – Stour and Orwell Estuaries

Chainage km km

Section 2 – Baseline information (current data relevant to the frontage)

Tide and water levels (mODN):

	LAT	MLWS	MLWN	MSL	MHWN	MHWS	HAT	Spring range	Neap range	Correction CD/ODN
Stour		-1.72	-1.02		1.48	2.18		3.9	2.5	2.02
Orwell		-1.77	-1.07		1.38	2.13		3.9	2.45	2.07
Harwich	-2.12	-1.62	-0.92	0.08	1.38	1.98	2.38	2.6	2.3	2.02

Extremes (mODN):

	Source/method	1:1	1:10	1:25	1:50	1:100	1:250	1:500	1:1000
Harwich	Royal Haskoning, 2007 Extreme Tidal Levels (East Region)	2.68	3.21	3.42	3.57	3.73	3.94	4.10	4.26

Notes:

Currents:

		Notes
Av. flood	Southwest	
Av. ebb	Northeast	
Net residual	Stour: Ebb dom. Orwell: Flood dom.	

Notes

- The Stour Estuary is ebb tidal dominant, a characteristic which increases towards its mouth. Typical peak spring tidal currents reach 1ms^{-1} on the ebb and 0.7ms^{-1} on the flood, at Shotley.
- Conversely, the Orwell is characterised by an overall flood dominant tide, particularly in the upper reaches of the estuary, where mean spring tidal currents reach 0.2ms^{-1} (ebb) and 0.3ms^{-1} (flood).
- The tidal range in both estuaries increases with distance inland. On a spring this is typically 3.6m at Shotley and 3.9m in the upper reaches of both estuaries.
- In general in this region, the flooding tide flows southwards and returns on the ebb to the north.

Wave climate:

The dominant waves approach this shoreline from the east-northeast to southeast, with the annual 10% exceedance significant wave height reaching 1.0 to 1.5m. As such, the location and orientation of both estuaries protects them from these larger waves, except in their lower reaches. Of the two estuaries, however, the Orwell is more exposed to these offshore generated waves, where they can reach 0.6-0.9m.

Locally generated wind-waves have the largest influence along the estuary lengths. In the Stour they can reach 0.2-0.3m in height, although if westerly winds prevail and are prolonged heights can reach over 1.0m. In the Orwell, these locally generaled wind waves are typically only 0.1-0.2m high.

The developments in the lower reaches of the estuaries causes increased wave energies (ship waves) and wave reflections.

Frontage A – Stour and Orwell Estuaries

Chainage km km

Section 2 – Baseline information (current data relevant to the frontage)

Accretion/ erosion:

Stour: Overall erosion along entire length due to ebb tidal dominance. Vertical erosion of mudflats has led to reduction in vertical elevation of 10mm/yr^{-1} 1925-1985. Horizontal erosion of saltmarsh is now occurring at 4ha/year. Over half the total area of saltmarsh was lost between 1973 and 1988 (Burd, 1992). The rate of loss has reduced between 1988-1997 to 1.8% a year losses. Cliffs at Jaques Bay are eroding at rates of 0.5m/$year^{-1}$ (Posford, 2002). Wave focussing into interestuarine bays exacerbates erosion in these areas, particularly on the eastern flanks.

Orwell: Generally an accretive estuary due to its flood tidal dominance. In the lower reaches, however, vertical erosion of mudflats has led to a reduction in elevation of between 15-18mmyr^{-1}. In the upper reaches, upstream of Levington Creek, mudflats actually accreted at an average rate of 13-14mmyr^{-1} between 1994 to 1999. Saltmarsh is still being eroded horizontally at a rate of 1hayr^{-1}, although rates have slowed from 2.2% a year (1973-1988) to 1.7% a year (1988-1997) (Burd, 1992). Unprotected stretches of banks are eroding at a rate of: 0.1myr^{-1} along 6.5km of on northern shore and 0.2m myr^{-1} along 6.5km of southern shore (IECS, 1993).

EA profiles from north to south along the frontage south of Harwich show: at Harwich, little change, with a small steepening of the profile; At Dovercourt, an average erosion rate of -0.4myr^{-1}, with a halving of the beach width from c12m to c6m (1992-1997); At middle beach, south of Dovercourt, a retreat averaging 1.5myr^{-1}, associated with a flattening of the profile, whilst saltmarsh fronting the clay embankment has retreated c27m between 1992-2006. The last profile on this frontage, just north of Little Oakley shows a mean slightly erosional, steepening trend.

Average rates (myr^{-1} unless stated)[2]					Intertidal				Foreshore	
Location	general	crest	face	toe	MHWS	MSL	MLWN	Mean Rate	Trend	Source
Average of EA profiles E1D1A to					-0.49	-0.20	-0.30	-0.33	Variable trend across the	EA coastal Trends analysis, 2008

Section 2 – Baseline information (current data relevant to the frontage)

	E1D5, located from Harwich to Little Oakley									frontage. The majority of the profiles are steepening, but a flattening is occurring at Middle Beach.	

Sediment:

Overview: The Stour/Orwell Estuaries are largely self-contained coastal units, although suspended fine sediments are sourced from offshore and local cliff erosion also.				
Material	Substrates are muddy throughout the Orwell, but are generally fine at the upper reaches of the Stour and get coarser towards the mouth. Sand substrates front the Dovercourt shoreline to the south.			
Sources	External:	Fine sediment is sourced from a number of locations, including: • Erosion of Suffolk clay cliffs • Erosion of Essex clay cliffs • Suspended sediment in the southern North Sea	Internal:	Wave and current activity erodes intertidal material within the estuaries and tidal currents redistribute them within the estuary system.

Movement:	**Location**	**SSC (mg/l)**	**Source**
Movement in the estuaries is relatively self-contained. Sediments are mobilised by waves and transported with residual tidal currents. The Orwell is accreting in its upper reaches, as finer	**Stour; Parkeston**	>1000 (Spring Tide)	Royal Haskoning, 2003
	Stour: Stutton Mill	6-20 Spring Tide)	Royal Haskoning, 2003

[2] The rates highlighted in bold are those used when determining NAI and WPM baseline scenarios (section 4).

Section 2 – Baseline information (current data relevant to the frontage)

	sediments are imported from external sources on the dominant flood tide and eroding in its lower reaches. Conversely, the Stour is an eroding system, overall Some of the sediment sourced from erosion at The Naze is transported north and is deposited along the Dovercourt frontage, south of Harwich, and towards the Stour/Orwell estuary complex. At Harwich, a net marine sediment input has been measured at an average 8000tonnes per tide (Royal Haskoning, 2003)	**Location** **Orwell: Mouth**	Near Bed sediment concentrations >500mg/l (large spring tide)	Source Royal Haskoning, 2003

Section 3 - Geomorphology

Process Description: Overall description of current processes: sources, transport and sinks	Geomorphologically, the Stour and Orwell have many similarities. They both contain extensive areas of mudflat, low cliffs, and saltmarsh, with additional small areas of vegetated shingle and grazing marsh. As described before, both estuaries are constrained by steeply rising London Clay cliffs and land along their lengths, although this is less true of the Stour, which is characterised by a wider floodplain. The Stour/Orwell southern North Sea region is associated with an ebb dominant tide, which travels to the northeast, directing the offshore sand transport (Royal Haskoning, 2003). Temporally, the ebb tide is of a faster velocity but shorter duration; with asymmetry increasing upstream in the Stour. Suspended sediment which is eroded from the estuaries can be tranported in an anti-clockwise circulation around the Hamford Water area, and then follows the northeasterly residual tide (Royal Haskoning, 2003). Intertidal sediments are fine grained in both estuaries, however the Stour has a higher sand fraction than the Orwell at its mouth, with sediments becoming finer inland. Sediments are sourced internally, being eroded by waves and transported by tides, or come from cliff erosion in Suffolk, Essex or from suspended sediment in the southern North Sea (Royal Haskoning, 2003). The fluvial input of sediment is low for both rivers, so suspended and bedload sediment concentrations increase with distance seaward. Generally, the Stour is an erosive estuary, with the exception of only its most upper reaches, whilst the Orwell exhibits a flood dominant tide and has been accreting upstream of Levington Creek. Saltmarsh is being lost from both estuaries (4hayr^{-1} in the Stour, 1ha yr^{-1} in the Orwell), due to scour, waves and coastal squeeze through sea level rise. In the Stour, saltmarsh erosion has been focussed on the eastern banks of inter-estuarine bays. Accretion has predominantly been subtidal, especially in the lower reaches around Harwich, where dredging of the navigation channel has created a sediment sink for fine grained material. Approximately 8000 tonnes of sediment is deposited in the harbour on each tide (Royal Haskoning, 2003).
Patterns of change:	**Past development:** The estuaries are, historically, a sink for fine sediments and have been accumulating and accreting with the Holocene marine transgression. Sediments in suspension in the southern North Sea have come from offshore, and from cliff erosion (the cliffs in North Norfolk to the north contain have a high

proportion of fines) where they are eroded and mobilised by waves and transported by tidal currents. 6km offshore from the Stour/Orwell estuary complex (off Languard Point) exists Cork Sands, one of the numerous sand banks in the region, however there apears to be little or no sediment transfer between the estuaries and this feature. The Dovercourt Bay frontage is erosional, with a history of landsliding in the London Clay sea cliffs and lowering of the foreshore basement. Over the past 150 years the subtidal channel has widened and deepened (Halcrow, 2005). Further to this, dredging of the approach channel has been carried out with the onset of development, since the 1960s, and material has been deposited offshore, or occasionally used for reclamation at Bathside Bay, Felixstowe or for intertidal recharge projects within Hamford Water (Halcrow, 2005). Dredging between 1967 and 1986 within the Stour is thought to have mobilised sediments which were subsequently deposited on adjacent intertidal areas (Royal Haskoning, 2003).

Recent trends:
The intertidal habitats of the Stour have been eroding horizontally (saltmarsh) and vertically (mudflats), although the rate has been slowing (Posford, 2002). It is postulated that dredging creates a fine-sediment sink in the harbour area, where accretion occurred at 8000m^3 day^{-1} between November 2000 and February 2001, which reduces the potential for deposition on adjacent and upstream intertidal areas, despite findings by Royal Haskoning, 2003, which suggest the opposite effect. 72% (dry mass) of the sediment accumulating in the harbour is disposed at sea, leaving 28% to be dispersed within the Harbour, or for subtidal placement and water column recharge in the Stour (Halcrow, 2005).

Increased wave energies from wind/ship and reflected waves from quay walls affects the lower reaches of both estuaries by increasing intertidal erosion rates.

The Dovercourt Bay frontage has shown variable trends; the majority of the frontage has experienced erosion and a subsequent steepening of its profile, however landslipping now occurs less frequently due to the coastal defences in the region.

Future evolution (unconstrained):
It is predicted (CHaMP, 2002) that if current trends continue (maintaining sea defences at current standards) then in 50 years 180ha of saltmarsh and 200ha of mudflat will be lost in the Stour/Orwell complex. If defences are *not* maintained, LIDAR elevation data has been used to show that there is the potential for creating 206ha of intertidal habitat, including 48ha of saltmarsh and 158ha of mudflat, in 7 out of the 20 Flood Management Units (FMU's),

as described in the Flood Risk Management Study (Halcrow, 2007).

If dredging is continued, there may, however, be more sediment available for intertidal deposition, and ebb tidal dominance may be weakened, decreasing the rate of intertidal erosion (Halcrow, 2005).

Erosion of the Dovercourt Bay frontage may continue at a faster rate if defences were left to deteriorate. Landsliding would be a particular problem, with an associated lowering of the shore platform. This erosion might be used to be deposited sub- and inter-tidally in the Stour/Orwell and Hamford Estuaries.

Dependency: Factors affecting the evolution of the frontage both internally and externally.

Control and sensitivities

Natural
- High ground restirct channel development and potential for intertidal habitat creation
- Waves in lower reaches (wind and ship/reflected)
- Ebb dominant tide
- Sea Level Rise
- Erosion of adjacent coastal areas

Anthropogenic
- Defences
- Port developments; constricts natural processes
- Dredging; alters tidal hydrodynamics

Control features	Significance	Dependence	Chainage
Dredging		Increases ebb dominance; decreases sediment availability	
Naze Erosion		Provides sediment for intertidal deposition and	
Cork Sands		If removed/eroded, increased wave energy at the estuary mouth	
Steep land	Primary	Constricts estuary channel	

Frontage A – Stour and Orwell Estuaries **Chainage km km**

	Landguard Point		Shingle outputs for adjacent frontages	

Internal interaction	**External interaction**
Dredging of the channel removes fine sediment that might otherwise eventually be deposited in intertidal areas, altering estuary sediment dynamics by creating a sediment sink. It also allows larger waves to propogate into the channels. (Halcrow, 2005). Ship wave creation Fine sediments in the cliffs at Dovercourt may be transported into the Stour/Orwell estuaries and deposited sub-tidally or onto the intertidal habitats.	Erosion of the Naze (coastal unit B) provides an essential sediment supply which maintains the beaches fronting the Dovercourt Bay frontage. Believed that reduction of this may therefore increase erosion rates.

Sea level / climate change

For recent Defra (2006) guidance on sea level rise due to climate change, see section 1.4 in the main report.

Influence:
Factors which may influence evolution of other areas.

The area is considered to be fairly self-contained in terms of sediment dynamics. However, the international importance of the wetland areas, and the species that they support mean that any change in their extent, and numbers, will have a significant impact ecologically. Due to its SPA/Ramsar designations, the coastal grazing marsh at Shotley is a protected habitat that requires compensation if any is lost.

If the rate of erosion of the London Clay cliffs at Dovercourt slows, there may be a reduction in the amout of fine sediments available for deposition within Hamford Water (coastal unit B) to the south. This needs to be confirmed by definition of sediment transport pathways, and is likely to be small in comparison to the volume of sediment derived from offshore. In addition to this fine sediment input, there is speculation that interruption of shingle transport at Landguard Point may be causing more rapid erosion of the cliffs at The Naze (coastal unit B), but this is disputable (Futurecoast, 2002).

Section 4 – Baseline management scenarios[3,4]

No active intervention (NAI)

Scenario description

This scenario assumes that defences are no longer maintained and will therefore fail over time. This includes defences associated with port developments, and all channel maintenance dredging activities. Timing of exact defence failure cannot be deduced, but a failure epoch can be determined, as shown in the ' Assessment of coastal defences' report

Shoreline response

Under a scenario of NAI, all defences are likely to fail by epoch 2.

Dredging activities currently have the largest impact on estuarine processes. If stopped, the ebb dominance of the Stour may be reduced, slowing the rate of erosion of intertidal habitats. The sediment sink in the harbour region would be removed, providing more fine sediment for deposition on the intertidal habitats and in subtidal channels. It is still disputed, however, over whether or not the system is naturally ebb or flood dominant (Halcrow, 2005).

Defences at Shotley and Trimley would fail, allowing the reversion of coastal grazing marsh back to intertidal habitat. This may increase bed shear stresses due to an increase in tidal prism (Posford, 2002).

Habitat losses would occur with no active intervention; in 30-100 years the following losses have been predicted:
Stour: -150ha mudflat; -110ha saltmarsh
Orwell: -75ha wet grassland; -50ha saltmarsh

Cliffs along the Orwell would continue to erode at the rates observed, and may increase if the tidal prism is increased dramatically. Cliff erosion at Jaques Bay is assumed to continue too. The cliffs at Dovercourt would also continue eroding, through landsliding in the London Clay, and fine sediments released would continue to feed the Stour/Orwell and Hamford Water systems.

[3] All management scenarios assume that the current management practices undertaken in adjacent SMP study areas will continue.
[4] All assessments of shoreline response have a band of uncertainty, which increases for later epochs.

Epoch	Sea level rise (myr^{-1})	Beach slope	Erosion rate (myr^{-1})
1 (2008 – 2025)	0.004		
2 (2025 – 2055)	0.0085		
3 (2055 – 2085)	0.012		
3 (2085 – 2105)	0.015		

Epoch 1: Years 0 – 20 (2025)		Epoch 2: Years 20 – 50 (2055)		Epoch 3: Years 50 – 100 (2105)	
Defences	**Natural coast**	**Defences**	**Natural coast**	**Defences**	**Natural coast**
Wil remain	Present day processes would continue; defences still active. Sea level rise would cause continued coastal squeeze.	Complete defence failure.	Continued erosion of intertidal habitats, as bed shear stresses increase after failure of defences at Shotley and Trimley. Rapid erosion of London Clay Dovercourt frontage.	Complete defence failure.	Slowing down or reversal of vertical erosion of intertidal habitats, but continued coastal squeeze against steep land.

With present management (WPM)

Scenario description

This scenario assumes that the current policy of Hold the Line for the frontage continues. This will usually involve maintaining defences and dredging activities to provide a similar level of protection to that provided at present and regularly inspecting and maintaining the defences

Shoreline response

Minimal change is expected under this scenario, because the estuaries are presently considered to be in equilibrium with their current defences (Posford, 2002). Coastal squeeze of designated habitats would be the largest impact, with loss predictions of:

Stour: -150ha mudflat; -120ha saltmarsh

Orwell: -50ha mudflats; -60ha saltmarsh

Over the next 30-100 years

The present profile at Dovercourt would be fixed, which would reduce the susceptibility of the sea cliffs to landsliding . Coastal squeeze of the foreshore would continue with rising sea levels.

Epoch 1: Years 0 – 20 (2025)		**Epoch 2: Years 20 – 50 (2055)**		**Epoch 3: Years 50 – 100 (2105)**	
Defences	**Natural coast**	**Defences**	**Natural coast**	**Defences**	**Natural coast**
Will remain	Rates of intertidal habitat loss would be the same as present day losses	Will remain	Increased rate of intertidal habitat loss.	Will remain	Complete loss of intertidal habitat in the Stour/Orwell.

F2.3 Frontage B - Hamford Water

Frontage B – Hamford Water	Chainage	km	km

Section 1 –Description

General:	Hamford Water is a large, shallow, sheltered basin of mud and sand flats and saltmarshes and is characterised by the presence of islands. It is located between Dovercourt, which is to the south of Harwich, and Walton-on-the-Naze, which forms part of the southern spit flanking the entrance. The area is considered to be geologically and ecologically important, and attracts many visitors who use it for walking, horse riding, bird watching, fishing and sailing.
Physical:	Hamford Water is more commonly described as a tidal embayment, because of the very low fluvial input into its basin. Geologically, it rests on the London Clay bedrock which predominates in the region. It differs from the other Essex Estuaries in that it used to be very short and very broad; today this is still true, with a total length of 7km and a total width of 2.1km, giving it the highest ratio of mouth width to estuary length, at 0.5. It is comprised of fine sediments, which have accumulated throughout the marine transgression of the Holocene. In addition to the fine inner-estuary sediments, Hamford Water is flanked by two shingle spits, which are topped by sand dunes and shell banks. These are; Crabknowle, in the north, and Stone Point, which extends northwards from the Naze, on the southern tip of the embayment mouth. Cliff erosion at The Naze releases a lot of sediment which is predominantly transported north, where some of it is deposited on Stone Point spit, and extending Pye Sands, a bank which blocks and protects the mouth of the embayment.

The Naze is designated as a SSSI due to its geology. It provides an example of the Waltonian (earliest) subdivision of the Pleistocene Red Crag and holds many marine molluscs and invertebrate fossils. Pleistocene stratigraphy is therefore well preserved here. The Tertiary London Clay which forms the bedrock of the region contains plant material and is the only location with preserved angiosperms (flowering plants) from this period. Bird evolution is also well documented here by the preservation of fossils. As well as the London Clay bedrock laid down 55million years ago, there is also a small area of Norwich Crag, Red Crag and Chillisford clay within the Naze.

The embayment and surrounding hinterland consists of: a total 2377ha, including: total 1570ha intertidal, comprising 621ha saltmarsh, and 949 mudflat; 807ha subtidal, and 67.7ha coastal grazing marsh. At 0.8, the embayment has one of the largest ratios of saltmarsh to mudflat. The hinterland area is generally low lying and has an absence of human development.

Defences[5] and manmade features:

Around 33km of defences protect the hinterland of Hamford Water. They mostly consist of clay embankments with slopes of 1:2 and 1:3, but there are also revetments and walls, protecting 658ha of agricultural land, 13ha of residential land and 72ha of industrial land.

Reclamation of land from coastal influences has been undertaken at Hamford Water since before 1574, commencing at Dovercourt. Today, the only remaining reclaimed areas include Bramble Island, some areas along the southern banks and the Walton Peninsula, and some parts of Horsey Island. The impact of reclamation is still being felt today, as the embayment is drastically altered in shape and volume.

There has been a barrage breakwater of sunken barges put in place in the northeast of Horsey Island, and over 500,000m³ of dredged material from Harwich harbour has been placed here, and at Foulton Hall and Stone Point, to reverse salt marsh loss. The former recharge used fill sediments that were slightly coarser than the natural substrate; the impact of this required close monitoring and was found to have been unsuccessful at recruiting flora and fauna. The tidal embankment at Foulton Hall has needed reinforcement in recent years due to deterioration taking place as a result of falling beach levels and increased wave action.

On Bramble Island is the ExChem Ltd. Factory, which is associated with some contamination of surrounding land. Other developments are related to recreation and tourism, particularly boating, with some commercial businesses at Walton.

[5] A full list of defences is provided in the ' Assessment of Coastal Defences' report

Section 2 – Baseline information (current data relevant to the frontage)

Tide and water levels (MODN):

	LAT	MLWS	MLWN	MSL	MHWN	MHWS	HAT	Spring range	Neap range	Correction CD/ODN
Walton-on-the-Naze	-2.16	-1.76	-1.06	0.04	1.24	2.04	2.44	3.8	2.3	-2.16

Extremes (MODN):

Walton on the Naze is the Standard Port (Admiralty Tide Tables, 2009, NP 201-209)

	Source/method	1:1	1:10	1:25	1:50	1:100	1:250	1:500	1:1000
Walton-on-the-Naze	Royal Haskoning, 2007	2.71	3.24	3.45	3.60	3.76	3.97	4.13	4.29

Notes:

Currents:

		Notes
Av. flood	Southwest	The tidal range in Hamford Water embayment reaches 4.2m. The estuary is ebb tidal dominant. There are no fluvial gauges on any of the streams which discharge into the embayment.
Av. ebb	Northeast	
Net residual	Ebb tidal dom.	

Wave climate: Southerly waves predominate due to the shelter provided by Orford Ness in the north, but these are small. Larger, more infrequent waves generally come from the northeast and these have the largest impact on erosion rates.

Accretion/ erosion:

- The largest erosion rates in Essex occur at The Naze, where the 12m high, unprotected cliffs here are retreating at an average rate of 1.8myr^{-1} (Halcrow, 2007). The retreat (38m between 1993 and 2005, in some places) and steepening of the spit in the north shows that the infrequent, larger storm waves from the north east have the largest impact on erosion rates. The steepening of the intertidal zone is exacerbating the problem as wave attenuation is decreased.

- Within Hamford Water there has also been the largest loss of saltmarsh in Essex, with losses of 25% in 25 years (Defra, 2002), caused by sea level

Section 2 – Baseline information (current data relevant to the frontage)

Sediment:

rise and associated increases in wave energy. The rate of erosion has increased in recent years; from 0.8% a year losses, to 1.6% a year, as a percentage of 1973 total area of saltmarsh.

- The two flanking spits are retreating landward with sea level rise, encroaching on the adjacent saltmarsh.

Average rates (myr^{-1} unless stated)[6]					Intertidal				Nearshore	
Location	general	crest	face	toe	MHWN	MSL	MLWN	Mean Rate	Trend	Source
Average of EA profiles E1D6 to E1C4A, located to the north of the estuary, and along The Naze.					-1.48	-1.75	-1.63	-1.62	A flattening north of the mouth, steeping at the north of Stone Point Spit and no rotation elsewhere.	EA Coastal Trends analysis (2008)

Overview:

Hamford Water is an ebb dominant system, comprised of eroding soft sediments within the estuary, and eroding shingle spits on the outer estuary.

Material	The sediment inside the estuary is fine grained, associated with the formation of intertidal mudflat and saltmarsh habitats. At The Naze the spits are made of sand, shell and gravel deposits (Halcrow, 2005).			
Sources	External:	Sediment suspended by waves offshore is transported inland. Some fine sediment may also be sourced from erosion of the London Clay cliffs on the Dovercourt Bay frontage (coastal unit A). A link between shingle derived from Landguard Point, and	Internal:	Erosion of intertidal sediment within the embayment may be redistributed. Some fluvial input, although this is small.

[6] The rates highlighted in bold are those used when determining NAI and WPM baseline scenarios (section 4).

Section 2 – Baseline information (current data relevant to the frontage)

			rates of erosion at The Naze, and Walton-on-the-Naze has been discussed (Futurecoast, 2002).			
	Movement: Sediment movement in the mouth of Hamford Water is complicated and is strongly influenced by the larger estuaries of the Stour and Orwell, to the north. It has been postulated that the material comes from the eroded foreshore, especially at the Naze, and that the region is relatively self contained.			**Location**	**Net drift (m^3/yr x 1000)**	**Source**

Section 3 - Geomorphology

Process Description: Overall description of current processes: sources, transport and sinks

At present, Hamford Water has a high cross sectional area to volume ratio. There is low tidal power at the mouth, because of the large width (2.1km), relative to the whole length (7.0km). The tidal prism is small, and the tidal range is 4.2m, whilst the estuary as a whole is ebb dominant and intertidal sediments are being eroded and exported.

Storm waves from the north east are largely responsible for the rapid erosion and steepening of the spit flanking the estuary mouth, and the cliffs at The Naze. Pye sands, extending across the mouth of the embayment, offers a large amount of protection from waves, but erosion of, or at least reduced sediment supply to, this feature is threatening to decrease that protection.

Patterns of change:

Past development:

In the past, Hamford Water was an infilling estuary and was a sediment sink for fine grained substrates. The embayment used to have a 3.5km wide mouth, but erosion of sediments at the Naze to the south, and subsequent northerly sediment transport have created Stone Point Spit and extending Pye Sands, which have significantly reduced this width.

The embankments surrounding the embayment have caused land on the seaward side to continue accreting, while land behind the defences has settled and remained a constant elevation, causing it to be susceptible to flooding.

Recent trends:

Hamford Water is now erosional and the area of intertidal habitat is decreasing substantially, at an increasing rate. Erosion is particularly fast in the unprotected cliffed coastline of The Naze, where it reaches an average of 1.8myr^{-1}, releasing 10,000m^3yr^{-1}, (SNSSTS, 2002).

Frontage B – Hamford Water **Chainage km km**

Future evolution (unconstrained):

Erosion of the spits at the estuary mouth has the potential to cause a breach at areas where the spit crest is low, which would cause a large increase in the wave energy entering the estuary. Sea level rise threatens to make existing defences ineffective in 100 years time (Halcrow, 2007). Coastal squeeze threatens the integrity of coastal habitats in the region, whilst contaminated land nearby, associated with the ExChem factory threatens to be eroded. Generally, there would be an inundation by tidal waters of lowlying land, with subsequent re-creation of tidal flats.

Dependency:
Factors affecting the evolution of the frontage both internally and externally.

Control and sensitivities	Control features	Significance	Dependence	Chainage
• Sea Level Rise will cause continued coastal squeeze. Intertidal habitat within Hamford Water is ecologically valuable. Horsey Island offers unpredated coastal grazing marsh which is used by many wintering wading bird species. The rare Hog's fennel (*Peucedanum officinale*), which tends to colonise in the lee of sea walls exists here, and in only one other site, in Kent. • Contaminated land, at Foulton Hall, associated with the ExChem factory, and landfill sites.	The Naze	Primary	Mouth protection from waves; sediment supply to spits.	

Internal interaction	External interaction
	Other than the release of sediments from erosion of The Naze, which feed Stone Point spit and Pye Sands at Hamford Water's embayment entrance, there is assumed to be little sedimentary interaction with the nearshore area and the estuary. However, there is a debate about whether interruption of shingle inputs by coastal defences at Landguard Point to the

		north (coastal unit A) is causing accelerated erosion at The Naze and Walton-on-the-Naze. This is dependent on an increased understanding of the sediment transport pathways in the region.
	Sea level / climate change For recent Defra (2006) guidance on sea level rise due to climate change, see section 1.4 in the main report	

Influence: Factors which may influence evolution of other areas.	Reduced erosion of The Naze may result in a reduction of sediment available for the development of Stone Point Spit and Pye Sands, which in turn would increase the amount of wave energy available within the estuary. This would significantly increase the amount of erosion of the valuable intertidal habitats wthin the embayment. It would also have an effect on the adjacent coastal unit A, as the beaches at Dovercourt Bay frontage rely on sediments eroded at the Naze.

Section 4 – Baseline management scenarios[7][8]

No active intervention (NAI)

Scenario description

This scenario assumes that defences are no longer maintained and will therefore fail at the start of epoch 2. This includes defences associated with port developments, and all channel maintenance dredging activities. Timing of exact defence failure cannot be deduced, but a failure epoch can be determined, as shown in the ' Assessment of coastal defences' report

Shoreline response

Under a scenario of NAI, all defences are likely to fail by epoch 2.

Sea level rise will have the largest impact on this embayment, having a number of effects:

- predicted that the system may become flood dominant over time (Halcrow, 2007).
- The spits flanking the estuary will continue to rollover landwards, and may breach in places (Halcrow, 2005).
- The whole estuary will continue to transgress landwards; erosion of the lower reaches and redeposition of the upper (Posford, 2002).
- As intertidal habitat is created landward of failed defences, the tidal prism of the estuary will increase, causing an enlargement of the channel (further increasing the tidal prism), until the average depth is low enough to create a cross section in equilibrium with the hydrological processes.
- Flooding of low lying hinterland and exposure of contaminated land to hydrodynamic processes.

[7] All management scenarios assume that the current management practices undertaken in adjacent SMP study areas will continue.
[8] All assessments of shoreline response have a band of uncertainty, which increases for later epochs.

Epoch	Sea level rise (myr^{-1})	Beach slope	Erosion rate (myr^{-1})
1 (2008 – 2025)	0.004		
2 (2025 – 2055)	0.0085		
3 (2055 – 2085)	0.012		
3 (2085 – 2105)	0.015		

Epoch 1: Years 0 – 20 (2025)		Epoch 2: Years 20 – 50 (2055)		Epoch 3: Years 50 – 100 (2105)	
Defences	**Natural coast**	**Defences**	**Natural coast**	**Defences**	**Natural coast**
Most of the defences fail by the end of epoch 1	As sea level rises, continued loss of intertidal habitats and erosion of the Naze.	Complete defence failure.	Estuary will begin to transgress landwards with intertidal habitat (mostly mudflat, without accretion) formation. Continued steepening of the intertidal zone, exacerbating erosion rates (Halcrow, 2007).	Complete defence failure.	Slowed erosion of the estuary as it becomes flood dominant. Importation of sediments which may raise the elevation of intertidal habitats., but possible breach/failure of spits, which would expose the coast to more intense wave action.

With present management (WPM)

Scenario description

This scenario assumes that the current policy of Hold the Line for the frontage continues. This will usually involve maintaining defences to provide a similar level of protection to that provided at present and regularly inspecting and maintaining the defences.

Shoreline response

- Extrapolating today's rate of intertidal habitat losses in Hamford Water to the year 2050, it is predicted that no saltmarsh will remain in Hamford Water, equating to a total loss of -722ha (there is 621ha there today) (Posford, 2002).

Epoch 1: Years 0 – 20 (2025)		Epoch 2: Years 20 – 50 (2055)		Epoch 3: Years 50 – 100 (2105)	
Defences	**Natural coast**	**Defences**	**Natural coast**	**Defences**	**Natural coast**
Defences would remain.	Assumed a continued horizontal erosion of saltmarsh wth coastal squeeze.	Defences would remain but have to be increased.	Complete loss of saltmarsh (Posford, 2002)	Defences would remain but would have to be increased.	Increased erosion and inundation of intertidal habitats. Erosion of the Naze would continue to provide sediment for spit development.

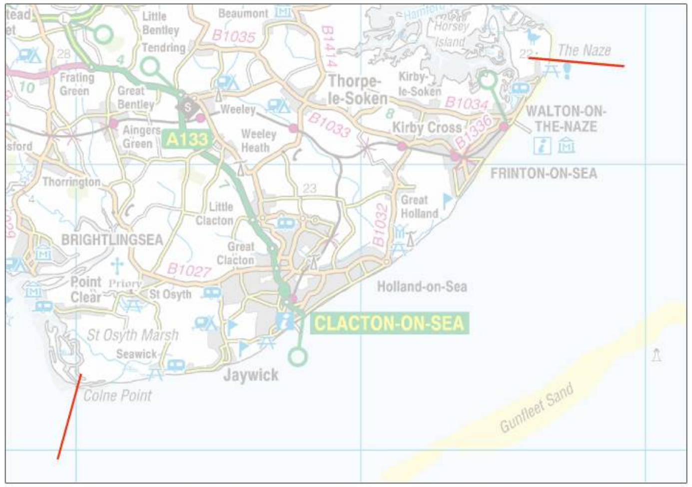
F2.4 Frontage C – Tendring Peninsula

Frontage C – Tendring Peninsula   **Chainage   km   km**

Walton-on-the-Naze to Colne Point (entrance of the Colne Estuary)

Section 1 –Description

General: The Tendring frontage Peninsula is located south of the Harwich Harbour. It covers several urban areas, some agricultural land and a small area of saltmarsh. This frontage is Key for tourism and recreation and includes the seaside resort of Clacton-on-Sea and the boating and tourist centre of Walton-on-Naze. There are also conservation areas, including the Osyth Nature Reserve, and ancient monuments. Fishery is one of the commercial activities.



Physical: The Tendring Peninsula as general orientation of north-east to south-west. This open coast environment comprises a narrow sand/ shingle beaches (sediments originated from the quaternary) fronting sea defences. To the north of this unit, Walton-on-the-Naze, the shore is backed by the Naze soft cliffs (London Clay) of 15m (CHaMPS, 2003). From Frinton to Holland and from Jaywick to Colne Point the frontage comprises of low-lying reclaimed land. Clacton-on-Sea is situated on high ground which extends south westwards to Jaywick.

South of the Tendring Peninsula there are a series of depositional shingle beach ridges forming part of a spit complex, which extends for 2.5 km between Jaywick and Sandy Point, into the entrance of the River Colne (Scoping study, 2004). There is a small area of saltmarsh, designated Nature Reserve, to the west of Seawick which has been formed due to the protection of this spit complex, the Colne barrier.

Offshore, the seabed increases to depths of 12m CD in the Walton Channel, approximately 5.5km from the low water mark. To the west of Clacton, the offshore

	area is shallower as a result of the presence of the offshore banks associated with the Blackwater and Colne estuaries. The Tendring Peninsula functions as an independent geomorphological unit, with little or no linkages with its adjacent estuaries (HR Wallingford, 2002) (Scoping study, 2004).
Defences[9] and manmade features:	This frontage is heavily defended. The defences consist of concrete seawalls and revetments as well as clay embankments and sections of rock armour and groyne fields. Between Frinton-on-Sea and Holland-on-Sea, the sea walls provide flood protection to the low-lying area, which was previously open to marine inundation. The urban frontage of Clacton-on-Sea is extensively developed, and flood and coastal protection is provided by seawalls and groynes which influence movement of beach material. Jaywick is also protected by seawalls. Effectively the coastal defences have been extensively redeveloped with fishtail breakwaters. From west Clacton to Jaywick beach recharge has taken place in 1986 to 1988 and most recently in 1999 beach recharge now takes place in front of the defence. Without the beach in front of the defences the seawall would now provide inadequate protection against flooding. The southerly coastal strip has extensive holiday developments, behind which there is a network of channels and ditches that drain St. Osyth Marsh. The seawall extends to Seawick, to the west of which the shoreline is largely unprotected.

A full list of defences is provided in the ' Assessment of Coastal Defences' report

Frontage C – Tendring Peninsula

Chainage km km

Section 2 – Baseline information (current data relevant to the frontage)

Tide and water levels (mODN):

	LAT	MLWS	MLWN	MSL	MHWN	MHWS	HAT	Spring range	Neap range	Correction CD/ODN
Walton-on-the-Naze	-2.16	-1.76	-1.06	0.04	1.24	2.04	2.44	3.8	2.3	-2.16

Walton on the Naze is the Standard Port (Admiralty Tide Tables, 2009, NP 201-209)

Extremes (mODN):

	Source/method	1:1	1:10	1:25	1:50	1:100	1:250	1:500	1:1000
Walton-on-the-Naze	Royal Haskoning, 2007	2.71	3.24	3.45	3.60	3.76	3.97	4.13	4.29
Brinton-on-Sea	Royal Haskoning, 2007	2.75	3.28	3.49	3.64	3.80	4.01	4.17	4.33
Holland-on-Sea	Royal Haskoning, 2007	2.84	3.36	3.57	3.73	3.88	4.09	4.25	4.40
Clacton-on-Sea	Royal Haskoning, 2007	2.87	3.39	3.60	3.75	3.91	4.12	4.27	4.43
Colne Point	Royal Haskoning, 2007	2.97	3.48	3.68	3.84	3.99	4.20	4.35	4.51

Notes:

Currents:

		Notes
Av. flood	South-westwards	Current data deduced from tidal diamond F (Chart No 1183).
Av. ebb	North-eastwards	The duration of the flooding tide is less than the ebbing tide leading to tidal asymmetry.
Net residual	Southwards	Asymmetries of the tidal system are exacerbated by channel morphology as the tidal wave moves landwards.

Wave climate:

The dominant incident wave direction is from the north-east. Hence, the Tendring peninsula is vulnerable to flood risk and erosion (Futurecoast, 2002). Cork, Gunfleet and Buxey sand banks are likely to provide some attenuation of the wave energy. The 1 in 10 year significant wave height is 1.0m to 1.5m (Futurecoast, 2002).

Frontage C – Tendring Peninsula

Chainage km km

Section 2 – Baseline information (current data relevant to the frontage)

	Average rates (myr^{-1} unless stated)[10]					Intertidal				Foreshore	
Accretion/ erosion:	Location	general	crest	face	toe	Mean rate	MSL	MHWN	MLWN	Trend	Source
	Walton to Jaywick (1975 - 1982) 20km Frontage	60,000 m^3yr^{-1}								Retreat	Clayton et al. 1983 (SNS2)
	Average of EA profiles E1C5A – E1A12					-0.34	-0.40	-0.41	-0.22	EA profiles exihibit variable movement i.e. flatenning, steepning and no rotation	EA Coastal Trend Analysis (2008)
	Overview: The predominant process at this frontage is one of beach erosion, currently counteracted by coast protection (defences and beach recharge).										

Sediment:	**Material**	Sediment comprises sand and shingle as well as clay cliffs (London Clay).			
	Sources	External:	Despite the assumptions of the SMP1 (1997). According to the SNS2 there is no evidence of a link between the offshore banks (Gunfleet and Cork sands) and the coast. Hence no external sources of sediment. Artificial Beach Recharge. The most likely source of material for beach recharge is the channel off the Harwich Harbour (assumption).	Internal:	Erosion of the shoreface and the cliffs at The Naze (SNS2)

Frontage C – Tendring Peninsula

Chainage km km

Section 2 – Baseline information (current data relevant to the frontage)

Movement:

The Naze is seen as a drift divide with movement of sediment towards north (Hamford water) and a stronger net drift to the south along the shore. The longshore transport along the Walton to Jaywick frontage is variable but essentially there is a weak net movement towards the southwest (Posford Duvivier, 2000). South of Holland Haven the data becomes more difficult to interpret and the transport direction may alternate between south-west and north-east depending on the dominant wave direction (Scoping Study, 2004, SNS2), hence the weak overall net drift.

Location	Net drift (m^3/yr x 1000)	Direction	Source
Naze (North)	254.900	Northwest	HR Wallingford (1997)
Naze (South)	26.600	North-northeast	HR Wallingford (1997)
Walton	45.100	South-Southwest	HR Wallingford (1997)
Clacton	4.675	Northeast	Posford Duvivier 2001
Frinton-On-Sea	16.350	Southwest	Posford Duvivier 2001
Holland Gap	5.450	Southwest	Posford Duvivier 2001
Holland-On-Sea	1.950	Southwest	Posford Duvivier 2001
Holland-On-Sea	2.725	Southwest	Posford Duvivier 2001
Jaywick	7.875	West-southwest	Posford Duvivier 2001
			Sediment Longshore transport rates based on SNS2 compilation of different studies. From SNS 2 we have extracted the most recent studies since SNS considers those to be more accurate.

[10] The rates highlighted in bold are those used when determining NAI and WPM baseline scenarios (section 4).

Section 3 - Geomorphology

Process Description: Overall description of current processes: sources, transport and sinks	The frontage between Walton-on-the-Naze and Clacton-on-Sea is dominated by sea cliffs comprised of London Clay cliffs intersected by lowland at Walton-on-the-Naze and Holland Gap. There is only a very narrow inter-tidal zone, containing sands with some shingle along the upper profile. At Walton-on-the-Naze, there is exposure of Crag, tertiary deposits composed of shelly, friable sand. Jaywick and Seawick are both low-lying areas fronted by a sand foreshore that contains localised shingle deposits (CHaMPS, 2003; Scoping Study, 2004). Beach erosion of the narrow beach is the dominant process throughout the frontage (Coastal Trend Analysis, 2008). The Cliff Erosion undergoing at the Naze provides the only source of material to this frontage along with artificial beach recharge. Furthermore, there is a weak net drift of material in the south-west direction (SNS2). The area between St. Osyth to St. Osyth Stone Point, west of Colne Point, contains a beach ridge composed of shingle, sand and mud. This complex ridge system fronts a small area of saltmarsh which is a nature reserve. According to the EA profiles Colne Point is an area undergoing accretion, hence is seen as a sediment sink for the weak net drift transport along the frontage.
Patterns of change:	**Past development:** The Gunfleet Sand is believed to have developed as a banner bank at the time when the Naze was located considerably further to the northeast. **Recent trends:** Leggett et al (1998) note that there was an average 3% increase in the beach volumes between the Naze and Colne Point between 1991 and 1996. There was stability in the northern part of the region, accretion along the front at Clacton, due to the use of beach control structures, but erosion down drift of the defences (Scoping Study, 2004). The down drift (Walton-on-the-Naze) beaches have been starved of sediment by the effectiveness of the beach control structures and have been undergoing erosion (Coastal Trend Analysis).

Fish-tail groynes have been constructed at Jaywick to locally retain beach sediment, and beach recharge is part of the coastal defence scheme. This has reduced the amount of sediment moving west beyond Jaywick to feed the beach ridges at Colne Point and Sandy Point (Scoping Study, 2004). However, there is no evidence to suggest that the beach ridges (Colne Point) have suffered erosion due to the construction of the groynes. It may be that a sufficient supply of sand and gravel comes from a sequence of Pleistocene terrace gravels exposed at mean sea level on the Colne Point foreshore to sustain the ridges (scoping Study, 2004, supported by coastal trend analysis i.e. accretion at Colne Point).

Future evolution:

Futurecoast (2002) predicts that under the unconstrained scenario that for the relatively narrow foreshore between Jaywick and Seawick 'there would be a high probability of segmentation and breaching causing large-scale inundation of the low-lying backshore. This would create 'a new tidal inlet with flats and saltmarshes landward of this frontage'.

Dependency: Factors affecting the evolution of the frontage both internally and externally.

Control and sensitivities

The frontage is sensitive to dominant wave climate (SNS2, 2002).

Sediment availability. There is a limited volume of sediment available to be transported, as the previous supply from the erosion of the frontage has been cut off by the development of the frontage. What material exists in the frontage is likely to be the limit of material available for drift.

Control features	Significance	Dependence	Chainage
Defences	Primary		
Beach Recharge	Secondary		
Sediment Availability	Secondary		

Internal interaction	External interaction
Colne Point is seen as sediment sink for net drift from the frontage (CHaMPS, 2003) . The mean interaction within the frontage is the weak net drift. Probably further weaken by the extent of beach protection (assumption)	The SNS2 (2002) measurement work and analysis of seabed sediment transport indicators provided strong proof of no link between the Gunfleet and the shore and no substantial link between the Cork Sands and the Naze. Such findings are contrary to observations of the SMP1 (1997). The SMP1 also infers that Clacton is a sediment divide. However, the

		SNS2 (2002), establishes the sediment divide at Clacton is not as strong as the sediment divide at the Naze; furthermore, the Clacton divide is more sensitive to direction of wave action.
	Sea level / climate change For recent Defra (2006) guidance on sea level rise due to climate change, see section 1.4 in the main report.	

Influence: Factors which may influence evolution of other areas.	Further protection of the Seawick frontage might influence sediment transition to Colne Point although current evidence does not suggest a detrimental impact to the Colne Point. Coastal protection may cause sediment starvation downdrift of the structures.

Section 4 – Baseline management scenarios[11][12]

No active intervention (NAI)

Scenario description

This scenario assumes that defences are no longer maintained and will therefore fail over time. Timing of exact defence failure cannot be deduced. However a failure epoch can be determined, as described in the 'Assessment of coastal defences' report.

Shoreline response

*comments on net drift are all assumption/interpretation. The same can be send to cliffy areas. Further investigation into cliff behaviour is required.

Epoch 1

As coastal and flood defences are likely to remain over epoch 1, it is expected that erosion rate is likely to increase as beach recharge ceases. At this stage, the actual rate of erosion for this scenario remains uncertain. Beach erosion will lead to narrowing of the beach; however, the presence of groynes is likely to limit the beach erosion. Some localised accretion on the lee of fish-tail groynes is expected. Coastal protection will continue to limit southwestwards sediment drift. Erosion at Seawick frontage coupled with accretion at Colne Point is likely to continue. Assumption: it is possible that net drift here is considerably stronger due to the absence of coastal protection, furthermore, erosion at seawick is exacerbated by coast protection (groyne field) eastwards.

Epoch 2

Coastal and flood defences are likely to fail at some point within epoch 2. Undermining of defences due to erosion is likely to be one of the reasons of failure. Under this scenario it is assumed that failed defences will have no residual function. Following failure of the defences erosion rates are likely to increase further due to absence of coastal protection. Narrowing of the beach is the most likely scenario; erosion rates remain largely unknown. On the relatively narrow foreshore between Jaywick and Seawick 'there would be a high probability of segmentation and breaching causing large-scale inundation of the low-lying backshore. This would create 'a new tidal inlet with flats and saltmarshes landward of this frontage'. The low lying

[11] All management scenarios assume that the current management practices undertaken in adjacent SMP study areas will continue.
[12] All assessments of shoreline response have a band of uncertainty, which increases for later epochs.

area in Holland Gap is also likely to be breached and form new intertidal areas. The High ground/cliffy areas of Frinton and Clacton will start to undergo erosion at unknown rates. As cliff erosion takes place more sediment will be available for the foreshore and some wave attenuation will occur. Assumption: Net drift rate are likely to increase leading to a smoother beach and further accretion a Colne Point.

Creation of a new tidal inlet or intertidal area at Jaywick-Seawick is likely to impact the development of the Colne estuary. The nature and degree of the impact is unknown.

Epoch 3

All processes and features for epoch 3 remain largely uncertain. The feature that can be described with most certainty is perhaps the continued development of ‘the new intertidal areas. High ground/cliff erosion is pexpected to reach some steady state as sediment is released to the foreshore and wave action is attenuated. Under such circumstances the beach are likely to be less narrow.

Notes:

Analysis of beach profiles will be required to clarify some of the uncertainity.

One of the main drivers for the predominant coastal processes is the predominant wave direction. It should be outlined that under the NAI and WPM we expect no change of the wave direction.

It should be noted that foreshore evolution within this frontage influences and it is influenced by Cliff behaviour.

One of the biggest uncertainties would also be the amount of net drift. Present net drift rates are probably limited by the coastal protection, removal of the coastal protection would allow for stronger net drift rates and greater rates of accretion at Colne point.

Epoch	Sea level rise (myr^{-1})	Beach slope	Erosion rate (myr^{-1})
Epoch 1 (2009 – 2025)	0.004		
Epoch 1 (2025 – 2055)	0.085		
Epoch 3 (2055 – 2105)	0.014		

Epoch 1: Years 0 – 20 (2025)		Epoch 2: Years 20 – 50 (2055)		Epoch 3: Years 50 – 100 (2105)	
Defences	**Natural coast**	**Defences**	**Natural coast**	**Defences**	**Natural coast**
Defences remain	It expected that little change would have occurred from the present shoreline position. Coast protection defences will remain. However erosion rates are likely to increase because there no longer be beach recharge	Defences will Fail	Beach erosion is likely to undermine defences. Coast will be set further back. There is a high probability of creation of new intertidal environments at low lying areas. Probable cliff erosion	Defences will fail	Continued development of 'new intertidal areas'. Possible stabilization of cliff erosion. Cliff sediment release is likely to widen foreshore.

With present management (WPM)

Scenario description

This scenario assumes that defences are maintained to provide a similar level of protection to that provided at present. This will involve regularly inspecting and maintaining defences.

Shoreline response

Epoch 1

As coastal and flood defences are likely to remain on epoch 1, erosion rates are likely to be counteracted. At this stage the actual rate of erosion for this scenario remain uncertain. Beach erosion will lead to narrowing of the beach; however, the presence of groynes is likely to limit the beach erosion. Some localised accretion on the lee of fish groynes is expected. Coastal protection will continue to limit southwestwards sediment drift.

Erosion at the Seawick frontage coupled with accretion at Colne Point is likely to continue. Assumption: it is possible that net drift here is considerably stronger due to absence of coast protection, furthermore, erosion at Seawick is exacerbated by coast protection (groyne field) eastwards.

Epoch 2
No significant changes to the development of Epoch 1 are expected. Rates of accretion at Colne Point and erosion at Seawick remain uncertain.

Epoch 3
No significant changes to the development of Epoch 1 are expected. Rates of accretion at Colne Point and erosion at Seawick remain uncertain.

Epoch 1: Years 0 – 20 (2025)		**Epoch 2: Years 20 – 50 (2055)**		**Epoch 3: Years 50 – 100 (2105)**	
Defences	**Natural coast**	**Defences**	**Natural coast**	**Defences**	**Natural coast**
Defences would remain	Coast will remain largely the same with some localised erosion/accretion a groynes	Defences would remain	Coast will remain largely the same with some localised erosion/accretion a groynes	Defences would remain	Coast will remain largely the same with some localised erosion/accretion a groynes

F2.5 Frontage D - Colne Estuary

Frontage D – Colne Estuary	**Chainage**	**km**	**km**

Colne Point to East Mersea

Section 1 –Description

General: The Colne estuary is located south of Colchester and converges with the Blackwater estuary at Mersea Island between Sales Point and Colne Point. The estuary harbours a diversity of coastal habitats and a number of rare and uncommon plant and invertebrate species which is reflected in the number of statutory and non-statutory designations which cover the area. The estuary is also a popular sailing area and has 4 conservation areas and 3 scheduled ancient monuments. Commercial activities include agriculture and fisheries (Mouchel, 1997).

Physical: Colne estuary is, in contrast to the other Essex estuaries, orientated north-south and this provides an explanation for its stable geomorphology (CHaMP, 2002). The estuary feeds into the south of Mersea Island, which is an isolated Island of London Clay. The estuary has an area of 2335ha (Buck, 1997) and extends for approximately 14km before reaching its tidal limit at the Colne Barrier, which is located on the downstream side of Wivenhoe. The estuary channel is significantly deep; >20m which suggests it is a relict feature of the proto-Thames. Colne point has formed two shingle spits which are a relict of extensive shingle ridges that up until the 1800's stretched between Walton-on-the-Naze and St Osyth (Halcrow, 2002).

With exception to the low-lying areas immediately north of Mersea Island and Brightlingsea, the Colne Estuary is defined by steep channel sides, steepening notably at its head. This results in a long narrow flood plain along the length of the estuary, parts of which have been reclaimed. The Colne estuary lies on the limb of the London tectonic base in a synclinical structure, the axis of which runs through the centre line of the estuary (D'Olier, 1972; Jones, 1981). It is inferred that this underlying geological structure is partially responsible for the rising land around the Colne estuary which provides a constraint to the system. The geology consists of Palaezoic syncline, overlain Tertiary (London Clays) and Quaternary sands and gravels (dissected sheets of Terrace Gravels) and glacial Till.

The estuary has a narrow intertidal zone which is predominantly composed of flats of fine silt with mud-flat communities. The estuary has a relatively large proportion of saltmarsh (695ha) in relation to its size and is also composed of 1381ha of mudflat, 310ha of grazing marsh and 333ha of subtidal areas. (CHaMP, 2002).

Defences[13] and manmade features:

The Colne estuary is almost entirely constrained by flood defences, comprising of 52km of defences (Mouchel, 1997 & Colne and Blackwater Floor Risk Management Strategy, Draft). In the upper reaches (at Colchester) the estuary is constrained between walls. As the estuary widens out the defences change and in the lower part the defences consist of natural banks or clay embankments which vary in condition and are usually protected by revetments.

Just beyond Wivenhoe is the tidal surge barrier which stretches across the width of the river valley. The barrier is 8m high and 130m wide, with a navigation opening of 30m (Colne and Blackwater Flood Risk Management Strategy, Draft). The main mechanism consists of 2m gates that operate in a similar method to those used as locks on canals and rivers. The barrier limits upstream water levels to 3.1m AOD (Colchester BC, 2003).

The River Colne provides a major reach for commercial activity, particularly fishing, in the north east of Essex. The Ports/ Harbours at Fingringhoe, Rowhedge, Colchester and Brightlingsea are all in use. Colchester Port Authority is responsible for maintaining the navigation routes throughout the Colne by dredging of 19,000m^3 annually. The material is dumped at two lagoons at Hythe (Mouchel, 1997).

[13] A full list of defences is provided in the ' Assessment of Coastal Defences' report

Frontage D – Colne Estuary

Chainage km km

Section 2 – Baseline information (current data relevant to the frontage)

Tide and water levels (mODN):

	LAT	MLWS	MLWN	MSL	MHWN	MHWS	HAT	Spring range	Neap range	Correction CD/ODN
Brightlingsea		-2.04	-1.24		1.36	2.56		4.6	2.6	-2.44

Extremes (mODN):

	Source/method	1:1	1:10	1:25	1:50	1:100	1:250	1:500	1:1000
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

Notes:

Currents:

		Notes
Av. flood	South west	The estuary is macro-tidal with a tidal range of 5.2m at Brightlingsea and is characterised by ebb dominant tidal 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 (Pethick and Stapleton, 1994). The ebb velocities range between 0.5-0.8m/s in the main channel and 0.1-0.4m/s along the estuary margins. Flow speeds are significantly less on the flood ranging between 0.1 and 0.7m/s (Colne and Blackwater Flood Risk Management Study, Draft).
Av. ebb	North east	
Net residual	Ebb dominant	

Wave climate: The lack of morphological change in the Colne is due to the orientation of the main channel which provides it with protection against locally generated waves during periods of dominant south west winds. The most significant wave action occurs in the outer reaches of the estuary. Offshore banks shelter the coastline from direct wave action, whilst intertidal flats play a very significant role in attenuating incoming wave energy before it reaches the shoreline of Mersea Island (Colne and Blackwater Flood Risk Management Study, Draft).

Accretion/erosion: Notes: Owing to the Colne estuary' orientation, it experiences the lowest erosion rates in the country.

Frontage D – Colne Estuary

Chainage km km

Section 2 – Baseline information (current data relevant to the frontage)

Average rates (myr^{-1} unless stated)[14]					Intertidal				Nearshore	
Location	general	crest	face	toe	backshore	Mean	MHWS	MLWS	Trend	Source
Mouth	-1.09x10^{9} kg mass into estuary Vs 1.3x10^{9} kg mass out of estuary								Export of sediment	Colne and Blackwater Flood Risk Management Strategy, Draft
Saltmarsh area	4.7ha/yr (0.6% / yr based on 1973 area)								Erosion	Cooper, 2000
Average of EA profiles										

Overview: The ebb dominance of the estuary implies a trend for the export of sediments.

Material	Shingle at estuary mouth and sand and coarse sand released from the Cudmore Cliffs. Fine grained silt and clay released from saltmarshes and mudflats.			
Sources	External:	Export of shingle to Outer Thames Estuary. Suspended sediment entering system from wave transport.	Internal:	Fine sediments eroded and exported. Shingle eroded and deposited along the east side of the estuary mouth.

Movement:	**Location**	**Net drift (m^3/yr x 1000)**	**Source**
Owing to the reduced wave climate at the estuary, sediment transport is governed by tidal currents. The Colne estuary is ebb dominant and expresses a trend for erosion within the estuary.			

[14] The rates highlighted in bold are those used when determining NAI and WPM baseline scenarios (section 4).

Frontage D – Colne Estuary

Chainage km km

Section 2 – Baseline information (current data relevant to the frontage)

	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, just downstream of the Roman River and the Colne Barrier. By 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.				

Frontage D – Colne Estuary **Chainage km km**

Section 3 - Geomorphology

Process Description: Overall description of current processes: sources, transport and sinks	The estuary is funnel shaped with 5 tidal arms branching off the main river channel. Its shape means that as the tidal wave passes up the estuary, its amplitude is increased giving a greater tidal range (Pethick and Stapleton, 1994). The tidal limit of the estuary is positioned at the Colne barrier at Wivenhoe, however the tide does progress a short length further upstream into the southern areas of Colchester. It is considered stable and close to equilibrium as it has not significantly changed in intertidal morphology over the past 150-200 years The saltmarsh boundary of the inner estuary has shown no change between 1838-1978. Between 1973-1982 11.7% of the total saltmarsh area was eroded, this is the lowest percentage for any Essex estuary however it is still significant. This loss was predominantly experienced at the mouth of the estuary between Colne Point and Mersea. The tidal channels have shown a slight decrease in mean depth mainly due to an increase in the elevation of the intertidal mudflats.
Patterns of change:	**Past development:** The estuary has remained relatively stable and close to equilibrium over the past 200 years. Comparison of maps from 1820-1970 (IECS, 1994) show that neither low water mark or high water mark has shown any appreciable change over this period. The bed slope of the estuary steepens markedly towards its head and north of the barrage the estuary dries at low water which leads to a rapid decrease in tidal prism (ChaMP, 2002). **Recent trends:** More recently saltmarsh erosion has accelerated. Regime modelling has shown that, although the mouth and outer estuary are almost precisely at equilibrium width, the inner estuary is much narrower than predicted owing to a tidal prism reduction. The ebb dominant nature of the estuary and the sediment flux results indicate that the estuary is exporting sediment and this in turn implies that despite the estuaries apparent stability it is still attempting to widen in order to achieve true equilibrium (Colne and Blackwater Flood Risk Management Strategy, Draft). **Future evolution (unconstrained):** Despite the lack of marked erosion in the Colne at the present time, the long term prognosis for the estuary is not good. Failure to adjust to sea level rise by a process of gradual morphological change as in the case of the Essex estuaries, may mean that the Colne is progressively drowned with loss of saltmarsh and mudflat and an increased flood risk for urban areas. The increased tidal prism in the Colne is predicted to lead to enlargement of the channel, a change achieved mainly by retreat of the saltmarsh boundary. The predicted increase in channel width over the 50 year period at Mersea Stone section is 250m decreasing approximately linearly to zero at the Wivenhoe barrier. The potential loss of saltmarsh as a result of sea level rise over the next 50 years is predicted to be 116ha (ChaMP, 2002).

Frontage D – Colne Estuary

Chainage km km

Dependency:

Factors affecting the evolution of the frontage both internally and externally.

Control and sensitivities

The geological structure of the Colne estuary is partially responsible for the topography and provides a constraint along most of the estuary length (Colne and Blackwater Flood Risk Management Strategy, Draft).

The Chenier ridges and Colne point currently shelter the estuary from significant wave action. If these features erode the mouth of the estuary will become more exposed and may be subjected to increased erosion.

Control features	Significance	Dependence	Chainage
Colne Point (Natural)	Primary	Fixed	
Chenier Ridges (Natural)	Primary	Fixed	
Shingle spit (Natural)	Primary		

Internal interaction

Colne Point is a sediment sink however there is recent concern that it is eroding (SNS2, 2002). The Chenier ridges at Colne Point have experience some changes over the past 40 years, changes that can be summarised as a landward transgression. Environment Agency profiles also demonstrate that the maximum elevation of the chenier ridges fell during the decade 1992-2001 by approximately 2cm per year. This may reflect some reduction in sediment supply from the inter-tidal mudflats, but is more likely to be associated with the increasing distance between the marsh cliff and the chenier bank so restricting the amount of sediment wash-over that can take place.

Colchester Port Authority maintains the navigation routes throughout the Colne from North Bridge in Colchester to Colne Point by dredging.

External interaction

Sea level / climate change

For recent Defra (2006) guidance on sea level rise due to climate change, see section 1.4 in the main report.

Influence:

Factors which may influence evolution of other

The lack of any extensive area of saltmarsh within the estuary coupled with the existing channels, which are narrower than equilibrium, may result in increased stress on the flood defences in the future.

The shingle spit at Mersea stone will require monitoring as loss of this feature would not only reduce the habitat area but also alter the processes in this area of the estuary.

If management at the estuary ceased then it is likely there will be a release of sediment caused by increased erosion as the estuary attempts to widen

areas.	towards equilibrium.

Section 4 – Baseline management scenarios[15][16]

No active intervention (NAI)

Scenario description

This scenario assumes that defences are no longer maintained and will therefore fail over time. Timing of exact defence failure cannot be deduced, but a failure epoch can be determined, as shown in the ' Assessment of coastal defences' report.

Shoreline response

Under the scenario of no active intervention all defences are likely to fail by epoch 2. In epoch 1 the recent trends observed in the estuary are likely to continue as the defences will constrain the channel morphology.

The ebb dominance of the estuary leads to a net export of material which suggests that the estuary is still attempting to widen. By epoch 2 there will be a complete failure of the defences. In an unconstrained scenario this likely to result in a channel increase of 250m in 50 years. This will predominantly be achieved by saltmarsh erosion. New areas of saltmrash and intertidal habitats would be created if defences fail and lowlying areas behind the defences are flooded. This process will continue throughout epoch 3.

Epoch	Sea level rise (myr^{-1})	Beach slope	Erosion rate (myr^{-1})
1 (2008 – 2025)	0.004		
2 (2025 – 2055)	0.0085		
3 (2055 – 2085)	0.012		
3 (2085 – 2105)	0.015		

[15] All management scenarios assume that the current management practices undertaken in adjacent SMP study areas will continue.
[16] All assessments of shoreline response have a band of uncertainty, which increases for later epochs.

Epoch 1: Years 0 – 20 (2025)		Epoch 2: Years 20 – 50 (2055)		Epoch 3: Years 50 – 100 (2105)	
Defences	**Natural coast**	**Defences**	**Natural coast**	**Defences**	**Natural coast**
Most of the defences fail by the end of epoch 1.	The natural coast is likely to remain relatively unchanged owing to the orientation and sheltered nature of the estuary.	Complete defence failure.	Failure of estuary to respond to sea level rise resulting erosion of the seaward edge of saltmrash and intertidal habitat but an overall increase as the intertidal habitats move landwards. Increase in the tidal prism resulting in channel enlargement	Complete defence failure.	Same as epoch 2.

With present management (WPM)

Scenario description

This scenario assumes that the current policy of Hold the Line for the frontage continues. This will usually involve maintaining defences to provide a similar level of protection to that provided at present and regularly inspecting and maintaining the defences.

Shoreline response

The estuary is currently almost entirely defended. Considering a continuation of this maintenance, combined with the effects of sea level rise in the first epoch the estuarine response will follow that of NAI. The estuary will continue its trend of sediment export upstream in order to broaden however the coastline will remain relatively unchanged owing to its orientation.

By epoch 2 sea level rise will put increasing pressure on the intertidal zone and drowning of the habitat is likely to occur, as most of the marshes are backed by hard defences which do not allow landward migration which is necessary for the marshes to retreat with sea level rise. Only the north end of the Geedon Saltings and the reserve at Fingringhoe Wick have natural landward limits but the slope behind will prevent any significant migration.

Therefore the total area of intertidal habitat will be reduced. Increased stress will be placed on the flood defences owing to the narrowing of the intertidal zone and loss of wave attenuation. Considering the saltmarsh area in 1998 (695ha) and a predicted loss of 116ha it is predicted that 579ha of the existing saltmarsh will remain in 50 years.

By epoch 3 defence strengthening will be required and coastal squeeze of the intertidal habitat will continue.

Epoch 1: Years 0 – 20 (2025)		**Epoch 2: Years 20 – 50 (2055)**		**Epoch 3: Years 50 – 100 (2105)**	
Defences	**Natural coast**	**Defences**	**Natural coast**	**Defences**	**Natural coast**
Defences would remain	Relatively unchanged coastline owing to the orientation of the estuary.	Defences would remain but increased stress.	Increased pressure on the intertidal habitat owing to sea level rise.	Defences would remain but an upgrade will be required .	Same as epoch 2. Continued erosion of the intertidal zone and coastal squeeze.

F2.6 Frontage E – Mersea Island

Frontage E – Mersea Island	Chainage	km	km

Mersea Island

Section 1 –Description

General: Mersea Island is located within the common mouth of the Colne and Blackwater estuary and is separated from the mainland by the Pyefleet channel. There are two villages located on the Island, East and West Mersea. The latter, larger settlement has become an important yachting centre. There is a large stretch of sandy beach located on the Mersea Island frontage with a number of beach huts available for rent or hire. Some areas of Mersea Island consist of Grade 2 agricultural land, Cudmore Grove on East Mersea is an Essex County Council Country Park. The frontage of Mersea island is designated as part of the cSAC and Ramsar site and includes some SSSI's.

Physical: Mersea Island is an isolated island of London Clay, situated where the Blackwater and the Colne estuary converge. It is the largest of 4 Islands located within the Blackwater river and is an important control on the Blackwater estuary channel morphology. Cudmore Grove in East Mersea is of geological importance with exposures showing organic Pleistocene deposits which occupy one or more post-Anglian interglacial periods.

Mersea Island is fringed to the north by a system of creeks, channels and saltings and to the south by an extensive foreshore of sandy beaches and mudflats. The seaward facing side also 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 inter-tidal flat. There is very little saltmarsh present along the foreshore (Mouchel, 1997).

Frontage E – Mersea Island

Chainage km km

Defences[17] and manmade features:

At Mersea Island, the Environment Agency defend the landward side of the island, the defences again consist of a clay embankment. To the seaward side of Mersea Island the defences are privately maintained and consist of a mixture of banks, revetments and groynes. At North Farm and Maydays Creek on Mersea Island, the Environment Agency are undertaking polder projects. Mersea Island to Rowhedge consists of natural banks that are reinforced in places. Adjacent to Mersea Island the low lying former marsh land is defended with clay embayments.

The town of West Mersea is well defended and is generally above the 5m contour. However, Cobmarsh Island, a small off-shore saltmarsh provides protection to West Mersea. The Island protects 5ha of commercial oyster farm, 1000 yacht moorings, 2 boatyards, 1ha of residential and 300ha of arable land around Mersea.

Beach recharge has been implemented at Cob Marsh, Mersea Quarters (15,000m3), Pewet Island (5,000m3) and Nass spit and Mersea Hard (1,000m3).

A sewage treatment works is situated on the outskirts of West Mersea.

Section 2 – Baseline information (current data relevant to the frontage)

Tide and water levels (mODN):

	LAT	MLWS	MLWN	MSL	MHWN	MHWS	HAT	Spring range	Neap range	Correction CD/ODN
Brightlingsea		-2.04	-1.24		1.36	2.56		4.6	2.6	-2.44

Extremes (mODN):

	Source/method	1:1	1:10	1:25	1:50	1:100	1:250	1:500	1:1000
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
Sales Point		3.07	3.58	3.78	3.93	4.08	4.29	4.44	4.59

Notes:

Currents:

		Notes
Av. flood	South west	Owing to the location of Mersea Island between the Colne and Blackwater estuaries it is affected by flows from both.
Av. ebb	North East	

[17] A full list of defences is provided in the ' Assessment of Coastal Defences' report

Frontage E – Mersea Island

Chainage km km

<table>
<tr><td></td><td colspan="12">Net residual</td></tr>
<tr><td>Wave climate:</td><td colspan="12">The seaward face of Mersea Island is exposed to wave attack from the Outer Thames Embayment and therefore waves largely govern coastal processes along this shoreline. At high water it is evident that waves are focussed to the bank on the south side of Mersea Island. Offshore banks shelter the coastline from direct wave action, whilst intertidal flats play a very significant role in attenuating incoming wave energy before it reaches the shoreline. The chenier ridges near Sales Point further limit wave penetration onto the upper marsh surface, as a result waves suffer a considerable loss of energy.</td></tr>
<tr><td rowspan="6">Accretion/ erosion:</td><td colspan="12">There is a general trend for erosion along the seaward frontage of Mersea Island with significant erosion at Cudmore Grove country park and Fen Farm Caravan Park owing to severe wave attack of the intertidal area. Under calm conditions Mersea Flats experience cohesive sediment accretion.</td></tr>
<tr><td>Average rates (myr⁻¹ unless stated)[18]</td><td colspan="4"></td><td colspan="4">Intertidal</td><td>Nearshore</td><td colspan="2"></td></tr>
<tr><td>Location</td><td>general</td><td>crest</td><td>face</td><td>toe</td><td>Mean Rate</td><td>MSL</td><td>MHWN</td><td>MLWN</td><td>Trend</td><td colspan="2">Source</td></tr>
<tr><td>East Mersea</td><td>0.42m/yr</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>Erosion</td><td colspan="2">Mouchel (1997)</td></tr>
<tr><td>Cobmarsh Island</td><td>2-3m/yr</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>Erosion</td><td colspan="2">Mouchel (1997)</td></tr>
<tr><td>Average of EA profiles</td><td></td><td></td><td></td><td></td><td>-1.64</td><td>-3.31</td><td>-0.20</td><td>-1.41</td><td>Erosion</td><td colspan="2">Coastal Trend Analysis (EA, 2008)</td></tr>
<tr><td rowspan="9">Sediment:</td><td colspan="12">Overview: There is a general trend for erosion across the seaward facing frontage.</td></tr>
<tr><td>Material</td><td colspan="11">Sandy beach material along seaward frontage.</td></tr>
<tr><td>Sources</td><td>External:</td><td colspan="5"></td><td>Internal:</td><td colspan="4">Nearshore beach erosion</td></tr>
<tr><td colspan="6" rowspan="6">Movement:</td><td>Location</td><td colspan="2">Net drift (m³/yr x 1000)</td><td colspan="3">Source</td></tr>
<tr><td></td><td colspan="2"></td><td colspan="3"></td></tr>
<tr><td></td><td colspan="2"></td><td colspan="3"></td></tr>
<tr><td></td><td></td><td></td><td colspan="3"></td></tr>
<tr><td></td><td></td><td></td><td colspan="3"></td></tr>
</table>

[18] The rates highlighted in bold are those used when determining NAI and WPM baseline scenarios (section 4).

Frontage E – Mersea Island

Chainage km km

Section 3 - Geomorphology

Process Description: Overall description of current processes: sources, transport and sinks

Owing to the location of Mersea Island between the two estuaries, it is subjected to the influence of tidal flows from both estuaries respectively..

Patterns of change:

Past development:

Mersea Island is an isolated island of London Clay within the Blackwater estuary owing to its high topography.

Recent trends:

The seaward frontage of Mersea island is subject to significant erosion owing to ithe role it plays in attenuating incoming wave energy. The Brushwood groynes along the West Mersea beach frontage do not appear to be successful.

Future evolution (unconstrained):

Erosion rates along the foreshore are expected to accelerate. Therefore the Cudmore Grove Marshes may be expected to be entirely removed within the next 200-500years.

Dependency: Factors affecting the evolution of the frontage both internally and externally.

Control and sensitivities

Geological constraint of the Pleistocene gravels at West Mersea.

The island is currently sheltered from significant wave action by the Chenier ridges at Sales Point. If these features erode the seaward facing side of Mersea Island will become more exposed and may be subjected to increased erosion.

Control features	Significance	Dependence	Chainage
Pleistocene Gravels	Primary	Fixed	
Chenier Ridges	Primary	Fixed	
Cobmarsh Island	Primary	Fixed	

Cobmarsh Island currently provides additional protection to the west Mersea Island, however it is subject to extreme erosion and will increase vulnerability of the land behind to flooding. Location of the sewage Treatment works at West Mersea. North of Mersea Island, the estuary is constrained at Feldy Marshes and Wick/Langenhoe Marsh. The lack of active marsh fronting theses defences suggests that the defences are constraining the estuary channel. Between these locations, at Ray Island, active saltmarsh is present, although there is virtually no flood plain present. This suggests that the underlying geology and topography are controlling the estuary at this point. This could relate to the outcrop of Pleistocene Terrace Gravels which are responsible for constraining the mouth of the Blackwater Estuary. Taking these findings into account, it is likely that the flows around Mersea Island are constrained, although flows are also likely to be reduced by the presence of Ray Island peninsula.				

Internal interaction	**External interaction**

Sea level / climate change
For recent Defra (2006) guidance on sea level rise due to climate change, see section 1.4 in the main report.

Influence: Factors which may influence evolution of other areas.

Cobmarsh Island currently provides additional protection to the west Mersea Island, however it is subject to extreme erosion and will increase vulnerability of the land behind to flooding.

Section 4 – Baseline management scenarios[19][20]

No active intervention (NAI)

Scenario description

This scenario assumes that defences are no longer maintained and will therefore fail over time. Timing of exact defence failure cannot be deduced, but a failure epoch can be determined, as shown in the ' Assessment of coastal defences' report.

Shoreline response

Considering the unconstrained scenario there will be rapid erosion of the foreshore at Mesea Island.

Epoch	Sea level rise (myr^{-1})	Beach slope	Erosion rate (myr^{-1})
1 (2008 – 2025)	0.004		
2 (2025 – 2055)	0.0085		
3 (2055 – 2085)	0.012		
3 (2085 – 2105)	0.015		

Epoch 1: Years 0 – 20 (2025)		Epoch 2: Years 20 – 50 (2055)		Epoch 3: Years 50 – 100 (2105)	
Defences	**Natural coast**	**Defences**	**Natural coast**	**Defences**	**Natural coast**
Most of defences fail by end of epoch	Erosion of the seaward facing frontage of Mersea Island.	Complete failure of defences	Accelerated erosion of frontage as defences fail	Complete failure of defences	High erosion rates at Cudmore Grove Marshes

[19] All management scenarios assume that the current management practices undertaken in adjacent SMP study areas will continue.
[20] All assessments of shoreline response have a band of uncertainty, which increases for later epochs.

With present management (WPM)

Scenario description

This scenario assumes that the current policy of Hold the Line for the frontage continues. This will usually involve maintaining defences to provide a similar level of protection to that provided at present and regularly inspecting and maintaining the defences.

Shoreline response

Erosion of the seaward facing frontage will continue. Coastal squeeze of the narrow intertidal zone will continue.

Epoch 1: Years 0 – 20 (2025)		Epoch 2: Years 20 – 50 (2055)		Epoch 3: Years 50 – 100 (2105)	
Defences	**Natural coast**	**Defences**	**Natural coast**	**Defences**	**Natural coast**
Defences would remain	Same as NAI, high erosion of the seaward facing frontage.	Defences would remain. Upgrading will be required when Cobmarsh erodes.	High erosion rates along the foreshore are likely to continue and increase resulting in significant erosion of Cudmore Grove Marshes.	Defences would remain.	Same as Epoch 2.

F2.7 Frontage F - Blackwater Estuary

Frontage F – Blackwater Estuary

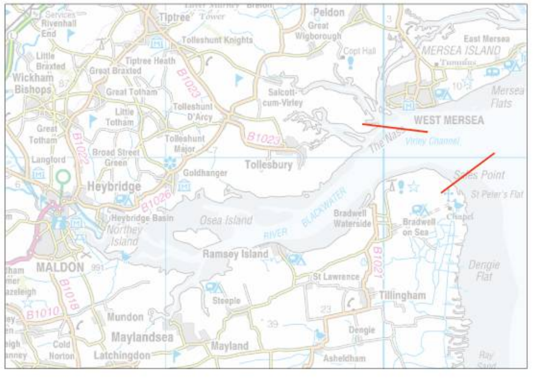
Chainage km km

The Blackwater Estuary: Sales Point to East Mersea

Section 1 –Description

General: The Blackwater estuary is situated between Sales Point and West Mersea and extends inland to Langford, a distance of 21km (Mouchel, 1997). The estuary is a valuable and popular recreation and tourism resource and has a rich cultural heritage including conservation areas, and scheduled ancient monuments. Extensive mudflats and saltmarsh once characterised the estuary but the latter have been progressively reclaimed leaving less than 700ha at present (Mouchel, 1997). The estuary supports a range of habitats that are of ecological importance which is reflected by several environmental designations.

Physical: The Blackwater estuary is the largest estuary in Essex north of the Thames, with a plan area of 5184ha (CHaMP, 2002). The estuary is defined as a coastal plain type estuary (Buck, 1997) that is enclosed by a shingle spit.



A significant feature of the estuary is it is wider landward than it is at its mouth owing to the geological constraints imposed by the Terrace Gravel geology at Bradwell and Mersea. The mouth of the estuary is 3.5km wide between West Mersea and Sales Point. The estuary channel is particularly deep (<20m) and Pethick (2003) suggests that this channel may mark the mouth of the proto-Thames. To the west of Bradwell and again at Osea, the estuary widens (Posford haskoning, 2002). Osea and Northey Island are two major London Clay islands located within the estuaries tidal area. Mersea Island is also an isolated island of London Clay, situated where the Blackwater and the Colne estuary converge.

The Blackwater has a range of habitat types including river channels, creeks, shingle and shell banks and saltmarsh. The Channel of the estuary is particularly deep with a substrate dominated by sand and gravel. The estuary contains one of the largest areas of saltmarsh in Essex (694ha) which is subject to high levels of erosion. The estuary also comprises of 2631ha of mudflats and 1869ha of subtidal areas (CHaMP, 2002).

Frontage F – Blackwater Estuary

Chainage km km

Defences[21] and manmade features:

Almost the entire length of the Blackwater estuary is constrained by flood defences. This totals 102km and these are, for the most part, maintained by the Environment Agency. The defences are predominantly clay embankments protected by a revetment. At the head of the estuary lie Maldon and Heybridge. Maldon is generally above tidal flooding while Heybridge lies below and has been the subject of a recent tidal defence scheme (Mouchel, 1997).

Beach recharge has been implemented at Cob Marsh, Mersea Quarters (15,000m^3), Pewet Island (5,000m^3) and Nass spit and Mersea Hard (1,000m^3) Mouchel, 1997). Several managed realignment sites have been established within the Blackwater estuary at: Orplands, Abbotts Hall, Tollesbury and Northey Island.

Commercial navigation of the Blackwater estuary is limited, historically the Port of Maldon was commercially active but now holds less importance. The estuary's main use now lies with recreation (Mouchel, 1997).

A power station is located at Bradwell, 2km west of Sales Point and occupies 1.2Km^2 area and a sewage treatment works is situated on the outskirts of West Mersea (Mouchel, 1997).

Section 2 – Baseline information (current data relevant to the frontage)

Tide and water levels (mODN):

	LAT	MLWS	MLWN	MSL	MHWN	MHWS	HAT	Spring range	Neap range	Correction CD/ODN
Bradwell Waterside		-2.28	-1.38		1.52	2.52		4.8	2.9	2.68
Osea Island		-2.23	-1.43		1.67	2.67		4.9	3.1	2.63

Extremes (mODN):

	Source/method	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
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

Notes:

		Notes
Av. flood	South west	The Blackwater estuary is macro tidal with a tidal range of 5.2-5.8m. A tidal curve for the Blackwater estuary shows that the

[21] A full list of defences is provided in the ' Assessment of Coastal Defences' report

Frontage F – Blackwater Estuary

Chainage km km

Currents:

Av. ebb	North East	flood tide does not propagate upstream of the estuary at a constant speed owing to variations in the morphology. The ebb velocities range between 0.6 and 1.1m/s in the main channel and reduce to 0.6-0.1m/s across the intertidal flats and estuary margins. Flow speeds are slower on the flood tide with maximum flows ranging between 0.5-1.0m/s in the main channel and 0.1-0.5m/s across the intertidal flats and estuary margins (Colne and Blackwater Flood Risk Management Strategy, Draft).
Net residual	Ebb Dominant	

Wave climate:

The most significant wave action occurs in the outer reaches. Offshore banks shelter the coastline from direct wave action, whilst intertidal flats play a very significant role in attenuating incoming wave energy before it reaches the shoreline of Mersea Island and Dengie. The chenier ridges near Sales Point further limit wave penetration onto the upper marsh surface, as a result waves suffer a considerable loss of energy. In the Blackwater estuary modelling shows that wave heights of 1.2m can propagate upstream as far as Mill Point. Landwards of Mill Point, the penetration of waves is more limited by the shallower morphology and locally generated waves become more important (Leggett, 1993).

Accretion/ erosion:

Notes: Considering volume and accretion volumes within the estuary, when averaged over the surface area of the estuary it is equivalent to a potential vertical increase of 0.004m/yr, approximately equal to the relative rate of sea level rise in this estuary over the past decade. It can be concluded from this that the estuarine response to sea level rise is to transgress landwards but also upwards, thus maintaining its position relative to the tidal frame. In order to achieve this transgressive movement, the estuary must re-distribute sediment landward but must also receive sediment inputs from marine sources equivalent to the rate of sea level rise.

In contrast to the horizontal recession of saltmarsh , in accordance with the transgressive model, rates of vertical accretion have been averaged at 0.008m/yr over a period of 1986-1990 at Mill Point (Pethick, 1992). Additional data on saltmarsh accretion rates is available from the monitoring of the managed realignment scheme at Tollesbury (Centre for Ecology and Hydrology, 2001). The monitoring shows accretion is taking place within the retreat site at rates of 24.9mm/yr whilst accretion rates on the adjacent Old Hall were 5.9mm/yr over the period of 1999-2000.

Sediment:

Average rates (myr^{-1} unless stated)[22]					Intertidal				Nearshore	
Location	general	crest	face	toe	backshore	Mean	MHWS	MLWS	Trend	Source

	Sales Point-Stansgate	548,000m^3/yr								Erosion (1978-1997)	Pethick (1998)
	Middle and inner Blackwater (Stansgate and Beeleigh)	746,000m^3/yr								Accretion (1972-1998)	Pethick (1998)
	Mouth	-6.92×10^9kg mass of sediment in Vs 7.41×10^9Kg mass of sediment out								Erosion	Colne and Blackwater Flood Risk Management Strategy, Draft
	Middle	-1.55×10^9 kg mass of sediment in Vs 1.46×10^9Kg imported								Import	Colne and Blackwater Flood Risk Management Strategy, Draft
	Upper	-4.5×10^7kg mass of sediment in Vs 9.9×10^6 mass of sediment out								Import	Colne and Blackwater Flood Risk Management Strategy, Draft
	Saltmarsh area	5.28ha/yr (0.6% / yr based on 1973 area)								Erosion	Cooper(2002)
	Average of EA profiles										
	Overview: The ebb dominance of the estuary results in a net export of material from the estuary which is supported by the high saltmarsh erosion rates experienced in the estuary.										
	Material	Tertiary (London Clay) and Quaternary Sands and gravels (Terrace Gravels), overlain bu Holocene sands and muds.									
	Sources	External:	Mud sized sediment is eroded from mouth and exported due to ebb dominance.	Internal:	Export of coarse grained sediment from in situ erosional sources of Quaternary Terrace Gravels. Net input of fine grain sands and muds.						
	Movement: The rapid inflow of tides to the outer Blackwater estuary	**Location**	**Net drift (m^3/yr x 1000)**	**Source**							

[22] The rates highlighted in bold are those used when determining NAI and WPM baseline scenarios (section 4).

	results in the erosion of the outer estuary. The majority of this material is exported from the mouth owing to the ebb dominance however some material is transported on the flood tide and deposited in the wider and shallower reaches in the upper estuary beyond Osea Island (Leggett, 1993). There is a similar pattern in the middle of the estuary however this system expresses a net overall input. The constriction in width at the mouth leads to bed scour so that deposition has not taken place and the channel remains extremely deep here (Posford Haskoning, 2002).				

Frontage F – Blackwater Estuary **Chainage km km**

Section 3 - Geomorphology

Process Description: Overall description of current processes: sources, transport and sinks

The estuary morphology has been significantly modified owing to the effects of climate change. The lower intertidal mudflats have experienced recession along with the upper mudflats and saltmarsh. It is notable that the saltmarsh in this estuary has not developed as extensively as it has in the other Essex estuaries. This can be attributed to a process of natural coastal squeeze, where the geology has constrained and limited the Holocene transgression. This is further exagerated by issues of foreshore steepening and loss of wave attenuation leading to increased erosion (CHaMP, 2002). The highland of the Islands of Osea and Northey and the mainland valley sides at Steeple and Mundon, mean that the estuary channel is forced to subdivide resulting in a greater proportion of mudflat in comparison to saltmarsh.

However, four managed set back trials are already underway within the estuary and it may be that, if these are successful, a more extensive programme of set back flood embankments may be initiated. Such a programme would allow a more natural development of the estuary in response to sea level rise resulting in a wider, shallower estuary which maintains its ecological habitat as well as reducing flood risk and erosion (Mouchel, 1997).

Patterns of change:

Past development:

The Blackwater estuary is located on the northern section of the Greater Thames Embayment, considering the depth of the estuary and the unique features at its mouth the estuary is assumed to have been part of the proto-Thames.

Recent trends:

Regime analysis shows that the mouth of the Blackwater estuary is currently narrower than equilibrium form, whilst the middle and upper parts are wider. This suggests that the mouth needs to widen to achieve an ideal form, whilst the middle and upper parts need to narrow. These predicted tendencies are consistent with the sediment flux results which illustrate that the mouth of the estuary is exporting sediment, whilst the middle and upper parts of the estuary are importing sediment (Colne and Blackwater Flood Risk Management Strategy, Draft).

Future evolution (unconstrained):

The tendency for the Blackwater saltmarshes to erode, principally at their outer boundary, will continue as sea level rises over the next 50 years. This will be accompanied by a widening of the first order creeks, a phenomenon already noted in Old Hall Marshes (Pethick, 1992). The total area of potential intertidal loss is predicted to be 600-700ha over the 50year period (CHaMP, 2002).

Dependency: Factors affecting the evolution of the frontage both

Control and Sensitivities	Control features	Significance	Dependence	Chainage
Geological constraints between Sales Point and West Mersea and Ramsey Island.	Pleistocene Gravels (natural)	Primary	Fixed	
	Chenier Ridges	Primary	Fixed	

internally and externally.	The estuary mouth is currently sheltered from significant wave action by the Chenier ridges at Sales Point. If these features erode the mouth of the estuary will become more exposed and may be subjected to increased erosion. Four managed retreat sites have been established within the Blackwater estuary at: Orplands, Abbotts Hall, Tollesbury and Northey Island. Location of the Power station at Bradwell and the sewage Treatment works at West Mersea.	(natural)			

Internal interaction	**External interaction**
The landward transgression of the estuary is difficult to measure in the field since the rates of movement involved are low and no fixed markers can be used. The presence of a sediment null-point at the landward end of the saline intrusion can, however, it can be identified in the Blackwater with reasonable precision. This null point is marked by an abrupt transition from fine-grained sediment, carried landward by residual and tidal currents, and coarse grained sediments, mainly gravels, carried seaward by fluvial fresh water flows. In the Blackwater this transition was, in 1998, located at the Maldon Town Bridge. In 1972, however, the null point was located at Heybridge, some 300 m seaward of its 1998 location. This movement of 300m in 26 years or 11.6myr^{-1} gives a reliable indication of the estuarine transgression rate. It is interesting to note that this rate is equivalent to an increase in elevation of 0.004myr^{-1} on the low-water bed slope at Maldon of 1:3000, suggesting that landward and upward transgressions are synonymous.	

Sea level / climate change
For recent Defra (2006) guidance on sea level rise due to climate change, see section 1.4 in the main report.

Frontage F – Blackwater Estuary

Chainage km km

Influence: Factors which may influence evolution of other areas.	The lack of any extensive saltmarsh area, coupled with the existing channels which are narrower than equilibrium imposes increased stress on the flood defences.

Section 4 – Baseline management scenarios[23][24]

No active intervention (NAI)

Scenario description

This scenario assumes that defences are no longer maintained and will therefore fail over time. Timing of exact defence failure cannot be deduced, but a failure epoch can be determined, as shown in the ' Assessment of coastal defences' report.

Shoreline response

Under a scenario of NAI, all defences are assumed to fail by epoch 2.

The estuarine response to sea level rise is to transgress landwards and upwards, thus maintaining its position relative to the tidal frame. Considering the saltmarsh vertical accretion rates of 7-8mm/yr (IECS, 1989; Pethick, 1992) it is considered that without the constraint of flood defences the marshes would transgress and maintain their area with sea level rise.

Epoch	Sea level rise (myr^{-1})	Beach slope	Erosion rate (myr^{-1})
1 (2008 – 2025)	0.004		
2 (2025 – 2055)	0.0085		
3 (2055 – 2085)	0.012		
3 (2085 – 2105)	0.015		

[23] All management scenarios assume that the current management practices undertaken in adjacent SMP study areas will continue.
[24] All assessments of shoreline response have a band of uncertainty, which increases for later epochs.

Epoch 1: Years 0 – 20 (2025)		Epoch 2: Years 20 – 50 (2055)		Epoch 3: Years 50 – 100 (2105)	
Defences	**Natural coast**	**Defences**	**Natural coast**	**Defences**	**Natural coast**
Most of defences will fail by end of epoch.	Middle and upper estuary will continue to accrete whilst the mouth erodes in order to achieve equilibrium.	Complete failure of defences.	Considering vertical accretion rates saltmarsh will transgress landward and maintain position.	Complete failure of defences.	Sea level rise will exceed vertical accretion and lead to saltmarsh erosion- geological constraints.

With present management (WPM)

Scenario description

This scenario assumes that the current policy of Hold the Line for the frontage continues. This will usually involve maintaining defences to provide a similar level of protection to that provided at present and regularly inspecting and maintaining the defences.

Shoreline response

The Blackwater estuary is almost entirely constrained by defences which prevents the landward transgression of the upper shoreline. Consequently, erosion of the intertidal zone is occurring and is predicted to continue over the next 50 years. This results in foreshore steepening which allows larger waves to reach the defences.

In epoch 2 the tendency for saltmarsh to horizontally erode will continue, resulting in a widening of first order creeks. It is estimated that by 2050, owing to the process of coastal sqeeze there could be no saltmarsh left. This will place increased pressure on defences. This process will continue into epoch 3 however the widening of the estuary mouth will be constrained by the geology at Bradwell and Mersea.

Epoch 1: Years 0 – 20 (2025)		Epoch 2: Years 20 – 50 (2055)		Epoch 3: Years 50 – 100 (2105)	
Defences	**Natural coast**	**Defences**	**Natural coast**	**Defences**	**Natural coast**
Defences will remain.	Moderately high erosion of the intertidal area will continue in the estuary. Widening of first order creeks as alreading observed at Old Hall Marshes.	Defences will remain. Upgrade will be required owing to the increasing wave energy approaching the toe of the structure.	Same as epoch 1, potential loss of entire saltmarsh area as a result of coastal squeeze.	Defences will remain.	Widening of first order creeks and mouth of estuary.

F2.8 Frontage G - Dengie Flat

Frontage G – Dengie Flat	**Chainage**	**km**	**km**

Sales Point (Blackwater entrance) to Holliwell Point (entrance to River Rouch)

Section 1 –Description

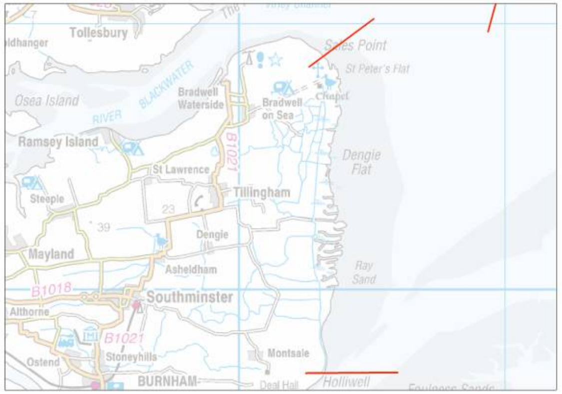
General: This frontage covers the Dengie Peninsula, an area which incorporates the Dengie Flats, St Peter's Flats and the Ray Sand (areas of mudflat) and the Bradwell, Tillingham and Dengie marshes. There are no formal recreational activities and commercial activities include agriculture and fisheries to a very small extent. The Dengie Peninsula also holds areas of conservation importance such as the Dengie National Nature Reserve, Bradwell Birds Observatory and St Peter Chapel.

PhysicaL:

This coastal unit has a north-south orientation and is characterised by extensive low lying intertidal area with 2790 ha of mudflats and upper salt marsh covering approximately 427ha. The low water mark at the Dengie flats can extend between 1.5 and 3 km offshore. Further, offshore the frontage protected by the complex system of offshore sands of Buxey and Gunfleet on a north-east to south-west orientation and relatively deeper pockets to the north.

These low wave energy environment forms a rare example of an open coast marsh. The protected land is lower than the saltmarshes on the seaward side of the embankments.

There are *Chenier* features near Sales Point. The Dengie and Bradwell marshes north of the River Crouch are much dissected by small creeks but form a single compact area since reclamation.



Frontage G – Dengie Flat

Chainage km km

Defences[25] and manmade features:

This frontage is defended by a continuous flood embankment which protects extensive reclaimed marshland. The embankments are primarily composed by clay underlying concrete and rock revetments. The large extent of saltmarsh and mudflats provide an important role in coastal defence and the first line of defence.

Reclamation of these areas for agriculture has gone on for centuries and further natural saltings have developed seawards of the embankments.

Section 2 – Baseline information (current data relevant to the frontage)

Tide and water levels (mODN):

	LAT	MLWS	MLWN	MSL	MHWN	MHWS	HAT	Spring range	Neap range	Correction CD/ODN
Holiwell		-2.25	-1.35		1.55	2.55		4.8	2.9	2.75

Extremes (mODN):

	Source/method	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

Notes:

Currents:

		Notes
Av. flood	South-westwards	Current data deduced from Tidal Diamond G (Chart No 1183).
Av. ebb	North-eastwards	The duration of the flooding tide is less than the ebbing tide leading to tidal asymmetry.
Net residual	Southwards	Asymmetries of the tidal system are exacerbated by channel morphology as the tidal wave moves landwards.

Wave climate:

The dominant incident wave direction is from the north-east. Hence, the Tendring peninsula is vulnerable to flood risk and erosion.

There are major banks including Cork Sand, Gunfleet and Buxey sand are likely to provide some attenuation of the wave energy.

Accretion/ erosion:

Notes:

Evidence from the EA profiles on the Dengie marshes, analysed for the CHaMPS 2003, shows that over the period 1992 to 2001 the central Dengie Marshes (i.e. between Marsh House and Grange outfalls) experienced vertical accretion rates averaging 0.02ma^{-1}. Both these accretion rates are in excess

Sediment:

of the rate of sea level rise and therefore accretion is more rapid due to the presence of the flood embankments.

Average rates (myr^{-1} unless stated)[26]					Intertidal				Foreshore	
Location	general	crest	face	toe	Mean rate	MSL	MHWN	MLWN	Trend	Source
Saltmrash (E3E2 and E3E3) (1992-2007)	1.6 km/ year								Erosion* (highest rate of erosion)	Coastal Trend Analysis (EA, 2008)
Average of EA profiles E2A15 - E3D6					6.20	6.22	-1.20	19.87	Flatenning (all profiles)	Coastal Trend Analysis (EA, 2008)

Overview:

During the Holocene sea level rose extensively as the glaciers retreated and melted into the open sea. As sea level rose, sands and gravels were transported landwards into the estuarine channels and built linear, sub-tidal banks. It has been postulated that these banks form a principal control of (some of) the estuaries. Finer materials have been removed from the coarse deposits by tidal- and wave-driven transport and have been deposited further landward in the inner estuary channels.

The supply of suspended sediment is critical to the development of the coastal plains.

The annual 10% exceedance significant wave height is 1.0 to 1.5 m (Futurecoast, 2002).

Material	Mud and sands deposits			
Sources	External:	Suspended sediment is derived mainly from marine sources, with negligible fluvial input. It is held in suspension offshore, where it forms relatively high concentrations of up to 80 mg/l.	Internal:	Tidal movement likely to cause re-suspension and deposition of the final material within the system . This process is unlikely to cause any significant movement (interpretation).

Movement:	**Location**	**Net drift (m^3/yr x 1000)**	**Source**
According to the Coastal Trend Analysis (2008), there has been	Satlmarsh	0.5% loss of 1973	CHaMPS, 2003

[26] The rates highlighted in bold are those used when determining NAI and WPM baseline scenarios (section 4).

	an overall horizontal accretion of mudflats. However, as indicated by the movement of the high water mark there has been horizontal erosion of saltmarshes. CHaMPS (2003) previous analysis of profiles on the Dengie marshes shows that over the period 1992 to 2001 the central Dengie Marshes (i.e. between Marsh House and Grange outfalls) experienced vertical accretion rates averaging 0.02ma-1. Both these accretion rates are in excess of the rate of sea level rise and therefore accretion is more rapid due to the presence of the flood embankments. It can be concluded that the coastal squeeze process on the Essex coast is concentrating existing sediment volumes into a smaller area as sea level rises and increases local rates of vertical accretion (CHaMPS, 2003).	(1973 - 1988)	levels, 2.5 ha/year		
		Satlmarsh (1988 - 1998)	0.6% loss of 1973 levels, 2.68 ha/year		CHaMPS, 2003
					Saltmarsh area: 1973 – 473.8 ha; 1988 – 436.5ha; 1998 – 409.7ha;

Section 3 - Geomorphology

Process Description: Overall description of current processes: sources, transport and sinks	The frontage contains large widths of inter-tidal mudflats and saltmarshes that front very extensive areas of low-lying land previously reclaimed from the sea. There are Chenier features near Sales Point, Dengie and just south of Foulness Point. The Dengie and Bradwell marshes north of the River Crouch are much dissected by small creeks but form a single compact area since reclamation. Accretion of fine to medium sand in the Dengie Flats is considered as the main sedimentary process. Suspended sediment concentrations are high and increase towards the coast and within estuaries. The high concentrations are maintained through tidal exchanges with open water. In order for the sediment concentrations to keep pace with rates of sea level rise, sediment accretion must be balanced with marine sources or coastal sediments redistribution.
Patterns of change:	**Past development:** The flats are crossed by a number of shallow drainage channels flowing from reclaimed marsh sluiced-outfalls and exhibit an interesting series of stratigraphic bands suggesting an erosional surface that has experienced decreased slope gradients (CHaMPs, 2003). During the Holocene sea level rose extensively as the glaciers retreated and melted into the open sea. As sea level rose, sands and gravels were transported landwards into the estuarine channels and built linear, sub-tidal banks. It has been postulated that these banks form a principal control of (some of) the estuaries. Finer materials have been removed from the coarse deposits by tidal- and wave-driven transport and have been deposited further landward in the inner estuary channels. **Recent trends:** Coastal squeeze of saltmarshes in front of the flood defences and development of mudflats are the prevalent processes of Dengie Peninsula. According to CHaMPs (2003) shore profile analysis showed that the saltmarsh changes are associated with horizontal erosion. In contrast the saltmarsh surface is actually accreting at a rate of 0.02 m per year (1992-2001) in excess of sea-level rise. This provides support for a conceptual model (the transgressive model) put forward by Pethick (1999) whereby sediment released through erosion of the saltmarsh edge is transported landward onto the saltmarsh surface. However, the presence of the flood embankment promotes coastal squeeze. Between Deal Hall and St Peter's Church the outer edge of these saltmarshes is deeply dissected into 'mud-mounds' probably a response to wave erosion.

The Coastal Trend Analysis (Shoreline Management Group, 2008) shore profiles provide an accurate measurement of the changes in mudflat morphology on the open coast over the past decade. The surveys show that the inter-tidal slope has flattened indicating horizontal accretion.

Future evolution (unconstrained):
The presence of large expanses of saltmarsh over the past 2000 years indicates that the rate of deposition of fine-grained sediment along this coast has kept pace with sea-level rise. However, it is difficult to predict future fine-grained sediment budgets for the Essex coast. It may be that increased demand, such as that exerted by accelerated sea-level rise or even by extensive managed realignment of areas lying at low elevations in the tidal frame may not be met by the sources of supply (Posford Haskoning, 2002).

The model predictions show that mudflats on the open coast will continue to decrease in slope angle over the next 50 years due to the accelerated rise in sea-level. This decrease in slope is the normal response by any intertidal beach to an increase in wave energy, brought about here due to increased wave propagation towards the shore in the deeper water following sea-level rise.

However, before the slope has managed to adjust the saltmarsh boundary will erode as the wave energy is insufficiently dissipated on the mudflat. Once the mudflat has attained a lower slope, wave energy will be dissipated and the saltmarsh boundary will begin to accrete. These predictions for the next 50 years are, of course, identical to the processes that have allowed saltmarsh advance over the Holocene, despite rapid rates of sea-level rise (CHaMPS, 2003).

The effect of sea level rise is to increase the accretion rates, presumably due to the reduction of bed shear in the deeper water and the increase in suspended sediment in a deeper water column. The predictions indicate that the rate of lower inter-tidal accretion will drop after 50 years, apparently towards some form of steady state, but the accretion at the salt marsh boundary will continue for an unspecified period (CHaMPS, 2003).

The vertical accretion rates are expected to reduce gradually towards a steady state. The predicted average annual rate of horizontal erosion of saltmarshes, during the initial 50 years, is likely to decrease significantly compared to the observed rates over the last decade. An average recession of 1.04m per year is predicted, compared to the 1992-1998 figures of 3.0m per year (CHaMPS, 2003).

Dependency: Factors affecting the evolution of the frontage both internally and externally.

Control and sensitivities
The quaternary terrace gravels, have acted as the landward limit for development of the Dengie flats.
The shoreline is controlled by estuarine processes (e.g. tidal movement) rather than coastal processes (e.g. wave actions).

Currently one of the major controls to development of intertidal saltmarsh

Control features	Significance	Dependence	Chainage
Defences			
Quaternay geology			
Sediment Availabity			

	is the coastal defences.				

	Internal interaction	**External interaction**
	Sediment release to water column through saltmarsh horizontal erosion is likely to remain within the system and promote mudflat dvelopment and saltmarsh vertical accretion.	Open water suspended sediments are likely to be a source of sediment allowing current mudflat development. Literature does not infer into any links between this frontages and nearby estuaries or fronatges.
	Sea level / climate change For recent Defra (2006) guidance on sea level rise due to climate change, see section 1.4 in the main report.	

Influence:
Factors which may influence evolution of other areas.

Section 4 – Baseline management scenarios[27][28]

No active intervention (NAI)

Scenario description

This scenario assumes that defences are no longer maintained and will therefore fail over time. Timing of exact defence failure cannot be deduced. However a failure epoch can be determined, as described in the 'Assessment of coastal defences' report.

Shoreline response

Within the frontage the most important features in terms of shoreline response are: the low lying area landward of the embankments, the saltmarsh/mudflat boundary and mudflat seaward boundary.

Epoch 1

Under NAI the defences are likely to remain. The low lying areas fronted by the defences will therefore remain unchanged. The saltmarsh/mudflat boundary will continue to erode at similar rates as currently observed, i.e. erosion of saltmrash edge will continue occur at lower rates than to those observed over the past decade. Effectively, as sea level rises not enough energy is dissipated through the mudflats and the wave action promotes erosion of saltmarsh edge. The development of mudflats, i.e. horizontal accretion and slope flattening, will continue as a response to sea level rises. Sea level rise promotes the reduction of bed shear in the deeper water and the increase in suspended sediment in a deeper water column. Vertical accretion of both saltmarsh and mudflats will continue to take place; however, the actual rates of accretion are likely to reduce gradually towards a state of equilibrium (CHaMPS, 2003).

Epoch 2

At some point whithin Epoch 2 the defences are likely to fail, it assumed that failed defences will have no residual function. The low lying area formerly protected by the defences is likely to start becoming inundated and generated new intertidal areas. The extent and character of this new intertidal areas is at this stage unknown. Evaluation of ground levels and future tidal levels will provide an insight into extent and nature of this new intertidal areas. According to FutureCoast (2002), under NAI, following failure of the defences there would be large-scale inundation of the reclaimed backshore areas by tidal water with initial tendency for dominance of mudflats and possibly lower saltmarsh species over the 'newly created intertidal'. As sea level continues to rise however, 'the existing and newly created saltmarshes would experience landward transgression' enabling

[27] All management scenarios assume that the current management practices undertaken in adjacent SMP study areas will continue.
[28] All assessments of shoreline response have a band of uncertainty, which increases for later epochs.

the area of saltmarsh and tidal flats to maintain there position relative to the increasing tidal frame.

Epoch3

During Epoch 3 the development of 'the newly created' will continue as in epoch 2. As sea level continues to rise however, 'the existing and newly created saltmarshes would experience landward transgression' enabling the area of saltmarsh and tidal flats to maintain there position relative to the increasing tidal frame.

Epoch	**Sea level rise (myr^{-1})**	**Beach slope**	**Erosion rate (myr^{-1})**
Epoch 1 (2009 – 2025)	0.004		
Epoch 1 (2025 – 2055)	0.085		
Epoch 3 (2055 – 2105)	0.014		

Epoch 1: Years 0 – 20 (2025)		**Epoch 2: Years 20 – 50 (2055)**		**Epoch 3: Years 50 – 100 (2105)**	
Defences	**Natural coast**	**Defences**	**Natural coast**	**Defences**	**Natural coast**
Defences remain	The low lying areas behind the defences will remain unchanged. Erosion of saltmarsh edge will continue as well as the development of mudflats (horizontal accretion). Both saltmarsh and mudflats will continue to accrete	Defences will fail	Creation of new intertidal area	No defences	Development of the new intertidal area

With present management (WPM)

Scenario description

This scenario assumes that defences are maintained to provide a similar level of protection to that provided at present. This will involve regularly inspecting and maintaining defences.

Shoreline response

Under WPM scenario, the low lying areas will remain unchanged due to the protection provided by the defences

Epoch1

The saltmarsh/mudflat boundary will continue to erode at similar rates as currently observed, i.e. erosion of saltmrash edge will continue occur at lower rates than to those observed over the past decade. Effectively, as sea level rises not enough energy is dissipated through the mudflats and the wave action promotes erosion of saltmarsh edge. The development of mudflats, i.e. horizontal accretion and slope flattening, will continue as a response to sea level rises. Sea level rise promotes the reduction of bed shear in the deeper water and the increase in suspended sediment in a deeper water column. Vertical accretion of both saltmarsh and mudflats will continue to take place; however, the actual rates of accretion are likely to reduce gradually towards a state of equilibrium (CHaMPS, 2003).

Epoch 2

The mudflats will continue to decrease in slope angle and experienced horizontal accretion due to the accelerated rise in sea-level as it attempts to reach equilibrium. Equilibrium, i.e. slope stability of mudflats, is likely to be reached towards the end of epoch 2. The rate of horizontal erosion of the saltmarsh edge will continue to decrease until equilibrium is reached. At this point mudflats will promote sufficient wave dissipation and the saltmarsh boundary will begin to accrete. Vertical accretion for both zones is also likely to continue until equilibrium is reached. According to CHaMPS (2003) these predictions for the next 50 years are, identical to the processes that have allowed saltmarsh advance over the Holocene, despite rapid rates of sea-level rise.

Epoch 3

Mudflat accretion will drop after equlibrium, however accretion of saltmarsh boundary will continue for an unspecified period.

However is uncertain if the seaward boundary of the mudflats will carry moving on the seaward direction.

Epoch 1: Years 0 – 20 (2025)		Epoch 2: Years 20 – 50 (2055)		Epoch 3: Years 50 – 100 (2105)	
Defences	**Natural coast**	**Defences**	**Natural coast**	**Defences**	**Natural coast**
Defences will remain	The same as NAI scenario	Defences will remain	Erosion of saltmarsh and development of mudflats will continue as in epoch 1. However, as we reach the end of epoch 2, they will be reaching an equilibrium state. At this point saltmarsh erosion will cease and turn into accretion and mudflat accretion will slow down	Defences will remain	Accretion of saltmarsh will continue for an unspecified period and mudflat accretion will cease

F2.9 Frontage H - Crouch and Roach Estuaries

Frontage H – Crouch and Roach Estuaries

Chainage km km

Section 1 –Description

General: The Crouch-Roach estuary drains into the Outer Thames Estuary between two large areas of reclaimed marshes, the Dengie Peninsula to the north and the Islands of Foulness, Potton and Wallasea to the south. The lower Crouch Estuary and the Roach, is largely undeveloped apart from farming and military establishments at Foulness and Havengore and the Baltic Terminal at Wallasea. The upper Crouch Estuary is considered to be a separate landscape unit constrained by the ridges on either side. The area is used extensively for yachting, dingy sailing, water-skiing and motor cruising (Mouchel, 1997). The banks of the Crouch and the Roach consist of highly productive agricultural land, providing a significant contribution to the areas economy. The Estuary Complex is also designated as a SPA and cSAC, and there are many freshwater SPA sites located behind existing flood defences, which could be lost as a consequence of implementing Managed Realignment policies (Mouchel, 1997).

Physical: The river Roach runs in a north easterly direction from Rochford joining with the river Crouch at Wallasea, the Island is bounded by the estuaries. Anthropogenic interference in the area has resulted in the combination of the Crouch and Roach estuary into a single tidal morpho-dynamic system. The Crouch estuary is tidal to Battlesbridge and the Roach to Rochford.

The geological structure and physiological features of the estuaries classify them as coastal plain estuaries as they deepen and widen towards their mouth. Although the relief produced by the Eocene and quaternary rocks is subdued, rising only to around 40m ODN, it has nevertheless played an important part in constraining the coastal landform development, limiting the transgression of Holocene deposits both on the open coast and in the estuaries. 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 (CHaMP, 2002).

The estuary complex covers 2754ha and constitutes a complex series of interlinked habitats, of which 477ha are mudflats, 1059ha are saltmarsh and 1218ha are subtidal (Mouchel, 1997). The saltmarshes have been very largely enclosed by sea walls, producing a very narrow canalised estuary along the River Crouch and a series of Islands with a network of creeks around the Roach and Foulness. The saltmarshes, grazing marshes and sea walls of the complex complement those of the previous coastal unit and the extensive intertidal area of Maplin Sands (CHaMP, 2002).

Frontage H – Crouch and Roach Estuaries

Chainage km km

Defences[29] and manmade features:

The total length of the defences within this unit is approximately 168km resulting in the estuary frontage being almost entirely defended. The defences are extensive and protect the islands of Foulness, New England, Havengore, Wallasea, Rushley as well as Potton Creek, Paglesham Creek, Rochford and the entire length of the River Crouch. The defences consist mostly of clay embankments, often protected by a revetment on rural frontages with hard defences to the urban frontage. They are away from the open coast and therefore not directly exposed to storms but there is an ongoing problem with erosion of the foreshore (Mouchel, 1997).

There are short lengths of undefended frontage (e.g. at Bridgemarsh Island) and some lengths protected by sheet-piled walls topped with concrete sea walls (e.g. at Burnham-on-Crouch). The primary failure mechanism for the existing defences is due to excessive overtopping, although toe erosion and seepage of water through fissures in the crest and rear face of the embankments are also significant (Mouchel, 1997).

The estuary is known to have landfill sites within the floodplain as well as some flood defences comprising potentially contaminated material.

Section 2 – Baseline information (current data relevant to the frontage)

Tide and water levels (mODN):

	LAT	MLWS	MLWN	MSL	MHWN	MHWS	HAT	Spring range	Neap range	Correction CD/ODN
Holliwell		-2.25	-1.35		1.55	2.55		4.8	2.9	2.75

Extremes (mODN):

	Source/method	1:1	1:10	1:25	1:50	1:100	1:250	1:500	1:1000
Burnham-on-Crouch		3.17	3.67	3.87	4.02	4.17	4.37	4.52	4.67
North Fambridge		3.37	3.79	3.97	4.08	4.23	4.40	4.51	4.63
Hulbridge		3.46	3.86	4.02	4.15	4.27	4.43	4.56	4.63
Paglesham Eastend		3.48	3.88	4.04	4.17	4.29	4.45	4.58	4.65
Rochford		3.44	3.87	4.06	4.18	4.31	4.44	4.51	4.57

Notes:

Currents:

		Notes
Av. flood	South west	The Crouch estuary has a macrotidal spring range of 5.7m at Burnham, decreasing inland towards North Fambridge, where

[29] A full list of defences is provided in the ' Assessment of Coastal Defences' report

Av. ebb	North east	the maximum range is 5.5m. The shape of the channel gives rise to the flood tide being more dominant than the ebb tide (flood assymetry).
Net residual	Flood dominant	

Wave climate:

Accretion/ erosion:

Notes: Based upon aerial photography the erosion rate of saltmarsh within the Crouch estuary between 1973 and 1998 has been established as 34.1% which is equivalent to 1.36% a year. No data is available for the Roach estuary.

Average rates (myr^{-1} unless stated)[30]					Intertidal				Nearshore	
Location	general	crest	face	toe	backshore	Mean	MHWS	MLWS	Trend	Source
Crouch estuary	7.9ha/yr 1973-1988 (based on 1973 area)								Erosion	Crouch and Roach Flood Risk Management Study, Draft
	3.73ha/yr 1988-1998 (based on 1973 area)								Erosion	Crouch and Roach Flood Risk Management Study, Draft
Average of EA profiles										

Sediment:

Overview: The Crouch/ Roach estuary are in artificial balance owing to the presence of flood defences.

Material	Soft, fine sediments (Crouch and Roach Flood Risk Management Study, Draft)			
Sources	External:	Unknown sources of sediment in response to sea level rise are unclear, assumed significant inputs from North Sea (Crouch and Roach Flood Risk	Internal:	Balance of erosion and accretion

			Management Study, Draft)			
	Movement: The flood dominance of the estuaries leads to a tendency for sediment deposition. Therefore subtidal accretion is currently taking place at the mouth, erosion along the Wallasea reach but accretion resumes in the inner estuary (CGP, 2000). As well as reflecting the modifications to the channel resulting from reclamation, this pattern of accretion and erosion also reflects the rollover model of response to sea level rise. Owing to the constraints of the flood defences most of the sedimentary response to sea level rise must be derived from marine sources; however the ultimate sources of this are unclear. The present sediment budget in the Roach/ Crouch appears to be balanced (Newcastle University, 2000) however; the amount deposited may be an underestimate as there is so little intertidal area available. Therefore if areas of the estuary are realigned then more sediment will be required to bring these new areas up in the tidal frame and to maintain the vertical position of all the intertidal with rising sea level. This increased demand for sediment will have to be met from outside the present system; mainly from the Thames embayment, given the very low fluvial input, but also maybe from sacrificial realignments at the mouths of the estuary.		**Location**	**Net drift (m^3/yr x 1000)**		**Source**

[30] The rates highlighted in bold are those used when determining NAI and WPM baseline scenarios (section 4).

Section 3 - Geomorphology

Process Description: Overall description of current processes: sources, transport and sinks	Most of the intertidal areas of the estuaries have been reclaimed resulting in relatively deep, narrow channels flanked by narrow intertidal areas. This channel morphology gives rise to a marked flood tide assymetry and thus to a tendency for net sediment accumulation in the estuary. The inhibition of the channel width due to the continuous flood embankment along the entire estuary means that any deposition which takes place as a result of flood assymetry leads to a decrease in channel dimension, an increase in velocity and erosion of the deposited material. This apparent morphological equilibrium is in fact an artificial one induced by the flood embankments which are consequently placed under stress and require maintenance (CHaMP, 2002). A second outcome of the large area of reclamation in this estuary system has been the change in the outer-sub tidal channels, particularly the abandoning of the Ray Channel, formerly the main channel of the estuary, during the period 1880-1930. This change is coincident in time with the last major advance in reclamation and appears to reflect the relationship between tidalprism and channel dimensions. Further changes possibly associated with this adjustment are noted at the north-eastern extreme of the Maplin Sands where the marsh and mudflat edge has advanced north-eastwards by 1.12km, presumably as a result of continued deposition at the Whitaker Spit, while the western edge of the Sands, fronting the Whittaker Channel have advanced by a similar amount (CHaMP, 2002).
Patterns of change:	**Past development:** The Roach and Crouch Estuary Complex is located in the northern section of the Greater Thames embayment, characterised by subtidal and intertidal estuarine mudflat and marshes. The underlying geology of the outer Thames consists of a platform of Eocene rocks and London Clay, upon which lie a sequence of Quaternary sands and gravels and, above these, the Holocene sands and muds. The Quaternary terrace gravels, in particular, have acted both as major controls of estuarine morphology, limiting channel width on the River Crouch at Burnham, and also acting as the landward limit of the Foulness and Dengie coastal Holocene plains (CHaMP, 2002). Furthermore, it is important to appreciate the major impact that the proto-Thames has had on modern morphology. During the late Pleistocene the Thames flowed east and then north-east along a channel crossing the present day courses of the Rivers Crouch and Blackwater. The Roach and Crouch were historically meandering rivers but due to human intervention and construction of ‘hard’ defences the estuarine and hydraulic and geomorphologic processes have become forced (Crouch and Roach FRM, Draft). **Recent trends:** Although reclamation has had a major impact on this estuary, geological constraints are also important, in particular the constraint to the development of the channel presented by the abrupt rise in valley side slopes at Burnham, due to the Terrace gravel deposits, and paralleled by lower but significant

gravel deposits outcropping on Wallasea Island. This geological constraint means that the channel in this reach is narrower than would be expected for equilibrium morphology and results in bed scour and over-deepening. The reclamation of Wallasea Island has exacerbated this natural tendency for scour by decreasing channel width even further.

One effect of this natural deepening is for the channel to attempt to develop a meandering path, as a response to the steeper slopes and high power expenditure in a relatively straight, deep channel. Bathymetric survey of the bed of the Crouch show a tendency for riffle and pool development to occur along the channel, these are the precursors of natural channel meanders and are seen to result in channel bank erosion, as at Grassland Point.

Despite the almost canal-like nature of the estuarine channels in this system, regime analysis shows that the Crouch/Roach is much wider between Dengie and Foulness Point than would be expected for an equilibrium estuary. The analysis also demonstrates the constraints of the channel between Wallasea and Burnham and the comparatively wide channel west of Black Point. This pattern of channel variation is matched by the erosion and accretion in the Crouch and Roach.

Future evolution (unconstrained):

The response of the estuary to sea level rise is towards a wider, shallower channel a development which is prevented by the presence of flood embankments. Maximum increase in channel width occurs at the mouth and totals 60-91 over the 50 year period (CHaMP, 2002; Crouch and Rouch FRM, Draft). The combination of a wider channel needed to achieve equilibrium with present day sea level plus the impact of 50 years of sea level rise at 6mm per year, would mean a total increase of 321ha in the channel area of the Crouch. This widening process would involve the erosion of saltmarsh where it existed and therefore in theory, all of the existing saltmarsh area of 308 ha would be lost over the next 50 years.

Although a wider channel would help to spread the increased tidal energy over a wider area, the enlarged creek system would allow a higher wave energy to propagate inland.

Dependency:	**Control and sensitivities**	**Control features**	**Significance**	**Dependence**	**Chainage**
Factors affecting the evolution of the frontage both internally and externally.	Presence of continuous flood embankments which constrain the material deposition.	Flood defences (Human)		Human Intervention	
	Internal interaction	**External interaction**			

	Sea level / climate change For recent Defra (2006) guidance on sea level rise due to climate change, see section 1.4 in the main report.	
Influence: Factors which may influence evolution of other areas.	The relatively narrow channels of the Crouch and Roach formed by the existence of a continuous flood embankment along the entire estuary means that any deposition which takes place as a result of flood assymetry leads to a decrease in channel dimension, an increase in velocity and erosion of the deposited material. Sea level rise will result in a rapid increase in velocity and tidal amplitudes thus increasing both the stresses on the toe of the embankment and also the probability of overtopping.This cyclical process places stress on the embankments. With sea level rise potential changes in bank stress suggest that potential increase in width appears to fall into two distinct groups with a boundary at the junction between the Roach and Crouch (5km from the mouth).	

Section 4 – Baseline management scenarios[31][32]

No active intervention (NAI)

Scenario description

This scenario assumes that defences are no longer maintained and will therefore fail over time. Timing of exact defence failure cannot be deduced, but a failure epoch can be determined, as shown in the ' Assessment of coastal defences' report.

Shoreline response

Considering an unconstrained scenario, this will result in an adjustment of the current artificial sediment budget. The overall response of the estuary will be to return to a more natural, meandering morphology as opposed to its current narrow and canalised form. As indicated by the formation of pools and riffles already noted on the channel bed. However owing to the geological constraint imposed on the estuary, this is likely to occur outside of the time frame considerred.

Accretion will continue owing to the flood dominance of the estuary.

Epoch	Sea level rise (myr^{-1})	Beach slope	Erosion rate (myr^{-1})
1 (2008 – 2025)	0.004		
2 (2025 – 2055)	0.0085		
3 (2055 – 2085)	0.012		
3 (2085 – 2105)	0.015		

[31] All management scenarios assume that the current management practices undertaken in adjacent SMP study areas will continue.
[32] All assessments of shoreline response have a band of uncertainty, which increases for later epochs.

Epoch 1: Years 0 – 20 (2025)		Epoch 2: Years 20 – 50 (2055)		Epoch 3: Years 50 – 100 (2105)	
Defences	**Natural coast**	**Defences**	**Natural coast**	**Defences**	**Natural coast**
Most of defences fail by the end of epoch 1.	The artificial balance of accretion and erosion imposed by the flood defences will continue.	Complete defences fail.	Widening of estuary channel to reach equilibrium combined with sea level rise resulting in loss of saltmarsh.	Complete defences fail.	River will undermine flood defences as it attempts to meander. The widening of the mouth will enable a greater wave energy to propagate inland and therefore increasing erosion at certain areas.

With present management (WPM)

Scenario description

This scenario assumes that the current policy of Hold the Line for the frontage continues. This will usually involve maintaining defences to provide a similar level of protection to that provided at present and regularly inspecting and maintaining the defences.

Shoreline response

Considering the high degree of geological constraint, it is unlikely that the full equilibrium of the channel will evolve in the epochs considered. Therefore the response of the estuary complex to sea level rise is sub optimum. Sea level rise will increase the stresses on the channel but these will not result in channel changes unless human constraints are removed.

Considering epoch 1; the outer Crouch is sufficiently wide at present and therefore little impact will be observed for some years. The artificial balance imposed by the defences will remain.

By epoch 2, for the inner estuaries the effects of increasing stress due to rollover may be more immediate with increased stress in the mouth areas along the banks of Wallasea Island. Estuary widening will result in the loss of the entire saltmarsh area owing to coastal squeeze.

In epoch 3, estuary widening will result in a greater penetration of wave energy into the estuary. This will place increasing stress on the defences combined with the lack of natural frontage to attenuate wave energy before reaching the toe of the structure.

Epoch 1: Years 0 – 20 (2025)		Epoch 2: Years 20 – 50 (2055)		Epoch 3: Years 50 – 100 (2105)	
Defences	**Natural coast**	**Defences**	**Natural coast**	**Defences**	**Natural coast**
Defences will remain.	Same as the NAI scenario for epoch 1. Channel scour will maintain a deep channel.	Defences will remain. Strengthening of defences to compensate for loss of saltmarsh area.	Erosion of saltmarsh boundary as estuary widens, coastal squeeze. Unclear response of estuary to sea level rise due to uncertainty in sediment sources.	Defences will remain. Upgrading of defences required to prevent undermining as the river attempts to meander.	Same as epoch 2

F2.10 Frontage I - Foulness Island

Frontage I – Foulness Island **Chainage km km**

Holliwell Point (entrance to River Rouch) to North Shoebury

Section 1 –Description

General: Foulness Island is a large area of reclaimed marsh. Within this frontage there are several areas of conservations importance including the Foulness SSI, SPA and SACs. There is a highly productive agricultural land providing a significant contribution to the areas economy (SMP1).

Physical: This frontage has a north-east to south-west orientation. To the north, this open coast environment comprises extensive intertidal low-lying areas of mudflats, including 8850ha in Maplin Sands, which can extended up to 6km offshore. The saltmarsh area, up to 87ha, are principally located behind a Chenier ridge between Northern Corner and Foulness Point and therefore sheltered. At Shoebury, southern end, the coast comprises clay sea cliffs fronted by fronted by mud and fine sand foreshore or sand and shingle.

Offshore, lays the main entrance to the Thames Estuary with channel up to 20m deep.

Frontage I – Foulness Island

Chainage km km

Defences[33] and manmade features:

This frontage is largely artificial in nature due to a succession of seawall enclosure and extensive reclamation of saltmarsh during the period 1650 and 1850. Currently the defences consist of earth embankment underlying concrete revetments and concrete cladding in some sections. In Foulness, the protected land is lower than the saltmarsh on the seaward side of the embankments, with large extents of mudflats providing an important role in coastal defences and the first line of defence.

The Thames contains the largest port in UK, consequently it there is a long history of dredging within the estuary. Dredging has been maintained level of < 200,000 $m^3 yr^{-1}$ (SMP1, 1997).

There are military establishments at the Foulness Island.

Section 2 – Baseline information (current data relevant to the frontage)

Tide and water levels (mODN):

	LAT	MLWS	MLWN	MSL	MHWN	MHWS	HAT	Spring range	Neap range	Correction CD/ODN
Holiwell Point		-2.25	-1.35		1.55	2.55		4.8	2.9	2.75
Southend-on-Sea		-2.40	-1.5		1.8	2.9		5.3	3.3	2.90

Extremes (mODN):

	Source/method	1:1	1:10	1:25	1:50	1:100	1:250	1:500	1:1000
Shoeburyness	Royal Haskoning, 2007	3.38	3.87	4.06	4.21	4.35	4.55	4.69	4.84

Notes:

		Notes
Av. flood	South-westwards	Current data deduced from tidal diamond C (Chart No 1183). The duration of the flooding tide is less than the ebbing tide leading to tidal asymmetry. Asymmetries of the tidal system are exacerbated by channel morphology as the tidal wave moves landwards.
Av. ebb	North-eastwards	

[33] A full list of defences is provided in the ‘ Assessment of Coastal Defences’ report

Frontage I – Foulness Island

Chainage km km

Currents:

Net residual Southwards

Wave climate:

The dominant incident wave direction is from the north-east. At this coastal unit the wave energy is channelled towards the estuaries, and the sand banks dissipate some of the wave energy. Effectively, the saltmarsh and sand flats reduce the extremity of incoming wave energy as waves are transformed from deep channels to inter-tidal zones.

The annual 10% exceedance significant wave height is 1.0m to 1.5m (Futurecoast, 2002).

Accretion/ erosion:

Notes: For the rates below the profile E3E4 has been excluded since it would give rise to a miss representation of the rates.

Average rates (myr^{-1} unless stated)[34]					Intertidal				Foreshore Trend	
Location	general	crest	face	toe	Mean rate	MSL	MHWN	MLWN	Trend	Source
Average of EA profiles					24.18	10.79	-0.01	65.49	Profile Flattening	Coastal Trend Analysis, 2008

Sediment:

Overview:

During the Holocene sea level rose extensively as the glaciers retreated and melted into the open sea. As sea level rose, sands and gravels were transported landwards into the estuarine channels and built linear, sub-tidal banks. It has been postulated that these banks form a principal control of (some of) the estuaries. Finer materials have been removed from the coarse deposits by tidal- and wave-driven transport and have been deposited further landward in the inner estuary channels.

The supply of suspended sediment is critical to the development of the coastal plains.

Material	Mud and fine sand foreshore deposits and quaternary sand and shingle			
Sources	External:	Suspended sediment is derived mainly from marine sources, with negligible fluvial input. It is held in suspension offshore, where it forms relatively high concentrations of up to 80 mg/l.	Internal:	Tidal movement likely to cause re-suspension and deposition of the final material within the system . This process is unlikely to cause any significant movement

Frontage I – Foulness Island

Chainage km km

					(interpretation).
	Movement: According to the Coastal Trend Analysis (2008), there has been an overall horizontal accretion of mudflats. In addition, profiles surveyed in this frontage show little horizontal movement of saltmarsh (1992-2007) from Foulness Point to Havengore Head, with areas of small levels of accretion. South of the Haven Point there is evidence of saltmarsh retreat of up to approximately 30m (E3A2, 1991-2007). CHaMPS (2003) previous analysis of profiles on the Dengie marshes shows that over the period 1992 to 2001 the central Dengie Marshes (i.e. between Marsh House and Grange outfalls) experienced vertical accretion rates averaging 0.02myr^{-1}. Both these accretion rates are in excess of the rate of sea level rise and therefore accretion is more rapid due to the presence of the flood embankments.	**Location**	**Net drift (m^3/yr x 1000)**		**Source**

[34] The rates highlighted in bold are those used when determining NAI and WPM baseline scenarios (section 4).

Section 3 - Geomorphology

Process Description: Overall description of current processes: sources, transport and sinks

The frontage from Dengie to Foulness contains large widths of inter-tidal flats and saltmarshes that front very extensive areas of low-lying land previously reclaimed from the sea. Accretion of fine to medium sand at mudflats is the dominant sedimentary process. In addition horizontal erosion of saltmarshes also takes place. There are *Chenier* features near Sales Point, Dengie and just south of Foulness Point (SNS2). Deposition of suspended sediment in the water column and reworking of local sedimentary deposits are the likely the main sources. Given the current accretion trend, is fair to assume that the Dengie flats act as a sediment sink (interpretation)

The southern end of the frontage, Shoebury, comprises of some saltmarshes and London clay Cliffs fronted by quaternary sand and shingle undergoing accretion. The source of the material promoting beach erosion is uncertain; however, redistribution of quaternary sediments exacerbated by dredging practices is a probable cause (pure interpretation).

Patterns of change:

Past development:

There is evidence to suggest that the River Thames often switched position and may have flowed east and north east during the late Pleistocene and formed its mouth at the location of the present Blackwater estuary, between Bradwell and West Mersea (CHaMPS, 2003).

The Quaternary ice advances were responsible for a series of deposits ranging from tills in the west to outwash sands and gravels in the east and covering much of the present near shore zone. Pethick and Leggett (1993) suggested the high suspended sediment concentrations in the Thames embayment coupled by sea transgression, which pushed sedimentary deposits landward, has allowed the development of coastal plains during the Holocene (CHaMPS, 2003).

The time interval between 1650AD and 1850AD is characterised by a slight regressive phase, also referred to as the Little Ice Age. During this period reclamation of the salt-marshes was a height, and was paralleled by natural seaward extension of coastal landforms. The Foulness Point spit has extended in this period.

Recent trends:

The sediment budget of the Thames Estuary, despite dredging activity, extensive reclamation of the intertidal areas, and sea level rise, appears to be in balance. Mudflat accretion has kept pace with sea level rise over the present century (SMP1). Evidence from the Coastal Trend Analysis (2008) suggests accretion of mudflats over the recent years (1991/1992-2007) with little movement of saltmarsh.

Frontage I – Foulness Island **Chainage km km**

Foreshore beach is likely to provide to protection to the Shoebury Cliffs.

Future evolution (unconstrained):
Under the unconstrained scenario there would be large-scale inundation of the reclaimed backshore areas by tidal water with initial tendency for dominance of mudflats and possibly lower saltmarsh species over the 'newly created intertidal' (Futurecoast 2002). As sea-level continues to rise however, 'the existing and newly created saltmarshes would experience landward transgression enabling the area of saltmarsh and tidal flats to maintain there position relative to the increasing tidal frame (Futurecoast, 2002).

Under the constrained scenario, Futurecoast predicts that due to the presence of flood defences under increased rates of sea level rise 'the foreshore would narrow due to coastal squeeze' this will result in less attenuation of wave and tidal energy and increased damage to flood and coastal defences (CHaMPS, 2003).

These predictions from the Futurecoast project are in contrast to those provided by the CHaMPS (2003) modeling which show a recovery of the saltmarshes of the Dengie (and by implication of Foulness) within the next 50 years. The explanation for this difference in predicted outcomes is that Futurecoast relies on extrapolation of existing rates of change whereas the predictive model incorporates feedback between sedimentary processes and demonstrates a non-linear evolution in the coastal morphology. (CHaMPS, 2003).

Dependency: Factors affecting the evolution of the frontage both internally and externally.

Control and sensitivities
The quaternary terrace gravels, have acted as the landward limit for development of the Foulness frontage.

Currently one of the major controls to development of intertidal saltmarsh is the coastal defences.

Control features	Significance	Dependence	Chainage
Defences			
Quaternary geology			
Maplin Sands			

Internal interaction	External interaction
Sediment release to water column through saltmarsh horizontal erosion is likely to remain within the system and promote mudflat dvelopment and saltmarsh vertical accretion. Redistribution of sedimentary deposits.	Open water suspended sediments are likely to be a source of sediment allowing current mudflat development. Re-suspension promoted by dredging may release sediment which may become avilable for deposition. Literature does not infer into any links between this frontages and nearby

		estuaries or frontages.
	Sea level / climate change For recent Defra (2006) guidance on sea level rise due to climate change, see section 1.4 in the main report.	

Influence:
Factors which may influence evolution of other areas.

Section 4 – Baseline management scenarios[35][36]

No active intervention (NAI)

Scenario description

This scenario assumes that defences are no longer maintained and will therefore fail over time. Timing of exact defence failure cannot be deduced. However a failure epoch can be determined, as described in the 'Assessment of coastal defences' report.

Shoreline response

Within the frontage the most important features in terms of shoreline response are: the low lying area landward of the embankments, the saltmrash/mudflat boundary and mudflat seward boundary.

Epoch 1

Under NAI the defences are likely to remain. The low lying areas fronted by the defences will there fore remain unchanged. The saltmarsh/mudflat boundary will continue to erode at similar rates as currently observed, i.e. erosion of saltmarsh edge will continue occur at lower rates than to those observed over the past decade. Effectively, as sea level rises not enough energy is dissipated through the mudflats and the wave action promotes erosion of saltmarsh edge. The development of mudflats, i.e. horizontal accretion and slope flattening, will continue as a response to sea level rises. Sea level rise promotes the reduction of bed shear in the deeper water and the increase in suspended sediment in a deeper water column. Vertical accretion of both saltmarsh and mudflats will continue to take place; however, the actual rates of accretion are likely to reduce gradually towards a state of equilibrium (CHaMPS, 2003).

Epoch 2

At some point whithin Epoch 2 the defences are likely to fail, it assumed that failed defences will have no residual. The low lying area formely protected by the defences is likely to start becoming inundated and generated new intertidal areas. The extent and character of this new intertidal areas is at this stage unknown. Evaluation of ground levels and future tidal levels will provide an insight into extent and nature of this new intertidal areas. According to Futurecoast (2002), under NAI, following failure of the defences there would be large-scale inundation of the reclaimed backshore areas by tidal water with initial tendency for dominance of mudflats and possibly lower saltmarsh species over the 'newly created

[35] All management scenarios assume that the current management practices undertaken in adjacent SMP study areas will continue.
[36] All assessments of shoreline response have a band of uncertainty, which increases for later epochs.

intertidal'. As sea level continues to rise however, 'the existing and newly created saltmarshes would experience landward transgression' enabling the area of saltmarsh and tidal flats to maintain there position relative to the increasing tidal frame.

Epoch 3

During Epoch 3 the development of 'the newly created' will continue as in Epoch 2. As sea level continues to rise however, 'the existing and newly created saltmarshes would experience landward transgression' enabling the area of saltmarsh and tidal flats to maintain there position relative to the increasing tidal frame.

Epoch	**Sea level rise (myr^{-1})**	**Beach slope**	**Erosion rate (myr^{-1})**
Epoch 1 (2009 – 2025)	0.004		
Epoch 1 (2025 – 2055)	0.085		
Epoch 3 (2055 – 2105)	0.014		

Epoch 1: Years 0 – 20 (2025)		**Epoch 2: Years 20 – 50 (2055)**		**Epoch 3: Years 50 – 100 (2105)**	
Defences	**Natural coast**	**Defences**	**Natural coast**	**Defences**	**Natural coast**
Defences will remain	Mudflat development at the same rate. Saltmarsh erosion at the same rate	Defences will fail	Creation of new intertidal area after failure of defences	No defences	Landward transgression of new intertidal area in order to move towards a state of stability

With present management (WPM)

Scenario description

This scenario assumes that defences are maintained to provide a similar level of protection to that provided at present. This will involve regularly inspecting and maintaining defences. Other current management practices will also remain the same.

Shoreline response

Under WPM scenario, the low lying areas will remain unchanged due to the protection provided by the defences

Epoch1

The saltmarsh/mudflat boundary will continue to erode at similar rates as currently observed, i.e. erosion of saltmrash edge will continue occur at lower rates than to those observed over the past decade. Effectively, as sea level rises not enough energy is dissipated through the mudflats and the wave action promotes erosion of saltmarsh edge. The development of mudflats, i.e. horizontal accretion and slope flattening, will continue as a response to sea level rises. Sea level rise promotes the reduction of bed shear in the deeper water and the increase in suspended sediment in a deeper water column. Vertical accretion of both saltmarsh and mudflats will continue to take place; however, the actual rates of accretion are likely to reduce gradually towards a state of equilibrium (CHaMPS, 2003).

Epoch 2

The mudflats will continue to decrease in slope angle and experienced horizontal accretion due to the accelerated rise in sea-level as it attempts to reach equilibrium. Equilibrium, i.e. slope stability of mudflats, is likely to be reached towards the end of epoch 2. The rate of erosion of the saltmarsh edge will continue to decrease until equilibrium is reached. At this point mudflats will promote sufficient wave dissipation and the saltmarsh boundary will begin to accrete. Vertical for both zones is also likely to continue until equilibrium is reached. According to CHaMPS (2003) these predictions for the next 50 years are, identical to the processes that have allowed saltmarsh advance over the Holocene, despite rapid rates of sea-level rise.

Epoch 3

Mudflat accretion will drop after equlibrium, however accretion of saltmarsh boundary will continue for an unspecified period.

However is uncertain if the seaward boundary of the mudflats will carry moving on the seaward direction.

Epoch 1: Years 0 – 20 (2025)		**Epoch 2: Years 20 – 50 (2055)**		**Epoch 3: Years 50 – 100 (2105)**	
Defences	**Natural coast**	**Defences**	**Natural coast**	**Defences**	**Natural coast**
Defences will remain	The same as NAI scenario	Defences will remain	Erosion of saltmrash and development of mudflats will continue as in epoch 1. However, as we reach the end of epoch 2 will be reching an equilibrium state. At this point saltmrash erosion will cease and turn into accretion and mudflat accretion will slow down	Defences will remain	Accretion of saltmarsh will continue for an unspecified period and mudflat accretion will cease

F2.11 Frontage J - Southend-on-Sea and Shoebury

Frontage J – Southend-on-Sea

Chainage km km

From North Shoebury to the Two Three Island

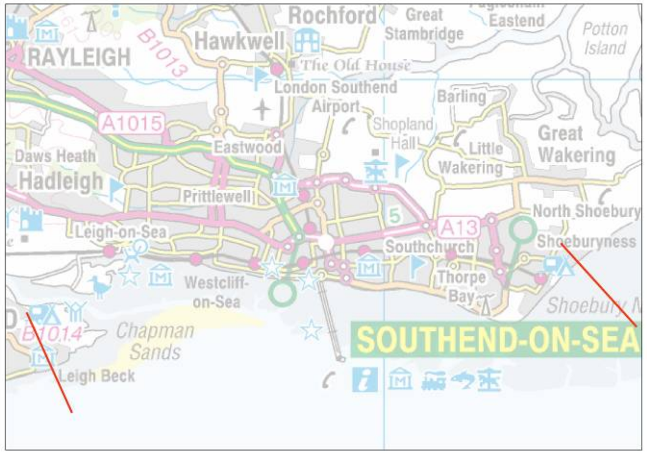
Section 1 –Description

General: North Shoebury to Southend-on-Sea is an area of extensive urban development and a major centre of tourism, leisure and recreation. Other commercial activities include fisheries and transport (Thames Estuary Port). There are also areas of conservation (Mouchel, 1997).

Physical: This frontage has an east to west orientation and is located at the left bank of the eastern end of the Thames Estuary close to its mouth.

The frontage is composed of London Clay sea cliffs which constitutes the areas of high ground. The cliffs are fronted by a predominantly mud and fine sand foreshore (intertidal flats); however, there is some coarse sand and shingle trapped within the groyne compartments along the eastern Southend-on-Sea frontage and Shoebury.

Beyond the Southend Flats, depths in the Thames Estuary reach up to 17m.



Frontage J – Southend-on-Sea

Chainage km km

Defences[37] and manmade features:	This frontage is currently defended to a standard of 1:10,000 for flood protection by 4.3km of vertical high walls mainly from brick and masonry or concrete (EA et al., 2006). In addition, the there are groynes which provide coastal protection. Recharging of the beach to the east of Southend as far as Thorpe Esplanade in 2002 has created a new beach at the Southend-on-Sea. The Southend Pier, the Thorpe Esplanade and the structure at Shoeburyness are relatively large structures that may influence longshore drift.

[37] A full list of defences is provided in the ‘ Assessment of Coastal Defences’ report

Frontage J – Southend-on-Sea

Chainage km km

Section 2 – Baseline information (current data relevant to the frontage)

Tide and water levels (mODN):

From Admiralty Chart

	LAT	MLWS	MLWN	MSL	MHWN	MHWS	HAT	Spring range	Neap range	Correction CD/ODN
Admiralty Chart 1183		-2.4	-1.5		1.8	2.9		5.3	3.3	2.90

Extremes (mODN):

	Source/method	1:1	1:10	1:25	1:50	1:100	1:250	1:500	1:1000
Southend-on-Sea		3.50	4.00	4.22	4.30	4.50	4.66	4.83	5.00

Notes:

Currents:

		Notes
Av. flood	Westwards	Current data deduced from Tidal Diamond A (Chart 1183)
Av. ebb	Eastwards	The increasing tidal range upstream is due to the funneling effect of the estuary (EA et al., 2006).
Net residual	Eastwards	The Thames Estuary is Ebb dominated (Mouchel, 1997)

Wave climate:

The extensive offshore bank and channel system located to the east of Southend protects much of the estuary from the long period southern North Sea storm waves. Wave activity in the Thames Estuary west of these banks is generated by locally wind-generated waves at this location (EA et al., 2006). Wind generated 1 in 100 year wave height can reach 1.3 to 1.5 m (EA et al., 2006). The annual 10% exceedance significant wave height is 1.0 to 1.5 m (Halcrow, 2002).

Accretion/

Notes: The relative accretion rates reported by the Coastal Trend Analysis (EA, 2008) are likely to be a result of beach rehcarge.

Section 2 – Baseline information (current data relevant to the frontage)

erosion:	**Average rates (myr^{-1} unless stated)[38]**					Intertidal				Foreshore	
	Location	general	crest	face	toe	Mean rate	MSL	MHWN	MLWN	Trend	Source
	Average of EA profiles E4A2 to E4B6					0.73	0.96	0.31	0.93	Accretion. Profile Movement has shown variablity: flatenning, steepning and no movement.	Coastal Trend Analyis (2008).

Sediment:

Overview:

The predominant process at this frontage is the beach erosion which is largely counteracted by beach recharge and coastal protection. The supply of suspended sediment is critical to the development of the coastal plains.

During the Holocene, as sea level rose, sands and gravels were transported landwards into the estuarine channels and built linear, sub-tidal banks. It has been postulated that these banks form a principal control of (some of) the estuaries. Finer materials have been removed from the coarse deposits by tidal- and wave-driven transport and have been deposited further landward in the inner estuary channels (Posford Haskoning, 2002b).

Material	Quaternary sand and shingle also fine sands and muds further away from the land			
Sources	External:	Beach Recharge Dredging areas situated to the northeast and outside 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	Internal:	Tidal movement likely to cause re-distribution of sedimentary deposits.

[38] The rates highlighted in bold are those used when determining NAI and WPM baseline scenarios (section 4).

Section 2 – Baseline information (current data relevant to the frontage)

			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. The general direction of movement is westwards from Knock Deep and Long Sands (HR Wallingford, 2002).		

	Movement:	Location	Net drift (m^3/yr x 1000)		Source
	No rates of longshore drift are available. However, the Thames Estuary is an ebb dominated environment and observation of sediment accumulation on the up drift of groynes indicates some drift on the eastwards direction. At Shoebury there is also no information on net drift. Overall coastal protection is likely to retain sediment in place.				

Section 3 - Geomorphology

Process Description: Overall description of current processes: sources, transport and sinks	The coastal area between Shoeburyness to 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 with groyne compartments along the eastern Southend-on-Sea frontage. (CHaMPS, 2003, SNS2, 2003). The Southend Flats and the Chapman Sands fronting Leigh on Sea continue the wide inter-tidal area westwards into the Thames estuary. However, the inter-tidal flats fronting Canvey Island and those to its west are narrow and discontinuous. The outer Thames flats are characterised by sediment with high sand content due to the winnowing action of waves that propagate into the outer estuary from the North Sea but sediment grain sizes are fine markedly towards Canvey Point and to its west (CHaMPS, 2003, SNS2, 2003). Saltmarshes are more likely to occur to west of this coastal unit hence, outside of the study boundary. Consequently the tidal flats fronting this frontage are likely to a sediment sink of sediment suspended within the Thames Estuary and the Offshore banks act as sources Transport of those sediments is likely to take place due to tidal movement and wave action (Interpretation). Beach erosion and development of tidal flats (mud and sands) are the dominant processes. However, beach erosion is not translated into EA Profile survey due to beach recharge (Interpreation). These pathways are weak and variable but may be reinforced by storm surge conditions.
Patterns of change:	**Past development:** The Thames is a very unnatural system. In the past has been a strong sinks for fine sediment, but with reclamation it has become weak source of fine sediment to the outer estuary (Futurecoast, 2002). A review of the geomorphology of the Thames estuary by IECS (1992) concluded that it had reached a dynamic equilibrium with tidal and wave forces over the Holocene, despite the continued human interference in the system including industrial and urban development on its banks and navigation dredging in it sub-tidal channels. The report showed that mudflat accretion in the estuary had kept pace with sea level rise over the past 100 years although its salt marshes had suffered considerable losses in area, a factor that continues to cause concern. **Recent trends:**

Frontage J – Southend-on-Sea

Chainage km km

Due to the coastline being heavily defended against erosion and flooding, upper shore has no response to the energy environment modifications. Beach recharge is likely to be stopping a process of beach erosion.

Future evolution (unconstrained):

It is calculated that the total annual sediment input into the Thames Embayment is approximately 10million m^3, although only 1 million m^3 of sediment is available at any one time. The total sediment demand of the Greater Thames embayment assuming a 2mm rise in sea level would be 5 million m^3 per year and 15 million m^3 per year assuming a 6mm sea level rise. This suggests that sediment budgets within the estuaries of the embayment could become increasingly depleted over the next 50 years and go into deficit over the next 50 to 100 years (SNS 2).

Dependency: Factors affecting the evolution of the frontage both internally and externally.

Control and sensitivities	Control features	Significance	Dependence	Chainage
London Clay Geology	Defences			
Thames Estuary sediment availability	Sediment Availability			

Internal interaction	External interaction
Redistribution of sediment.	Retention of beach material, may have an impact down drift (Shoebury) (Interpretation)

Sea level / climate change

For recent Defra (2006) guidance on sea level rise due to climate change, see section 1.4 in the main report.

Influence: Factors which may influence evolution of other areas.

Changes at this frontage are likely to have little impact to the frontage within the Essex SMP. Howerver, it may impact impact environments further into the Thames Estuaries.

Section 4 – Baseline management scenarios[39][40]

No active intervention (NAI)

Scenario description

This scenario assumes that defences are no longer maintained and will therefore fail over time. Timing of exact defence failure cannot be deduced. However a failure epoch can be determined, as described in the 'Assessment of coastal defences' report. This scenario also assumes that all other management practices, including beach recharge and dredging will cease.

Shoreline response

There are three main morphological features of which the shoreline response will be assessed: the London Clay cliffs, the sand and shingle beach and the intertidal sands and muds.

Epoch 1

As coastal and flood defences are likely to remain on epoch 1, it is expected that erosion rate are likely to increase as beach recharge ceases. At this stage the actual rate of erosion for this scenario remain uncertain. Beach erosion will lead to narrowing of the beach; however, the presence of groynes is likely to limit the beach erosion. No cliff movement is expected. The intertidal sands and flats will continue to accrete at similar to the rates registered now. In addition, the tidal flats will continue to flatten as a response to sea level rise and increased wave energy, effectively, waves propagate more towards the shore.

It remains uncertain whether increasing of the extent of intertidal flats is likely to reduce beach erosion due to attenuation of waves.

Epoch 2

Coastal and flood defences are likely to fail at some point within epoch 2. Under this scenario is assumed that failed defences will have no residual function. Following failure of the defences erosion rates are likely to increase further due to absence of coastal protection. Narrowing of the beach is the most likely scenario; erosion rates remain largely unknown. It is uncertain whether such erosion will continue and eventually breach the London Clay cliffs. Furthermore, as defences fail it might be the base that the london clay cliffs will start to erode due to instability and/or wave-tidal action

[39] All management scenarios assume that the current management practices undertaken in adjacent SMP study areas will continue.
[40] All assessments of shoreline response have a band of uncertainty, which increases for later epochs.

and release sediment to the frontage. Rate of accretion of the intertidal flats is likely to slow as less sediment becomes available within the Thames Estuary and the environmental reaches stability to sea level rise. With defence failure, an increase in tidal prism is expected. However due the geological contrastaint (lodon cliffs). It is unlikely that the tidal prism would increase or that such increase would be insgnificant.

The present erosion rates are uncertain due to. Effectively erosion/accretion rates recorded by the Coastal Trend Analysis due not factor out the beach recharge.

Epoch 3

Coastal and floods defences will have failed, note that under this scenario it is assumed that failed defences will no residual function. It is uncertain whether the beach will continue to erode or would have reached stability as sea level rises. Due to interaction between the foreshore and the cliffs it is also uncertain if the London clay cliffs will reach stability or continue to undergoe erosion. Due to the increased sediment demand within the Thames estuary it is likely that no more sediment will be available for intertidal flats development. Under those circumstances two processes may occur: the intertidal flats will start undergoing erosion or they would have had already reached stability hence will not change significantly.

It should be noted that foreshore evolution whithin the his frontage influences and it is influenced by cliff behaviour.
The present erosion rates are uncertain due to. Effectively erosion/accretion rates recorded by the Coastal Trend Analysis due not factor out the beach recharge.

No quantitative analysis can be undertaken regarding the sediment input generated by dredging, although is know that dredging is likely to liberate sands into the sediment pathway. Given the long history of dredging, and the still required the need for nourishment of beaches, the contribution of the sands liberated due to dredging is taken has being negligible for the purpose of these assessment. However the real contribution is uncertain.

Analysis of beach profiles will be required to clarify some of the uncertainity.

Epoch	**Sea level rise (myr^{-1})**	**Beach slope**	**Erosion rate (myr^{-1})**
Epoch 1 (2009 – 2025)	0.004		
Epoch 1 (2025 – 2055)	0.085		
Epoch 3 (2055 – 2105)	0.014		

Epoch 1: Years 0 – 20 (2025)		Epoch 2: Years 20 – 50 (2055)		Epoch 3: Years 50 – 100 (2105)	
Defences	**Natural coast**	**Defences**	**Natural coast**	**Defences**	**Natural coast**
Defences remain	The beach frontage will remain at the present postion. It is expected that some level of erosion will have occur downdrift (to the east) of the groynes and pier. This is already evident at Shoeburyness. The protected london Cliffs will also remain in place. Tidal flats will continue to develop.	Defences will fail	Further erosion of the beach frontage is expected as defences fail. Some Cliff retreat is probable. Intertidal flats will continue to develop, however, at much slower rates.	No defences	Beach may continue to erode or it may reach stability.This uncertainty is also observed and linked to cliff movement. Intertidal flats will cease to accrete. They may begin to erode or remain stable.

With present management (WPM)

Scenario description

This scenario assumes that defences are maintained to provide a similar level of protection to that provided at present. This will involve regularly inspecting and maintaining defences. This scenario also include the assumption that other management practices such us dredging will also continue at the present level.

Shoreline response

Epoch 1

Under a WPM, there would be no Cliff retreat throughout the Southend-on-Sea frontage. The position of the shoreline will be held largely at the same position, however, there would be local changes to the foreshore with likely accretion of sands updrift of the groynes and conversely there could also be some localised erosion donwdrift. Beach erosion/accretion rate will are expected to remain unchaged. The development of the intertidal flats is not constrained by the defences, hence it is assume that they will display the same behaviour as in a NAI scenario.

Epoch 2
Same as Epoch 1

Epoch 2
Same as Epoch 2

Epoch 1: Years 0 – 20 (2025)		**Epoch 2: Years 20 – 50 (2055)**		**Epoch 3: Years 50 – 100 (2105)**	
Defences	**Natural coast**	**Defences**	**Natural coast**	**Defences**	**Natural coast**
Defences will remain	No cliff movement. Beach levels will remain the same, within some localised accretion/erosion due to coast protection. The intertidal flats will display the same behaviour as in a NAI scenario	Defences will remain	Same as Epoch 3. Intertidal flats will development as they would under a NAI.	Defences will remain	Same as Epoch 2. Intertidal flats will development as they would under a NAI.

F3. ASSESSMENT OF COASTAL DEFENCES

F3.1 Introduction

The aim of Task 2.1 as a whole is to review coastal behaviour and dynamics. The appreciation of these processes underpins the sound development of the SMP. This included assessment of the natural features as well as considering the existing defences. The results from this task will be used to identify risks, and test the response and implications of different management policy scenarios over three separate timescales (present day to 2025, 2025 to 2055 and 2055 to 2105).

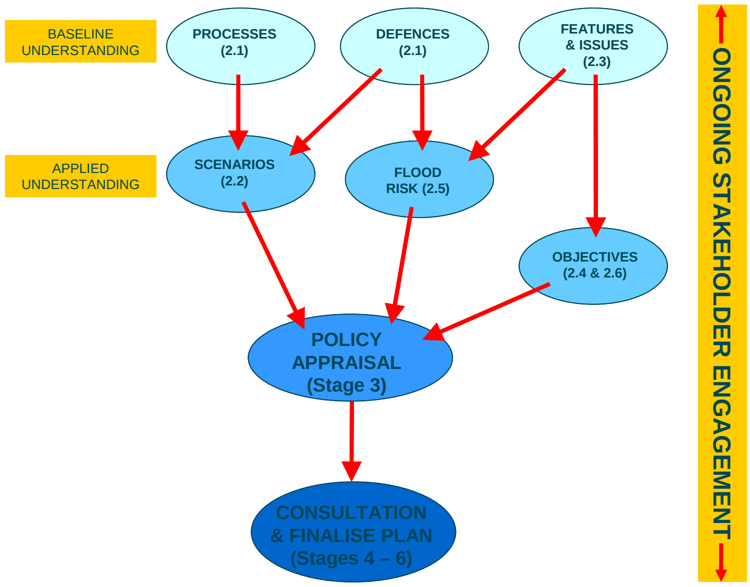


Figure 3-1 Stages within the SMP process

Task 2.1 is divided into two explicit tasks, and this note reports on Task 2.1b, following extensive review. It consists of the assessment, in broad terms, of every coastal and estuarine defence within the boundaries of the SMP study area. It has been further split into two stages:

- Theoretical approach based on condition, according to the SMP guidance;
- Validation by asset managers.

An initial assessment of coastal defences took place earlier on in the SMP process and it was presented to the Client Steering Group (CSG) on the 12/09/2008. Following input from Tendring District Council, Southend-on-Sea Borough Council, Thames Estuary 2100 and the Environment Agency Asset Management Team, fundamental changes were incorporated into the method of assessment, particularly on the determination of residual life of the flood defences.

This note aims to outline the methodology developed by the Environment Agency's Essex Asset Management team and Royal Haskoning and details how the asset information sourced from the different local authorities was incorporated. This revision is intended as a conclusion for the assessment of coastal and flood defences incorporating all the comments and concerns raised during the review period.

F3.2 Residual Life

F3.2.1 SMP Guidance

The SMP guidance provides residual life numbers based on the existing defence condition grades for a number of defence types (Table 3-1). This information has been derived from previous National Appraisal of Defence Needs and Costs (NADNAC) deterioration profiles.

Defence Description		Estimate of Residual Life (years)				
		Grade 1	Grade 2	Grade 3	Grade 4	Grade 5
Seawall (concrete/masonry)	Fastest	25	15	10	5	0
	Slowest	35	25	15	7	0
Revetment (concrete/rock)	Fastest	25	15	10	5	7
	Slowest	35	25	15	7	0
Timber groynes/timber structures	Fastest	15	10	8	2	0
	Slowest	25	20	12	7	0
Gabion	Fastest	10	6	4	1	0
	Slowest	25	10	7	3	0

Table 3-1 Estimate of deterioration for assessment of residual life (from SMP guidance)

The SMP guidance does not contain residual life estimates for grassed earth embankments, which constitute a high proportion of the flood defences of the Essex coast. A method to estimate residual life was initially applied in accordance with the approach developed for the Wash and North Norfolk SMP. Table 3-2 defines the residual life assessments previously adopted to use for the grassed earth embankments (sea banks) of Essex.

Table 3-2 Estimate of deterioration for assessment of residual life adopted for grassed earth embankments (sea banks)

Defence Description		Estimate of Residual Life (years)				
		Grade 1	Grade 2	Grade 3	Grade 4	Grade 5
Sea bank	Fastest	25	15	10	3	0
	Slowest	40	25	15	5	0

F3.2.2 Essex and South Suffolk SMP Approach – 'Estimated Unmaintained Life'

Following review of the SMP guidance approach and its analysis results, the EA Asset Management Team and Royal Haskoning developed an alternative approach. Effectively, according to the EA Asset Management Team, the SMP guidance approach to derive residual life from Condition Grade led to a poor estimation of the defences' actual residual life under No Active Intervention. A summary description of the methodology developed can be found below:

- All defences were to be divided into 4 main asset classes which would be assessed differently (Table 3-3). The process to establish the 'estimated unmaintained life' (i.e. residual life under No Active Intervention) begun with an 'Assumed Design Life' and then the exposure and material type were factored in. The defence class has been determined by the EA Asset Managers.

Table 3-3 Essex Defence classes

Reinforced Concrete Wall	Steel Sheet Piling	Revetted Embankment	Unrevetted Embankment
1	2	3	4

- The exposure factor attributed was dependent on the exposure classification category. Those are detailed below:

Table 3-4 Essex Defences' exposure categories

HIGH	MEDIUM	LOW
Very exposed sites, such as open coastline southern banks of estuaries **without** salting of mudflat protection.	Includes northern banks of estuaries as well as defences **with** salting protection.	Includes top of creeks and areas of high foreshore.

The physical characteristics of the defence material were also taken into account, particularly for the revetted embankments. The categories in question included: open stone asphalt, Canewdon, grouted and ragstone, block work and grass.

The flow chart below details the process undertaken to determine the defences' 'estimated Unmaintained Life.

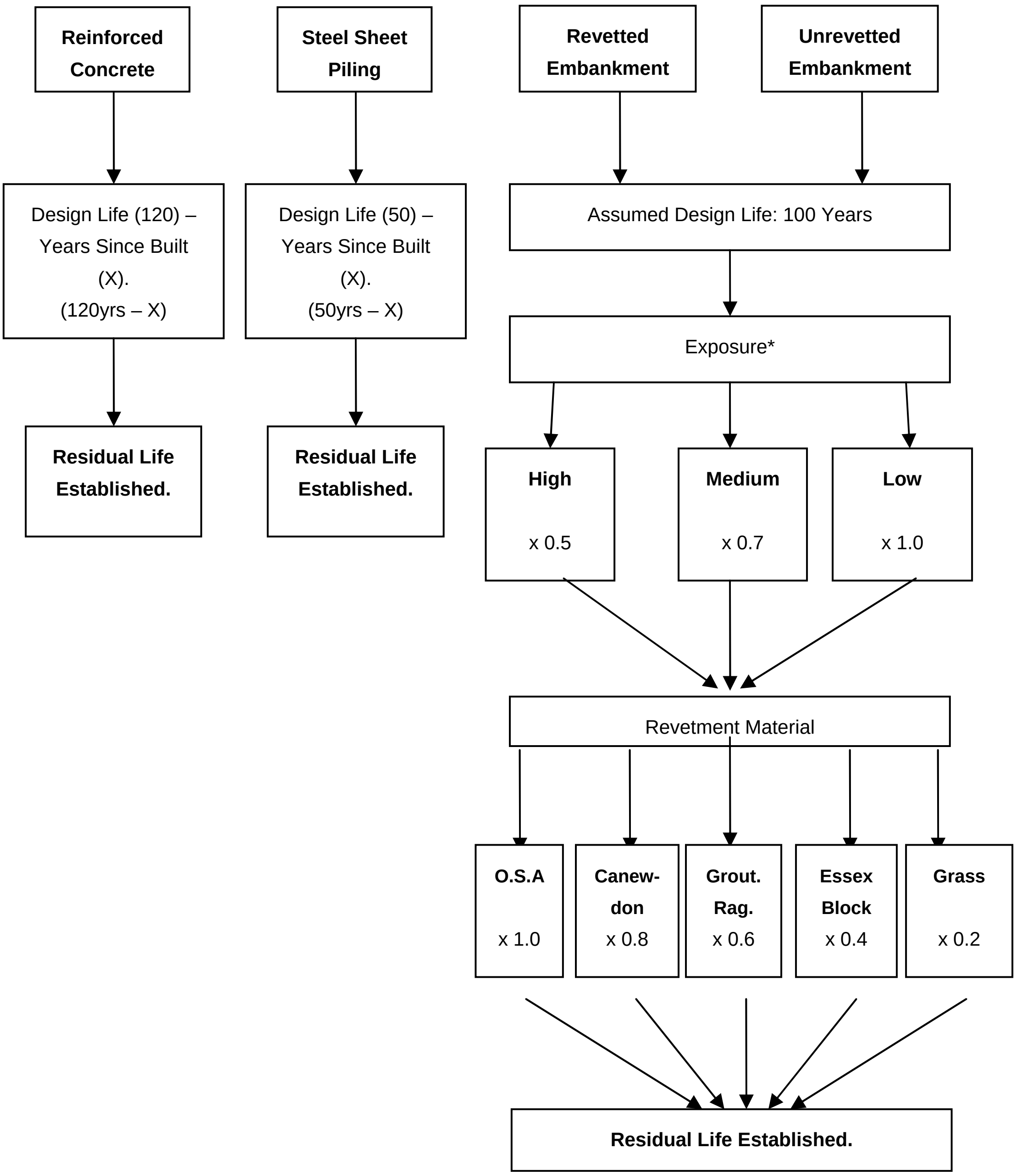


Figure 3-2 Determination of Estimated Unmaintained Life

Considerations recommended by the EA Asset Management Team:

- All counter walls are to be given a residual life of 100 years and excluded from this assessment.
- All assets upstream of the Colne Barrier (0510914700101C99) are only exposed to tides up to 3mAoDN as this is the Barrier's operational level. No wave action is experienced.
- East Mersea Hall Wall (Clay embankment - Asset 051CDBLAC0301C01) was assigned a residual life of 1-2 years without consideration of the flow chart. This is due to its sandy clay

core in conjunction with its location and therefore if any blocks are removed these would need replacing as a matter of urgency as wave action would severely damage the wall.

F3.2.3 Approach for non-EA defences

For flood defence frontages not maintained by the EA the Essex and South Suffolk SMP approach has been applied for the purpose of consistency. However, for the coastal erosion frontages the original SMP Guidance approach was still deemed relevant.

The defences not maintained by the EA are listed below:

- Walton-on-the-Naze – Tendring District Council
- Frinton-on-Sea – Tendring District Council
- Clacton-on-Sea – Tendring District Council
- Langenhoe Ranges – MoD
- Potton Island
- Rushley Island
- Havengore Island – MoD
- Foulness Island – MoD
- Shoeburyness Ranges – MoD
- Southend Frontage – Southend Borough Council (as far west as Leigh train station TQ8320685784, then EA maintained westwards.

It should be noted that the National Flood and Coastal Defences Database (NFCDD) was used as the main source of information, with further information provided by Local Authorities and local knowledge validation.

<u>Local Authorities</u>

As mentioned above the SMP guidance approach was applied to coastal erosion defence. That includes the frontages of Tendering and Southend-on-Sea. Since the EA are not responsible for the maintenance of such defences, information provided by the Tendering District Council was used to update and validate the data contained within the NFCDD. The Tendring District Council data set included an Asset register for defences in Brightlingsea, Clacton & Holland, Dovercourt and Harwich and Frinton & Walton.

The asset inspections of the Tendring defences did not apply the condition grade classification approach. However nomenclature of the categories was identical and the conversion was undertaken as below.

Table 3-5 Tendring District Council defences categories and relationship with NFCDD classification

Tendring DC	NFCDD Conversion	
Very Good	1	Very Good
Good	2	Good
Fair	3	Fair
Poor	4	Poor
Very Poor	5	Failure

As well as the grading system, the data provided by the Tendring DC included residual life under maintenance. The assessment ensured that the estimated unmaintained life calculated using the SMP approach did not exceed the maintained residual life described under such scenarios.

The Southend-on-Sea coastal protection and flood defences were attributed to estimated unmaintained life (residual life under NAI) in accordance with EA and Local Authority asset managers and operations' delivery expert knowledge.

For other local authorities and private defences the Essex and South Suffolk SMP method was applied for flood defences and the SMP approach for the coastal erosion frontages.

Felixstowe Port

The data on the Felixstowe Port defences was not contained within the NFCDD and it was acquired within Royal Haskoning. The data in question refers to the Felixstowe South Reconfiguration Flood Risk Assessment Revision produced by Royal Haskoning in March 2008. Since the Felixstowe Harbour is contained within the Flood Zone, application of the Essex and South Suffolk SMP method was deemed appropriate. Appendix E lists the data available for the Felixstowe Port.

The flood defences in Foulness Island, protecting a flood zone, are owned and maintained by the Ministry of Defence. The Essex and South Suffolk SMP method was applied in line with the consistency approach discussed above.

F3.2.4 Assumptions and Considerations

- Application of the Essex and South Suffolk SMP method for Reinforced Concrete and Steel Sheet Pilling defences require knowledge of the year of build. An average year of build of all defences in Essex and South Suffolk SMP area was calculated and the few defences for which the year of build was not provided were attributed the average year of build.

- Particularly for coastal defences, the primary line of defences was the one taken into account when considering the defence failure.
- Fluvial defences were not included.

F3.3 Validation by Asset Managers and Operations Delivery

Following the application of the SMP Guidance approach to the coast protection defences and the Essex and South Suffolk SMP approach to flood defences the resulting estimated unmaintained lives were reviewed and validated by EA and Local Authorities Asset Managers and Operations Delivery personnel as well as other groups with expert and local knowledge (e.g. Land Owners). These reviews and validations took place in during Key Stakeholder Group meetings, Land Owners' meetings and EA internal meetings.

As a result, several estimated unmaintained lives of defences were altered to better reflect the expert knowledge and their actual condition. The results of the assessment and the relevant maps are outlined on section F3.4.

F3.4 RESULTS

F3.4.1 Referencing of the defences

A unique 'SMP2 Reference' has been assigned to all relevant defences within the SMP study boundary. Defences will be numbered in numerical order according to the alphabetic order of the NFCDD reference. Ideally we would number the defences from North to South; however, due to the large data set it is impractical to do so. Defences with no NFCDD reference number such as Felixstowe and Two Tree Island were added at the end.

F3.4.2 Assessment

The results of Task 2.1b are shown in Appendix A and B. This table provides an overview of the defences present within the study area and includes each individual defence's location, description and maintainer. Up to this column all information comes directly from NFCDD. The table also summarises the defined asset classes, exposure and material categories and the fastest and slowest estimates of 'unmaintained life'. The Defence Category column relates to the With Present Management scenario.

The 'estimated unmaintained life' for each defence has also been used to define the Epoch during which the defence is likely to fail. The three Epochs are defined under the SMP guidance for Task 2.2:

- Epoch 1 - Present day to 2025;
- Epoch 2 - 2025 to 2055;
- Epoch 3 - 2055 to 2105.

This will provide vital information for the completion of the tasks on flood risk, erosion risk and policy appraisal.

It is important to note that there are a large number of defences that could fail within Epoch 1, but may not fail until Epoch 2. This is a result of the uncertainty in the estimation of residual life of defences, particularly for coastal defences at erosion frontages. Essentially, the defences were assigned residual life based on their slowest and fastest rate of deterioration, giving rise to two estimations for the year of failure. This uncertainty will need to be taken into account in subsequent tasks.

In order to prepare the defence assessment output for the 'With Present Management (WPM)' scenario, for policy appraisal and shoreline response testing, it was necessary to define the functions of the defence 'practice' rather than simply the specifics of the structure itself. As a result an extra column has been inserted into the output table in Appendix A1 to this note (labelled 'Defence Category') in order to determine how the present management and practices in the study area affect shoreline processes and behaviour. Defences have been categorised using Table D2 in Appendix D of the SMP Guidance (volume 2). A summary of the categories and the assumptions for each are included in Table 5.

Table 3-6 Assumptions for the With Present Management baseline assessment

Defence Type Category	Example Structure	Brief Assumptions
Linear Stoppers	Seawall, Revetments, Grassed embankments	Minimise breach, structural integrity remains and wall is rebuilt at a similar standard of effectiveness
Linear Reducers	Maintained shingle barrier	Continues to reduce erosion, although level of effectiveness may change and therefore rate of erosion may change
Cross-shore interrupters	Groynes, breakwaters	Continues to interrupt drift but not necessarily the same amount
Changers	Recharge/recycling	Continues to recharge with same amount, sediment type and timing

Note that we have assumed that maintained grassed embankments will act as linear stoppers, just like seawalls.

The 'estimated unmaintained life' for each defence is mapped in Figure 3-4 to Figure 3-10.

F3.4.3 Discussion

The analysis took into consideration 1524 defence records Figure 3-4 to Figure 3-10 from the sources previously described. Reinforced concrete (15%), sheet pilling (6%), revetted banks (51%) and unrevetted banks (10%) are the predominant defence types in the Essex and South Suffolk Coast (Figure 3-3 to Figure 3-10). Flood embankments, revetted and unrevetted embankments can be found in estuarine and coastal environments such as Colne, Bradwell, Dengie and Foulness. Seawalls (reinforced concrete) can be found protecting shingles beaches of the Tendring Peninsula and the coastline from the Naze and Clacton-on-Sea.

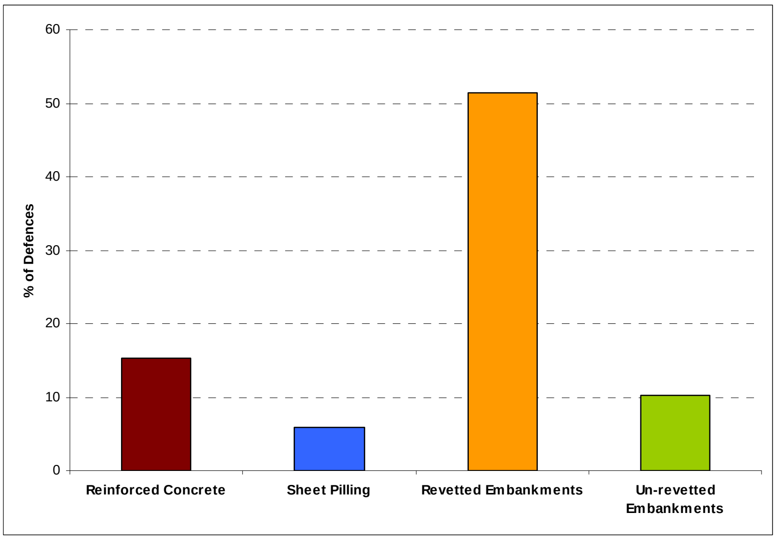


Figure 3-3 Essex Coastal Defences – SMP defence category

Figure 3-4 to Figure 3-10 indicate the estimated unmaintained life of defences throughout Essex and South Suffolk. The weakest lines of defence fall within the areas of coastal erosion including Mersea Island and Tendring. The strongest line of defence can be found in the River Stour, the Crouch and Southend-on-Sea.

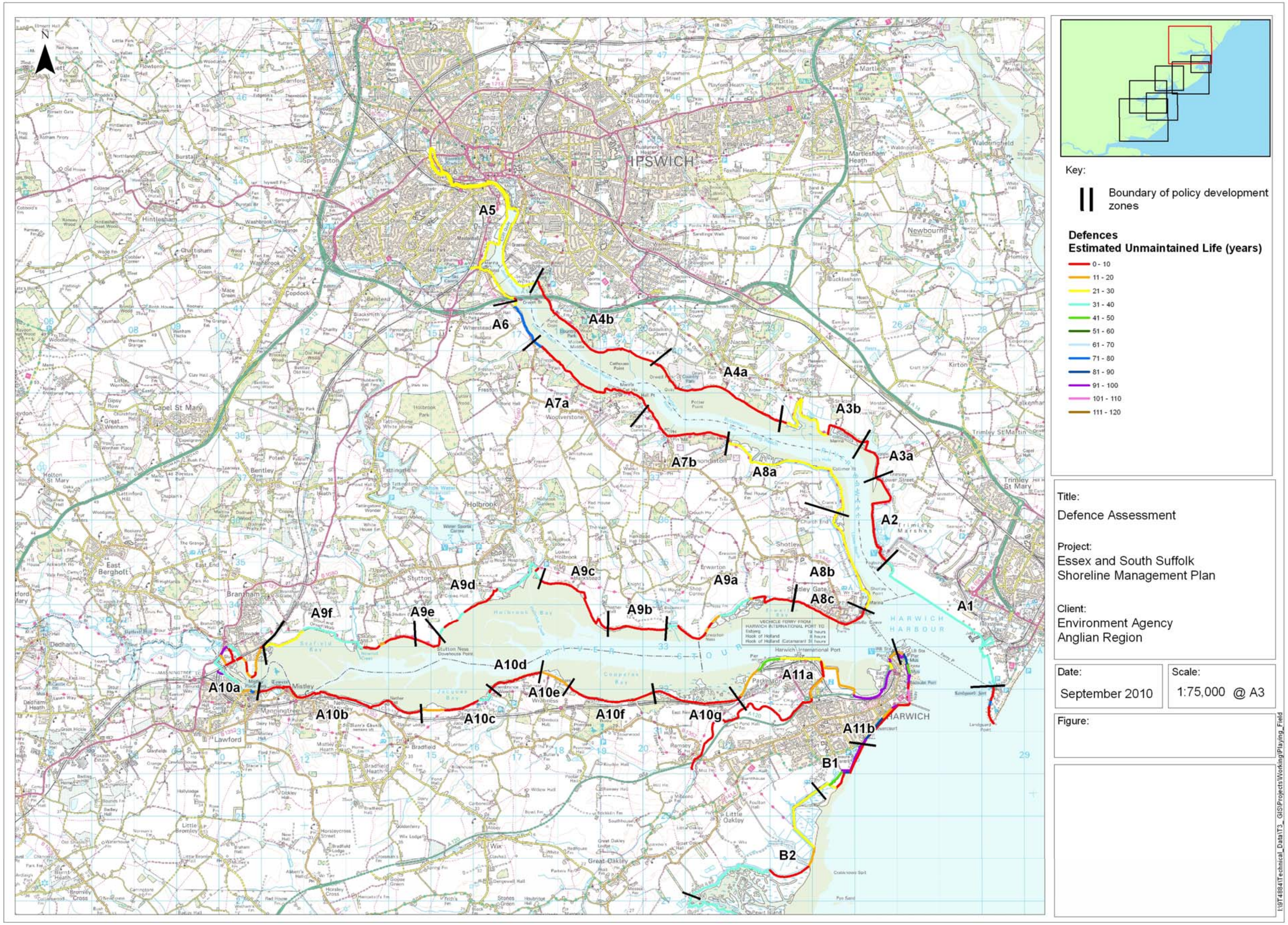


Figure 3-4 Estimated Unmaintained Life of Defences in Stour and Orwell

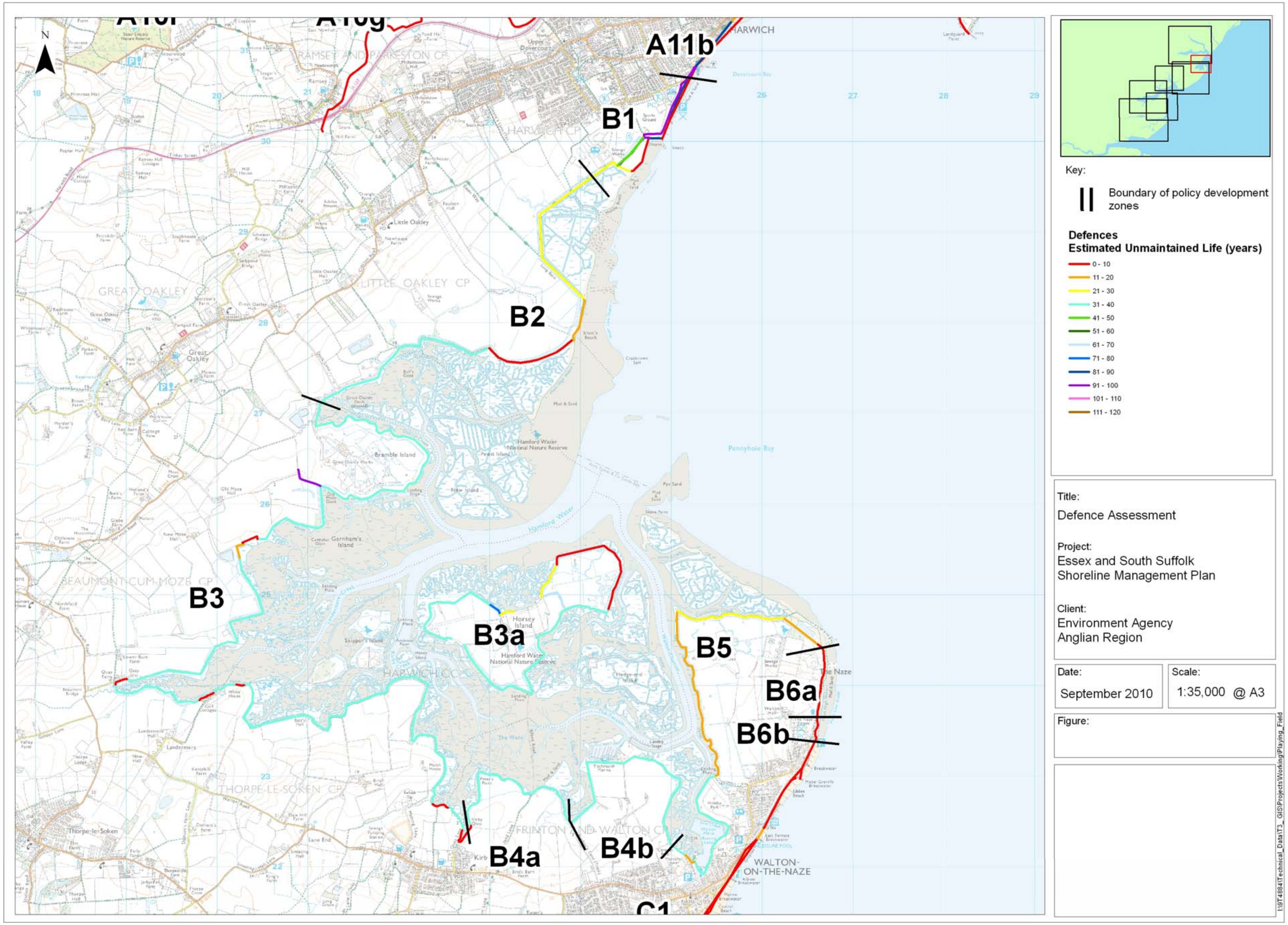


Figure 3-5 Estimated Unmaintained Life of Defences in Hamford Water

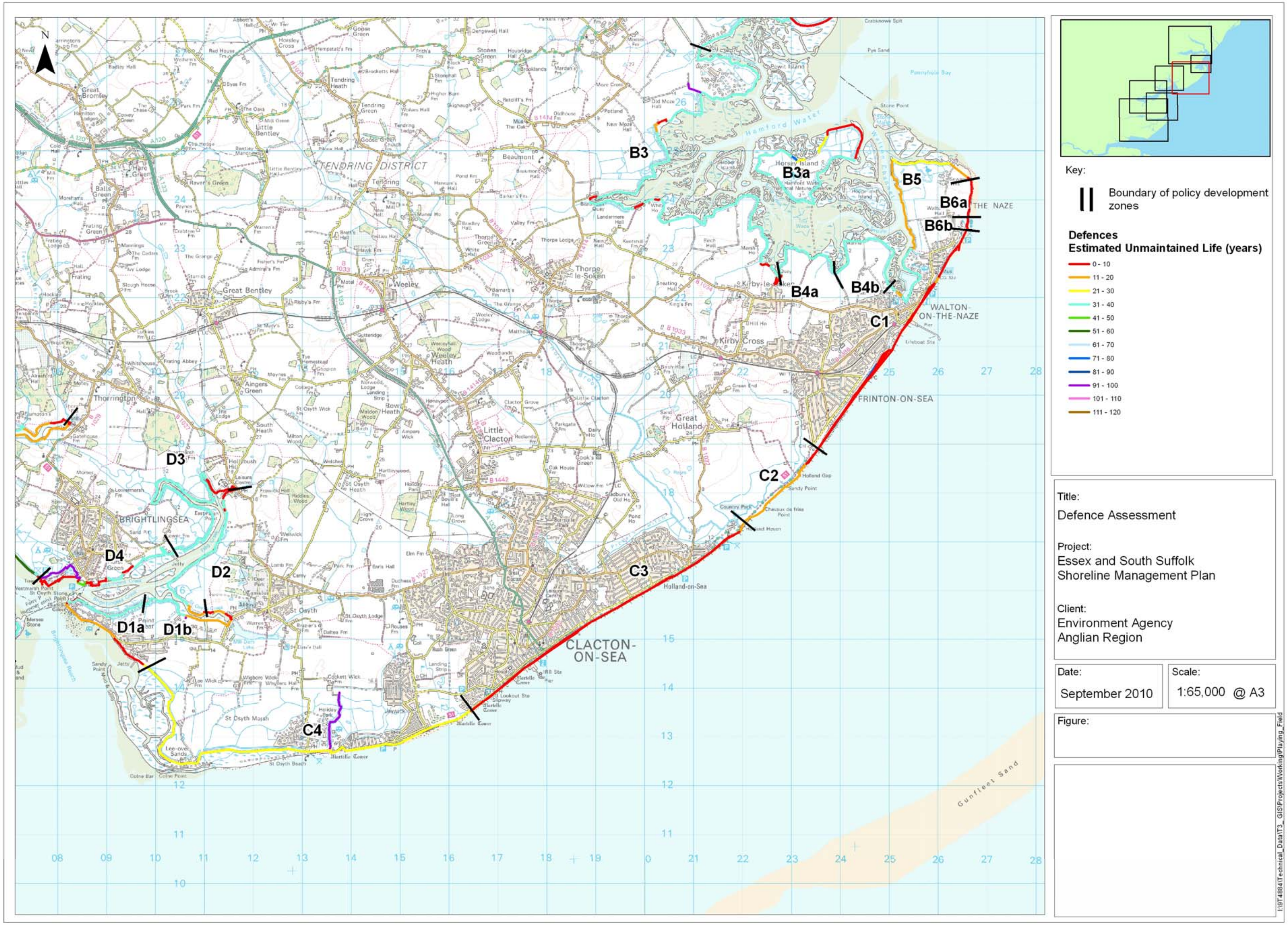


Figure 3-6 Estimated Unmaintained Life of Defences in Tendring

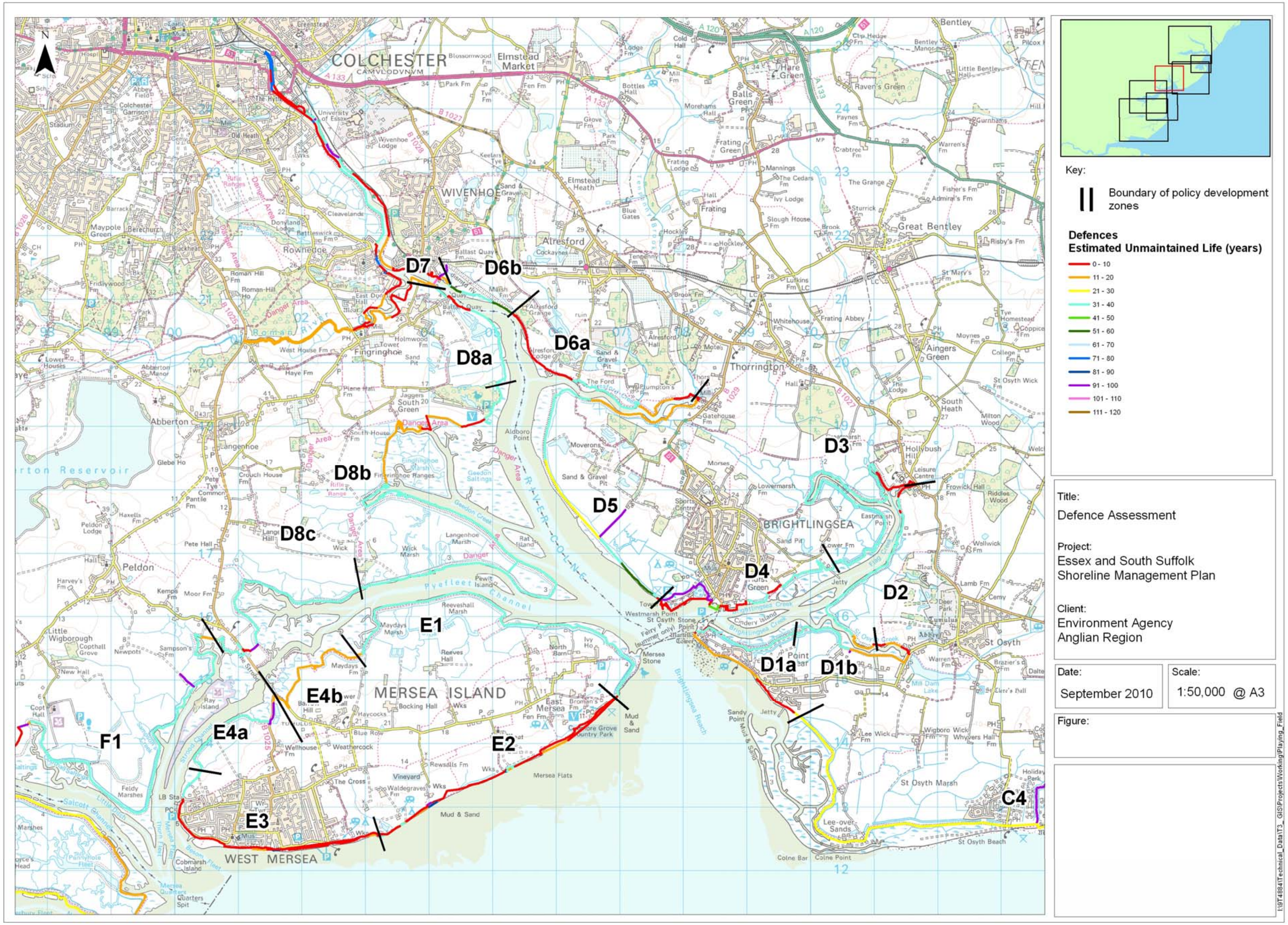


Figure 3-7 Estimated Unmaintained Life of Defences in the Colne Estuary and Mersea Island

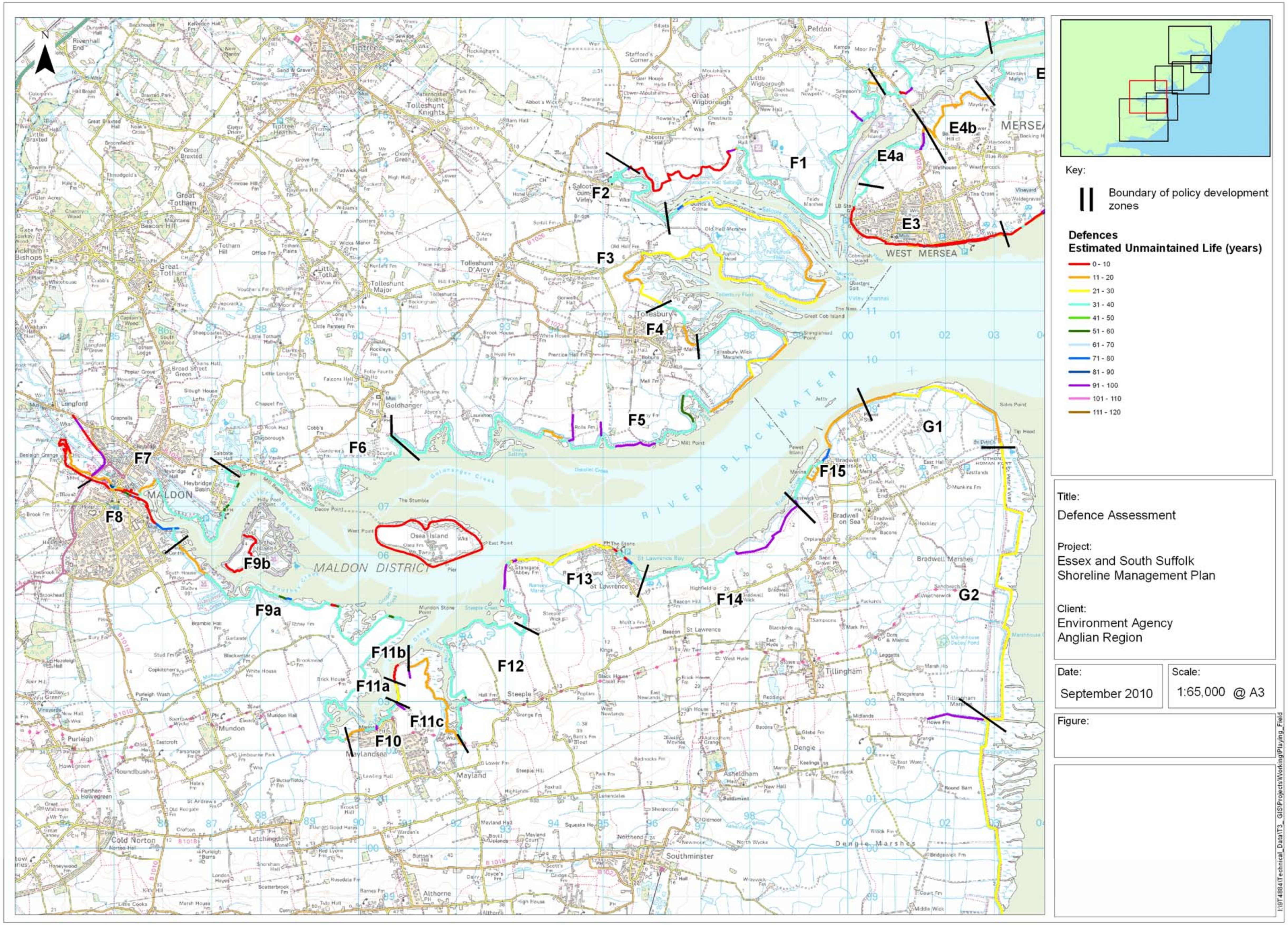


Figure 3-8 Estimated Unmaintained Life of Defences in the Blackwater Estuary

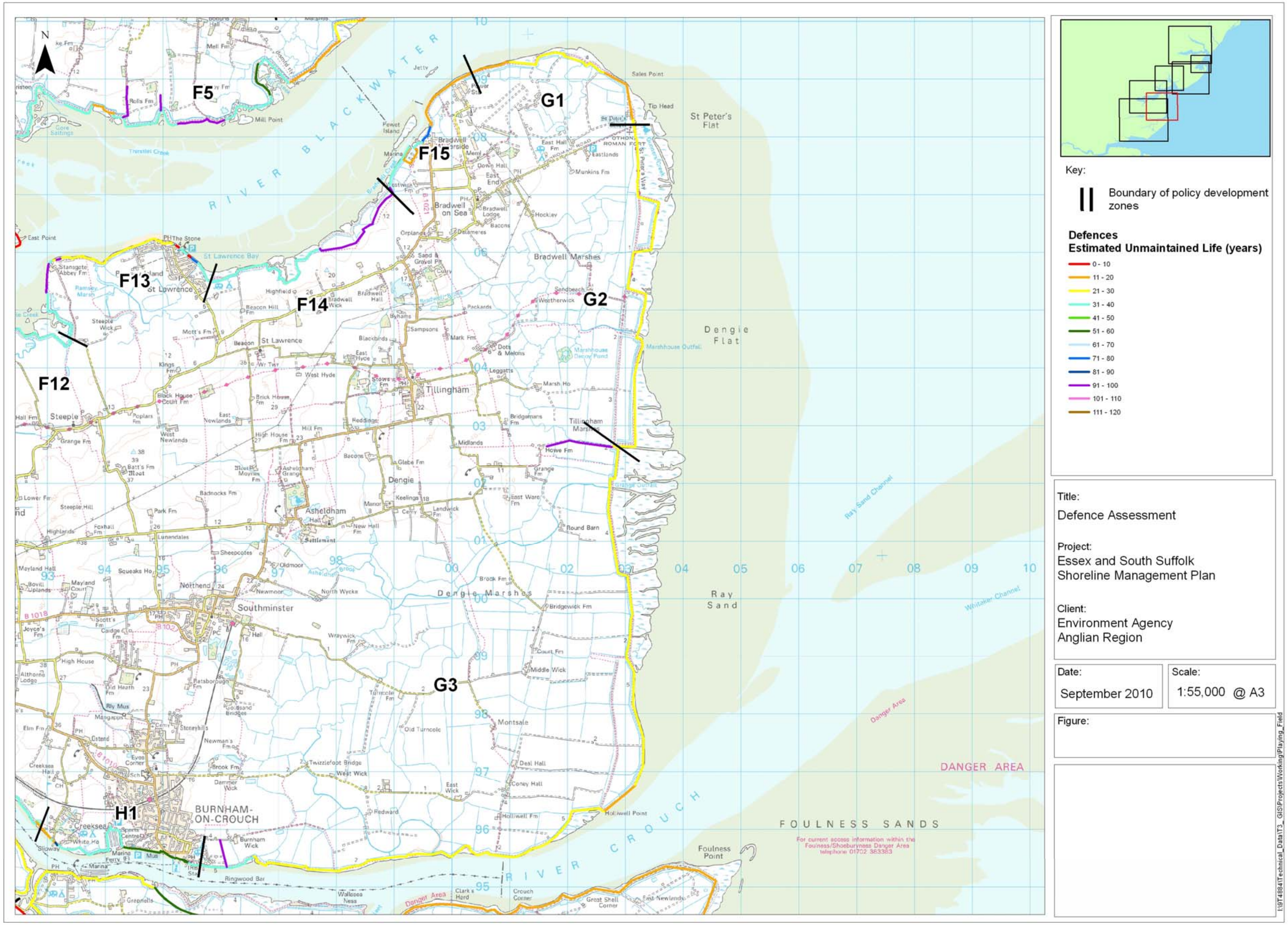


Figure 3-9 Estimated Unmaintained Life of Defences in the Dengie Peninsula

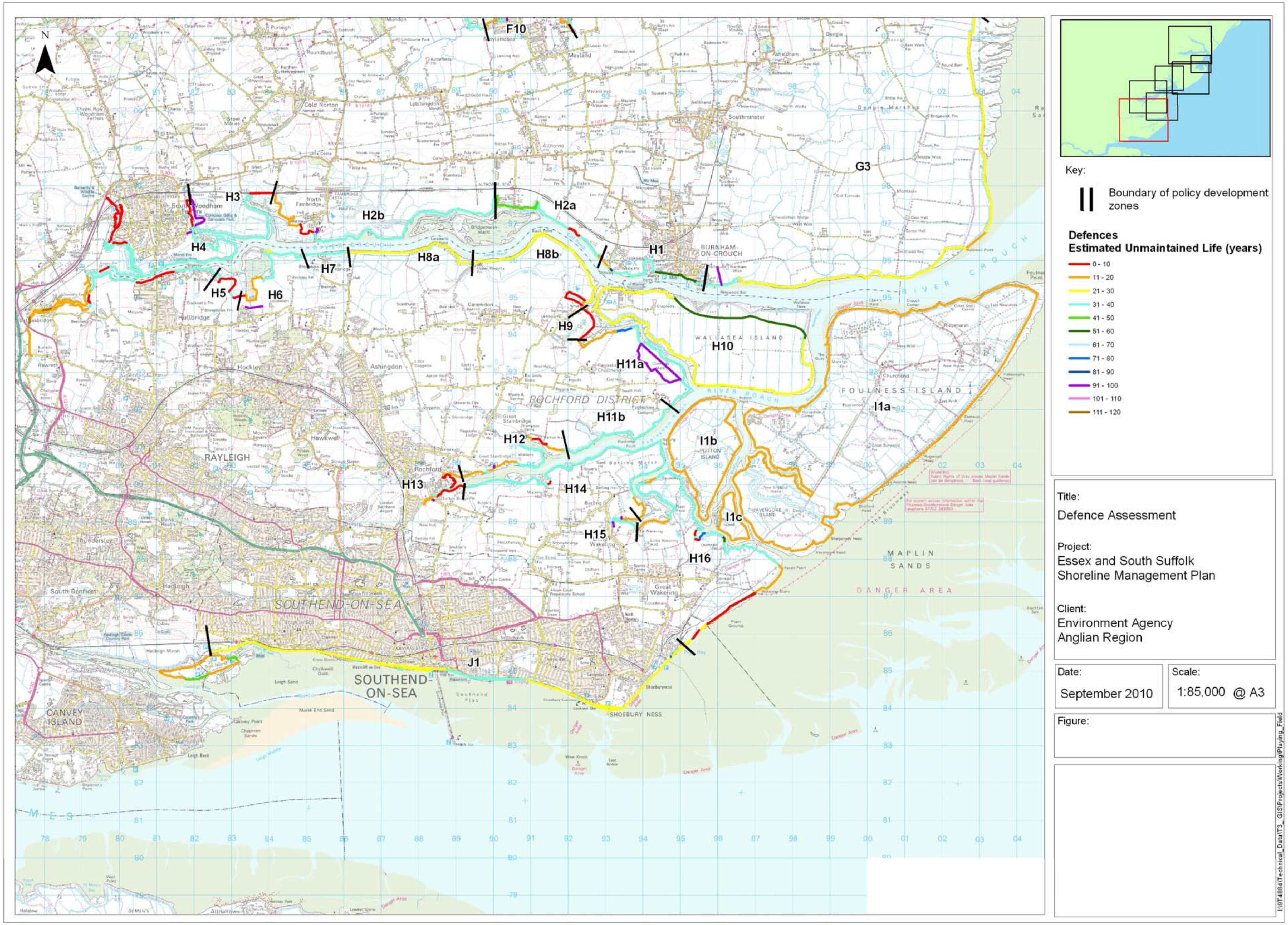
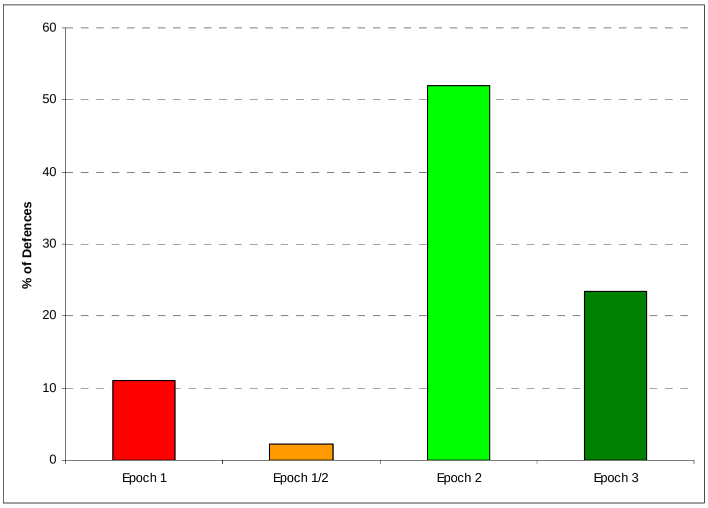


Figure 3-10 Estimated Unmaintained Life of Defences in the Crouch and Roach, Foulness and Southend



In summary, the majority of the sea defences along the Essex coast are expected to fail within Epoch 2 (52%) under a policy of NAI. There are also a large proportion of defences (23%) likely to fail in Epoch 3. Defences likely to fail in Epoch 1 can be found in Tendring, Mersea Island and Shoeburyness.

F4. COASTAL RISK MAPS

F4.1 Introduction

Over the past ten years, following the production of the first Essex SMP (1997) many projects have been initiated to study the dynamics of the Essex and South Suffolk coast in more detail. These studies have produced a wealth of knowledge on both the estuaries and open coastal frontages of Essex and South Suffolk. As a result, the studies have lead to a better understanding of the coastal and estuary processes that determine coastal behaviour and provided the evidence to identify key issues and opportunities with regards to significant pressures at the Essex and South Suffolk coast. Particularly important has been to link the pressure points of the coast to the coastal defences and assess how coastal pressure and residual defence lives are interlinked. Identifying those 'risky' areas where coastal processes are putting the defences under threat has been a key milestone in the process of developing the Essex and South Suffolk SMP. Evidence has been predominantly derived from the following strategic level studies as they have specifically been beneficial to enhancing the understanding of the vulnerability of the coast:

- 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;
- Coastal Trends Analysis - Essex (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.

For each of the nine management units the evidence put forward by the above mentioned reports was mapped jointly with the information on the defences under pressure. These 'coastal risk maps' were presented to the CSG and EMF. Subsequently the coastal risk maps were presented at KSG meetings where stakeholders were able to review and share their local knowledge during in-depth discussions. The following section will provide a summary of the key findings per management unit and presents the coastal risk maps in Figure 4-1 to Figure 4-7.

F4.2 Stour and Orwell

F4.2.1 General description

The Stour and Orwell Estuary complex is viewed as an integrated coastal unit. The two rivers share a mouth, located between Landguard Point and Harwich, to the south of Felixstowe.

The Orwell/Stour estuaries are home to an extensive area of intertidal habitats, and as such are internationally recognised by SPA and Ramsar designations. Between the two estuaries there exists a total 2000ha of mudflats, 190ha of saltmarsh and 75ha of coastal grazing marsh, which all provide a feeding and breeding ground for many important wintering bird species. Intertidal regions of the Orwell vary between 100-400m wide, with larger areas on the northern bank. Mudflats border the channel of the Orwell and provide a habitat for many plant species, such as Glasswort and Cordgrass. Saltmarsh is restricted to higher elevations than mudflats, and on the Orwell it only exists in four main areas. Agricultural areas adjacent to the Orwell, which aren't officially protected by SPA or Ramsar designations, are important in their own right; Trimley and Shotley, on the lower reaches of the Orwell, are examples of this "supporting habitat" and provide resources for a population of the protected Brent Goose.

In the Stour the most extensive intertidal flats are located within the sheltered inter-estuarine bays. The most significant of these are Seafield, Holbrook and Erwarton on the northern bank, and Copperas and Bathside on the southern bank. Typically, saltmarsh habitat exists above the influence of the smallest (neap) tides, and is 50-100m wide, but extending to 200m, 600m and 300m wide at Sleafield, the eastern part of Copperas and western part of Erwarton Bays, respectively. Erosion of the intertidal habitats has been occurring since the 1920s in the Stour, associated with a large die-back of Eelgrass which holds the fine sediments together. In 1925-1965 an average 20mm per year of the vertical elevation of mudflats was lost. Although this has slowed today (a lowering on average of 13mm per year, 1994-1999) it is still significant, at 1.8% losses per year. Predominantly, these losses are caused by land claim and erosion.

F4.2.2 Key estuarine processes and issues

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 1m/s on the Stour, and 0.8m/s on the Orwell, at Shotley. Despite the similarities in tidal hydrodynamics in both estuaries, overall, the Orwell is considered to be flood-dominant, 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.

The Stour and Orwell Rivers are considered to provide a negligible supply of fresh water and sediment to the estuaries, in comparison to marine inputs. Average flows are just $1.4m^3/s$ in the Orwell and $3.5m^3/s$ in the Stour (at Stratford St Mary), compared with a peak flood-tidal discharge of $10{,}000m^3/s$, in the Stour. 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 propagating along the whole of this estuary. Any waves that do 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.

F4.2.3 Zones of erosion and accretion

Environment Agency profiles from north to south along the frontage south of Harwich show: at Harwich, little change, with a small steepening of the profile; at Dovercourt, an average erosion rate of $-0.4myr^{-1}$, with a halving of the beach width from c12m to c6m (1992-1997); at middle beach, south of Dovercourt, a retreat averaging $1.5myr^{-1}$, associated with a flattening of the profile, whilst saltmarsh fronting the clay embankment has retreated c27m between 1992-2006. The last profile on this frontage, just north of Little Oakley shows a mean slightly erosional, steepening trend.

The Orwell is a confined estuary and there is little room for adaptation. The upper reaches of the Orwell are constrained by a narrow, steep sided valley. On the northern side of the estuary the banks are consistently steep; particularly so at the Ridge to Fagbury cliff, behind Felixstowe Docks, and Sleighton Hill. High ground to the south of the estuary is located at Bourne Hill and Wolverstone, down to Collimore Point. Ridges at Crane’s Hill and Shotley Point on the eastern side guide the estuary down to its mouth. Erosion is taking place along the high ground frontage, which may act as a sediment source further upstream of the Orwell.

The Orwell is generally an accretive estuary due to its flood tidal dominance. In the lower reaches, however, vertical erosion of mudflats has led to a reduction in elevation of between $15\text{-}18mmyr^{-1}$. In the upper reaches, upstream of Levington Creek, mudflats actually accreted at an average rate of $13\text{-}14mmyr^{-1}$ between 1994 1999. Saltmarsh is still being eroded horizontally at a rate of $1hayr^{-1}$, although rates have slowed from 2.2% a year (1973-1988) to 1.7% a year (1988-1997) (Burd, 1992). Unprotected stretches of banks are eroding at a rate of: $0.1myr^{-1}$ along 6.5km of on northern shore and $0.2m\ myr^{-1}$ along 6.5km of southern shore (IECS, 1993).

The intertidal areas currently present in the Orwell are all subject to erosion, with the most severe erosional trend occurring between the estuary mouth and the middle estuary.

The Stour is classified as a confined estuary with little room for adaption. The channel itself is strongly influenced by its steeply rising banks, which consist of low boulder cliffs, but are interspersed with fringes of Spartina saltmarsh and a total of seven shallow bays along its length. Steeper land constraining the estuary is also located at Sutton Ness, Wrabness, Harkshead Point, Erwarton and Parkeston. Although the Stour is broader than the Orwell, specifically in the middle part, there are still signs of erosion taking place. The mouth of the Stour is highly exposed to incoming north-easterly waves causing erosion specifically at the Shotley frontage. The middle part of the Stour is subject to erosion, although there are also signs of stable and accreting areas of intertidal habitats.

The Stour shows overall erosion along entire length due to ebb tidal dominance. Vertical erosion of mudflats has led to reduction in vertical elevation of 10mm/yr^{-1} 1925-1985. Horizontal erosion of saltmarsh is now occurring at 4ha/year. Over half the total area of saltmarsh was lost between 1973 and 1988 (Burd, 1992). The rate of loss has reduced between 1988-1997 to 1.8% a year losses. Cliffs at Jaques Bay are eroding at rates of 0.5m/year^{-1} (Posford, 2002). Wave focussing into interestuarine bays exacerbates erosion in these areas, particularly on the north-eastern flanks.

F4.2.4 Opportunities

The Stour and Orwell Estuaries share the same problems of present day flood risk and a historical decrease in area of ecologically sensitive habitats. This currently threatens the highly valued assets and infrastructure, the ecological importance and amenity value of the region. There has been a slowing in the rate of intertidal habitat loss in the two estuaries over recent years, however, it has been predicted that within 50 years 180ha of saltmarsh and 200ha of mudflat may be lost if the existing coastal defences are maintained to today’s standard of protection.

F4.3 Hamford Water

F4.3.1 General description

Hamford Water is a large, shallow, sheltered basin with two shingle spits forming its mouth. It is located between Dovercourt, to the south of Harwich, and Walton-on-the-Naze, which forms part of the southern spit flanking its entrance. Horsey Island, towards the northeast of the estuary, provides a unique area of internationally recognized coastal grazing marsh, due to the lack of predation to the large number of wintering birds that feed and breed there. The embayment attracts many visitors who use the site for walking, horseriding, birdwatching, fishing and sailing.

Reclamation of land from coastal influences has been undertaken at Hamford Water since before 1574, commencing at Dovercourt. Today, the only remaining reclaimed areas include Bramble Island, some areas along the southern banks and the Walton Peninsula, and some parts of Horsey Island. The impact of reclamation is still being felt today, as the embayment has drastically altered in shape and volume.

There has been a barrage breakwater of sunken barges put in place in the northeast of Horsey Island, and over 500,000m³ of dredged material from Harwich harbour has been placed here, and at Foulton Hall and Stone Point, to reverse salt marsh loss. The former recharge used fill sediments that were slightly coarser than the natural substrate; the impact of this required close monitoring and was found to have been unsuccessful at recruiting flora and fauna. The tidal embankment at Foulton Hall has needed reinforcement in recent years due to deterioration taking place as a result of falling beach levels and increased wave action.

Today, the estuary covers a total area of 2377ha and is made up of mud and sand flats (864ha), saltmarshes (706ha) and coastal grazing marsh (67.7ha). The tidal mud and sand flats within the embayment are dissected by numerous tidal creeks and islands and are heavily designated as SSSI (Site of Special Scientific Interest), LNR (Local Nature Reserve), NNR (National Nature Reserve), SPA (Special Protection Area), and under the Ramsar convention on wetlands (1971). This is because of the large number of wintering bird species that they provide a habitat for, such as the Dark Bellied Brent Goose, Teal, Blacktailed Godwit, Redshank and Ringed plover. This attracts a large number of people to the area and provides a valuable site of education on these species.

F4.3.2 Key estuarine processes and issues

The tidal range in Hamford Water is 4.2m. Its short length (7km) means that, compared with the other estuaries in Essex, only a relatively small change in the volume of water within the embayment can occur (termed the tidal prism) on each tidal cycle. This results in low tidal currents at the mouth, allowing the formation of Stone Point Spit. This spit and the associated Pye Sands in the estuary mouth are formed by sediments that are eroded from the cliffs at the Naze, 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.

Today, the estuary is ebb dominant, which means that any eroded sediment has a tendency to be exported offshore. This is a large problem within this estuarine system, which is currently experiencing the largest losses of saltmarsh habitat of all the estuaries in the region, at a rate of 25% in 25 years (Defra, 2002), due to erosion and coastal squeeze. Southerly waves predominate due to the shelter provided by Orford Ness in the north, but these waves are small. Larger, more infrequent waves generally come from the northeast and these have the largest impact on erosion rates. 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. Cliffs at the Naze are currently eroding at a rate of 1.8myr^{-1}, which is significant because of their geological and archaeological importance; however, without this erosion, the coastline to both the north and south may be starved of sediment. The fluvial input into the estuary is restricted to just a few streams, which adds to the uniqueness of this geomorphological unit.

F4.3.3 Zones of erosion and accretion

In the past, Hamford Water was an infilling estuary and was a sediment sink for fine grained substrates. The embayment used to have a 3.5km wide mouth, but erosion of sediments at the Naze to the south, and subsequent northerly sediment transport have created Stone Point Spit and extending Pye Sands, which have significantly reduced this width. The embankments surrounding the embayment have caused land on the seaward side to continue accreting, while land behind the defences has settled and remained at a constant elevation, causing it to be susceptible to flooding. Hamford Water is now erosional and the area of intertidal habitat is decreasing substantially, at an increasing rate. Erosion is particularly fast along the unprotected cliffed coastline of The Naze, where it reaches an average of 1.8myr^{-1} (SNSSTS, 2002).

Horsey Island is the largest island in the backwater and protects the other islands and flood defences from erosion from wave action. Due to a foreshore recharge scheme to the north of Horsey Island new beaches, mudflats and saltmarsh have been created.

F4.3.4 Opportunities

Intertidal habitat within Hamford Water is ecologically valuable. Horsey Island offers unpredated coastal grazing marsh which is used by many wintering wading bird species. The rare Hog’s fennel (Peucedanum officinale), which tends to colonise in the lee of sea walls exists here, and in only one other site, in Kent.

F4.4 Tendring

F4.4.1 General description

The Tendring frontage Peninsula is located south of the Harwich Harbour. It covers several urban areas, some agricultural land and a small area of saltmarsh. This frontage is key for tourism and recreation and includes the seaside resort of Clacton-on-Sea and the boating and tourist centre of Walton-on-Naze. There are also conservation areas, including the Osyth Nature Reserve, and ancient monuments. Fishery is one of the commercial activities.

The Tendring Peninsula has a general orientation of north-east to south-west. At the northern part, Walton-on-the-Naze, the shore is backed by the Naze soft cliffs (London Clay) of 15m in height (CHaMPS, 2003). From Frinton to Holland and from Jaywick to Colne Point the frontage comprises of low-lying reclaimed land. Clacton-on-Sea is situated on high ground which extends southwestwards to Jaywick.

South of the Tendring Peninsula there are a series of depositional shingle beach ridges forming part of a spit complex, which extends for 2.5 km between Jaywick and Sandy Point, into the entrance of the River Colne (Scoping study, 2004). There is a small area of saltmarsh, designated Nature Reserve, to the west of Seawick which has been formed due to the protection of this spit complex. Offshore, the seabed increases to depths of 12m CD in the Walton Channel, approximately 5.5km from the low water mark. To the west of Clacton, the offshore area is shallower as a result of the presence of the offshore banks associated with the Blackwater and Colne estuaries. The Tendring Peninsula functions as an independent geomorphological unit, with little or no linkages with its adjacent estuaries (HR Wallingford, 2002) (Scoping study, 2004).

The Tendring frontage is heavily defended. The defences consist of concrete seawalls and revetments as well as clay embankments and sections of rock armour and groyne fields. Between Frinton-on-Sea and Holland-on-Sea, the sea walls provide flood protection to the low-lying area, which used to be open to marine inundation. The urban frontage of Clacton-on-Sea is extensively developed, and flood and coastal protection is provided by seawalls and groynes which influence movement of beach material.

Jaywick is also protected by seawalls. Effectively the coastal defences have been extensively redeveloped with fishtail breakwaters. From west Clacton to Jaywick, beach recharge has taken place from 1986 to 1988 and more recently in 1999 beach recharge took place in front of the defence. Without the beach in front of the defences, the seawall would not provide adequate protection against flooding. The southerly coastal strip has extensive holiday developments, behind which there is a network of channels and ditches that drain St. Osyth Marsh. The seawall extends to Seawick, to the west of which the shoreline is largely unprotected.

F4.4.2 Key coastal processes and issues

The dominant incident wave direction is from the north-east. Hence, the Tendring peninsula is vulnerable to flood risk and erosion (Futurecoast, 2002). Cork, Gunfleet and Buxey sand banks are likely to provide some attenuation of the wave energy. The 1 in 10 year significant wave height is 1.0m to 1.5m (Futurecoast, 2002).

At the Tendring frontage, there is a nearshore sediment divide in the vicinity of Clacton. To the south of Clacton, sediment moves along the shoreline to the southwest and accretes at Colne Point. To the north of Clacton, the net sediment drift is northwards with a sediment convergence, roughly in the vicinity of Walton, where it meets the southerly drift from the north leading to a sediment deposition at the Naze (Essex SMP1, 1996).

F4.4.3 Zones of erosion and accretion

The frontage is sensitive to the dominant wave climate (SNS2, 2002). There is a general lack of sediment derived from the North. The combination of a deficit in sediment and the alignment of the Tendring coastline, makes the frontage very vulnerable and subject to erosion. As a consequence, significant beach loss along the entire frontage is observed. There is some accretion taking place to the west of Seawick.

F4.4.4 Opportunities

Futurecoast (2002) predicts under the unconstrained scenario that for the relatively narrow foreshore between Jaywick and Seawick ‘there would be a high probability of segmentation and breaching causing large-scale inundation of the low-lying backshore. This would create ‘a new tidal inlet with flats and saltmarshes landward of this frontage’. At the moment, the entire frontage is subjected to erosion, with local accretion of sediment to the west of Seawick.

F4.5 Colne

F4.5.1 General description

The Colne estuary is located south of Colchester and converges with the Blackwater estuary at Mersea Island between Sales Point and Colne Point. The Colne estuary harbours an exceptional diversity of coastal habitats; many of these habitats are rare and in turn support a number of rare and uncommon plant and invertebrate species. This importance is reflected in a number of statutory and non statutory designations which cover the estuary and the surrounding areas. The estuary is a popular sailing area and includes four conservation areas. The estuary is funnel shaped and its mouth spans between Colne Point and East Mersea. The length of the estuary is approximately 14km, 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. 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 it 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.

F4.5.2 Key estuarine processes and issues

The Colne 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 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 and as a result it is subjected to the influence of tidal flows from both estuaries respectively. The dominant incident wave direction is from the north-east and the most significant wave action occurs in the outer reaches of the Blackwater and Colne estuary. Offshore banks shelter the coastline from direct wave action, whilst intertidal flats play a very significant role in attenuating incoming wave energy before it reaches the shoreline of Mersea Island. Owing to the reduced wave climate at the Colne, sediment transport is governed by tidal currents and the estuary experiences the lowest erosion rates in the country. The tidal channels have shown a slight decrease in mean depth mainly owing to an increase in the elevation of the intertidal mudflats.

F4.5.3 Zones of erosion and accretion

Although the Colne estuary system is close to equilibrium and is considered to be geomorphically stable, there are still signs of channel and foreshore erosion and accretion. Sediment is building up in the inner estuary near Colchester, and at the heads of the creeks such as Brightlingsea Creek and Geedon Creek. Sediment is building up at the southern side of Stone Point, however, is eroding at the Northern tip. Erosion is predominantly taking place at the entrance of Geedon Creek, both sides of the Brightlingsea creek, and at the eastern bank of the River Colne. The wave-induced hydrodynamic pressure causes movement of Pyefleet channel leading to erosion of both Langenhoe Marsh and the southern bank of Pyefleet channel.

F4.5.4 Opportunities

Despite the close to equilibrium status within the Colne estuary at present, the long term prognosis for the estuary is not positive. It is likely that the estuary will fail to respond to sea level rise by a process of gradual morphological change and as a result the estuary will be progressively drowned. This will result in a loss of saltmarsh and mudflat habitat and an increased flood risk to urban areas.

The tidal prism of the estuary is likely to increase (that is the amount of water that flows into and out of the estuary with the flood and the ebb tide) and it is predicted this will lead to channel enlargement. This will be achieved predominantly by retreat of the saltmarsh boundary. It is predicted that the width of the channel will increase by 250m over 50 years at Mersea stone, with an associated loss of 116ha of saltmarsh.

The main problems facing the Crouch and the Roach estuary in the future are summarized below:

- Increased flood risk (if defences are not maintained to a suitable standard of protection).
- Increased losses of intertidal habitats by coastal squeeze (if defences are maintained and no managed realignment is undertaken).
- Drowning of intertidal habitat owing to failure to respond to sea level rise.

F4.6 Mersea

F4.6.1 General description

Mersea Island is an isolated island of London Clay, the seaward facing side of which 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 inter-tidal flat. Two channels flow around Mersea Island: Strood channel to the west and Pyefleet channel to the east. Cobmarsh Island lies at the entrance of Strood Channel between West Mersea and Old Hall Marshes. The eastern section of Mersea Island is predominantly used for agricultural purposes. On the coast, to the southeast of Rewsalls Farms, lies a youth camp and recreational area. The majority of the properties at Mersea Island are outside the flood risk zone but there are several camping and caravan sites that are at risk. The landward side of the island is comprised of drained agricultural land behind the flood defences with a small area of saltmarsh.

Two areas of foreshore at East Mersea are of geological importance. Cudmore Grove Country Park and Mersea Stone Local Nature Reserve have local conservation and recreational value.

F4.6.2 Key coastal processes and issues

The dominant incident wave direction is from the north-east and the most significant wave action occurs in the outer reaches of the Blackwater and Colne estuary. Offshore banks shelter the coastline from direct wave action, whilst intertidal flats play a very significant role in attenuating incoming wave energy before it reaches the shoreline of Mersea Island.

F4.6.3 Zones of erosion and accretion

Due to the dominant wave direction the seaward facing frontage between West Mersea and Cudmore Grove Country Park is prone to erosion. Evidence suggests that due to channel movement and resulting hydrodynamic pressure the defences are being undermined at Reeveshall Marshes ad along the Strood Channel.