Medway Estuary and Swale Shoreline Management Plan SMP

Appendix C – Baseline Estuary Processes

Contents Amendment Record

This report has been issued and amended as follows:

Issue	Revision	Description	Date	Approved by
1	0	Consultation Draft	01/05/07	N Pontee
	1	Amendments following public consultation and QRG review	31/10/08	N Pontee
2	2	Final	19/11/09	N Pontee

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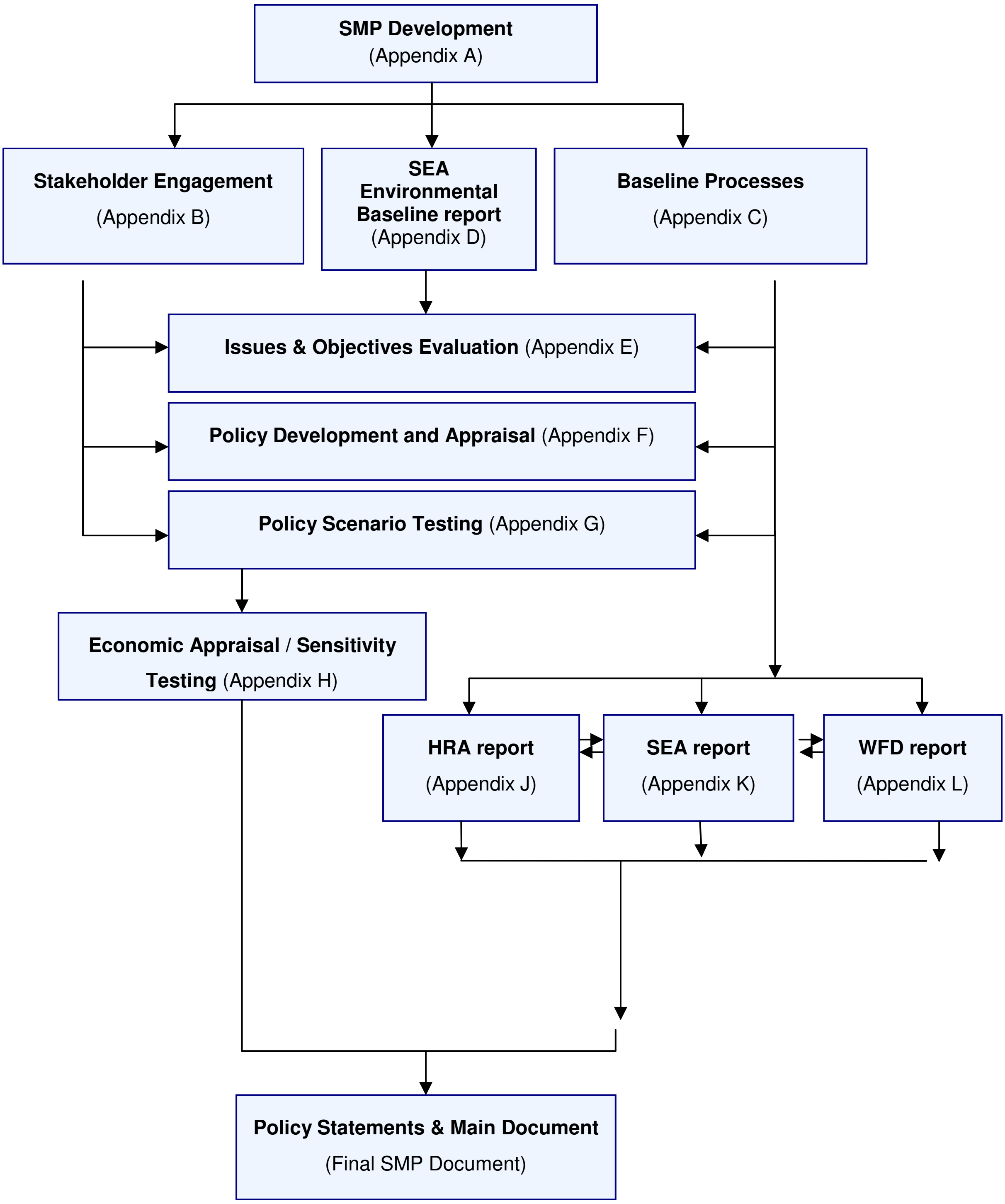
Appendix C: Baseline Process Understanding

The Supporting Appendices

This appendix and the accompanying documents provide all of the information required to support the Shoreline Management Plan. This is to ensure that there is clarity in the decision-making process and that the rationale behind the policies being promoted is both transparent and auditable. The appendices are:

A: SMP Development	This reports the history of development of the SMP, describing more fully the plan and policy decision-making process.
B: Stakeholder Engagement	All communications from the stakeholder process are provided here, together with information arising from the consultation process.
C: Baseline Process Understanding	Includes baseline process report, defence assessment, NAI and WPM assessments and summarises data used in assessments.
D: SEA Environmental Baseline Report (Theme Review)	This report identifies and evaluates the environmental features (natural environment, landscape character, historic environment, land use, infrastructure and material assets, and population and human health).
E: Issues & Objective Evaluation	Provides information on the issues and objectives identified as part of the Plan development, including appraisal of their importance.
F: Initial Policy Appraisal & Scenario Development	Presents the consideration of generic policy options for each frontage, identifying possible acceptable policies, and their combination into ‘scenarios’ for testing.
G: Scenario Testing	Presents the policy assessment and appraisal of objective achievement towards definition of the Preferred Plan (as presented in the Shoreline Management Plan document).
H: Economic Appraisal and Sensitivity Testing	Presents the economic analysis undertaken in support of the Preferred Plan.
I: Metadatabase and Bibliographic database	All supporting information used to develop the SMP is referenced for future examination and retrieval.
J: Habitat Regulations Assessment	Presents an assessment of the effect the plan will have on European sites.
K: Strategic Environmental Assessment	Presents the Strategic Environmental Assessment of the Plan.
L: Water Framework Compliance	Presents a retrospective Water Framework Directive Assessment.

Within each appendix cross-referencing highlights the documents where related appraisals are presented. The broad relationships between the appendices are as below:



C1 Assessment of Estuary Dynamics

C1.1 INTRODUCTION

This section summarises the present state of knowledge on the physical processes and geomorphological evolution of the Medway and Swale Estuary systems. The present report brings together the detailed historical change, physical process understanding and wider geomorphological understanding provided by a number of previous studies, including:

- The CHaMP, English Nature (2002);
- The North Kent Marshes Salt Marsh Survey, Kent County Council, (2002);
- The sediment budget of the erosional intertidal zone of the Medway Estuary, Kirby (1990); and,
- The Medway Estuary, Coastal processes and Conservation, IECS (1993).

This section presents:

- A conceptual model for the estuary, which explains the functioning of the estuary system;
- The driving forces that will influence the evolution of the estuary in the future;
- Previous workers predictions of future morphological changes;
- An assessment of the uncertainties in previous workers analysis; and,
- Further work required to reduce these uncertainties.

C1.2 BACKGROUND

The Medway and Swale estuaries are located in North Kent, on the east coast of the UK (Figure C1.1 – **Annex C1**). This report summarises the present understanding of the Medway and Swale with regard to coastal/estuarine processes and geomorphology. A number of approaches have been used to produce a conceptual model, which has been used as a basis for predicting the likely future morphological evolution of the estuary. This understanding is needed to assess the sustainability of future flood defence options in the estuaries.

The approach adopted within this report draws on the recommendations made in recent national research studies including both the Futurecoast study (Burgess *et al.*, 2001; Halcrow, 2002) and the Estuary Research Programme (EMPHASYS Consortium, 2000; Defra, 2002a).

The Futurecoast study recognised that coastal environments can be represented by a number of systems, which operate at different spatial and temporal scales. In this project, the approach adopted to enable the prediction of future coastal tendencies, involved the consideration of the Holocene evolution, the driving physical processes, the constraints, and the linkages between the different system elements. The application of this approach to the second round of Shoreline Management Plans (SMPs) in the UK, has led to the appreciation that SMPs need to consider the interaction of coastal and estuarine systems (Halcrow, 2003). Bearing these considerations in mind, Section C1.3 of the present report starts with a brief description of the open coast area in terms of its Holocene evolution, operative coastal processes and likely future evolution, since these factors are likely to influence the Medway and Swale system.

The successful prediction of future changes to estuary systems relies, in part, on the determination of the present day characteristics of the system. Section C1.4 of this report therefore describes the contemporary morphological form of the Medway and Swale estuary system, as well as the processes which exist within it. Understanding these processes, in terms of water and sediment movement, is important, since it is the operation of the processes that produce morphological change within the estuary system.

A further tenet in the prediction of further morphological change is a knowledge of how the estuary system has evolved in the past, in response to various driving forces and constraints. Section C1.5 therefore reviews the morphological historical changes that have occurred in the Medway and Swale estuary system. These changes include the mudflats, saltmarshes and the subtidal channels.

One of the most significant recommendations from the EMPHASYS study was that the complexity of estuarine systems, coupled with the uncertainties associated with individual techniques, means that understanding estuarine morphodynamics requires the synthesis of results from a variety of approaches. The present study has reviewed the outputs from a number of previous studies, which have used a range of different techniques. The various techniques used are summarised in Table C1.1.

Table C1.1: Techniques used to assess estuary processes and evolution in the present report.

Technique type	Description
Data analysis	Expert review of previous studies
Top-down regime analysis	Investigating the cross sectional area and tidal prism relationships throughout the estuary
Top-down expert analysis	Assessment of potential future evolution of the estuary and its morphology

Section C1.6 of the present report provides:

- A conceptual model for the estuary which explains the functioning of the estuary system;
- The driving forces that will influence the evolution of the estuary in the future; and,
- Predictions of future morphological changes.

Section C1.7 presents the conclusions from the work, and identifies where more detailed studies are required to improve the existing understanding of the morphological processes in the Medway and Swale estuaries and reduce the uncertainties in previous workers analysis.

C1.3 WIDER COASTAL SETTING

C1.3.1 Sea level and Holocene coastal evolution

The Medway and Swale estuary system (Figure C1.1) is located in the southern section of the Greater Thames Embayment, which lies within the southern part of the North Sea.

The Futurecoast study (Halcrow, 2002) considered that the Medway and Swale estuaries lay within a behavioural coastal system that extended from Harwich to North Foreland. The coastal morphology of the coastal system from Harwich to North Foreland is characterised by eroding cliffs, mud and sand flats, and estuary and island units. From the north to the south, the estuaries include the Deben, Orwell, Stour, Blackwater, Crouch, Thames, Medway and Swale. This study noted that the past evolution of this area has been strongly influenced by the Thames Estuary throughout the Holocene. The Thames represents a sink, not only for fine sediments, but also for the relatively small volumes of sand and shingle transported along the coast.

The underlying geology of the outer Thames consists of a platform of Tertiary and Quaternary Rocks, principally Eocene London Clays overlain by Pleistocene Terrace Gravels, upon which lie a sequence of Quaternary sands and gravels (glacial till) and, above these, the Holocene muds and sands (Table C1.2). The Tertiary and Quaternary rocks rise to around 40m ODN. Futurecoast (Halcrow, 2002) describes the geology of the shoreline and sub-tidal zone to be comprised of London Clay, overlain in places by recent glacial drift sediments. The position of the Medway is largely dictated by the position of outcrops of London Clay. The Isle of Grain is a ridge of London Clay which separates the Medway from the Thames. The Isle of Sheppey is also centred on a relatively large hill of London Clay.

Table C1.2: Geology of the Medway and Swale. Source: IECS (1993). All dates in bold taken from IECS (1993)

<table>
<tr><th>Date (millions of years ago, mya)</th><th>Geological Time (Era) Interval</th><th>Geological Time (Epoch) Interval</th><th>Geological Time (Period) Interval</th><th>Solid and Drift Formations</th><th>Lithological Description</th><th>Present Day Outcrops</th></tr>
<tr><td>0 – 2 mya</td><td>Quaternary</td><td>Pleistocene and Holocene</td><td>-</td><td>-</td><td>Glacial drift and flood plain deposits</td><td>• Isle of Grain
• Isle of Sheppey
• Chetney marshes</td></tr>
<tr><td rowspan="5">65 – 63 mya</td><td rowspan="4">-</td><td rowspan="4">Palaeocene and Eocene</td><td></td><td>London Clay</td><td rowspan="4">Thick series of sands and clays of fluvial, estuarine and marine origin</td><td>• North of Chattenden
• Isle of Sheppey
• Isle of Elmley
• Isle of Harty
• Isle of Grain
• Chetney marshes
• Some of the islands within the Medway (Steers 1981).</td></tr>
<tr><td>-</td><td>Oldhaven Beds</td><td rowspan="3">• A narrow strip along the northern edge of the North Downs
• isolated patches north of Rochester
• Isolated patches between Gillingham and the Swale.</td></tr>
<tr><td>-</td><td>Woolwich</td></tr>
<tr><td>-</td><td>Thanet Sands and arenaceous Reading</td></tr>
<tr><td>Tertiary</td><td>Oligocene and early Miocene periods</td><td>-</td><td>-</td><td>Chalk</td><td rowspan="2">The southern rim of the London basin runs close to the southern coast of the Thames estuary as the North Downs, almost touching the shore of the Medway at Gillingham.</td></tr>
<tr><td>144 – 65 mya</td><td>Mesozoic</td><td>-</td><td>Cretaceous</td><td>-</td><td>-</td></tr>
</table>

590-248 mya	Palaeozoic	-	-	-	-	

C1.3.2 Hydrodynamics and sediment transport

The outer Thames Embayment is affected by both estuarine and open coast processes and is characterised by a relatively mild wave climate (Halcrow, 2002). Waves are generally directed from the north-northeast to the southeast and have a significant swell component. These waves also have a long fetch, due to the coast’s orientation to the open North Sea (Figure C1.2). The most significant wave action occurs in the outer reaches of the Medway and Swale estuaries, and decreases into the estuary.

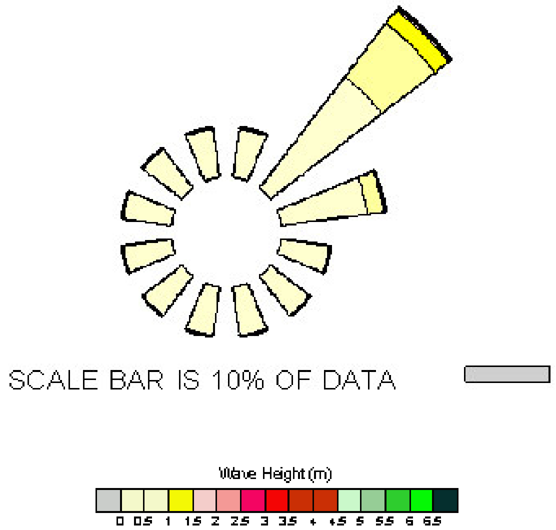


Figure C1.2: Inshore wave rose for Minster, also applicable to the Medway and Swale Estuaries. (The scale bar shows the annual 10% exceedance of significant wave height, which for Minster is between 1.0 and 1.5 m).

Outside the estuary shingle is transported westwards between Whitstable and Graveney/Nagden (Table C1.3). The orientation of the Swale and presence of the Isle of Sheppey, which decreases wave action, mean that shingle is not carried into the Swale. Tidal currents are however sufficient to move finer material into the estuary (CCC, 2004a). Beach sand, which CCC (2004a) reports to have high shell content, is transported from Seasalter to Graveney in the littoral transport system and then swept by tidal currents to the north from South Oaze along the Pollard Spit (CCC, 2004a).

Table C1.3: Actual and potential sediment transport rates. Source: CCC (2004a).

Location	Potential transport (m^3 / year)	Actual transport (m^3 / year)
Graveney	0 – 1000 (to west)	300 – 700
Seasalter	1000 – 2,500 (to west)	800 – 900
Whitstable	order of 10,000 (to west)	0 – 1000

C1.4 CONTEMPORARY ESTUARY FORM, HYDRODYNAMICS AND SEDIMENT TRANSPORT

C1.4.1 Geomorphological Characteristics

The Medway Estuary

The Medway extends some 41km from the mouth at Sheerness to the tidal limit at Allington Lock. IECS (1993) and the CHaMP (2002) reported on the findings of Davidson (1991), who suggested that the estuary has a total area of 6441 ha at high water, of which Burd (1992) reported that, 645.5ha is saltmarsh, 3362.7ha is mudflats and 2432.8ha is sub-tidal. Table C1.4 summarises the key characteristics of the Medway Estuary.

Table C1.4: Key characteristics of the Medway Estuary

Feature		Source
Tidal range	5.1-5.6m	IECS (1993)
Geology	Tertiary London Clays, Quaternary Sands and Gravels.	
Shoreline length	143.3km	IECS (1993)
Length to normal tidal limit	40.9 km	IECS (1993)
Total length of defences	113 km	GIS analysis
Channel width	1-2km	IECS (1993)
Channel depth (sub-tidal)	0.1m-23m	IECS (1993)
Catchment area	176,100ha (1761km^2)	IECS (1993)
Total estuarine area	6441 ha 6351ha	Davidson (1991) CHaMP (2002) Based on sum of intertidal and subtidal areas as calculated by Burd (1992)
Sub-tidal area	2432.8ha	Burd (1992)
Inter-tidal area	3362.7ha	Burd (1992)
Salt marsh area	645.5ha	Burd (1992)
Ratio Sub-tidal area/total area *Ratio Inter-tidal area/total area*	0.38 0.53	Based on Burd (1992) Based on Burd (1992)

The Medway Estuary is defined in the Futurecoast Study (Halcrow, 2002) as a spit enclosed estuary. The Medway estuary can be divided into three reaches on the basis of channel morphology and tidal characteristics:

- Outer - Sheerness to Chetney Marshes – which has a constrained ebb dominant channel, bordered by mudflats that are relatively narrow and steep;
- Middle – Chetney Marshes to Gillingham - which is flood dominant, overly wide and has extensive intertial areas; and,
- Inner – Gillingham to Allington Lock - which is ebb dominant, and has a narrow meandering channel with limited intertidal areas.

The town and port of Sheerness occupies a narrow spit at the mouth of Medway. It is suggested by Futurecoast (Halcrow, 2002) that the spit could be the shore-attached remnant of a former barrier system extending across the mouth of the Swale estuary that became breached at some point earlier in the Holocene. The Swale channel connects with the Medway estuary, behind the Isle of Sheppey.

The main sub-tidal channel within the estuary exceeds 20m in depth at its confluence with the Thames estuary at Sheerness. IECS (1993) suggest this is a result of over deepening which occurred during period of lower sea levels in the Pleistocene Ice Age. The mean depth of the sub-tidal channel from Sheerness to Oakham Ness, located 8km from the estuary mouth, is 10m below low water level (IECS, 1993). Historically, the Medway has two mouths; the existing one and one at Alhallows. IECS (1993) suggest that the second mouth closed as a result of land reclamation in the Roman times, which in turn resulted in the silting of the mouth to form a narrow channel and eventually salt marsh.

IECS (1993) suggest the mudflats cover around 3362ha, approximately 52% of the total area of the estuary. This is similar to the result obtained by Kirby (1990) who calculated that the mudflats occupied 65% of the estuary area. IECS (1993) report that the area of mudflat was increasing as the saltmarshes continued to erode and were replaced with mudflat. The mudflats are comprised of silty sands and clays and contain areas of more consolidated sediments that represent the eroded remains of saltmarshes which covered the area previously (IECS, 1993; MESP, 2001).

The mudflats generally lie between 0 and 3m OD (IECS, 1993; and CHaMP, 2002) and slope gently between the sub-tidal channel and the margins of the estuary. In some cases this distance can be over 3.5km, although at the mouth of the estuary, particularly between Elphistone Point and Cockershell Hard, the mudflats become narrow (30-250m) and steeply inclined (IECS, 1993).

IECS (1993) reports that the saltmarshes within the Medway are highly fragmented and only cover 10% (645.5 ha) of the total estuarine area (Burd, 1992). The largest areas of marsh can be found to the south of the sub-tidal channel in the shelter of the Chetney peninsula. These are the Greenborough and Slayhills Marshes and cover an area of approximately 180ha, 28% of the total saltmarsh area (IECS, 1993). CCM (2002) identified the key areas which represent saltmarsh in the Medway Estuary as:

- Chetney Marshes;
- Barksore Marshes;
- Millfordhope Marsh;
- Greenborough Marshes;

- Burntwick Island;
- Nor Marsh;
- Hoo Salt Marsh;
- Oakham Marsh;
- Stoke Saltings; and,
- Between West Point and the Kingsferry Bridge in Long Reach.

KCC (1997) report that there is approximately 3000ha of grazing marsh within the Medway and Swale. English Nature (2006) however has found that there is approximately 601ha of grazing marsh in the Medway and 2762ha of grazing marsh in the Swale, an increase of 363ha on KCC (1997) estimates. These marshes have been artificially developed for the purpose of agriculture, by enclosing saltmarsh and preventing inundation by the tide. The result is undulating wet grassland, often up to a metre below high tide levels, drained by a system of fleets which were previously tidal creeks. Many of these fleets are brackish in nature and have tidal sluices to allow drainage water to escape to the sea (IECS, 1993). According to IECS (1993) the main grazing marsh areas in the Medway include:

- Isle of Grain;
- Kingsnorth Power Station;
- Nor Marsh;
- Slayhills Marsh; and
- Rushenden Marshes.

<u>The Swale Estuary</u>

The Swale Estuary has a channel length of 18.4km from its eastern mouth at Whitstable to the Kingsferry Bridge. The channel length between the western mouth at Queenborough and the Kingsferry Bridge is approximately 6km. The Swale Estuary is defined by Futurecoast (Halcrow, 2002) as a spit enclosed estuary. The Swale is effectively a tidal channel with two mouths (English Nature, 2002). The western mouth comprises of a narrow channel which joins the Medway estuary at Queenborough, while the eastern mouth is wider and is located between the Isle of Sheppey (Shell Ness), from which a small spit of sand and shingle extends, and south of Whitstable on the mainland. Table C1.5 summarises the key characteristics of the Swale Estuary.

Table C1.5: Key characteristics of the Swale Estuary

Feature		Source
Tidal range	4.9m	JNCC (1997)
Geology	Tertiary London Clays, Quaternary Sands and Gravels.	
Shoreline length	79.3km (12.3km)*	JNCC (1997)

Feature		**Source**
Length of channel between Kingsferry Bridge and Whitstable	18.4km	JNCC (1997)
Total length of defences	82km	GIS analysis
Channel width	1.5km (approximate)	
Channel depth (sub-tidal)	Varies between 3 and 15m	IECS (1993)
Catchment area	No available data	
Total estuarine area	3283ha	JNCC (1997)
Sub-tidal area	No available data	
Inter-tidal area	2696ha (244)*	JNCC (1997)
Salt marsh area	384ha	English Nature (2006)
Total inter-tidal area	2996ha	GIS analysis
Ratio Sub-tidal area/total area *Ratio Inter-tidal area/total area*	No available data 0.82	 Based on JNCC (1997)
* = associated intertidal/shoreline		

In plan-shape most of the Swale is relatively uniform in width from the seaward to the landward parts, although the eastern mouth (from Whitstable to Nagden Marshes) is almost double the width (2-3km). The Swale has extensive intertidal mudflats, which become more sandy and gravelly towards the eastern mouth (Halcrow, 2002). Saltmarsh has developed on both shores of the Swale, but the most extensive areas are on the north side of the estuary (JNCC, 1997). There has been extensive reclamation and construction of sea walls throughout the Swale. On the north side however, there are natural marshes grading into grazing land (Halcrow, 2002). Saltmarsh reclaimed for grazing is now intersected by brackish and freshwater ditches (JNCC, 1997).

The Swale estuary can be divided into three reaches:

- Outer – Whitstable to Shell Ness, which represents the wide eastern mouth region;
- Middle – Nagden Marshes/Isle of Harty to Elmley Island/Kemsley, which forms the main channel; and,
- Inner – Long Reach/West Swale channels, which comprises a narrow canalised channel leading to the western narrow mouth region at Queenborough.

IECS (1993) report that the Swale channel varies in depth between 3 and 7m below low water, although the depth increases significantly to over 15m at Long Point. The Swale channel becomes separated from the Medway channel as is flows past Chetney peninsula.

It has been suggested that the Swale represents a former course of the Medway (IECS, 1993). However, the significantly deeper base of the Medway (-32m OD, compared to -4.5m OD for the Swale channel), suggests that the Swale channel was formed after the Medway

(IECS, 1993). The subtidal channel of the Swale increases in width from west (0.1km) to east (0.9km), with a marked increase in width at Fowley Island.

The CHaMP (2002), which takes figures from KCC (1997), suggests that there is 2042ha of mudflat in the Swale. Recent figures from English Nature (2006) however, suggest that there is around 2416ha of mudflat in the Swale at present. To the west of Milton Creek, the mudflats are narrow due to the presence of flood embankments, although they widen to the east with the exception of a narrow strip at the Isle of Harty (CHaMP, 2002). CCC (2004a) report that the intertidal flats are covered by a thin layer of fine grained shelly sand bars lying directly upon a weathered London Clay surface. The mudflats also contain patches of mixed mussel beds and immobile shingle.

English Nature (2006) reports that there are 384ha of saltmarsh in the Swale Estuary. Saltmarsh is generally located in the wider eastern Swale, although there are some areas in the narrower eastern channel. The key areas of saltmarsh include:

- Sharfleet Creek;
- Cockleshell;
- Wellmarsh Creek;
- Dutchman's Island (south side of Windmill Creek);
- The small embayment east of Dutchman's Island; and,
- The lee of Shellness.

The main grazing marsh areas in the Swale are:

- Horsham Marsh;
- Chetney Marshes; and,
- Queenborough Marshes on the Isle of Sheppey (IECS, 1993).

Ordnance Survey (OS) mapping indicates that there are two main areas of shingle that are located at the eastern mouth of the Swale Estuary, on the north bank at Shell Ness and on the south bank, between Whitstable and the boundary of Nagden/ Graveney Marshes.

CCC (2004a) reported on the mixed sand and shingle beaches between Whitstable and Seasalter. Most of the beaches have been heavily replenished with imported shingle over the last twenty five years and consist of large flint cobbles, rounded and angular flints, sand and shells with a mean diameter of between 8 and 20 mm. CCC (2004a) found that the shingle is sorted in an estuary down-drift direction. The size of shingle decreases between Seasalter and Graveney and sand content of the intertidal area increases. The upper beach at the eastern end of Graveney consists of abraded flints, black pebbles and claystone with a mean diameter of about 6 mm. The lower beach is much sandier. Shingle is not transported further east than Graveney, since Faversham Creek acts as a barrier to the westward littoral drift.

The majority of the coastal frontage along the Swale is low-lying, however there are small pockets of higher ground, that exist as a result of the underlying more-resistant London Clay deposits. CCC (2004a) reports that the hinterland at Seasalter consists of graded clay coastal slopes of 3 to 15 m height. Historically, there have been minor slope failures and landslides.

However this activity has been largely prevented by the provision of the seawall and drainage to the slopes. Present day sediment inputs from cliff failure to the beaches are limited.

C1.4.2 Tidal dynamics

The Medway is a macro tidal estuary with a spring tidal range of 4.9m at its mouth (measured at Sheerness) increasing to 5.1m inland (at Rochester). The tidal limit is reached at Allington Lock, where the tidal range is 3.4m at springs and 2.4m at neaps. Tides are semi-diurnal with a very slight diurnal inequality, which amounts to a 0.1m difference on high water spring tides at Chatham (IECS, 1993).

In the southern North Sea, the tidal wave propagates southwards and from Harwich to the Thames and is ampflied by shallow water effects (HR Wallingford, 2001). IECS (1993) report that as the tidal wave enters the Medway channel it increases in amplitude along the length of the estuary until some point between New Hythe and Allington Lock. IECS (1993) suggests that the Medway is a resonant tidal estuary, where tidal wave reflection sets up a standing wave tide whose amplitude is increased towards the landward end of the channel.

In reporting the findings of Wright *et al.* (1973), IECS (1993) suggest that in theory, the development of a resonant tidal wave within an estuary leads to the development of a funnel shape channel plan. The fact that the present Medway channel fails to conform to such a theoretical shape, may be due to the extensive reclamation of the original multiple channel mouths around the Isle of Grain and Sheppey (IECS, 1993). IECS (1993) suggest that prior to this reclamation, in the early to middle Holocene, the form of the estuary may have exhibited a more exponential width increase towards the sea. IECS further suggest that this change in the hydro-dynamic shape of the estuary, caused by human interference, may be one reason why the estuary has suffered such severe inter-tidal erosion over the past century.

Variations in the dimensions of the sub-tidal and intertidal areas result in variations in the propagation of the tidal wave along the length of the Medway. According to IECS (1993), these changes produce areas of flood and ebb dominance:

- Outer – ebb dominant (compared to the flood tide, the ebb has a shorter duration and higher velocities);
- Middle – flood dominant (compared to the ebb tide, the flood has a shorter duration and higher velocities); and,
- Inner – ebb dominant.

IECS (1993) suggest that the ebb-dominance in the outer estuary is the result of the funnelling through the outer channel of the large tidal prism held on the mudflats of the tidal basin section. Tidal circulation within the outer estuary is complicated by tidal flow into and out of the northern mouth of the Swale Estuary. Halcrow (2002) suggested that the mouth of the Medway exhibited areas of both flood and ebb dominance. The CHaMP (2002) suggested that the ebb-dominant flow regime at the mouth results from:

- Narrow cross sectional area due to the geology; and,
- The increase in tidal prism generated by the salt marsh loss in the 1800's (Section C1.5.3).

The middle estuary becomes increasingly flood-dominated (e.g. at Bee Ness and Chatham) (IECS, 1993). The bathymetry of this central section of the estuarine channel consists of a series of relatively deep channels (a channel mean depth of 6m) within an extensive low elevation inter-tidal area (a mean depth of high water of 3m). This bathymetry results in the crest of the flood tidal wave advancing more rapidly than the trough of the ebb. This results in a flood tide that has a shorter duration and higher velocities than the ebb tide.

IECS (1993) reported that as the tidal wave passes into the meandering channel west of Chatham (the inner estuary), ebb dominance is gradually re-established. At Rochester, for example, the ebb duration is 28 minutes shorter than the flood. This landward development of ebb dominance may be due to the marked funnel effect of the channel as it passes through the Gillingham reach and the funnelling through the outer channel of the large tidal prism held on the mudflats of the tidal basin section. Here the mean water depth at high tide is less than that at low tide, due to the extensive areas of shallow water over intertidal flats at high water. This means that the tidal wave crest is retarded relative to the trough, which results in an ebb tide that has a shorter duration and higher velocities than the flood tide.

The Swale Estuary is open to tidal influence from both ends, producing a more complicated tidal regime (HR Wallingford, 1975; IECS, 1993; CHaMP, 2002). In general, the flood runs inwards from both entrances after slack water, the two streams meeting in the locality of Fowley Island. Approximately 5 minutes after high water the stream over the whole length of the channel turns seaward, flowing towards Shellness until approximately High Water + 0105 hours. At this time, the stream in the westward extreme of the channel from Long Point to the channel entrance changes direction to flow towards the Medway. Hence, at this time, the flows separate until slack water at low tide (IECS, 1993). The position of the separation point is not constant (IECS, 1993; CHaMP, 2002). Tables C1.6 and C1.7 provide a summary of flow speeds, tidal heights, durations of flood and ebb tides along the two estuaries.

Table C1.6: Summary of tidal conditions in the Medway. Source IECS (1993). *Tidal levels are adjusted to mOD, present levels (which are taken from Admiralty, 2006) exclude sea level rise.

Station	**Tidal Level**				
Tidal levels and range at Sheerness (mOD Newlyn)*	**MHWS**	**MHWN**	**MSL**	**MLWN**	**MLWS**
Sheerness	2.9	1.8	0.1	-1.4	-2.3
Station	**Spring Mean Range (m)**		**Spring Flood tide duration (hrs)**	**Spring Ebb tide duration (hrs)**	**Flood/ebb dominance**
Sheerness	5.10		6.40	5.95	Ebb dominance
Bee Ness	5.30		6.10	6.30	Flood dominance
Chatham	5.60		5.98	6.35	Flood dominance
Rochester	5.60		6.40	5.92	Flood dominance

Allington Lock	3.40	N/A	N/A	Ebb dominance
Tidal velocities (ms^{-1})		**Flood velocities (ms^{-1})**	**Ebb velocities (ms^{-1})**	
Medway		0.6 - 0.1	1.0 on average, although greater in some reaches.	

Table C1.7: Summary of tidal conditions in the Swale. Source IECS (1993). *Tidal levels are adjusted to mOD, present levels (which are taken from Admiralty, 2006) exclude sea level rise.

Station	**Tidal level**				
Tidal levels and range at Whitstable* (mOD Newlyn)	**MHWS**	**MHWN**	**MSL**	**MLWN**	**MLWS**
Whitstable	2.66	1.76	-1.24	-2.24	-2.74
Tidal velocities (ms^{-1})			**Flood velocities (ms^{-1})**	**Ebb velocities (ms^{-1})**	
Swale			0.6 - 0.1 on average, although greater in some reaches.	0.4 - 0.8 although in Long Reach velocities of up to 1.0	
			Measured peak spring flood velocities 1.0	Measured peak spring ebb velocities 1.5	

C1.4.3 Tidal currents

The tidal current asymmetry follows this pattern: the outer channel exhibits ebb current dominance with peak ebb velocities reaching 0.9ms^{-1} while flood velocities attain 0.4ms^{-1}. In the central section a flood current dominance is attained with maximum flood velocities of 0.95ms^{-1} and maximum ebb velocities of 0.55ms^{-1}. Within the inner channel section, IECS (1993) recorded ebb velocities of 0.6 ms^{-1} and flood velocities of 0.4 ms^{-1}. Modelling carried out by Halcrow (1991) suggests peak ebb velocities within the main channel at Oakham Ness and between Thamesport and Garrison Point are in excess of 1.0ms^{-1}. In general, the peak velocities are experienced on the inside of bends in the channel, with the maximum stream shifting from the north-west side of the channel at Thamesport to the eastern side at Garrison Point (IECS, 1993).

Lower peak ebb velocities are experienced within the Swale than in the Medway, generally being between 0.4 and 0.8ms^{-1}, although in Long Reach velocities of up to 1.0ms^{-1} are experienced (IECS, 1993). Peak flood velocities are generally lower than those experienced during the ebb, although they do exceed 1.0ms^{-1} off Sheerness. In general, velocities are between 0.6 and 1.0ms^{-1}, with the greatest velocities being found in the centre of the channel. Flood velocities in the Swale, are, however, slightly greater than the ebb, reaching in excess of 1.0ms^{-1} in Long Reach.

C1.4.4 Freshwater dynamics

As for many UK estuaries the inputs of freshwater to the Medway and Swale are relatively minor when compared to the volumes of water that enter and leave the estuaries on each tide.

The Medway Estuary drains an area of 1,761km^2 (680 sq miles), which includes the Rivers Eden and Beult catchments (IECS, 1993). IECS (1993) found that the only significant freshwater input into the Medway Estuary is via land drainage from the River Medway. The Environment Agency (2006) recorded a daily mean flow of 4.38m^3/second on the 8th January 2006 at Teston (a gauging station located approximately 10 miles upstream of Allington Lock). Analysis shows that the average daily flow between 1956 and 2006, at this location, is approximately 11m^3/second. Downstream of Allington Lock the river is tidal and all other creeks, such as Half acre, Stangate and East Hoo Creeks, carry no land drainage.

The CHaMP (2002) reported on the findings of BBR (2001). In their study, BBR (2001) reported that freshwater inputs to the Swale come from a series of smaller creeks at Faversham, Oare, Conyer and Milton which drain from the North Downs. Additional, but smaller input comes from smaller creeks on the Isle of Sheppey, including Windmill Creek, Bells Creek and Capel Fleet.

C1.4.5 Extreme water levels

Short-term fluctuations in Mean Sea Level (MSL) are often associated with the passage of storm surges and seasonal variations, which relate to temperature, pressure and wind regimes. Recorded extreme sea levels are given in Table C1.8.

Table C1.8: Recommended Extreme Sea Levels from JBA (2004)

Return Period (Years)	1	5	10	20	25	50	75	100	150	200	500	1000
Water Level (mODN)	3.5	3.8	4	4.1	4.12	4.3	4.4	4.4	4.5	4.6	4.6	4.8

CCC (2004a) reported that in the study area the most significant storms since 1950 occurred in:

- 1953 – a greater than 1 in 100 year event;
- 1978 – a 1 in 20 year event; and,
- 1996 - a 1 in 10 years event.

The 1953 event caused nearly all of the Isle of Sheppey to be inundated with flood water, Whitstable to be severely flooded, the Faversham to Thanet railway line to be breached at the Seasalter Marshes, and some 2,000 people to be made homeless.

C1.4.6 Waves

There is limited information on the wave climate in the Medway and Swale. The configuration of offshore banks and narrow estuary mouths mean that the estuaries are relatively protected from waves from the North Sea. The wave climate within the estuaries is therefore dominated by internally generated wind waves. The CHaMP (2002) reported on Posford Duvier (2000) findings that wave heights in the Medway are usually under 1m and extreme waves do not exceed 2m.

C1.4.7 Sediment transport regime

The CHaMP (2002) estimated that, at any one time, 25,000m^3 of material is suspended within the tidal prism of the Medway. The most significant source of sediment to the Medway is the offshore supply of suspended material from the Greater Thames Embayment (CHaMP, 2002; IECS, 1993; Pethick and Leggett, 1993). Potential supplies also include the relict sediments contained within:

- Saltmarshes (Kirby, 1990);
- Alluvium derived from the erosion of the chalk and sandstone hills by the ancient Medway River (Evans, 1953); and,
- Sediment contained in the London Clay cliffs, located along the north coast of the Isle of Sheppey (Evans, 1953).

Details of the sediment budget for the Medway and Swale are given in Section C1.5.4, based on historical rates of erosion and accretion.

C1.5 ESTUARY MORHPOLOGY – PAST

C1.5.1 Sea level and Pleistocene coastal evolution

During the periods of lower sea level experienced in and before the Pleistocene, the rivers of the area became deeply incised. During periods of stability or rising sea levels, these channels have become infilled with sandy gravels. This has resulted in a network of buried channels off the north Kent and Essex coasts (D'Olier & Maddrell, 1970). During interglacial periods, the higher sea levels have led to formation of river terraces which generally consist of deposited gravels and sands overlain with loamy clay deposits (Marsland, 1986). Dines *et al* (1954) identified four such terraces on the peninsula of Allhallows and Isle of Grain. A buried channel to a maximum depth of 32m (99ft) below OD has been identified on the south-east side of the Isle of Grain, passing to the east of the present course and under the Chatham dockyards, where it is c.9.5m (31ft) below OD (Dines *et al,* 1954).

The whole area of the Thames basin and its truncated tributaries, which now form the Essex Estuaries complex, is a drowned flood plain resulting from the end of the last glaciation (IECS, 1993), refer to Figure C1.3. As sea levels rose, the area around the North Sea was flooded to form a broad intertidal area. As IECS (1993) report, there is evidence for successive regressions and transgressions of the sea during the past 4000 years (Evans, 1953). IECS (1993), also reports on work by Devoy (1977), who studied Holocene sea-level changes in the lower Thames, and made reference to one location in the Medway area. These changes are summarised in Table C1.9.

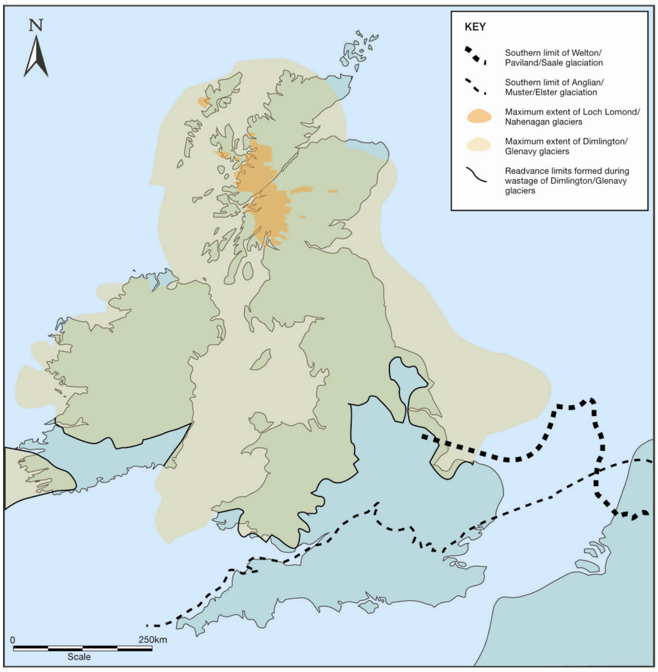


Figure C1.3: Limits of Glaciation in Great Britain and Ireland during the last (Devensian) and maximum (Anglian) glacial stages (after Bowen et al., 1986)

Table C1.9: Holocene sea level changes. Source: Devoy (1977), taken from IECS (1993).

Time (years BP)	Sea level change
8,500 – 7,000	rapid sea level rise (0.013m yr^{-1})
7,000 – 6,700	fall in sea level
6,600 - 5,500	sea-level rise (0.005m yr^{-1})
5,500 – 4,000	Major fall in sea-level
4,000 – 1,750	sea-level rise
1,750 – 1000	fall in sea level
Since 1000	sea-level rise

Under rising Holocene sea level the connection between the northern North Sea and the English Channel was finally made around 7,500 to 7,000 years BP, when sea level was around 10 to 15 metres below the present level. Tooley and Shennan (1987) quoted a mean trend since 5000 BP of – 1.17 ± 0.05 m 1000 yr^{-1} for the Thames Estuary.

During this time, the Thames flowed east and then north-east along a channel crossing the present day courses of the Rivers Crouch and Blackwater, and it has been suggested (IECS, 1993) that its mouth lay successively at the modern locations of Hamford Water, the Blackwater and the Crouch. These conditions formed the present day Thames Basin and its truncated tributaries.

IECS (1993), analysed sea level data for the period 1819 - 1983 and reported sea level rise of 3mm per year, taking into account a combination of eustatic sea-level rise, local subsidence and anthropogenic modifications to the tidal prism as a result of the constriction of the estuaries by the construction of sea walls and land reclamation. Estimates of subsidence outlined above generally indicate the land to be down-warping by approximately 0.2mm year. The findings of IECS (1993) are similar to those of Gordon and Suthons (1963), who used multivariate analysis of annual mean high and low water heights to calculate sea level rise of 3.3mm over the period 1819 to 1983.

C1.5.2 Historical Anthropogenic Activities

The contemporary form of the Medway and Swale has been influenced by a number of past anthropogenic actions, including:

- Sea defences construction;
- Land reclamation;
- Clay extraction for brick making; and,
- Dredging.

Sea defences and land reclamation

The majority of the frontage around the Medway and Swale is protected with flood and coastal defences. GIS investigations made in the present study show that the frontages defended by flood and coastal defences are 113km in the Medway and 82km in the Swale. These values equate to 79% of Medway shoreline (143km) and 97% of the Swale shoreline (82km).

IECS (1993) cited Evans (1953; 1957), who reported that sea defences in this area were first built across the marshes of the Isle of Grain by the Romans. Evans (1957) postulated that the Romans began to occupy this area following a fall in sea level, but by 1000BP the supra-tidal shores of the lower Medway had become subject to tidal inundations, which became progressively more frequent. This called for the extension of the existing flood embankments, so by the end of the 12th century (800BP), much of the former salt marsh areas had been enclosed by sea defences.

In many areas the construction of sea embankments has been associated with the reclamation of land, and this activity has removed large areas of intertidal habaitas and led to a corresponding decrease in tidal prism. For example, the CHaMP (2002) reports that Windmill Creek, reclaimed between 1869 and 1900, removed some 3 million m^3 (3% of the present day tidal prism).

Clay extraction

IECS (1993) reported that during the 19th Century, large volumes of mud were mined from the mudflats and saltmarshes of the Medway and Swale for the purpose of brick making. According to IECS (1993), this opened up salt marsh area to tidal flow, which increased the tidal prism dramatically. In turn, this triggered off a series of processes, including erosion due to increased tidal current speeds and increased wave activity due to the longer internal fetch lengths.

Dredging

IECS (1993) reported on the dredging that has taken place in the Medway:

- Main approach channel of the Medway Estuary – firstly in 1952 between 2.4 and 6.4 km from Garrison Point, when water depths were increased by about 0.2m. Secondly in the stretch between 6.4 and 4.4km off Garrison Point (HR Wallingford, 1975, taken from IECS, 1993);
- Further dredging campaigns took place over various stretches of the approach channel in 1957, 1968 and 1971, although whether these campaigns were for capital or maintenance purposes is not clear; and,
- During 1989 and 1990, the approach channel of the Medway was deepened to a depth of 11m. Approximately three million m^3 of mainly gravel-sized sediment was removed and deposited on the Lappel-Bank reclamation site.

Kirby (1990) reported that the annual removal of sediment by dredging was approximately 56,000tonnes/year. According to IECS (1993) the requirement for maintenance dredging is limited to the over-deepened berths and lock entrances within the Medway (Table C1.10).

Table C1.10 lists the dredging volumes in the Medway Estuary between 2001 and 2005.

Year	Sheerness Docks	Chatham Docks	Port of Rochester
1983	6,400	0	-
1984	7,124	9,322	-
1985	5,831	0	4,414
1986	4,290	16,246	-
1987	401,175	19,886	-
1988	4,134	0	-
1989	0	10,200	-
1990	11,259	20,924	-
1991	6,079	0	-
1992	0	23,748	-
Total	446,472	100,326	4,414

Table C1.11: Dredging Volumes in the Medway Estuary (m^3). Source: Telecoms with Medway Ports

Area	2001	2002	2003	2004	2005	Total
Chatham Lock Approaches	34,806	28,083	15,538	20,230	11,597	**110,254**
Spit in Sheerness Harbour marked by the North kent Buoy		4,335	2,097	2,356	4,949	**13,737**
Medway Approach Channel	15,468	45,100	123,000		151,960	**335,528**
Area between buoys 4 and 6, and 6 and 8 in the Medway Approach				4,091		**4,091**

Area	2001	2002	2003	2004	2005	Total
Channel						
Sheerness Docks - General	8,475			726	16,349	**25,550**
Sheerness Docks – Berth 1			4,375			**4,375**
Sheerness Docks – Berth 3				547		**547**
Sheerness Docks – Berth 6 and 7				3,281		**3,281**
Area to the east of Sheerness Docks Berth 10				3,969		**3,969**
Strood Pier			308			**308**
Total	**58,749**	**77,518**	**145,318**	**35,200**	**184,855**	**521,640**

According to IECS (1993), all current disposal sites within the Medway involve the depositing of spoil onto land-based sites at Hoo Island and Rushenden Marsh (Kirby, 1990). As a result, the sediments removed from the tidal areas of the estuary are not returned into the system and are therefore unavailable for re-distribution and deposition.

Material dredged from the Medway approach channel is deposited 45 nautical miles, offshore, at South Falls. During the last 5 years or so, the deposition of dredge spoil onto Hoo and Rushenden Marhses has decreased significantly (telecoms with Medway Ports). During this time, approximately one load of dredge spoil from Chatham has been placed onto Hoo Island (telecoms with Medway Ports), any other material placed here has been dredged from the Thames Estuary. Medway Ports now own only half of Rushenden and have currently applied for a waste management license that would allow the further deposition of dredge spoil at this location.

Agitation dredging and plough dredging takes place in the river section of the Medway, such as alongside jetty frontages, however the majority of this dredged material is released into the deep water channel at Chatham.

C1.5.3 Historical morphological changes

Cliffs

CCC (2004a) reported that there have been two recorded landslips at Seasalter cliff, one at the eastern end and one at the western end where excavation of the railway cutting just inland has probably alleviated further ground-water influence. Their impact on the foreshore below is unknown. However, at present sea defences at the base of the cliffs prevents toe erosion and the supply of material to the beaches.

Shingle beaches

Garrison Point, located on the east of the mouth of the Medway, has been reclaimed. Prior to this, the accretion of shingle took place under the berths. Since land reclamation and construction of the Ro-Ro terminal, there has been little change to the shoreline (Scott Wilson, 1998a). Scott Wilson suggest that the reclamation has resulted in the ebb current being pushed together offshore, which led to the deposition of material in the main deep water channel of the Medway Estuary.

Scott Wilson (1998b) found the shingle spit at Shellness, on the north side of mouth of the Swale, to have shown a general trend of accretion in the past century (Scott Wilson, 1998b).

Grazing marshes

Much of the grazing marsh in the Medway has been lost since 1840 (IECS, 1993). Due to the combined affect of land improvement schemes carried out by the Lower Medway Internal Drainage Board and Southern Water Authority and the progressive reclamation of part of the Chetney Marshes for arable usage (IECS, 1993). IECS (1993) reported on the findings of Williams *et al* (1983), who in their paper, compared the areas of grazing marsh as shown by the Land Utilisation Surveys of 1935 and 1968, and aerial photographs from 1979 to 1982. The results of this study are summarised in Table C1.12.

Table C1.12: The reduction in the area of grazing marsh in North Kent, 1935 to 1982 (Williams et al, 1983) * Note: 725ha of land in the Sheerness area of the Isle of Sheppey was not surveyed in 1979.

	1935	1968	1979	1982
Grazing Marsh (ha)	14,750	12,250	8,200	7,450
Area converted to grazing marsh (ha)	-	200	-	-
Total area of grazing marsh (ha)	14,750	12,450	275	225
Net loss per annum (ha)	-	70	361	267

Saltmarsh and mudflats

Map evidence shows the extensive saltmarsh existed during the late 1600's, however by the mid 1800s, a large proportion of these saltmarshes had disappeared (CHaMP, 2002).

IECS (1993) reports that between 1809 and 1988, erosion of saltmarsh resulted in a reduction in saltmarsh area from 2157ha to 645ha. The rate of erosion between these times increased from 8.2ha per year between 1809 and 1970 (Burd, 1992), to 11ha per year from 1970 to 1988 (IECS, 1993). KCC (2002) also found there to be a loss of saltmarsh in the Swale; between 1900 and 1925, approximately 1334ha (280%) of saltmarsh was eroded**.** CCC (2004a) also report that there is evidence (from the Ordnance Surveys of 1872 and 1896) for an inland retreat of the High Water Mark (HWM) of up to 150 metres at Sea Salter. This resulted from the erosion of approximately 1.5 km^2 of `The Saltings' during a period of 24 years at the end of the 19th century. Old maps also show that an extensive area of saltings fronted the coastline between Faversham Creek and Seasalter at is time. CCC (2004a) found that between 1872 and 1895 further sea defence and drainage works were carried out in the Nagden Salts area, such that the defence line was moved seawards to its present day position. Since 1895 the saltings fronting this section of the study area have almost been entirely eroded away and the area known as Castle Coot is all that remains today. A summary of saltmarsh changes is provided in Table C1.13.

Kirby (1990) found that the primary areas of erosion included the banks of the marsh creeks and cliffs. Kirby reported that this erosion had produced a saltmarsh cliff up to 3m high in some locations, e.g. Deadman's Island, Burntwick Island, Stoke Marshes and Bishops Kirby.

Kirby (1969; 1990) identified a number of potential causes for saltmarsh and mudflat erosion, including:

- Coastal squeeze – a combination of seawall and embankment construction (Section C1.5.2) and rising sea levels (especially 1940-1990; Kirby, 1990). This may explain the erosion which occurred prior to mud mining (CCC, 2004a); and,
- Mud mining (Kirby, 1990) – the removal of mud for the brick and clay industry exacerbated the loss of mudflat and salt marsh in the estuary. This was a result of increased tidal currents due to increased tidal prism; and increased wave action due to the increase in fetch distances caused by the mud extraction.

Studies carried out for the period between 1998 and 2002 (KCC, 2002; and CCM, 2002) found that even though some loss of saltmarsh had occurred, the general trend was net accretion in the Medway and Swale. KCC (2002) reported a gain of 15ha in the Swale and 39ha in the Medway from 1998 to 2002. Over a longer timescale from 1988 and 2002 the same authors suggest a net gain of 60ha in the Medway and 33ha in the Swale. By comparison the CHaMP (2002) reports increases in salt marsh area of 55ha in the Medway and 16ha in the Swale between 1988 and 2000 (Table C1.14).

Table C1.13: Summary of changes to salt marsh habitat based on data taken from IECS (1993) unless stated otherwise.

Time	Saltmarsh	Morphological change
1809-1867	Area south of Burntwick Island	Marsh deteriorated into fragments.
1909	Gillingham, Rainham, Medway, King's Ferry and Twinney marshes	Loss of marsh due to erosion and reclamation.
	Stoke, Rainham (KCC, 2002), Hoo, Bishop Nor and Bedlams Bottom marshes	Dissection of marshes following commencement of mud extraction, resulting in the internal expansion of saltmarsh creeks.
	Milfordhope	Reclaimed, which resulted in erosion of marsh that formerly linked Milfordhope Marshes to the land, so that it became separated from the coast.
1921	Stoke, Hoo, Bishop, Nor and Bedlams Bottom marshes	Loss of saltamarsh due to continued erosion.
	Burntwick Island, Slayhills, Milfordhope and Barksore marshes	Breaching of embankments, resulted in a switch from grazing marsh to saltmarsh
1940	Stoke, Bishop, Nor, Burntwick Island, Slayhills and Milfordhope marshes	Loss of saltmarsh due to continued erosion.
	Deadman's Island	Loss of saltmarsh due to continued erosion.
	Hoo saltmarsh	Hoo saltmarsh was reclaimed and enclosed. Deposition of material from naval dockyards at Chatham resulted in accretion.
1970	Stoke, Bishop, Nor, Burntwick Island, Slayhills and Milfordhope marshes	Loss due to continued erosion.
	Bedlams Bottom marshes	Loss of marsh due to erosion.
	Deadman's Island	Marsh became detached from Chetney peninsula as a result of erosion.
	Greenborough marshes	Breaching of embankments led to reversion of grazing marshes to saltmarsh
	Barksore and Hoo marshes	Accretion can be accounted to the deposition of river dredgings on the Barksore and Hoo marshes.

Time	Saltmarsh	Morphological change	
1988	Stoke, Bishop, Slayhills, Greenborough and Mildford Marshes	Overall loss of 21% from 1973 to 1988, Low Marsh – 11%, Mid Marsh – 14%, Upper Marsh – 28%, Pioneer Marsh – 30%, Reclaimed Marsh – 18.2ha (from Burd, 1992).	Little change to saltmarsh.
	Nor marshes, part Burntwick Island		Breaching of embankments, resulted in the majority of this area lying below MHW, which resulted in the reformation of saltmarsh.
	Barksore marshes		Switch from saltmarsh to grazing marsh.

Table C1.14: Summary of saltmarsh change in the Medway and Swale estuaries. Source: CCM (2002), taken from CHaMP (2002).

Year	Area Lost (ha)	Rate of retreat	Area Gained (ha)	Rate of accretion	Net Change
Medway Estuary					
1988					750.7
2000	152.4	12.7ha/year	207.5	17.29ha/year	Net gain of 62.8ha, 5.23ha/year natural accretion
Swale Estuary					
1988					264.9
2000	35.4	2.95ha/year	51.3	4.27ha/year	Net gain of 15.9ha, 1.32ha/year natural accretion

The CHaMP (2002) reported on the findings of CCM (2002), who used historical aerial photographs to assess saltmarsh change. Combined with the findings of KCC (2002) and IECS (1993), the areas of accretion and erosion are listed below. Overall intertidal change in the Medway/Swale Estuary is provided in Table C1.15 and Table C1.16.

Table C1.15: Summary of saltmarsh change in the Medway and Swale estuaries. Source: CHaMP (2002).

	Medway	Swale
Eroding	Deadmans Island	Cleve Marshes
	Oakham Marsh	Nature reserve to the west of Cleve Marsh
	Nor Marsh	Spitend Point
		Marsh patches surrounding Wellmarsh and Sharfleet Creeks
		Fowley Island
Accreting	Chetney Hill	south of Shellness
	Ooze/Halstow area	south of Dutchman's
	Stoke Saltings	Spitend Point
	Damhead Creek	Lilies seaward of Milton Creek

Table C1.16: Change in saltmarsh area in the Medway and Swale Estuary between 1860 and 2002. Source: KCC, 2002. Note limitations provided in KCC, 2002.

		1860	1900	1961	1972	1988	2002
Medway	Saltmarsh area (ha)	1205	805	764	722	752	791
	% of 1860 value	100	67	63	60	62	66

		1860	1900	1961	1972	1988	2002
	% Difference from 1860		33	37	40	38	34
Swale (KCC, 2002)	Saltmarsh area (ha)	358	303	317	333	369	384
	% of 1860 value	100	85	89	93	103	107
	% Difference from 1860		15	11	7	-3	-7
**A negative value indicates accretion							

The CHaMP (2002) suggests that the expansion of saltmarsh is due to the growth of *Spartina anglica* and the loss of established and more diverse saltmarsh communities.

Using measurements of scoured out bi-valve shells, Kirby (1969) estimated the rate of inter-tidal mudflat lowering. These gave a vertical erosion rate of 0.02m yr^1, representing a loss of 20, 000m^3 km^2 yr^1. This rate gives the amount of sediment input from the 4.67km^2 of tidal flats within Stoke Marshes to be 93, 400m^3 yr^1. IECS (1993), developed these findings further to suggest that 228ha to be accreting, whilst 364ha was stable and 2771ha was eroding; to provide a net erosion of 104, 394m^3/year.

C1.5.4 Sediment Budget

A number of previous studies have reported that overall the Medway and Swale are undergoing accretion (IECS, 1993; MESP, 2001; CHaMP, 2002; and Halcrow, 2002). The estuaries are generally believed to act a weak sink for fine grained material. It appears that the volumes of sediment being deposited on the surfaces of the saltmarshes, the lower intertidal and (most significantly) in the subtidal channels exceed the volume of sediment supplied from the lateral retreat of saltmarsh cliffs and the vertical erosion of the upper mudflats.

In a strategy for the Medway and Swale MESP (2000) found that the sediment budget of the Medway and Swale is thought to be in equilibrium, with slight net inputs and outputs within specific compartments.

IECS (1993) produced overall sediment budgets for the Medway, including both intertidal and subtidal areas, based on two cases (Table C1.17):

- Case 1 - Under the assumption that the channel morphology remained constant until 1840, when mud extraction commenced the net accretion rate would be 300,000m^3 $yr\text{-}^1$; and
- Case 2 - Under the alternative assumption that the observed changes in the sub-tidal channel were continuous at least between the two survey dates of 1688 and 1987, the net accretion rate would be 150,000m^3 yr^1.

Table C1.17: Volumetric summary of intertidal changes in Medway. Source: IECS (1993).

Environment	Area (ha)	Accretion/ erosion rate (m yr^1)	Case 1: volumetric change (m^3/yr)	Case 2: volumetric change (m^3/yr)
Salt marsh surfaces	645	+0.0034	+22,334	+22,334
Salt marsh boundaries	loss of 13ha/yr	-1.0000	-132,000	-132,000

Environment	**Area (ha)**	**Accretion/ erosion rate (m yr^{1})**	**Case 1: volumetric change (m^3/yr)**	**Case 2: volumetric change (m^3/yr)**
Accreting mudflats	228	+0.0150	+34.155	+34,155
Eroding mudflats	2771	-0.0050	-138,550	-138,550
Stable mudflats	364	0.0000	0	0
Sub-tidal channels	1200 (partial survey see section 3.1)	N/A	+300,00 (since 1840)	+150,000 (since 1688)
Sub-tidal accretion due to sea level rise	1200 (partial survey see section 3.1)	0.001	+12,000	+12,000
Total			+97,939	-4061

C1.6 ESTUARY MORPHOLOGY – FUTURE

The assessment of future evolutionary trends in the Medway and Swale is best achieved through the construction of a conceptual model. This conceptual model aims to explain the key characteristics of the estuary system in terms of its morphological form and operative processes. A knowledge of these aspects, the driving factors for future change, and a wider understanding of behavioural response of estuary systems, allows the future evolutionary tendencies for the estuary system to be assessed.

C1.6.1 Conceptual model

Medway

IECS (1993) proposed that the Medway estuaries experienced rapid intertidal accretion after the main post-glacial sea level rise. This was facilitated by the import of marine sediment under a flood dominant regime. This regime was produced by the deep proto-estuary channel. This accretion produced an extensive saltmarsh area, covering over half of the estuary area, which existed from at least 1590 to 1800. This produced conditions of quasi-stability (dynamic equilibrium), with the high intertidal areas and relatively deep channels resulting in greater ebb dominance and a reduction in accretion rates. This quasi equilibrium state was disturbed by a number of factors which brought about the saltmarsh and mudflat erosion.

IECS (1993) believed that the most significant factor for the switch to an erosive regime was the extraction of mud for the brick industry in the 19th and 20th centuries. Increasing rates of sea level rise throughout the 20th century are believed to have exacerbated these erosional processes and according to IECS (1993) the rates of erosion have increased over the last 50 years. Added to this, both the Medway and Swale have been the subject of extensive land reclamation through the construction of sea defences, which has led to coastal squeeze. The over-deepening of the estuary channel by capital and maintenance dredging has led to an increase in sediment demand within these areas, with the dredged material generally being disposed of outside the system.

At present the Medway is characterised by having a channel that is constrained at its mouth (outer region) and overly wide in its middle region. The mouth is characterised by mudflats that are narrower and steeper than those of the middle estuary. In the inner estuary, the main channel narrows and becomes highly sinuous with limited intertidal areas.

These morphological changes are associated with changes in flood/ebb dominance with the outer estuary being ebb dominant, the middle estuary being flood dominant and the upper estuary being ebb dominant. IECS (1993) reported that there is a net export of sediment at the mouth of the Medway Estuary, which results from the ebb dominance; whilst in the upper estuary, a net import of sediment is observed, a result of the flood dominance. For the Medway and Swale overall, IECS (1993) found that although the upper intertidal areas were generally eroding, the lower mudflats and sub-tidal channels were accreting. IECS noted that re-advance of low salt marsh over previously eroded mudflats was occurring at Bishop's Ooze and Bedlams Bottom in the middle estuary. These trends produced a slight net accretion overall, and marshes have shown expansion over the last 50 years.

Swale

Previous workers have not commented extensively on the functioning of the Swale. In terms of its morphological evolution it would appear that it has followed a similar pattern to the Medway. Rapid intertidal accretion after the main post glacial sea level rise would be expected to have led to the formation of extensive saltmarsh and mudflats throughout the estuary. This would have been facilitated by a flood dominant regime, which would have decreased over time as the former margins of the deep central channel were infilled with intertidal sediments. Reclamation of these marshes is likely to have begun in Roman times (1000 BP), facilitated by a slight drop in sea levels. After this time the rise in sea level, coupled with the presence of defences may have initiated coastal squeeze in some areas. The Swale lacks the wide middle reach of the Medway and can be split into three regions. The eastern mouth is wider than expected, the middle shows an expected decrease in width and depth, and the inner western mouth essentially, represents a canalised channel. Historical analysis shows the saltmarshes of the Swale to have undergone slight accretion over the last 50 years.

C1.6.2 Future evolution

In general terms, the amount of geomorphological change experienced is dependent on the degree of change in the driving forces, such as sea level rise and storminess, as well as the ability of the system to respond, for example by landward migration. The ability of the system to respond is limited by constraints such as the underlying geology, sea defences and available sediment supply. The system responses can usefully be considered as those concerning (i) the mouth, (ii) the import/export of sediment and hence the infilling of the estuary, and (iii) the estuary form response.

Sea level

Over the last 70 years, average rates of mean sea level rise in south east England have been between 1 and 3 mm/yr (Woodworth *et al.*, 1991; Shennan and Woodworth, 1992). Detailed spatial analyses for east coast of England suggest that, over the same period, extreme sea levels have risen at around 1.3 mm/yr (Dixon and Tawn, 1995).

Sea level rise is estimated, from tidal maxima measured at sheerness, as between 1mm and 3mm per year up to 1920 and increasing to 4mm between 1920 and 1983. There is some evidence that the rate of increase in high water maxima may have been as much as 8mm per year in the period 1954-1983 (IECS, 1993).

In 1999, MAFF (now Defra) estimated that over a period of 50 years, sea level rise around the East coast was in the region of 6mm/year (MAFF, 1999). More recently, UKCIP02 (Defra, 2002b) recommended that over the next 100 years, sea level in Eastern England could rise by between 0.17-0.77mm/year. UKCIP estimated that under a low emissions scenario, a net sea level change of 22cm by 2080, relative to 1961-90; and under a high emissions scenario net sea level change could increase to 82cm. These calculations of sea level rise based on estimates of present rates of relative land/ sea-level changes (or isostatic adjustments) from Shennan (1989). Since then, the isostatic adjustment data has been updated (Shennan and Horton, 2002) and UKCIP (2005) have used these to update the calculation of regional net sea-level change for the UK. The predictions of sea level change for the Eastern England are presented in Table C1.18.

Table C1.18: Updated rates of vertical land movement due to isostaic adjustment for Eastern England [Source: Estimated from Shennan and Horton, 2002]. Also shown is net sea-level change for Eastern England relative to 1961-1990 for the full range of global sea-level changes estimated by the IPCC (2001), incorporating the updated isostatic adjustment data. Source: UKCIP (2005).

	Regional Isostatic Uplift (+ve) or Subsidence (-ve) (mm/yr)	Net Sea-level Change (mm) Relative to 1961-90					
		Low Emissions ’Low’ IPCC Estimate			High Emissions ’High’ IPCC Estimate		
		2020’s	2050’s	2080’s	2020’s	2050’s	2080’s
Eastern England	-0.8	80	130	170	180	420	770

More recent interim policy guidance published by Defra (2006) however, now predicts that net sea level rise will rise exponentially over the next 125 years, updated figures for the Kent coast are found in Table C1.19. New indicative sensitivity ranges are also included in the interim guidance and are shown in Table C1.20. Indicative sensitivity ranges are used to cover peak rainfall intensity, peak river flow volume, offshore wind speed and extreme wave heights to help fully understand the potential impacts of climate change in catchments and on the coast.

Table C1.19: Updated sea level rise estimates for the east coast of England (Defra 2006).

Region	Assumed Vertical land Movement (mm/yr)	Net Sea-Level Rise (mm/yr)				Previous allowances
		1990 - 2025	2025 - 2055	2055 - 2085	2085 - 2115	
East of England, East Midlands, London, SE England (south of Flamborough Head)	-0.8	4.0	8.5	12.0	15.0	6 mm/yr constant

Table C1.20: Updated Indicative Sensitivity Range Estimates (Defra 2006).

Parameter	1990 - 2025	2025 - 2055	2055 - 2085	2085 - 2115
Peak rainfall intensity (small catchments)	+ 5%	+ 10%	+ 20%	+ 30%
Peak river flow volume (large catchments)	+10 %	+ 20%		
Offshore wind speed	+ 5%		+ 10%	+ 10%
Extreme wave height	+ 5%		+ 10%	+ 10%

Storminess

There is considerable uncertainty regarding the temporal change in the wind-wave climate around the UK. In the North Sea, Halcrow (1991) found a decrease in the number of gales over the last 60 years, but an increase over the last 20. Bacon and Carter (1991) found an increase in wave height from 1960 to 1980 with a decrease after this, whilst Leggett *et al*. (1996) found that between 1973 and 1995 there was a general increase in wave heights in the North Sea. Such uncertainties mean that it is difficult to establish if wave heights have increased or decreased over the last 100 years. The suggestion is that any long term trends are obscured by variation on shorter timescales.

A report prepared by the Hulme and Jenkins (2002) predicts that wind speeds for the East Anglian coast could vary by +/-2% by 2020; will increase by 6% by 2050; and will increase by 8% by 2080. The report proposes that since wave height is a function of the square of wind speed, then existing wave heights will increase in the ratio 1:1.04 by 2020; 1: 1.12 by 2050; and 1.17 by 2080.

Precipitation and Freshwater flow

In the Kent area, changes in river flow may arise as a result of climate change in the future. Increases in fresh water flow could lead to more stratified water column, especially in the upper reaches of the estuary. It is difficult to assess the impacts of these changes on estuary morphology, although experience in other estuaries, such as the Mersey and Humber, has illustrated that freshwater flows can influence the morphology of the low water channel in terms of overall position and siltation rates (Pontee *et al*., 2004). In the Humber for example, high freshwater flows have been observed to reduce siltation rates in the dredged regions of outer estuary. However, the catchment area of the Medway (1761km^2) is significantly less than the Humber (24,240km^2), and the impacts of freshwater flows would be expected to be correspondingly smaller in magnitude, although further work would be required to confirm this. Despite this, it is still possible that changes in freshwater flows could have a greater significance in the inner reaches of the estuary. Recent interim guidance on climate change (Defra, 2006) also includes new indicative sensitivity ranges (Table C1.20). Indicative sensitivity ranges are used to cover peak river flow volume in large catchments, such as the Medway and Swale, help fully understand the potential impacts of climate change in these catchments.

Further investigations of the impacts on climate change in the Kent area would also be needed to clarify any changes to the Medway and Swale estuary system that might arise.

C1.6.3 Future morphological evolution

A number of previous studies have suggested that the future evolution of the Medway and Swale will involve substantial intertidal accretion. This has been based on:

- A conceptual model for estuary accretion/erosion and tidal asymmetry;
- Extrapolation of historical saltmarsh expansion rates; and,
- Estuary regime analysis.

The conceptual model for estuary infilling is based on changes in tidal dominance, with sediment import leading to accretion and export leading to erosion (Dronkers, 1986; Pethick, 1993). IECS (1993) used this model to suggest that if the present trend for the erosion of the upper intertidal and the accretion of the lower intertidal and subtidal continued in the Medway, then it could lead to the return of more flood dominant conditions. The return of such conditions could lead to the restoration of accretion processes on the intertidal and the re-advance of saltmarshes over the mudflats. However, the IECS (1993) noted that the establishment of such accretional conditions could be prevented by increases in the rate of sea level rise. The return of such accretional conditions is also reliant on the existence of sufficient sediment supply. The CHaMP (2002) suggest that in the Medway the sediment supply from the Greater Thames Embayment and internal sources was sufficient to meet demand over the next 50 years, but could go into deficit within the next 100 years. For the Swale, the CHaMP (2002) considers that sediment supply is sufficient to meet demand over the next 100 years. CCM (2002) suggest that accretion is possible despite sea level rise, since the original cause for the initiation of saltmarsh erosion (mud mining in the 1800's) has now ceased.

CCM (2002) used two lines of analysis to support the proposed expansion of saltmarsh in the Medway and Swale. Firstly, extrapolation of the trend of increasing saltmarsh area between 1961 and 2000 forward to the year 2100 suggests that further marsh growth will occur. Secondly, regime analysis of the estuary geomorphological form suggests that accretion on the upper intertidal is necessary in order to achieve an equilibrium form in both the Medway and the Swale. Figures C1.4 to C1.8 show the best fit regression lines for the extrapolated data and the results of the regime analysis.

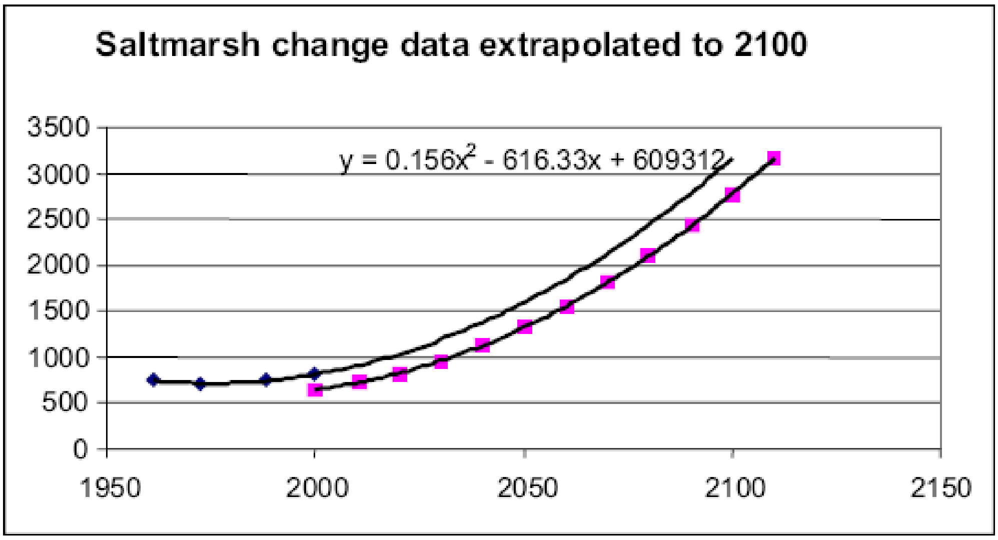


Figure C1.4: Best fit regression to CCM data extrapolated to 2100 assuming zero sea level rise (blue) and assuming a sea level rise of 6mm per year (pink), CHaMP (2002).

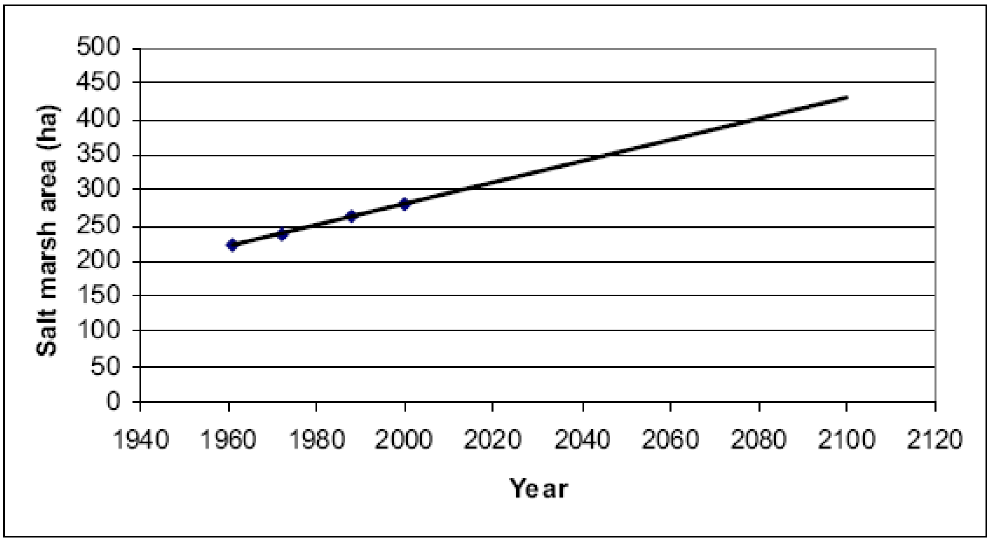


Figure C1.5: Rates of extension of the saltmarsh area in the Swale 1961-2000 extrapolated to 2100, CHaMP (2002).

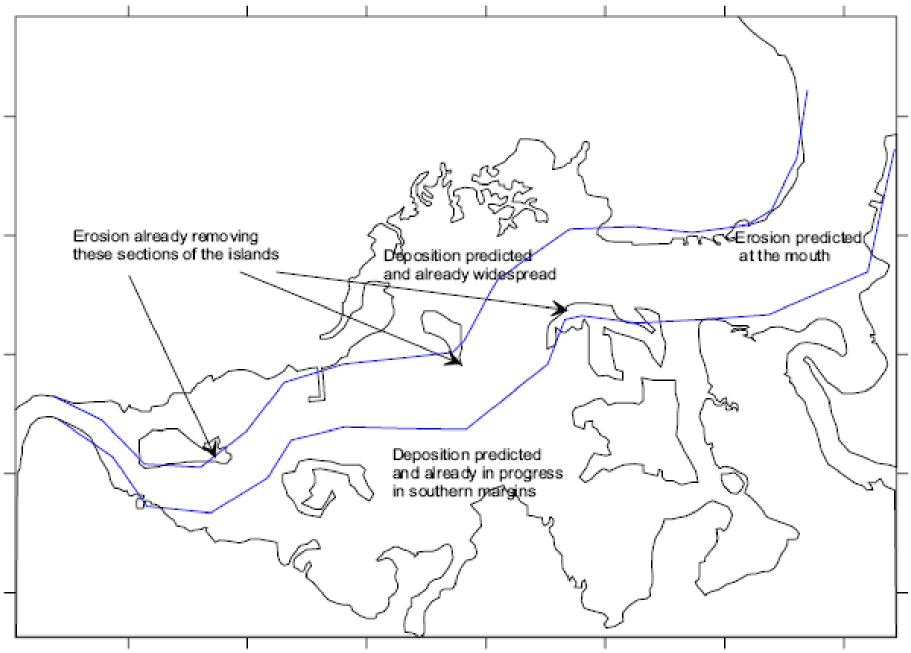


Figure C1.6: Equilibrium width (blue lines) assuming zero sea level rise, CHaMP (2002).

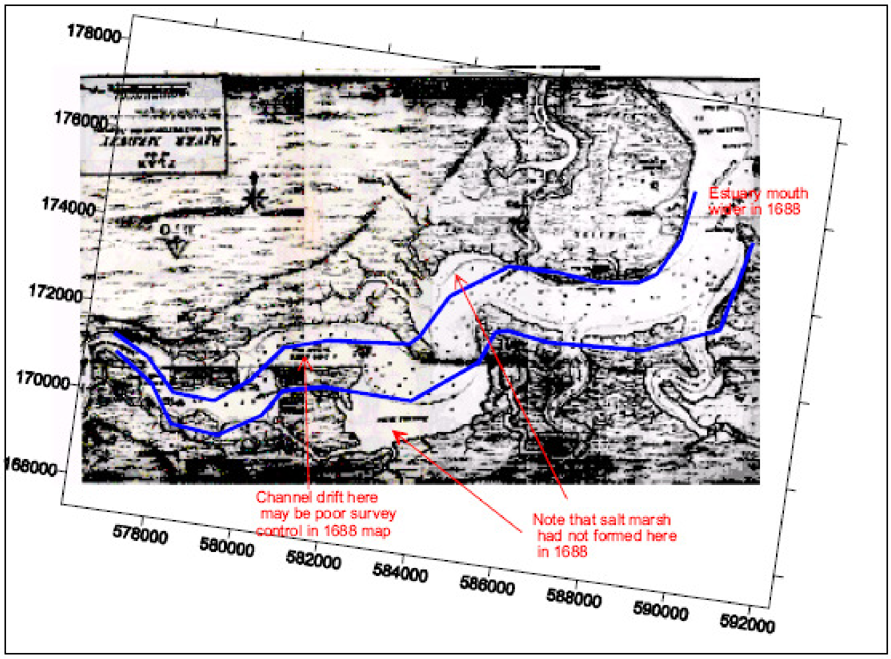


Figure C1.7: Comparison between Medway map of 1688 and model predictions for equilibrium channel in 2002, CHaMP (2002).

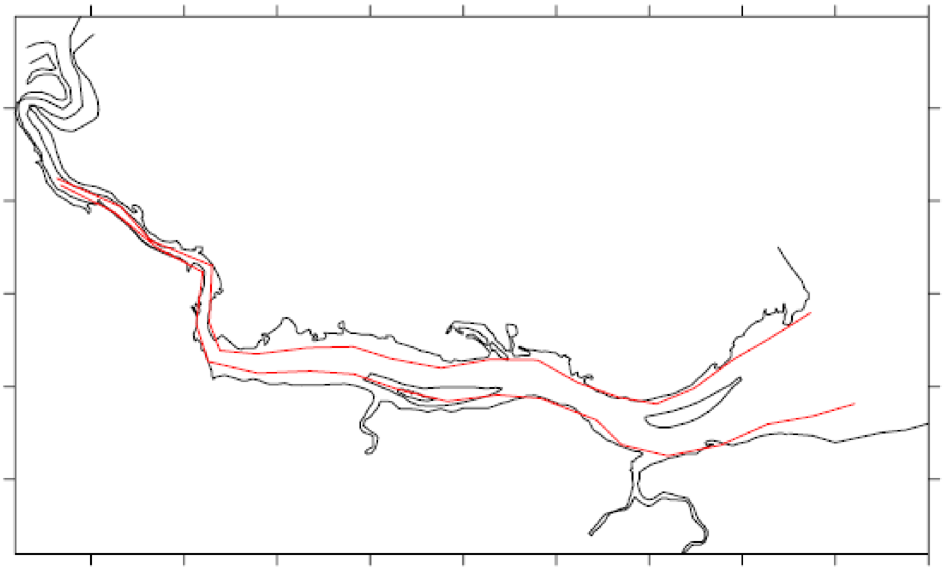


Figure C1.8: Equilibrium morphology of the Swale as predicted by the regime model (red line) compared to the existing morphology, CHaMP (2002).

In the Medway, the historical analysis suggests an increase in the area of saltmarsh to 3800ha, by 2100, whilst regime analysis suggests an increase of 3000ha with a rate of sea level rise of 6mm/yr. Both of these figures represent a massive increase (367%, 268%) in the present day area of saltmarsh (813ha). In the Swale, the historical analysis suggests an increase in the area to 484 ha, whilst regime analysis suggests an increase of 481ha with a rate of sea level rise of 6mm/yr. Both of these figures represent a significant increase (72%, 70%) in the present day area of saltmarsh (282ha). The CHaMP (2002) notes that increases in the rate of sea level rise are unlikely to alter the predicted expansion of the saltmarsh. However, in the Swale increases in the rate of sea level rise could reduce the amount of saltmarsh expansion.

In the Medway, CCM (2002) considered that:

- The majority of saltmarsh growth would occur in the central flood dominated section and the heads of the creeks leading off this section. This was observed to be occurring at present on the southern margins of the middle estuary where the present day form is wider than the equilibrium form;
- Where the equilibrium form of the estuary is narrower than the actual form there would be continued erosion of the mudflat/saltmarsh boundary. This was expected to occur along the main channel, main islands and outer sections of the internal creek system; and,
- Where coastal defences are present, coastal squeeze will dominate and the saltmarshes will erode, and eventually they could disappear. This prediction is only likely to be realised where fronting marshes are not experiencing accretion.

In the Swale, CCM (2002) considered that:

- The eastern mouth is currently wider than its predicted equilibrium form, suggesting that intertidal accretion is likely in this location;
- Between 4 and 5 km upstream of the eastern mouth, the equilibrium and present day form are equal, which implies that there is a geological constraint to the estuary in this region;

- To the West of Windmill Creek the existing channel is wider than the equilibrium form which may explain the development of Fowley Island; and,
- West of Fowley Island, between Elmley and Kelmsley, the equilibrium and present form are the same, implying a geological constraint to the estuary form.

However, the extrapolation of historical data presented in the CHaMP (2002) was based on just 4 data points between 1961 and 2000, and the extrapolation of these to 2100 needs to be treated with caution. The predicted massive expansion of saltmarshes in the Medway results from the fitting of a curved rather than linear trend line. Fitting of a linear trend line would reduce the predicted areas of marsh to approximately 1000 ha (an expansion of some 23%). Although there is some evidence for historical growth of saltmarshes in the middle region of the Medway, there are other areas where erosion is taking place.

C1.7 CONCLUSIONS

C1.7.1 Present understanding of estuary morphology and processes

The Medway and Swale lie within the Outer Thames Embayment which itself forms part of larger coastal behavioural system that extends from Harwich in the north to North Foreland in the South. The Medway is some 41km in length, has a spit at its mouth and can be divided into three reaches:

- Outer - Sheerness to Chetney Marshes - which has a constrained ebb dominant channel bordered by mudflats that are relatively narrow and steep;
- Middle – Chetney Marshes to Gillingham - which is flood dominant, overly wide and has extensive intertial areas; and,
- Inner – Gillingham to Allington Lock - which is ebb dominant, and has a narrows meandering channel with limited intertidal areas.

The Swale estuary channel is approximately 24km long, is open to tidal influences at both ends and has a spit at its western end. The channel can be divided into three reaches:

- Outer – Whitstable to Nagden Marshes: which represents a wide mouth region;
- Middle – Nagden Marshes to Elmley Island: which forms the main channel; and,
- Inner – Long Reach/West Swale – which comprises a narrow canalised channel to the western mouth.

Both the Medway and the Swale have been subject to extensive intertidal reclamation and most of their present shorelines are protected by flood embankments.

Previous workers (IECS, 1993, CCM, 2002, CHaMP, 2002) have proposed that the Medway and Swale estuaries experienced rapid intertidal accretion after the main post-glacial sea level rise under a flood dominant regime. This produced conditions of quasi-stability, with the high intertidal areas and relatively deep channels resulting in greater ebb dominance and a reduction in accretion rates. This quasi-equilibrium state was disturbed by extraction of mud for the brick industry in the 19th and 20th centuries, which initiated the erosion of marshes and mudflats. Increasing rates of sea level rise throughout the 20th century are believed to have exacerbated these erosional processes. Despite this erosion there has been a trend for increasing saltmarsh area from 1961 to 2000, and it is believed that this has the potential to continue in the future. In the Medway there is some evidence of accretion on the lower intertidal and more significantly in the subtidal channels. Sediment budget is believed to be sufficient to meet the proposed expansion of saltmarshes over the next 50 years, but could go into deficit after this time. In the Swale the sediment budget is believed to be sufficient to meet the proposed expansion of saltmarshes over the next 100 years.

Previous workers have proposed that the future evolution of the Medway and Swale will involve both accretion and erosion. The predicted rates of saltmarsh expansion are subject to high degrees of uncertainty since they are based in part on the extrapolation of a limited historical data set. In the Medway in particular, a linear extrapolation of the data would produce substantially lower rates of expansion than those predicted in the CHaMP (2002). In the Medway intertidal accretion is likely to be centred on the Middle reach of the estuary in the heads of creek systems. In the Medway, erosion is likely to continue to occur along the margins of the main channel in the middle estuary and more especially the mouth which is narrower than its equilibrium form. In the Swale, intertidal accretion is likely to occur in areas of the channel which are wider than their equilibrium form, including the eastern mouth and area to the West of Windmill Creek. IECS (1993) also considered that the loss of intertidal habitats could still occur in areas backed by flood defences due to coastal squeeze. The loss of such habitats could increase pressure on flood defences in these areas either by wave or current scour. This has the potential to increase the risk of flood defence failure.

C1.7.2 Limitations of Coastal Processes Desk Study and Key Recommendations for Further Work

There is some uncertainty regarding the predictions made by previous workers in terms of saltmarsh expansion and sediment supply. The uncertainty in the predicted expansion of saltmarshes could be reduced by undertaking further work:

- Reanalysing the original data used to derive saltmarsh extents;
- Carrying out new analysis of marsh areas for present day the Medway and Swale; and,
- Use of this data to extrapolate trends of marsh growth.

The future supply of sediment to the Medway and Swale is a key factor in determining whether or not an estuary system can accrete or will erode in the future. As a starting point the CHaMP (2002) multiplied a single suspended sediment concentration by the volume of the spring tidal prism. A more rigorous assessment of the volumes of sediment supplied to the estuary would require field measurements and a modelling exercise. This would allow the determination of net deposition/erosion patterns after a series or spring/neap tides. This exercise could also be supported by a re-analysis of the historical changes that have occurred in the estuary changes to intertidal and subtidal areas, in order to quantify the past locations and volumes of erosion and accretion.

It is suggested that the future management of flood defences in the study area may also be assisted by the collection and analysis of LiDAR and bathymetry data to determine the extent of intertidal habitats and areas of erosion and accretion. Such data would also allow predictions of future morphological change to be refined.

C2 Defence Assessment

The Table overleaf provides a summary of the existing defences along the SMP frontage together with an assessment of their residual life. An assessment of residual life under a 'no active intervention' policy was undertaken using the condition data together with NADNAC condition deterioration curves (CDC), using the Table below (Defra, 2006) as a guide.

Defence Description	Estimate of residual life (years) under NAI policy				
	Existing Defence Condition Grade				
	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5
Seawall (concrete/ masonry)	25 to 35	15 to 25	10 to 15	5 to 7	0
Revetment (concrete/ rock)	25 to 35	15 to 25	10 to 15	5 to 7	0
Timber groynes and other timber structures (e.g. breastwork/ revetments)	15 to 25	10 to 20	8 to 12	2 to 7	0
Gabion	10 to 25	6 to 10	4 to 7	1 to 3	0
Note: Grade 5 is not used in the CPSE, but is included here as a measure of failure.					

Source: Defra, 2006 (Shoreline Management Plan Guidance Vol. 2 Appendices, March 2006).

Note: Where a single defence length in the table has incorporated more than a single asset length and therefore has two or more separate standards, the lowest is quoted. This appears to give inconsistent results for the river reaches where standards of protection seem to fluctuate dramatically between 1 in 2 and 1 in 1000 over short distances. This may be due to the presence of naturally high ground or secondary defences that are not included within the National Flood and Coastal Defence Database (NFCDD).

C2.1 DEFENCE ASSESSMENT TABLE

Location	**Present Defence Form, Condition & Residual Life**	**Approximate Standard of Protection**	**Foreshore Features**
Specific to information presented. Could include NG co-ordinates.	*Brief description of the type of defence present.* *Condition Grade 1-5* *Estimate of residual life (under No Active Intervention) provided for each defence form, where relevant.*	*<1:5 year* *>1:5 to 1:20 year* *>1:20 to 1:50 year* *>1:50 to 1:100 year* *>1:100 year*	*Brief description foreshore and shoreface as contribute to defence performance & condition.*
Allhallows-on-sea to Yantlet Creek TQ8426978638 to TQ8551678390	Earth embankment revetted with a mixture of concrete slabs, concrete blocks (Essex block) and stone. As the embankment turns inland along the creek there is no revetment and the defence is a simple earth embankment. Condition Grade 3 Residual Life >20 yrs	50 to 100	Wide tidal mudflats
Yantlet Creek to Cockleshell Beach TQ8639178442 to TQ8719178281	Earth embankment with rock revetment. Condition Grade 2 Residual Life <20 yrs	50 to 100	Wide tidal mudflats
Cockleshell Beach to Grain Village TQ8719178281 to TQ8855077400	Earth embankment with rip rap protection. Condition Grade 2 Residual Life >20 yrs	100	Wide tidal mudflats

Location	Present Defence Form, Condition & Residual Life	Approximate Standard of Protection	Foreshore Features
Specific to information presented. Could include NG co-ordinates.	*Brief description of the type of defence present.* *Condition Grade 1-5* *Estimate of residual life (under No Active Intervention) provided for each defence form, where relevant.*	*<1:5 year* *>1:5 to 1:20 year* *>1:20 to 1:50 year* *>1:50 to 1:100 year* *>1:100 year*	*Brief description foreshore and shoreface as contribute to defence performance & condition.*
Grain Village to Grain Power Station TQ8855077400 to TQ8919076600	To the north of the village the cliffs are undefended, whereas south of the car park there is a groyned beach and revetment. The undefended natural cliffs to the north of the village are gradually eroding. The Gravel Company tip spoil over the face of the cliff when they become concerned. <u>Condition</u> Grade 2 <u>Residual Life</u> <20 yrs	50 to 100	Wide tidal mudflats
Grain Power Station to Grain Container Terminal TQ8919076600 to TQ8931975577	Earth embankment. Upper section revetted with concrete blocks, wide concrete slab apron, lower section revetted with stone. <u>Condition</u> Grade 2 <u>Residual Life</u> >20 yrs	>100	Tidal mudflats
Grain Container Terminal TQ8931975577 to TQ8574975558	Concrete seawalls. <u>Condition</u> Grade 2 <u>Residual Life</u>	>100	No foreshore

Location	**Present Defence Form, Condition & Residual Life**	**Approximate Standard of Protection**	**Foreshore Features**
Specific to information presented. Could include NG co-ordinates.	*Brief description of the type of defence present.* *Condition Grade 1-5* *Estimate of residual life (under No Active Intervention) provided for each defence form, where relevant.*	*<1:5 year* *>1:5 to 1:20 year* *>1:20 to 1:50 year* *>1:50 to 1:100 year* *>1:100 year*	*Brief description foreshore and shoreface as contribute to defence performance & condition.*
	>20 yrs		
Colemouth Creek Damhead Creek TQ8532575072 to TQ8121572292	Earth embankment, with some short sections revetted with stone. <u>Condition</u> Grade 2 <u>Residual Life</u> >20 yrs	5 to 20	Wide tidal mudflats and extensive saltmarsh
Kingsnorth Power Station TQ8121572292 to TQ8103071793	Earth embankment, with south facing defences being revetted with rock. <u>Condition</u> Grade 2 <u>Residual Life</u> >20 yrs	>100	Tidal mudflats
Kingsnorth Power Station to Hoo Marina TQ8103071793 to TQ7780371241	The undeveloped sections of the coast are defended by earth embankments. Around the Hoo Marina Park the defences comprise concrete seawall, steel sheet piles and rock revetments. <u>Condition</u> Grade 2 <u>Residual Life</u> >20 yrs	5 to 20	Wide tidal mudflats with areas of saltmarsh in sheltered locations
Hoo Marina to Whitewall	Apart from the Cookham Woods, which has a natural shingle beach,	5 to 20	Narrow tidal mudflats

Location	Present Defence Form, Condition & Residual Life	Approximate Standard of Protection	Foreshore Features
Specific to information presented. Could include NG co-ordinates.	*Brief description of the type of defence present.* *Condition Grade 1-5* *Estimate of residual life (under No Active Intervention) provided for each defence form, where relevant.*	*<1:5 year* *>1:5 to 1:20 year* *>1:20 to 1:50 year* *>1:50 to 1:100 year* *>1:100 year*	*Brief description foreshore and shoreface as contribute to defence performance & condition.*
Creek TQ7780371241 to TQ7560269598	the remainder of the frontage is defended by vertical concrete or masonry walls with some steel sheet piling or rock revetments. Exposed sections of the Whitewall Creek earth embankments are revetted with rock. Condition Grade 4 Residual Life >20 yrs		Shingle beach at Cockham woods
Whitewall Creek to Rochester Bridge TQ7560269598 to TQ7402868989	Steel sheet piled walls up to Chatham Ness. No NFCDD info from here to the Rochester Bridge. Condition Grade 2 Residual Life >20 yrs	5 to 20	Narrow tidal mudflats. No foreshore in areas adjacent to vertical defences
Rochester Bridge to Medway Bridge TQ7402868989 to TQ7222967063	Immediately south of the bridge the defences comprise timber and concrete walls. From the scrap yard upstream these are replaced with earth embankments. South of Temple Marsh and along the leisure park frontage the defences are concrete walls. Condition Grade 5 Residual Life	5 to 20	Narrow tidal mudflats with some areas of saltmarsh in sheltered embayments

Location	**Present Defence Form, Condition & Residual Life**	**Approximate Standard of Protection**	**Foreshore Features**
Specific to information presented. Could include NG co-ordinates.	*Brief description of the type of defence present.* *Condition Grade 1-5* *Estimate of residual life (under No Active Intervention) provided for each defence form, where relevant.*	*<1:5 year* *>1:5 to 1:20 year* *>1:20 to 1:50 year* *>1:50 to 1:100 year* *>1:100 year*	*Brief description foreshore and shoreface as contribute to defence performance & condition.*
	<20 yrs		
Medway Bridge to Halling (left bank) TQ7222967063 to TQ7075564015	The majority of the defences are natural channel banks or flood embankments. Some short lengths are defended by concrete or timber walls. Condition Grade 5 Residual Life <5 yrs	<5	Narrow tidal mudflats
Halling (left bank) TQ7075564015 to TQ7086763180	Concrete walls with a short length of concrete bag wall. Condition Grade 4 Residual Life >20 yrs	<5	Natural river channel
Halling to Aylesford Paper Mills TQ7086763180 TQ7138860347	Earth embankments with some isolated short lengths of concrete walls. Condition Grade 5 Residual Life <5 yrs	<5	Natural river channel
Aylesford Paper Mills to	Combination of steel sheet piles, gabions and concrete walls.	50 to 100	Natural river channel

Location	**Present Defence Form, Condition & Residual Life**	**Approximate Standard of Protection**	**Foreshore Features**
Specific to information presented. Could include NG co-ordinates.	*Brief description of the type of defence present.* *Condition Grade 1-5* *Estimate of residual life (under No Active Intervention) provided for each defence form, where relevant.*	*<1:5 year* *>1:5 to 1:20 year* *>1:20 to 1:50 year* *>1:50 to 1:100 year* *>1:100 year*	*Brief description foreshore and shoreface as contribute to defence performance & condition.*
Aylesford Train Station TQ7138860347 to TQ7229558734	Condition Grade 4 Residual Life <20 yrs		
Aylesford Train Station to Allington Lock (left bank) TQ7229558734 to TQ7481658155	Earth embankments with some lengths of timber walls and faggot embankments Condition Grade 4 Residual Life >20 yrs	<5	Natural river channel
Allington Lock (right bank) to opposite Aylesford Paper Mills TQ7483858181 to TQ7155859805	Combination of concrete, masonry, timber and steel sheet piled defences. Some short lengths of natural embankment. Condition Grade 5 Residual Life <5 yrs	<5	Natural river channel
Aylesford Paper Mills to Medway Bridge TQ7155859805 to TQ7252466885	Combination of natural and earth embankments except for two sections of concrete wall opposite Holborough Marshes and at Wouldham. Condition	<5	Natural river channel

Location	Present Defence Form, Condition & Residual Life	Approximate Standard of Protection	Foreshore Features
Specific to information presented. Could include NG co-ordinates.	*Brief description of the type of defence present.* *Condition Grade 1-5* *Estimate of residual life (under No Active Intervention) provided for each defence form, where relevant.*	*<1:5 year* *>1:5 to 1:20 year* *>1:20 to 1:50 year* *>1:50 to 1:100 year* *>1:100 year*	*Brief description foreshore and shoreface as contribute to defence performance & condition.*
	Grade 4 Residual Life <20 yrs		
Medway Bridge to Cinque Port Marshes TQ7252466885 to TQ7925969070	No NFCDD information available, however defences comprise mainly 'hard' vertical defences.	20 up to St Mary's Island – no SoP info until next unit	Narrow tidal mudflats. No foreshore in areas adjacent to vertical defences
Cinque Port Marshes to Otterham Creek TQ7925969070 to TQ8319367904	Defences comprise mainly of stone revetted banks. Condition Grade 3 Residual Life >20 yrs	<5	Extensive tidal mudflats with large areas of saltmarsh in sheltered areas
Otterham Creek to Ham Green (east) TQ8319367904 to TQ8495469138	Defences comprise mainly of stone revetted banks. Condition Grade 4 Residual Life >20 yrs	5 to 20	Tidal mudflats with some areas of saltmarsh in sheltered embayments
Ham Green (east) to Barkshore Marshes TQ8495469138 to	Defences comprise mainly of stone revetted banks. Condition Grade 4	50 to 100	Tidal mudflats and narrow saltings. More extensive saltmarsh in sheltered embayments

Location	**Present Defence Form, Condition & Residual Life**	**Approximate Standard of Protection**	**Foreshore Features**
Specific to information presented. Could include NG co-ordinates.	*Brief description of the type of defence present.* *Condition Grade 1-5* *Estimate of residual life (under No Active Intervention) provided for each defence form, where relevant.*	*<1:5 year* *>1:5 to 1:20 year* *>1:20 to 1:50 year* *>1:50 to 1:100 year* *>1:100 year*	*Brief description foreshore and shoreface as contribute to defence performance & condition.*
TQ8678868668	Residual Life >20 yrs		
Barkshore Marshes TQ8678868668 to TQ8758667944	Defences comprise mainly of stone revetted banks. Condition Grade 5 Residual Life <20 yrs	5 to 20	Tidal mudflats and narrow saltings (approximately 20m wide) More extensive saltmarsh in sheltered embayments
Raspberry Hill Lane (B-road running adjacent to coast) TQ8758667944 to TQ8902968555	Defences comprise mainly of stone revetted banks. Condition Grade 3 Residual Life >20 yrs	<5	Extensive tidal mudflats and saltmarsh approximately 120m wide
Chetney Marshes to Ferry Marshes TQ8902968555 to TQ9041569649	Defences comprise mainly of stone revetted banks. Condition Grade 4 Residual Life <20 yrs	<5	Tidal mudflats and narrow saltings (approximately 20m wide) More extensive saltmarsh in sheltered embayments
Ferry Marshes to Milton Creek	Earth embankments with rock revetment. Condition	>100	Tidal mudflats and narrow saltings (approximately 20m wide) Some isolated pockets of more extensive

Location	**Present Defence Form, Condition & Residual Life**	**Approximate Standard of Protection**	**Foreshore Features**
Specific to information presented. Could include NG co-ordinates.	*Brief description of the type of defence present.* *Condition Grade 1-5* *Estimate of residual life (under No Active Intervention) provided for each defence form, where relevant.*	*<1:5 year* *>1:5 to 1:20 year* *>1:20 to 1:50 year* *>1:50 to 1:100 year* *>1:100 year*	*Brief description foreshore and shoreface as contribute to defence performance & condition.*
TQ9041569649 to TQ9254966284	Grade 3 Residual Life >20		saltmarsh
Milton Creek to Conyer Creek TQ9254966284 to TQ9608265718	Earth embankment with shotcrete revetment. Rock at toe. Condition Grade 3 Residual Life >20 yrs	5 to 20	Tidal mudflats
Conyer Creek to Faversham Creek TQ9608265718 to TR0185564574	Earth embankment with revetment (Essex block in places, remainder stone). Condition Grade 3 Residual Life >20 yrs	5 to 20	Saltmarsh approximately 120m wide in front of Uplees Marshes. Tidal mudflats along the remainder
Shell Ness to Isle of Harty TR0524668146 to TR0257465961	Earth embankments. Condition Grade 1 Residual Life <20 yrs	5 to 20	Saltmarsh – width varies between 160m and 600m

Location	Present Defence Form, Condition & Residual Life	Approximate Standard of Protection	Foreshore Features
Specific to information presented. Could include NG co-ordinates.	*Brief description of the type of defence present.* *Condition Grade 1-5* *Estimate of residual life (under No Active Intervention) provided for each defence form, where relevant.*	*<1:5 year* *>1:5 to 1:20 year* *>1:20 to 1:50 year* *>1:50 to 1:100 year* *>1:100 year*	*Brief description foreshore and shoreface as contribute to defence performance & condition.*
Isle of Harty TR0257465961 to TR0103566380	No formal defences. Flood embankments either side of the Isle of Harty tie into the high ground at this point.	N/A	Saltmarsh 120m wide
Isle of Harty to Elmley Hills TR0103566380 to TQ9277067218	Earth embankments with rock or concrete revetment on exposed sections. Condition Grade 2 Residual Life <20 yrs	5 to 20	Between the Isle of Harty and Spitend Point the saltmarsh is approximately 450m wide. West of foreshore is tidal mudflats.
Elmley Hills to Kingsferry Bridge TQ9277067218 to TQ9158769374	Earth embankments with stone revetment. Condition Grade 2 Residual Life <20 yrs	5 to 20	Mainly tidal mudflats with some pockets of saltmarsh
Kingsferry Bridge to Queenborough Creek TQ9158769374 to TQ9047472009	Earth embankments. Condition Grade 4 Residual Life <20 yrs	>100	Mainly tidal mudflats with some small pockets of saltmarsh

Location	Present Defence Form, Condition & Residual Life	Approximate Standard of Protection	Foreshore Features
Specific to information presented. Could include NG co-ordinates.	*Brief description of the type of defence present.* *Condition Grade 1-5* *Estimate of residual life (under No Active Intervention) provided for each defence form, where relevant.*	*<1:5 year* *>1:5 to 1:20 year* *>1:20 to 1:50 year* *>1:50 to 1:100 year* *>1:100 year*	*Brief description foreshore and shoreface as contribute to defence performance & condition.*
Queenborough Creek to Sheerness Docks TQ9047472009 to TQ9079275542	Steel and concrete quay walls in Queenborough and concrete seawall between creek and Sheerness. <u>Condition</u> Grade 2 <u>Residual Life</u> <20 yrs	>100	Tidal mudflats

C3 BASELINE SCENARIO 1 – No Active Intervention

C3.1 INTRODUCTION

This section assesses the evolution of the Medway and Swale estuaries assuming the scenario of ‘No Active Intervention’ (NAI). The section describes the expected shoreline response considering that there is no expenditure on maintaining or improving defences and that defences will fail at a time dependent upon their residual life (see Section C2, Table C2.1) and the condition of the fronting intertidal areas. Prediction of the evolution of the fronting intertidal mudflats and saltmarsh areas around the Medway and Swale is subject to considerable uncertainty and a range of further studies would be required to more accurately assess the long term evolution of the estuaries (see Section C5).

C3.2 SUMMARY

This section provides a general summary of the analysis of estuary response under the NAI scenario. Further information on estuary morphological response is provided in Section C5 of this appendix.

The Medway and Swale estuaries have different morphological forms and therefore show different patterns of morphological response. Within each estuary there are areas of accretion and erosion and some reaches experience both. In some areas the estuaries are constrained by high land and/or the presence of defences. However in other areas, the estuaries are unconstrained and have room for further habitat development within the existing estuary limits.

The failure of defences will inundate large areas of low lying land surrounding the present day estuaries. Analysis of estuary form suggests that defence failure in the Medway and Swale, and the creation of new intertidal mudflat and saltmarsh areas, has the potential to move the estuaries away from their equilibrium morphological forms. In general terms, the creation of realigned areas would increase the tidal prism and flow speeds downstream of the realignment areas, especially for realigned areas that are large in comparison to the existing estuary channel. Such changes would increase the potential for erosion in confined areas of the estuary channel. Flows into and out of the realigned areas would also lead to the localised erosion of channels in the vicinity of breaches in the defences. The exact nature of morphological change within the estuaries will depend on how and when the defences fail and the sequence of failure.

Within the Medway and Swale estuaries there are a limited number of areas that are potentially at risk from erosion under a NAI scenario. These can be classified as either shorelines of high land, shorelines with narrow floodplains (backed by high land) and shorelines on the outside of meanders (see Table C3.1).

Table C3.1: Areas potentially at risk from erosion under a NAI scenario. (Erosion rates taken from: Defra, 2002)

HIGH LAND	NARROW FLOODPLAIN	OUTSIDE OF MEANDERS
MEDWAY ESTUARY		
North of Grain village (Clay – approximately 0.5m/yr)	Borstal / Rochester (Chalk – approximately 0.1m/yr)	Cuxton (Alluvium – approximately <0.5m/yr)
Cliffs at Lower Upnor / Cockham Wood (Clay – approximately 0.5m/yr)	Limestone Reach Chatham (Chalk –approximately 0.1m/yr)	Halling (Alluvium – approximately <0.5m/yr)
Temple Marsh (Alluvium – approximately <0.5m/yr)	Gillingham (Clay – approximately 0.5m/yr)	Wouldham (Alluvium – approximately <0.5m/yr)
	Bedlams Bottom (Alluvium – approximately <0.5m/yr)	North Burham Court (Alluvium – approximately <0.5m/yr)
Ham Green (Clay / Alluvium-approximately 0.5m/yr)	Hoo Salt Marsh (Alluvium – approximately <0.5m/yr)	Snodland (Alluvium – approximately <0.5m/yr)
		Limestone Reach Chatham (Chalk – approximately 0.1m/yr)
SWALE ESTUARY		
Rushenden Disposal Tip (Alluvium – approximately <0.5m/yr)	Kemsley Down (Clay/Alluvium – approximately <0.5m/yr)	Kemsley Down (Alluvium – approximately <0.5m/yr)
Elmley Hills (Clay – approximately 0.5m/yr)		East Chetney Marshes (Alluvium – approximately <0.5m/yr)

The following text provides a summary of the analysis of the shoreline response, with details specific to each location and epoch contained with the Scenario Assessment Table. In addition to this, maps illustrating the position of the shoreline under NAI scenario are located in **Annex C2**.

<u>Epoch 0-20 years</u>

In the Medway, a significant number of defences have residual lives of less than 20 years (see Section C2 – Table C2.1), indicating that they are likely to fail under a scenario of NAI during this epoch. Over the 0-5 year period a number of defences located south of the Medway Bridge toward Allington Lock are predicted to fail. Over 0-20 years, a number of defence types are likely to fail throughout the Medway estuary.

In the Swale, no defences are expected to fail over the 0-5 year period. Over the 0-20 year period a number of defences on the Isle of Sheppey are likely to fail (see Section C2 – Table C2.1).

In areas near the Medway estuary mouth and the eastern Swale mouth, the failure of groynes on beaches will potentially allow greater rates of long shore transport. Depending on the balance between supply of sediment from updrift beaches and offshore sources, and the loss of sediment to downdrift beaches, this may result in the increase or decrease in beach width. For present purposes however, it is assumed that a continuation of present trends will occur,

Shingle beaches located near to the Medway estuary mouth, backed by defences that fail and are exposed to increasing levels of wave energy, are likely to undergo landward rollover during this epoch. Assuming that the offshore sediment source will continue to feed Shell Ness, the shell spit and beach will continue to accrete during this epoch. As groynes fail along this frontage the spit is expected to narrow and recurve towards the shore. Other shingle beaches within more protected parts of the estuary, backed by high land, will experience coastal squeeze with rising sea levels.

In some low lying areas of the Medway and Swale, defence failure would create intertidal mudflat and saltmarsh habitats within the realigned areas. The type of new intertidal habitat created would depend on the elevation of the land, future sedimentation rates and the colonisation of the areas by saltmarsh vegetation. In other low lying areas the failure of defences would lead to the flooding of existing infrastructure and built assets.

The failure of defences in areas backed by rising land and exposed to significant levels of wave energy (eg the Medway estuary mouth) would lead to the increased erosion of the hinterland. In areas of high land, sheltered from wave action, erosion rates following defence failure are likely to be lower and will be governed by the fluvial and tidal flows.

Where existing defences constrain channel meanders, defence failure would allow the reassertion of natural meandering behaviour, with erosion being concentrated on the outside of the meanders. This erosion would be increased with sea level rise and the potential for higher fluvial flows due to climate change. There would be increased uncertainty over time as to how the channel will meander and consequently where erosion will occur.

Over this epoch, the intertidal mudflat and saltmarsh areas in front of the defences in the Medway and Swale are likely to continue to respond as at present (see Section C4). These estuary wide trends will be modified by the localised failure of defences and the creation of new intertidal mudflat and saltmarsh areas. The flows into and out of these new intertidal areas are likely to erode the sea defences and create new channels or result in the expansion of existing creek networks across intertidal mudflat and saltmarsh areas. Where defence failure leads to the inundation of large areas, the flows will increase downstream of the new intertidal area and may cause erosion of intertidal and subtidal areas.

Epoch 20 – 100 years

In the Medway, those defences that are expected to remain viable over the 0-20 year period are expected to fail within the 20-50 year epoch. The majority of defences are located near to significant assets such as power stations, marinas, ports, and towns. In the Swale, those defences with a residual life of greater than 20 years are all located on the southern bank and are earth embankments with either rock or shotcrete revetments. These defences are also are expected to fail within this epoch.

Near the Medway estuary mouth, beaches that began to roll landwards in the first epoch following the failure of defences, will continue to move landwards under rising sea levels until constrained by high land. The shingle beach at Cockham Wood will continue to narrow as sea levels rise. Ultimately this will result in the complete loss of this feature. Consequently cliffs behind the beach will be reactivated and will begin to suffer erosion. As sea levels rise, the supply of sediment to shell spit and beach at Shell Ness are expected to decrease. The spit and beach will continue to narrow and eventually breach.

The trends described in the previous epoch for backing hinterland, intertidal mudflat and saltmarsh areas, downstream estuary channel regions and meanders would be exacerbated over the 20-50 year epoch.

Where defences have already failed in the first epoch and created new areas of intertidal habitat, the habitats will continue to become more established. Their establishment will be governed by the rate of sea level rise and the availability of sediment to allow their vertical accretion within the tidal frame.

Where primary defences have failed in the first epoch, secondary defences that lie behind them would be expected to fail within the 20-50 year epoch as they suffer increased exposure to wave and tidal action. Where primary defences have failed in the first epoch and are backed by high land, there would be a continuation of erosive trends governed by wave action, tidal currents and fluvial flows.

Predictions of the evolution of the behaviour of the intertidal mudflat and saltmarsh regions of main estuary channel become subject to greater levels of uncertainty through this epoch. In some areas there will be a continuation of the 0-20 year trends. In other areas it is possible that these trends will be modified by changes in the rate of sea level rise and the availability of sediment for intertidal accretion. With low rates of sea level rise and high rates of sediment supply there is likely to be a continuation of accretional trends. With high rates of sea level rise and low rates of sediment supply there is likely to be a reduction in accretional trends, and intertidal mudflat and saltmarsh zones may suffer erosion (coastal squeeze) where defences or high land constrain landward movement of the shoreline. For present purposes it has been assumed that continual accretion will occur in most areas as per the predictions of previous workers.

By the end of this epoch it is assumed that defences outside of the study area will also have failed under a NAI scenario, thereby increasing the number of eroding areas and potentially raising sediment supply to the Medway and Swale estuaries.

C3.3 SCENARIO ASSESSMENT TABLE – NO ACTIVE INTERVENTION

The following Scenario Assessment Table provides a summary of the analysis of shoreline response under a 'No Active Intervention' scenario, with details specific to each location. Transect number locations relate to those described in Section C5.

Location	**Baseline Scenario 1 – No Active Intervention**		
	Predicted Change For		
	Years 0 - 20	**Years 20 - 50**	**Years 50 - 100**
Medway – north/west bank			
North of Grain village to Middle Stoke Transects Medway 1, 2, 3, 4, 5, 6	**Timber groynes and revetment at Grain would fail within this period (<20 years). The earth embankment, revetment and seawalls (>20 years) between Grain and Middle Stoke would remain.**	**Earth embankment, revetment and concrete seawalls between Grain and Middle Stoke are expected to fail within this period (>20 years).**	**No defences.**
	The village of Grain sits on a localised area of high ground on the Isle of Grain. Towards the end of this epoch, the failure of groynes at Grain, near the estuary mouth, at will potentially allow greater rates of long shore transport. As backing defences fail and energy levels increase the beach is likely to undergo landward rollover. The power station at Grain, container terminal and associated infrastructure would continue to be protected by defences throughout this epoch. Over this epoch, the intertidal mudflat and saltmarsh areas in front of defences are likely to continue to respond as at present where mudflat and marsh erosion would continue in the confined areas near the estuary mouth. It is predicted that saltmarsh at Stoke Saltings would continue to	In areas near the estuary mouth, beaches that began to roll landwards in the first epoch, following the failure of defences, will continue to move landwards under rising sea levels until constrained by high land. In this case, the beach at Grain is predicted to erode as it experiences coastal squeeze as sea levels rise Failure of defences would lead to the large scale inundation of the low lying area between Grain Container terminal and Middle Stoke effectively leaving the high land at Grain as an island. Flooding of existing infrastructure and built assets along the Grain coastline would result. Extensive flooding would result in the estuary channel increasing in size as the shoreline	With predicted increases in sea level rise, further inundation of low lying areas is anticipated. High land on the Isle of Grain, predominatly consisting of London Clay, would become subject to erosion (approximately 0.5-1m/yr). A breach at Stoke Saltings could potentially create a second estuary mouth by connecting Yantlet Creek to the estuary to the west of the Isle of Grain (Isle of Grain to South Foreland SMP2, in progress). IECS (1993) report that this area represents a former second mouth of the Medway estuary that was closed by reclamation in Roman times. This connection would have the potential to increase the width of the

Location	**Baseline Scenario 1 – No Active Intervention**		
	Predicted Change For		
	Years 0 - 20	**Years 20 - 50**	**Years 50 - 100**
	experience net accretion.	realigns. This however would move the estuary away from its ideal form, increasing the tidal prism and the potential for downstream erosion in the estuary. An increase in flow speeds and a corresponding increase in the potential for erosion would also occur at this location. In low lying areas defence failure would encourage the creation of intertidal habitats within the realigned areas. Flows into and out of these new intertidal areas are likely to create new channels or result in the expansion of the existing creek network.The inundation of large areas will increase downstream flows and may cause erosion of intertidal and subtidal areas. The exact nature of morphological change within the estuaries will depend on how and when the defences fail.	estuary further.at the mouth, which would move the estuary at this location towards a more ideal form. Intertidal mudflat and saltmarsh erosion/accretion trends, assumed to continue as in previous epochs, would be exacerbated with rising sea levels and climate change, however behaviour of intertidal areas become subject to greater levels of uncertainty through these epochs.
Shoreline Movement	Narrowing of Grain beach, coastal squeeze of foreshore/intertidal area in front of existing defences.	Large scale flooding is predicted between Grain Container terminal and Middle Stoke.	A potential second mouth of the Medway may develop from increased flooding. The Isle of Grain would potentially become an island.
Middle Stoke to Lower Upnor Transects Medway 7, 8, 9, 10, 11, 12	**The earth embankments, rock revetments and seawalls (>20 years) would remain.**	**Earth embankments, rock revetments and seawalls are expected to fail within this period.**	**No defences.**
	This section of the estuary comprises of extensive intertidal and saltmarsh areas and a	The shingle beach at Cockham Wood would be expected to narrow further under coastal squeeze as sea levels rise. Ultimately this will result in the complete loss of this feature.	

Location	Baseline Scenario 1 – No Active Intervention		
	Predicted Change For		
	Years 0 - 20	**Years 20 - 50**	**Years 50 - 100**
	small narrow shingle beach at Lower Upnor. The shingle beach fronting Cockham Wood, Lower Upnor, being backed by rising land and clay cliffs, would experience coastal squeeze with rising sea levels, historic map analysis indicates a beach erosion rate of approximately 0.4m/yr. Intertidal mudflat and saltmarsh areas in front of defences are likely to continue to respond as at present where it is predicted that saltmarsh at Stoke Saltings would continue to experience net accretion. Oakham Marsh would continue to undergo marsh erosion. Similarly frontages around Hoo St Werburg would expect to continue to undergo mudflat erosion due to the confined nature of the channel at this location.	Consequently clay cliffs behind the beach will be reactivated and will suffer erosion (approximately 0.5m/yr). Failure of defences would result in the estuary channel increasing in size as the shoreline realigns. This however would move the estuary away from its ideal form, increasing the tidal prism and the potential for downstream erosion in the estuary. In low lying areas defence failure would create intertidal habitats within the realigned areas. Habitats will continue to become more established throughout these epochs. Higher land on Hoo Salt Marsh Island would begin to erode (approximately <0.5m/yr). Intertidal mudflat and saltmarsh erosion/accretion trends, which are assumed to continue as per the previous epoch, would be exacerbated with rising sea levels and climate change, however behaviour of intertidal areas becomes more uncertain through these epochs.	
Shoreline movement	Coastal squeeze of foreshore/intertidal area in front of most existing defences and of the beach at Cockham Wood (approximately 0.4m/yr).	Large scale flooding of low lying land. Cliffs at Cockham Wood would begin to erode.	
Lower Upnor to Medway (M2) Bridge <u>Transects</u> Medway 13, 14, 15, 16, 17	**Timber walls, earth embankments and seawalls (<20 years) between Rochester Bridge and Medway Bridge would be expected to fail towards the end of this period. Concrete and masonry sea walls and rock revetments (>20 years) would remain.**	**Concrete and masonry sea walls and rock revetments will fail within this period.**	**No defences.**
	In this location the estuary channel takes on a fluvial form with an almost constant width and	Where defences have already failed in the first epoch and created new areas of intertidal habitats, the habitats will continue to become more established. Their establishment will be	

Location	Baseline Scenario 1 – No Active Intervention		
	Predicted Change For		
	Years 0 - 20	Years 20 - 50	Years 50 - 100
	limited area of intertidal flats. The estuary planform at this location is an ideal shape therefore the local erosion and deposition characteristics would be disrupted through failure of defences. In areas backed by high land, defence failure would result in low rates of erosion governed by the fluvial and tidal flows. Defence failure would render urbanised and industrial areas, such as Strood and Frindsbury, liable to flooding. Where defences constrain channel meanders, defence failure would allow the reassertion of natural meandering behaviour, with erosion being concentrated on the outside of meanders. Intertidal mudflat and saltmarsh areas in front of defences, e.g. north of Temple Marsh, are likely to continue to respond as at present where channels are predicted to be stable in regards to erosion and accretion. High land at Temple Marsh would begin to suffer erosion (approximately <0.5m/yr).	governed by the rate of sea level rise and the availability of sediment to allow their vertical accretion within the tidal frame. Temple marsh may revert to saltmarsh. Trends described in the previous epoch where defences failed, relating to backing hinterland, and meanders, would also apply in this epoch as the remaining defences fail. These trends would be exacerbated for those areas where defence failure occurred in the 0 – 20 year epoch and through these epochs. Intertidal mudflat and saltmarsh erosion/accretion trends, which are assumed to continue as per the previous epoch, would be exacerbated with rising sea levels and climate change, however behaviour of intertidal areas becomes more uncertain through these epochs.	
Shoreline movement	Coastal squeeze of intertidal area, reactivation of natural channel meandering, erosion concentrated on outside of channel meanders.	Inundation of low lying areas, natural channel meandering processes reactivated, erosion concentrated on outside of channel meanders.	
Medway (M2) Bridge to North of Snodland	**Earth embankments and channel banks (<5 years) would expect to fail during the first half of this period. Concrete seawalls (>20 years) would remain.**	**Concrete seawalls are expected to fail within this period.**	**No defences.**

Location	Baseline Scenario 1 – No Active Intervention		
	Predicted Change For		
	Years 0 - 20	**Years 20 - 50**	**Years 50 - 100**
<u>Transects</u> Medway 18, 19, 20, 21, 22, 23, 24			
	In this location the channel is fluvial in form, and narrows in width as it moves inland. For much of this stretch there are narrow intertidal areas. Failure of defences may result in the estuary channel increasing in width as the shoreline realigns. This however would move the estuary away from its ideal form, increasing the tidal prism and the potential for downstream erosion in the estuary. In low lying areas defence failure would create intertidal habitats within the realigned areas. Saltmarsh at Halling would become reactivated, while freshwater habitats at Holborough Marshes would become brackish and more saline. Flows into and out of these new intertidal areas are likely to erode defences further and create new channels. The inundation of large areas will increase downstream flows. Where defences constrain channel meanders, defence failure would allow the reassertion of natural meandering behaviour, with erosion being concentrated on the outside of meanders (erosion rates of approximately <0.5m/yr). In this section this would potentially increase the likelihood of erosion at North Halling, Halling and Snodland.	Where defences have already failed in the first epoch and created new areas of intertidal habitats, the habitats will continue to become more established. Their establishment will be governed by the rate of sea level rise and the availability of sediment to allow their vertical accretion within the tidal frame. Trends described in the previous epoch where defences failed, relating to backing hinterland, habitat creation and meanders, would also apply in this epoch as the remaining defences fail. These trends would be exacerbated for those areas where defence failure occurred in the 0 – 20 year epoch and through these epochs.	

Location	Baseline Scenario 1 – No Active Intervention		
	Predicted Change For		
	Years 0 - 20	**Years 20 - 50**	**Years 50 - 100**
Shoreline movement	Inundation of low lying areas, erosion concentrated on outside of channel meanders, reactivation of channel meandering behaviour.	Inundation of low lying areas, erosion concentrated on outside of channel meanders, natural channel meandering processes reactivated.	
Snodland to Allington Lock <u>Transects</u> Medway 25, 26, 27, 28, 29, 30, 31, 32, 33, 34	**Earth embankments and channel banks (<5 years) would expect to fail during the first half of this period. Sheet piling, gabions and concrete walls (<20 years) would expect to fail towards the end of this period. Embankments and timber walls (>20 years) between Aylesford Train Station and Allington Lock would remain.**	**Embankments and timber walls between Aylesford Train Station and Allington Lock are expected to fail within this period.**	**No defences.**
	In this section the river is fluvial in form, is considerably narrower than other sections and is very constrained by developments along its southern shore. In low lying areas defence failure would create intertidal habitats within the realigned areas. Freshwater habitats originally landward of defences would become brackish and more saline. Flows into and out of these new intertidal areas are likely to erode defences further and create new channels. Leybourne lakes would eventually be inundated with water from the Medway channel, increasing the width of the river considerably along this section. The inundation of such a large area would increase flows and erosion downstream. The southern built up section of the river towards Allington has no intertidal or marsh areas, therefore there is no	Where defences have already failed in the first epoch and created new areas of intertidal habitats, the habitats will continue to become more established. Their establishment will be governed by the rate of sea level rise and the availability of sediment to allow their vertical accretion within the tidal frame. Trends described in the previous epoch where defences failed, relating to backing hinterland, habitat creation and meanders, would also apply in this epoch as the remaining defences fail. These trends would be exacerbated for those areas where defence failure occurred in the 0 – 20 year epoch and through these epochs.	

Location	Baseline Scenario 1 – No Active Intervention		
	Predicted Change For		
	Years 0 - 20	**Years 20 - 50**	**Years 50 - 100**
	opportunity for new habitat creation if defences fail in this area. Where defences constrain channel meanders, defence failure would allow the reassertion of natural meandering behaviour, with erosion being concentrated on the outside of meanders (erosion approximately <0.5m/yr).		
Shoreline movement	Inundation of low lying areas, erosion concentrated on outside of channel meanders, reactivation of channel meandering behaviour.	Inundation of low lying areas, erosion concentrated on outside of channel meanders, natural channel meandering processes reactivated.	
Medway (east and south bank)			
Allington Lock to Medway (M2) Bridge <u>Transects</u> Medway 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34	**Concrete, steel, masonry and timber defences (<5 years) north of Allington Lock would expect to fail towards the beginning of this period. Natural and earth embankments (<20 years) would expect to fail towards the end of this period.**	**No defences.**	
	In this section the river is fluvial in form and is constrained by developments along its southern shore towards Allington. The channel in the southern reach of the river is very narrow, but it widens as it moves towards the Medway Bridge. In low lying areas defence failure would create intertidal habitats within the realigned areas. Freshwater habitats originally landward of	New areas of intertidal habitats will continue to become more established. Their establishment will be governed by the rate of sea level rise and the availability of sediment to allow their vertical accretion within the tidal frame. Trends described in the previous epoch would be exacerbated through these epochs. Intertidal mudflat and saltmarsh erosion/accretion trends north of Wouldham would be exacerbated with rising sea levels and climate change, however behaviour of intertidal areas becomes more uncertain through these epochs.	

Location	Baseline Scenario 1 – No Active Intervention		
	Predicted Change For		
	Years 0 - 20	**Years 20 - 50**	**Years 50 - 100**
	defences would become brackish and more saline. Flows into and out of these new intertidal areas are likely to erode defences further and create new channels. Where defences constrain channel meanders, defence failure would allow the reassertion of natural meandering behaviour, with erosion being concentrated on the outside of meanders (erosion rate approximately <0.5m/yr). Potential erosion hot spots may therefore occur at Burham Court and Wouldham. The meander at Burham may potentially close, cutting off the current meander completely. Intertidal mudflat and saltmarsh areas in front of defences, north of Wouldham, are likely to continue to respond as at present where channels are predicted to be stable in regards to erosion and accretion.		
Shoreline movement	Inundation of low lying areas, erosion concentrated on outside of channel meanders, reactivation of channel meandering behaviour.	Inundation of low lying areas, erosion concentrated on outside of channel meanders, natural channel meandering processes reactivated.	
Medway (M2) Bridge to East of St Mary's Island <u>Transects</u> Medway 11, 12, 13, 14, 15, 16, 17	**Hard vertical defences (>20 years) would remain.**	**Hard vertical defences would be expected to fail.**	**No defences.**

Location	Baseline Scenario 1 – No Active Intervention		
	Predicted Change For		
	Years 0 - 20	**Years 20 - 50**	**Years 50 - 100**
	The channel is more fluvial in form than the outer estuary in this section. Most of this frontage has no intertidal area, however a small isolated patch of saltmarsh exists at Borstal, just north of the Medway Bridge. It would be expected that the hard defences would continue to protect the urbanised areas of Rochester and Chatham during this epoch. The small section of Intertidal mudflat and saltmarsh areas in front of defences are likely to continue to respond as at present, where channels are predicted to be stable, in regards to erosion and accretion.	In this location the estuary channel is fluvial in form with an almost constant width and limited area of intertidal flats. The channel shows a close correspondence to the ideal form in this region and any realignment due to failure of defences would perturb this. In areas backed by higher land, i.e. urban areas such as Rochester and Chatham that lie on chalk, defence failure would result in low rates of erosion (approximately 0.1m/yr) governed by the fluvial and tidal flows. Defence failure would render urbanised and industrial areas liable to flooding. Where defences constrain channel meanders, defence failure would allow the reassertion of natural meandering behaviour, with erosion (approximately <0.5m/yr) being concentrated on the outside of meanders, e.g. south of Chatham Reach. These trends will be exacerbated through these epochs. Intertidal mudflat and saltmarsh erosion/accretion trends, which are assumed to continue as per the previous epoch, would be exacerbated with rising sea levels and climate change, however behaviour of intertidal areas become subject to greater levels of uncertainty through these epochs.	
Shoreline movement	Coastal squeeze of intertidal areas.	Inundation of low lying areas, natural channel meandering processes reactivated, erosion concentrated on outside of channel meanders.	
St Mary's Island to West of Motney Hill Transects Medway 8, 9, 10	**Stone revetted banks (>20 years) would remain.**	**Stone revetted banks are expected to fail during this period.**	**No defences.**
	The estuary begins to widen along this section. The frontage differs considerably from those upstream, as it has extensive intertidal and saltmarsh areas and marsh islands. It would be expected that revetted banks would continue to protect the Gillingham frontage.	Failure of defences would result in the estuary channel significantly increasing in size as the shoreline realigns. This however would move the estuary away from its ideal form, increasing the tidal prism and the potential for downstream erosion in the estuary. Defence failure would render urbanised and industrial areas, such as Gilligham and St Mary's Island, liable to flooding. Higher land at Gillingham, which predominantly consists of London Clay, will begin to erode (approximately 0.5m/yr) due to the narrow flood plain at this location.	

Location	Baseline Scenario 1 – No Active Intervention		
	Predicted Change For		
	Years 0 - 20	**Years 20 - 50**	**Years 50 - 100**
	Intertidal mudflat and saltmarsh areas in front of defences are expected to continue to respond as at present; Erosion at the seaward edge of marshes at Nor Marsh and Rainham Creek would continue, however the remaining areas of saltmarsh would continue to accrete and/or be relatively stable.	In low lying areas defence failure would create intertidal habitats within the realigned areas. Flows into and out of these new intertidal areas would erode defences further, and create new channels or result in the expansion of the existing creek network. The inundation of large areas wouldl increase downstream flows and cause erosion of intertidal and subtidal areas. These trends will be exacerbated and new habitat will become more established through these epochs. Intertidal mudflat and saltmarsh erosion/accretion trends, which are assumed to continue as per the previous epoch, would be exacerbated with rising sea levels and climate change, however behaviour of intertidal areas becomes subject to greater levels of uncertainty through these epochs.	
Shoreline movement	Coastal squeeze of intertidal areas.	Inundation of low lying areas.	
Motney Hill to Kingsferry Bridge Transects Medway 3, 4, 5, 6, 7 Swale 18, 19, 20, 21, 22, 23	**Stone revetted banks (<20 years) around Barkshore, Chetney and Ferry Marshes would expect to fail within this period, banks (>20 years) along the other sections would remain.**	**Remaining stone revetted banks are expected to fail during this period.**	**No defences.**
	This section of the Medway estuary is very wide and has extensive intertidal and saltmarsh areas and marsh islands. The channel of the Swale, between Queenborough and the Kingsferry Bridge, is however more fluvial in form. Failure of defences would result in the estuary channel significantly increasing in size as the shoreline realigns. This however would move the estuary away from its ideal form, increasing the tidal prism and the potential for downstream	Where defences have already failed in the first epoch and created new areas of intertidal habitats, the habitats will continue to become more established. Their establishment will be governed by the rate of sea level rise and the availability of sediment to allow their vertical accretion within the tidal frame. Trends described in the previous epoch where defences failed, relating to backing hinterland, and meanders, would also apply in this epoch as the remaining defences fail. These trends would be exacerbated for those areas where defence failure occurred in the 0 – 20 year epoch and through these epochs. Intertidal mudflat and saltmarsh erosion/accretion trends, which are assumed to continue as	

Location	Baseline Scenario 1 – No Active Intervention		
	Predicted Change For		
	Years 0 - 20	Years 20 - 50	Years 50 - 100
	erosion in the estuary. In low lying areas defence failure would create intertidal habitats within the realigned areas. Flows into and out of these new intertidal areas are expected to erode defences further, and create new channels or result in the expansion of the existing creek network. The inundation of large areas will increase downstream flows and cause erosion of intertidal and subtidal areas. In areas where meanders are naturally constrained by high land, e.g. Motney Hill and Chetney Hill, defence failure would result in erosion governed by the fluvial and tidal flows. Where defences constrain channel meanders, defence failure would allow the reassertion of natural meandering behaviour, with erosion being concentrated on the outside of meanders, such as the Swale channel at Chetney Marshes. Intertidal mudflat and saltmarsh areas in front of defences are likely to continue to respond as at present; It is predicted that Burntwick Island and Greenborough marshes would continue to suffer marsh erosion. Saltmarsh at Millfordhope Marsh would continue to be relatively stable over this period. Saltmarsh accretion would continue along the eastern shoreline at Ham Green and Upchurch and along the west shoreline of Chetney Marshes and adjacent to Raspberry Hill Lane. North of Kingsferry Bridge, the channel is	per the previous epoch, would be exacerbated with rising sea levels and climate change, however behaviour of intertidal areas become subject to greater levels of uncertainty through these epochs.	

Location	Baseline Scenario 1 – No Active Intervention		
	Predicted Change For		
	Years 0 - 20	Years 20 - 50	Years 50 - 100
	predicted to continue to be stable over this period, with regards to erosion and accretion.		
Shoreline movement	Coastal squeeze of intertidal areas. Inundation of low lying areas, natural channel meandering processes reactivated in the Swale, erosion concentrated on outside of channel meanders.	Inundation of low lying areas, natural channel meandering processes reactivated in the Swale, erosion concentrated on outside of channel meanders.	
Swale (south bank)			
Kingsferry Bridge to Faversham Creek Transects Swale 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17	**Earth embankments and revetments (>20 years) are expected to remain.**	**Earth embankments and revetments are expected to fail within this period.**	**No defences.**
	The channel of the Swale, between the Kingsferry Bridge and Milton Creek is fluvial in form. From Milton Creek to Faversham Creek the channel widens and has large areas of intertidal mudflat, but relatively small areas of saltmarsh, e.g. Fowley Island. The channel width is constant from Milton Creek towards the estuary mouth, where it widens at Shell Ness. Large areas of former saltmarsh have been enclosed and reclaimed from the sea for agricultural use along this frontage. It would be expected that the defences would continue to protect the low lying land along this frontage and the urbanised areas of Sittingbourne	Failure of defences would result in the estuary channel significantly increasing in size as the shoreline realigns. This however would move the estuary away from its ideal form, increasing the tidal prism and the potential for downstream erosion in the estuary. Where primary defences have failed, any secondary defences that lie behind them would be expected to fail within the 20-100 year epoch as they suffer increased exposure to wave and tidal action. Secondary defence failure would threaten the urbanised and commercial areas of Sittingbourne and Faversham. In low lying areas defence failure would create intertidal habitats within the realigned areas. Flows into and out of these new intertidal areas would create new channels or result in the expansion of the existing creek network. The inundation of large areas would increase downstream flows and may cause erosion of intertidal and subtidal areas. These trends would be exacerbated and new habitat would become more established through these epochs. Where defences constrain channel meanders north of Elmley Hills, defence failure would allow the reassertion of natural meandering behaviour. Erosion would be concentrated on the	

Location	Baseline Scenario 1 – No Active Intervention		
	Predicted Change For		
	Years 0 - 20	Years 20 - 50	Years 50 - 100
	and Faversham. Intertidal mudflat and saltmarsh areas in front of defences are likely to continue to respond as at present. Faversham Creek and 'The Lillies' islands at the mouth of Milton Creek will continue to accrete. Saltmarsh along this frontage would continue to be stable, with the exception of marsh on Fowley Island which may continue to erode to the south.	outside of the meander of the Swale channel at Coldharbour Marshes (approximately <0.5m/yr), where high land at Elmley Hills constrains the river channel. Intertidal mudflat and saltmarsh erosion/accretion trends, which are assumed to continue as per the previous epoch, would be exacerbated with rising sea levels and climate change, however behaviour of intertidal areas become subject to greater levels of uncertainty through these epochs.	
Shoreline movement	Coastal squeeze of intertidal areas.	Large scale flooding of low lying land.	
Swale (north bank)			
Shell Ness to Kingsferry Bridge Transects Swale 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17	**No formal defences exist around the high land around the Isle of Harty.** **Earth embankments, revetments and groynes (<20 years) will fail during this period.**	**No defences.**	
	The channel of the Swale, between Faversham Creek and the Milton Creek is relatively wide, although of constant width, with extensive areas of saltmarsh and intertidal mudflats. The channel narrows, changing to a more fluvial form between Milton Creek and the Kingsferry Bridge. It is believed that material fed to the frontage at Shell Ness comes predominantly from offshore shell banks. Assuming this sediment supply	Where primary defences have failed in the first epoch, any secondary defences that lie behind them would be expected to fail within the 20-100 year epoch as they suffer increased exposure to wave and tidal action. Low lying land behind these secondary defences would potentially flood over these epochs if the defences fail. The flooding of low lying land behind the Isle of Harty would potentially create a new channel of the Swale, separating the Isle of Harty from the Isle of Sheppey. This channel may connect with the open coast north of Shell Ness, creating a third mouth to the Swale. New areas of intertidal habitats will continue to become more established. Their establishment will be governed by the rate of sea level rise and the availability of sediment to	

Location	Baseline Scenario 1 – No Active Intervention		
	Predicted Change For		
	Years 0 - 20	Years 20 - 50	Years 50 - 100
	remains, the shell/shingle beach is expected to continue to accrete (analysis of historic maps indicates an approximate accretion rate of 4.3m/yr at present), extending in a south-west direction. The failure of groynes along this frontage would allow greater rates of long shore transport. As a result the beach would begin to narrow and the tip of the spit would begin to recurve landwards. Landward rollover of the beach would occur in exposed locations, as backing defences fail and wave energy levels increase. Failure of defences along the southern shore of the Isle of Sheppey would result in extensive flooding along considerable lengths of the south of the island. Flooding would occur on every high tide. Defence failure would result in the estuary channel significantly increasing in size as the shoreline realigns. This however would move the estuary away from its ideal form, increasing the tidal prism and the potential for downstream erosion in the estuary. This would be most notable in the middle estuary, between Transects 8 (Bells Creek on the Isle of Sheppey to Luddenham Marshes) to 13 (Sharfleet Creek on the Isle of Sheppey to Tonge Corner), where the present day estuary channel is already larger than its equilibrium form. In low lying areas defence failure would create	allow their vertical accretion within the tidal frame. Trends described in the previous epoch, which are assumed to continue as per the previous epoch, would be exacerbated through these epochs. Intertidal mudflat and saltmarsh erosion/accretion trends would be exacerbated with rising sea levels and climate change, however behaviour of intertidal areas become subject to greater levels of uncertainty through these epochs. With sea level rise it is assumed that sediment supply from the offshore source would decline, resulting in the spit at Shell Ness becoming increasingly unstable and eventually a breach would occur.	

Location	Baseline Scenario 1 – No Active Intervention		
	Predicted Change For		
	Years 0 - 20	Years 20 - 50	Years 50 - 100
	intertidal habitats within the realigned areas. Flows into and out of these new intertidal areas would create new channels or result in the expansion of the existing creek network. The inundation of large areas will increase downstream flows and cause erosion of intertidal and subtidal areas. Towards the south east of Sheppey, counterwalls and secondary defences would mean any flooding, due to a breach in the primary defences, would be contained. In areas backed by high land, for example the London Clay Islands around Elmley Hills and the Isle of Harty, defence failure would result in low rates of erosion (approximately 0.5m/yr) governed by the fluvial and tidal flows. Where defences constrain channel meanders, defence failure would allow the reassertion of natural meandering behaviour, with erosion being concentrated on the outside of meanders, such as the outside of the channel north of Elmley Island. Existing intertidal mudflat and saltmarsh areas are likely to continue to respond as at present. Mudflat and saltmarsh accretion would be expected to continue between Shell Ness and the Isle of Harty. Intertidal mudflat and saltmarsh erosion would continue where the channel narrows due to natural constraints, i.e Elmley		

Location	Baseline Scenario 1 – No Active Intervention		
	Predicted Change For		
	Years 0 - 20	**Years 20 - 50**	**Years 50 - 100**
	Hills.		
Shoreline movement	Inundation of low lying land. Accretion of spit (of approximately 4.3m/yr) until defences fail.	Extensive flooding of low lying land.	
Kingsferry Bridge to Sheerness Docks Transects Medway 1, 2 Swale 18, 19, 20, 21, 22, 23	**Earth embankments, seawalls and quay walls (<20 years) are expected to fail during this period.**	**No defences.**	
	The channel of the Swale, between the Kingsferry Bridge and Queenborough, is fluvial in form. The mouth of the Medway estuary at Sheerness is relatively small compared to the remainder of the outer Medway estuary. Failure of defences would result in the estuary channel increasing in size as the shoreline realigns. This however would move the estuary away from its ideal form, increasing the tidal prism and the potential for downstream erosion in the estuary. Defence failure would render urbanised and industrial areas liable to flooding, for example at Queenborough and Sheerness. High land at the Rushenden Disposal Tip would begin to suffer low rates of erosion (approximately <0.5m/yr). In low lying areas defence failure would create intertidal habitats within the realigned areas.	Where primary defences have failed in the first epoch, any secondary defences that lie behind them would be expected to fail within the 20-100 year epoch as they suffer increased exposure to wave and tidal action. Low lying land behind these secondary defences would potentially flood over these epochs if defences fail. New areas of intertidal habitats would continue to become more established. Their establishment will be governed by the rate of sea level rise and the availability of sediment to allow their vertical accretion within the tidal frame. Trends described in the previous epoch would be exacerbated through these epochs. Intertidal mudflat and saltmarsh erosion/accretion trends, which are assumed to continue as per the previous epoch, would be exacerbated with rising sea levels and climate change, however behaviour of intertidal areas become subject to greater levels of uncertainty through these epochs.	

Location	Baseline Scenario 1 – No Active Intervention		
	Predicted Change For		
	Years 0 - 20	Years 20 - 50	Years 50 - 100
	Flows into and out of these new intertidal areas are likely to create new channels or result in the expansion of the existing creek network. In areas where meanders are constrained by high land, defence failure would result in erosion governed by the fluvial and tidal flows. Where defences constrain channel meanders, defence failure would allow the reassertion of natural meandering behaviour, with erosion being concentrated on the outside of meanders, such as on the outside of the Swale channel at Rushenden (approximately <0.5m/yr).		
Shoreline movement	Coastal squeeze of intertidal areas infront of defences until defence failure. Inundation of low lying areas, natural channel meandering processes reactivated in the Swale, erosion concentrated on outside of channel meanders.	Flooding of low lying areas, natural channel meandering processes reactivated in the Swale, erosion concentrated on outside of meanders.	

C4 BASELINE SCENARIO 2 – With Present Management

C.4.1 INTRODUCTION

This section assesses the evolution of the Medway and Swale estuaries assuming the scenario of 'With Present Management' (WMP). This baseline scenario has considered that all existing defence practices are continued accepting that, in the majority of cases, this would require significant investment in replacement, improvement and maintenance of defences in order to maintain their integrity and effectiveness of the line of present defences, over the 100 year period. Currently defence design lives are considered to be 50 years, therefore all of the defences within the Medway and Swale estuaries will need replacing once, if not twice within the period of assessment (i.e. 100 years) under a 'with present management' scenario. Prediction of the evolution of the fronting intertidal mudflat and saltmarsh areas around the Medway and Swale is subject to considerable uncertainty and a range of further studies would be required to more accurately assess the long term evolution of the estuaries (see Section C5).

C.4.2 SUMMARY

This section provides a general summary of the estuary response under the WPM scenario. Further information on estuary morphological response is provided in Section C5 of this appendix.

The Medway and Swale estuaries have different morphological forms and therefore show different patterns of morphological response. Within each estuary there are areas of accretion and erosion and some reaches experience both. In some areas the estuaries are constrained by high land and/or the presence of defences. However in other areas, the estuaries are unconstrained and have room for further habitat development within the existing estuary limits.

The following text provides a summary of the analysis of the shoreline response, with details specific to each location and epoch contained with the Scenario Assessment Table.

Epoch 0 – 20 years

In the Medway, a significant number of defences have residual lives of less than 20 years, indicating that they will need a higher level of maintenance to extend their serviceable life or replacement or improvement in this epoch. Additionally, south of the Medway Bridge toward Allington Lock a number of defences will need maintenance, replacement or improvement over the next 5 years (see Section C2 –Table C2.1).

In the Swale, the majority of primary defences on the Isle of Sheppey would require maintenance, replacement or improvement within this epoch.

Shingle beaches located near to the Medway estuary mouth, which are backed by defences and exposed to increasing levels of wave energy, are likely to undergo coastal squeeze during this epoch. Depending on the rates of sediment supply, sea level rise and the amount of wave energy, this may result in the loss of narrow beaches and the increasing exposure of defences to wave and tidal action. Other shingle beaches, within more protected parts of the estuary that are backed by high land, will also experience coastal squeeze with rising sea levels. The shell spit and beach at Shell Ness will continue to accrete, assuming continual supply of sediment from the offshore source remains at present levels.

Over this epoch, the intertidal mudflat and saltmarsh areas in front of the defences in the Medway and Swale are likely to continue to respond as at present (see Section C5). In summary, the main expected trends in the Medway are:

- Erosion in the confined mouth region where existing intertidal habitats will be 'squeezed' between the defences and receding LWM;
- Continued accretion on marshes that are presently accreting within the middle estuary, especially towards the heads of creeks; and,
- Relative stability in the inner estuary.

In the Swale, the main expected trends are:

- Accretion in the mouth region, although this may be offset by increases in wave action;
- Accretion within parts of the middle estuary; and,
- Erosion in confined parts of the middle and inner estuary.

These trends are based on extrapolation of existing trends in saltmarsh extent plus an analysis of where the estuaries have space for further sedimentation or are restricted and might undergo erosion. The continuation of these trends in the future depends on a large number of factors including the rate of sea level rise and the supply of sediment to the estuaries.

Within the inner parts of the Medway estuary, where the channel becomes more fluvial in character, maintaining the current defence line will fix the channel position. Sea level rise and the potential for increased fluvial flows with climate change will increase water levels and pressure on existing defences. This may potentially lead to increased likelihood of overtopping and scour of footings. Such changes are likely to lead to the requirement for increased maintenance and improvement works.

Epoch 20 – 100 years

In the Medway and Swale, all defences are expected to require maintenance, improvement or replacement works over this epoch due to the combined effects of sea level rise and climate change. Additionally, new defences may be required in areas that are currently undefended.

Shingle beaches located near to the Medway estuary mouth, which are backed by defences, are likely to undergo coastal squeeze and narrowing during this epoch. Ultimately this will result in the complete loss of these features putting increased pressure on defences. The shingle beach at Cockham Wood in a more protected section of the estuary is backed by high land and cliffs. This beach will also continue to experience coastal squeeze with rising sea levels. Ultimately this will result in the complete loss of these features and the reactivation of erosion of the landward cliffs. The shell spit and beach at Shell Ness would continue to accrete as long as a sediment supply was available. With sea level rise however it is assumed that sediment supply from the offshore source would decline, resulting in the spit and beach at Shell Ness narrowing and the spit being increasingly susceptible to breach. This would place increasing pressure on landward defences in this area.

Prediction of the evolution of the behaviour of the intertidal mudflat and saltmarsh regions of main estuary channels become subject to greater levels of uncertainty through this epoch (Section C5). In some areas there will be a continuation of the 0-20 year trends. In other areas, it is possible that these trends will be modified by changes in the rate of sea level rise and the availability of the sediment for intertidal accretion. With low rates of sea level rise and high rates of sediment supply there is likely to be a continuation of accretional trends. With high rates of sea level rise and low rates of sediment supply there is likely to be a reduction in accretional trends and intertidal mudflat and saltmarsh zones may suffer erosion (coastal squeeze) where defences or high land constrain landward movement of the shoreline. For present purposes it has been assumed that a continuation of present day accretion will occur in most areas as proposed by previous workers. Areas not accreting may undergo erosion in the future under sea level rise, for example at the base of unprotected cliffs or on the outside of meanders. Erosion in these locations would put increased pressure on existing defences.

By the end of this epoch it is assumed that defences outside of the study area will also remain in place, or possibly increase, under a WPM scenario, suggesting that sediment supply to the Medway and Swale estuaries will remain at present levels or decline.

Within the inner parts of the Medway estuary the trends described or the 0-20 year epoch will be exacerbated over this epoch, leading to the requirement for increased maintenance and improvement as well as additional defences.

C.4.3 SCENARIO ASSESSMENT TABLE – WITH PRESENT MANAGEMENT

The following Scenario Assessment Table provides a summary of the analysis of shoreline response under a 'With Present Management' scenario, with details specific to each location. Transect number locations relate to those described in Section C5.

Location	**Baseline Scenario 2 – With Present Management**		
	Predicted Change For		
	Years 0 - 20	**Years 20 - 50**	**Years 50 - 100**
Medway – north/west bank			
North of Grain village to Middle Stoke Transects Medway 1, 2, 3, 4, 5, 6	**Earth embankments, revetments and concrete seawalls would remain (>20 years). Maintenance, improvement and/or eventual replacement of groynes and revetment at Grain will be required within this period (<20 years).**	**Maintenance and improvement of earth embankments, revetments and concrete seawalls would be required. Replacement of groynes and revetment at Grain will be needed.**	**Replacement, improvement and maintenance of defences will be required to allow for the combined effects of sea level rise and climate change.**
	The exposed shingle beach at Grain near the estuary mouth would experience coastal squeeze during this epoch. Depending on the rates of sediment supply, sediment loss, sea level rise and wave energy, this could result in beach narrowing. Consequently defences would become increasingly exposed to wave and tidal action. Over this epoch, the intertidal mudflat and saltmarsh areas in front of defences are assumed to continue to respond as at present. Mudflat and marsh erosion would continue in the confined areas near the estuary mouth. Consequently defences would become increasingly susceptible to erosion in these	The shingle beach at Grain is likely to undergo continued coastal squeeze and narrowing during these epochs as sea levels rise. The groynes would become redundant as the integrity of the beach is lost. Ultimately this will result in the complete loss of this feature. Consequently defences behind the beach would become increasingly susceptible to toe scour and erosion in this location. It is assumed that Intertidal saltmarsh and mudflat evolution will continue in the same pattern as in the previous epoch.	

Location	Baseline Scenario 2 – With Present Management		
	Predicted Change For		
	Years 0 - 20	Years 20 - 50	Years 50 - 100
	locations. It is predicted that saltmarsh at Colemouth Creek would continue to experience net accretion. **Saltmarsh at Stoke Marshes would continue to experience erosion.**		
Middle Stoke to Lower Upnor Transects Medway 7, 8, 9, 10, 11, 12	**Earth embankment, seawalls and shingle beach would remain (>20 years).**	**Maintenance and improvement of earth embankment and seawalls would be needed during this epoch.**	**Replacement followed by improvement and maintenance of defences will be required to allow for the combined effects of sea level rise and climate change.**
	This section of the estuary comprises of extensive intertidal and saltmarsh areas and a small narrow shingle beach at Lower Upnor. Although this shingle beach is within a more protected part of the estuary that is backed by high land and cliffs, the beach would experience coastal squeeze as sea levels rise. Over this epoch, the intertidal mudflat and saltmarsh areas in front of defences are likely to continue to respond as at present; It is predicted that saltmarsh at Stoke Saltings would continue to experience net accretion. Oakham Marsh would continue to suffer marsh erosion, consequently defences on this island will be increasingly subject to erosion. Frontages around Hoo St Werburg and Lower Upnor are expected to continue to suffer	The shingle beach is likely to undergo continued coastal squeeze and narrowing during these epochs as sea levels rise. Ultimately this will result in the complete loss of this feature. Consequently cliffs behind the beach will be reactivated and will suffer erosion as sea levels rise. Additionally new defences may be required in this currently undefended location. It is assumed that Intertidal saltmarsh and mudflat evolution will continue in the same pattern as in the previous epoch.	

Location	Baseline Scenario 2 – With Present Management		
	Predicted Change For		
	Years 0 - 20	**Years 20 - 50**	**Years 50 - 100**
	mudflat erosion due to the confined nature of the channel at these locations, again defences would be subject to increased erosion and undermining at this location.		
Lower Upnor to Medway (M2) Bridge Transects Medway 13, 14, 15, 16, 17	**Earth embankments, timber and concrete walls (<20 years) between Rochester Bridge and Medway Bridge would require replacement within this period. Sheet piled walls would remain (>20 years).**	**Sheet piled walls would require replacing during this epoch. Other defences would require increased maintenance and improvement works.**	**To allow for sea level rise and the effects of climate change, defences would require more frequent levels of maintenance, improvement and replacement.**
	In this location the estuary channel takes on a fluvial form with an almost constant width and limited area of intertidal flats. Over this epoch, the intertidal mudflat and saltmarsh areas in front of defences are likely to continue to respond as at present where existing channels and small pockets of saltmarsh would continue to be stable (see Section C5). Maintaining the current defence line would however fix the channel position, restricting natural channel processes.	Sea level rise and the potential for increased fluvial flows with climate change will increase water levels and pressure on existing defences. This may potentially lead to an increased likelihood of overtopping and scour of footings. Such changes are likely to lead to the requirement for increased defence maintenance and improvement works, which in turn may increase the potential for erosion of the limited intertidal areas along this frontage.	
Medway (M2) Bridge to North of Snodland Transects Medway 18, 19, 20, 21, 22, 23, 24	**Natural channel banks (<5 years) between Medway Bridge and Halling would require improvements and earth embankments (<5 years) between Halling and Snodland would require maintenance, improvement and replacing within the first 5 years of this period. Concrete walls (>20 years) at**	**Concrete walls would require maintenance, improvement and replacement during this epoch. Embankments and natural channel banks would also need to be raised, improved and replaced.**	**All defences would require increased levels of maintenance, improvement and replacement at varying times throughout this epoch due to the combined effects of sea levels rise and climate change.**

Location	Baseline Scenario 2 – With Present Management		
	Predicted Change For		
	Years 0 - 20	Years 20 - 50	Years 50 - 100
	Halling would remain.		
	In this location the channel is fluvial in form, and narrows in width as it moves inland. For much of this stretch there are narrow intertidal areas. Over this epoch, the intertidal areas in front of defences are likely to continue to respond as at present where channels would continue to be stable (see Section C5). The position of the channel would remain fixed due to the maintenance of the current defence line, consequently, natural channel processes would be restricted.	Sea level rise and the potential for increased fluvial flows with climate change will increase water levels and pressure on existing defences, potentially leading to an increased likelihood of overtopping and scour of footings. This is likely to lead to the requirement for increased maintenance, improvement works and eventual replacement of current defences with larger structures. Larger and harder defences would result in increased erosion of intertidal areas and the deepening of the channel during these epochs.	
Snodland to Allington Lock <u>Transects</u> Medway 25, 26, 27, 28, 29, 30, 31, 32, 33, 34	**Earth embankments (<5 years) between Snodland and Aylesford Paper Mills would require maintenance and improvement / replacement within the first 5 years of this period. Defences (<20 years) between Aylesford Paper Mills and Aylesford Train Station would require maintenance, improvement and replacement towards the end of this period, other defences (>20 years) would remain.**	**Embankments and timber walls between Aylesford Train Station and Allington Lock would require increased maintenance, improvement and replacement works. Other defences would need to be replaced and maintained during this epoch.**	**All defences along this frontage would need further maintenance, improvement and replacement with sea level rise and climate change.**
	In this section the river is fluvial in form, is considerably narrower than other sections and is very constrained by developments along its southern shore.	Sea level rise and the potential for increased fluvial flows with climate change will increase water levels and pressure on existing defences. This may potentially lead to increased likelihood of overtopping and scour of footings. Such changes are likely to lead to the requirement for increased maintenance and improvement works which in turn would increase erosion of intertidal	

Location	Baseline Scenario 2 – With Present Management		
	Predicted Change For		
	Years 0 - 20	Years 20 - 50	Years 50 - 100
	Over this epoch, channels would continue to be stable with no/little change (see Section C5). Maintaining the current defence line would however fix the channel position, restricting natural channel processes.	areas and increase channel depths over time.	
Medway (east and south bank)			
Allington Lock to Medway (M2) Bridge <u>Transects</u> Medway 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34	**Defences (<5 years) between Allington Lock and opposite Aylesford Paper Mills would require improvement and replacement within the first 5 years of this period, followed by maintenance and improvement during the remainder of the epoch. Natural and earth embankments (<20 years) along the remaining frontage would also require maintenance, improvement and eventually replacement towards the end of the period. Concrete walls (<20 years) opposite Holborough Marshes and at Wouldham would also need maintenance, improvement and possible replacement works during this epoch.**	**Defences would require ongoing maintenance, improvement and periodic replacement within this epoch.**	**All defences would require increased levels of maintenance and improvement, as well as replacement at varying times throughout this epoch as sea levels rise and due to the effects of climate change.**
	In this section the river is fluvial in form and is constrained by developments along its southern shore towards Allington. The channel in the southern reach of the river is very narrow, but it widens as it moves towards the Medway Bridge. Over this epoch, the intertidal areas in front of	Sea level rise and the potential for increased fluvial flows with climate change will increase water levels and pressure on existing defences, potentially leading to an increased likelihood of overtopping and scour of footings. This is likely to lead to the requirement for increased maintenance, improvement works and eventual replacement of current defences with larger structures. Larger and harder defences would result in increased erosion of intertidal areas and the deepening of the channel during these epochs.	

<table>
<tr><th rowspan="3">Location</th><th colspan="3">Baseline Scenario 2 – With Present Management</th></tr>
<tr><th colspan="3">Predicted Change For</th></tr>
<tr><th>Years 0 - 20</th><th>Years 20 - 50</th><th>Years 50 - 100</th></tr>
<tr><td></td><td>defences are likely to continue to respond as present where channels would continue to be stable with no/little change (see Section C5).
The position of the channel would remain fixed due to the maintenance of the current defence line, which in turn would restrict natural channel processes.</td><td colspan="2"></td></tr>
<tr><td>Medway (M2) Bridge to East of St Mary's Island
Transects
Medway 11, 12, 13, 14, 15, 16, 17</td><td>Vertical defences along this frontage will require maintenance and upgrading periodically, which will increase as sea levels rise.</td><td>Vertical defences along this frontage will require maintenance and upgrading periodically, which will increase as sea levels rise.</td><td>Vertical defences along this frontage will require maintenance and upgrading periodically, which will increase as sea levels rise.</td></tr>
<tr><td></td><td>Along this section the channel is more fluvial in form than in the outer estuary. Most of this frontage has no intertidal area, however a small isolated patch of saltmarsh exists at Borstal, just north of the Medway Bridge.
Over this epoch, the saltmarsh area in front of defences is likely to continue to respond as at present; Intertidal areas around St Mary's Island would continue to erode due to the confined nature of the channel at this location. Intertidal areas along the Gillingham frontage would continue to accrete. The channel towards the Medway Bridge would continue to be stable with no/little change (see Section C5). Maintaining the current defence line</td><td colspan="2">Sea level rise and the potential for increased fluvial flows with climate change will increase water levels and pressure on existing defences. This may potentially lead to an increased likelihood of overtopping and scour of footings. Such changes would to lead to the requirement for increased maintenance and improvement works of defences. Larger defences would cause coastal squeeze with sea level rise, and result in the erosion of intertidal areas.</td></tr>
</table>

Location	Baseline Scenario 2 – With Present Management		
	Predicted Change For		
	Years 0 - 20	Years 20 - 50	Years 50 - 100
	would fix the channel position, restricting natural channel processes.		
St Mary's Island to West of Motney Hill <u>Transects</u> Medway 8, 9, 10	**Stone revetted banks (>20 years)would remain.**	**Stone revetted banks would require maintenance, improvement and eventual replacement during this epoch.**	**Sea level rise combined with the effects of climate change would result in the increased frequency of defence maintenance, improvement and replacement.**
	The estuary begins to widen along this section. The frontage differs considerably from those upstream, as it has extensive intertidal and saltmarsh areas and marsh islands. Over this epoch, the intertidal mudflat and saltmarsh areas in front of defences are likely to continue to respond as at present; Erosion at the seaward edge of marshes at Nor Marsh and Rainham Creek would continue, however the remaining areas of saltmarsh would continue to accrete and/or be relatively stable. Erosion of marshes along Rainham Creek would result in the undermining and erosion of landward defences in this area.	During these epochs there is uncertainty regarding the evolution of mudflats and saltmarsh in this area. It is assumed however, that Intertidal saltmarsh and mudflat evolution will continue in the same pattern as in the previous epoch. Sea level rise would however exacerbate erosion in areas such as Nor Marsh and Rainham Creek while it is assumed that accretion would continue to keep pace with sea level rise in other areas.	
Motney Hill to Kingsferry Bridge <u>Transects</u> Medway 3, 4, 5, 6, 7 Swale 18, 19, 20, 21, 22, 23	**Stone revetted banks (<20 years) at Barkshore, Chetney and Ferry Marshes would require maintenance/upgrading within this period. Defences (>20 years) along the rest of the frontage would remain.**	**All defences would require maintenance, improvement and or replacement at various times during this epoch.**	**Increased frequency of maintenance, improvement and replacement of defences would be necessary due to the combined effects of sea levels rise and climate change.**

Location	Baseline Scenario 2 – With Present Management		
	Predicted Change For		
	Years 0 - 20	Years 20 - 50	Years 50 - 100
	This section of the Medway estuary is very wide and has extensive intertidal and saltmarsh areas and marsh islands. The channel of the Swale, between Queenborough and the Kingsferry Bridge, is however more fluvial in form. Over this epoch, the intertidal mudflat and saltmarsh areas in front of defences are likely to continue to respond as at present; It is predicted that Burntwick Island, Deadmans Island, Ham Green and Greenborough marshes would continue to suffer marsh erosion. Saltmarsh at Millfordhope Marsh would continue to be relatively stable over this period. Saltmarsh accretion would continue along the west shoreline of Chetney Marshes and at Bedlams Bottom. North of Kingsferry Bridge the Swale channel is predicted to continue to be stable over this period. The position of the channel would remain fixed due to the maintenance of the current defence line, which in turn would restrict natural channel processes.	During these epochs there is uncertainty regarding the evolution of mudflats and saltmarsh in this area. It is assumed however, that Intertidal saltmarsh and mudflat evolution will continue in the same pattern as in the previous epoch. Sea level rise would however exacerbate erosion in areas such as Burntwick Island, Deadmans Island, Ham Green and Greenborough marshes while it is assumed that accretion would continue to keep pace with sea level rise in other areas such as along the western shoreline of Chetney Marshes and at Bedlams Bottom.	
Swale (south bank)			
Kingsferry Bridge to Faversham Creek Transects	**Earth embankment and rock revetment (>20 years) would remain.**	**Earth embankment and rock revetment would require maintenance, improvement and replacement during this epoch.**	**Defences would require increased levels of maintenance, improvement and replacement with sea levels rise and the**

Location	**Baseline Scenario 2 – With Present Management**		
	Predicted Change For		
	Years 0 - 20	**Years 20 - 50**	**Years 50 - 100**
Swale 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17			**effects of climate change.**
	The channel of the Swale, between the Kingsferry Bridge and Milton Creek is fluvial in form. From Milton Creek to Faversham Creek the channel widens and has large areas of intertidal mudflat, but relatively small areas of saltmarsh, e.g. Fowley Island. The channel width is constant from Milton Creek towards the Isle of Harty then it gets increasingly wider towards the eastern estuary mouth at Shell Ness. Large areas of former saltmarsh have been enclosed and reclaimed from the sea for agricultural use along this frontage. Over this epoch, the intertidal mudflat and saltmarsh areas in front of defences are likely to continue to respond as at present; Faversham Creek and 'The Lillies' islands at the mouth of Milton Creek will continue to accrete. Saltmarsh and mudflat along this frontage should continue to be stable, with the exception of where the channel is constrained, e.g. where the channel narrows between the mouth of Milton Creek and Kingsferry Bridge, and at transects 5 (Ferry Inn Public house (Isle of Sheppey) to Faversham Creek (West Bank)) and 6 (Ferry Inn Public House (West)	Sediment is expected to meet demand within the Swale estuary over these epochs. The equilibrium form predicts an increase in saltmarsh growth (see Section C5 for further details). Coastal squeeze of intertidal areas would increase however, as defences constrain the landward migration of marshes as sea levels rise. Consequently, increased pressure would be put on defences as marshes and mudflats erode.	

Location	Baseline Scenario 2 – With Present Management		
	Predicted Change For		
	Years 0 - 20	Years 20 - 50	Years 50 - 100
	(Isle of Sheppey) to Uplees). Here intertidal areas would continue to suffer erosion throughout this epoch.		
Swale (north bank)			
Shell Ness to Kingsferry Bridge Transects Swale 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17	**Earth embankments and revetments (<20 years) would require significant levels of maintenance, improvement and replacement during this period.**	**Earth embankments and revetments would require increased levels of maintenance, improvement and replacement within this epoch.**	**The combined effects of sea level rise and climate change would result in the increased need for maintenance, improvement and replacement of defences.**
	The channel of the Swale, between Shell Ness and Milton Creek is of a relatively constant width, with extensive areas of saltmarsh and intertidal mudflats along the southern shoreline of the Isle of Sheppey. The channel changes to a more fluvial form between Milton Creek and the Kingsferry Bridge. The shell beach and spit at Shell Ness would continue to accrete as at present (analysis of historic maps indicates an approximate accretion rate of 4.3m/yr at present) assuming that a continual supply of sediment from offshore sources is available. Over this epoch, the intertidal mudflat and saltmarsh areas in front of defences are likely to continue to respond as at present where mudflat and saltmarsh accretion would be	Sediment is expected to meet demand within the Swale estuary over these epochs, where the equilibrium form predicts an increase in saltmarsh growth (see Section C5 for further details). Sea level rise however would increase coastal squeeze, resulting in intertidal erosion as defences constrain landward migration of the habitats. The shell spit and beach at Shell Ness would continue to accrete as long as a sediment supply was available. With sea level rise however it is assumed that sediment supply from the offshore source would decline, resulting in the spit and beach at Shell Ness narrowing and the spit being increasingly susceptible to breach. This would place increasing pressure on landward defences in this area.	

Location	Baseline Scenario 2 – With Present Management		
	Predicted Change For		
	Years 0 - 20	Years 20 - 50	Years 50 - 100
	expected to continue between Shell Ness and the Isle of Harty. Where the channel is constrained, e.g. where the channel narrows between Elmley Hills and Kingsferry Bridge, and at transects 5 (Ferry Inn Public house (Isle of Sheppey) to Faversham Creek (West Bank)) and 6 (Ferry Inn Public House (West) (Isle of Sheppey) to Uplees), intertidal areas would be subject to increased erosion.		
Kingsferry Bridge to Sheerness Docks <u>Transects</u> Medway 1, 2 Swale 18, 19, 20, 21, 22, 23	**Earth embankments and seawall (<20 years) would require maintenance, improvement and capital works within this period.**	**Defences would need to be maintained, improved and replaced within this epoch.**	**Increasing levels of maintenance, improvement and replacement will be required due to sea level rise and the effects of climate change.**
	The channel of the Swale, between the Kingsferry Bridge and Queenborough, is fluvial in form. The mouth of the Medway estuary at Sheerness is relatively small in width compared to the remainder of the outer estuary. Over this epoch, the intertidal mudflat and saltmarsh areas in front of defences are likely to continue to respond as at present; North of Kingsferry Bridge the channel is predicted to continue to be stable over this period, however	There would be increased potential for mudflat erosion in confined areas of the estuary channel, i.e. at the estuary mouth, due to faster flows through this restricted channel, due to the combined effects of sea level rise and climate change.	

Location	Baseline Scenario 2 – With Present Management		
	Predicted Change For		
	Years 0 - 20	Years 20 - 50	Years 50 - 100
	the maintenance of the current defence line will fix the channel in position and restrict natural fluvial processes. Mudflat and marsh erosion would continue in the confined areas near the Medway estuary mouth, which in turn would put pressure on and increase erosion of defences in this area.		

C5 Supporting Information

C5.1 INTRODUCTION

Section C1 provided a baseline understanding of estuary processes within the Medway and Swale. This assessment summarised previous workers' findings relating to the future evolution of the two estuaries. This section builds on this understanding by further analysing the geomorphological form of the estuaries and comparing it with the historical changes in saltmarsh area. This section is designed to support strategic decision making based on current levels of understanding. It is recommended that further studies are undertaken to resolve uncertainties prior to any actual implementation on the ground.

Corresponding figures are located in Annex C1.

C5.2 ESTUARY FORM ANALYSIS

C5.2.1 Background

The term 'estuary form' is here taken to be the two-dimensional or three-dimensional form of the estuary channel comprising both intertidal and sub-tidal areas. It is important to distinguish between the present day estuary form and the surrounding valley that the estuary is located within. In most UK estuaries, the limit of the present day estuary is substantially smaller than the surrounding valley due to the practice of reclaiming land by constructing flood embankments and reclaiming land for a variety of purposes.

The interpretation of estuary form makes the basic assumption that there is an 'equilibrium form' which the estuary is evolving towards over time. This approach is presently being formalised in a Defra funded research project FD2116 – 'The review and formalisation of geomorphological concepts and approaches for estuaries'. The approach adopted in the present report therefore represents an initial attempt at understanding estuary form, prior to more formalised guidance being released.

Estuary form represents a transition from marine conditions at the estuary mouth, (waves, littoral drift, bi-directional tidal currents) to fluvial conditions at the upstream end of the estuary, where unidirectional fresh water flows dominate. The equilibrium form of an estuary therefore represents a transition between entrance-type form relationships at the mouth (e.g. O'Brien, 1931) and fluvial regime-form relationships at the upper limit (e.g. Ackers, 1992). Whilst these relationships are complex, the ideal unconstrained equilibrium form of an estuary is generally held to exhibit some sort of smooth exponential decrease in width and depth away from the estuary mouth. Taking this as a starting point, the actual form of an estuary can be compared to the ideal form. This comparison aids understanding of the estuary system by highlighting areas where the present day estuary form is:

- Smaller than expected due to constraints imposed by flood defences or the underlying geology; or,
- Larger than expected e.g. due to overly large inherited valley system.

This analysis provides one indication of the areas of the estuary that might be expected to undergo accretion or erosion in the future in order to achieve a more ideal estuary form.

C5.2.2 Methodology

In the present report the analysis of estuary geomorphological form has been undertaken using GIS. This analysis has examined:

(i) The width of the channel at three levels:

- Mean low water (MLW), as indicated by the OS map;
- Mean high water (MHW) as indicated by the OS map; and,
- Seawall bases as indicated by the OS map, EA defence data and low level lidar data.

(ii) The width of the valley at level of Mean High Water Spring (MHWS) tides.

A MHWS level of 2.9m was taken for the purposes of the present analysis. Land elevation was derived from LiDAR data. This analysis makes no allowance for changes in the MHWS height along the length of the Medway and Swale and therefore should not be taken as an exact indicator of inundation extent.

These channel widths have been measured for a series of transects throughout the Medway and Swale. Transects were situated at approximately 1km centres along each of the estuaries.

A number of workers have investigated the relationship between the cross sectional area (CSA) of an estuary mouth and the tidal prism above this point (e.g. O'Brien, 1931; Townend, 2006). The tidal prism is defined as the volume of water that passes into and out of an estuary in each tide. This volume is represented by the difference between the volume of the estuary at low water and high water. Previous waters have demonstrated that the CSA of the estuary mouth at mean tidal level is proportional to the size of the tidal prism. Townend (2006) showed that for UK estuaries, the exact relationship is governed by the degree to which the estuaries have infilled with Holocene sediments. Pethick and Lowe (2000) analysed the variation in CSA and tidal prism along the lengths of individual estuaries.

The present report investigates the variation in CSA and tidal prism along the length of the Medway and Swale estuaries for the present day estuary channel. Tidal prisms have been calculated above each transect using a combination of bathymetric and LIDAR data. Spring tidal levels at different points along each estuary have been derived from Admiralty Tide Tables. These values have been extrapolated to obtain spring tidal levels for each transect. The tidal prism calculations allow for the change in tidal levels as the tidal wave propagates into each estuary. CSA values for each transect have been derived for the mean spring tidal level, which is the average of the MHWS and MLWS levels. Both the prism and area calculations were carried out using ArcView GIS software.

Figures C5.1 and C5.2 show variations in tidal prism and cross sectional area along the length of the Medway.

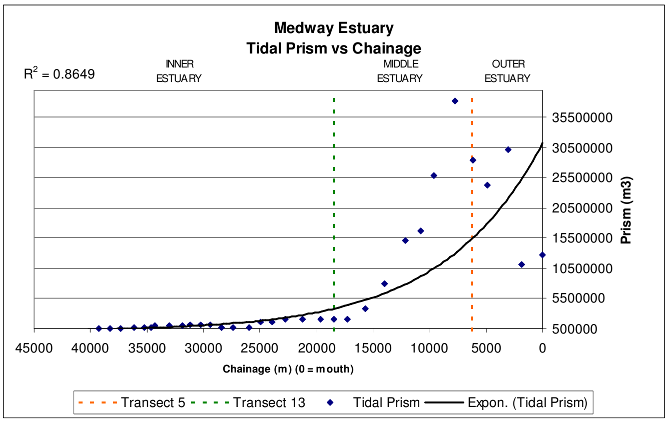


Figure C5.1: Tidal prism verses Chainage for Medway estuary.

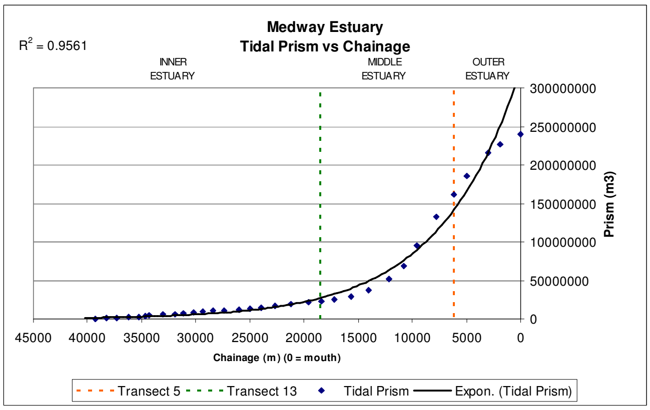


Figure C5.2: Cross Sectional Analysis (CSA) verses Chainage for Medway estuary.

Figures C5.3 and C5.4 show variations in tidal prism and cross sectional area (CSA) along the length of the Swale.

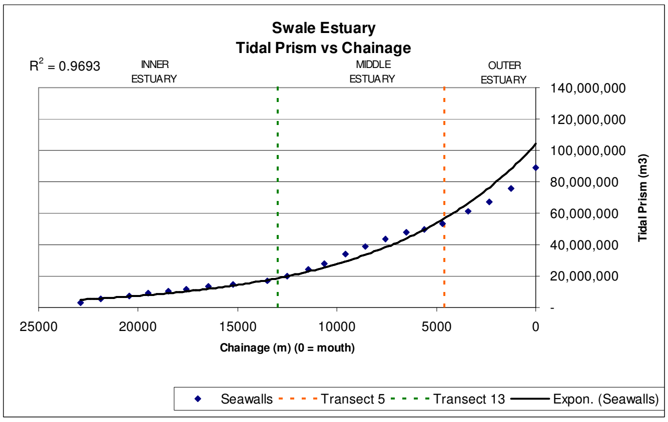


Figure C5.3: Tidal prism verses Chainage for Swale estuary.

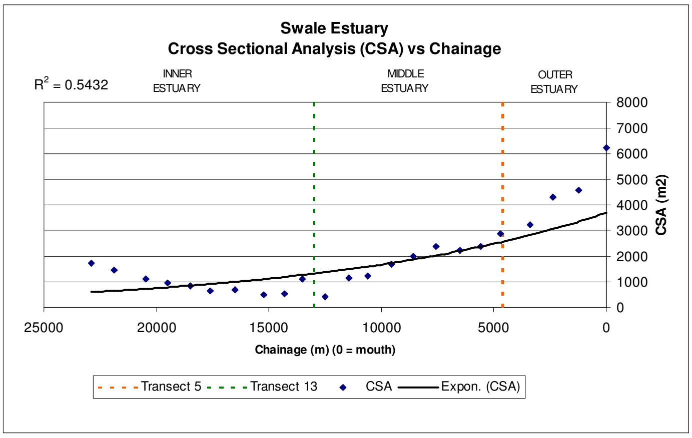


Figure C5.4: Cross-Section Analysis verses Chainage for Swale estuary.

Figures C5.5 to C5.12 (Annex C1) show transect locations in the Medway estuary. Figures C5.13 to C5.16 (Annex C1) show transect locations in the Swale estuary. Figures C5.17 to C5.21 show the widths of the Medway estuary channel at various levels.

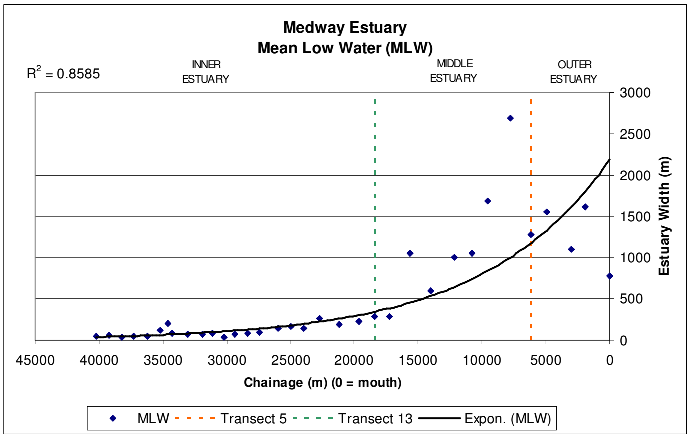


Figure C5.17: Width of Medway estuary for each transect location at Mean Low Water.

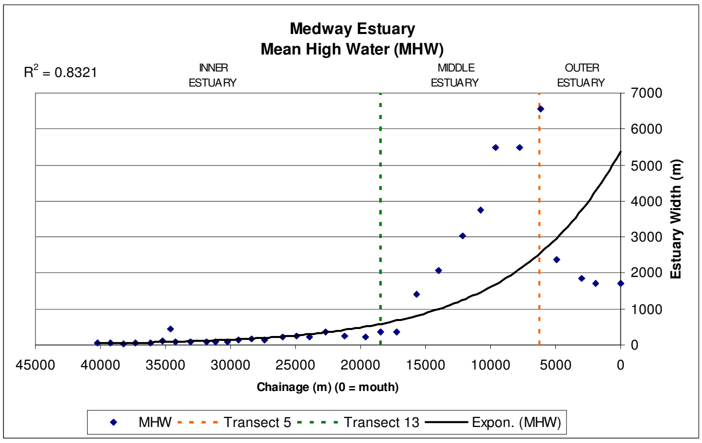


Figure C5.18: Width of Medway estuary for each transect location at Mean High Water.

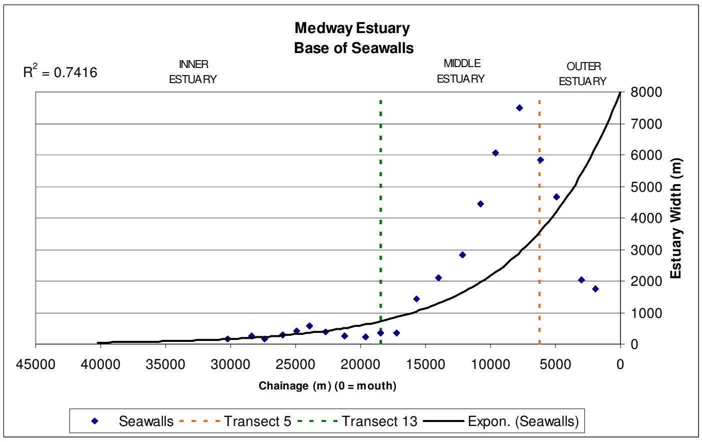


Figure C5.19: Width of Medway estuary for each transect location at the base of seawalls.

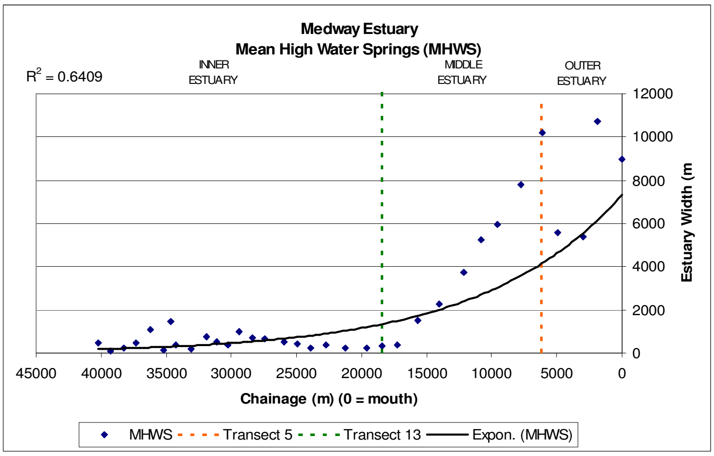


Figure C5.20: Width of Medway valley for each transect location at Mean High Water Springs.

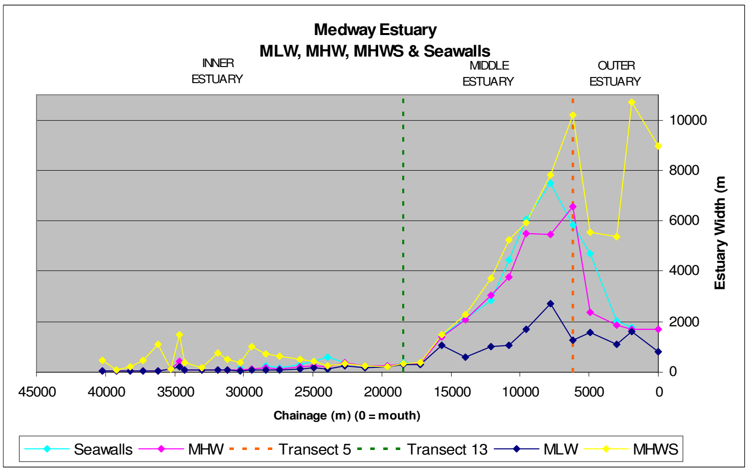


Figure C5.21: Width of Medway estuary and valley for each transect location at various levels.

Figures C5.22 to C5.26 show the width of the Swale estuary channel at various levels.

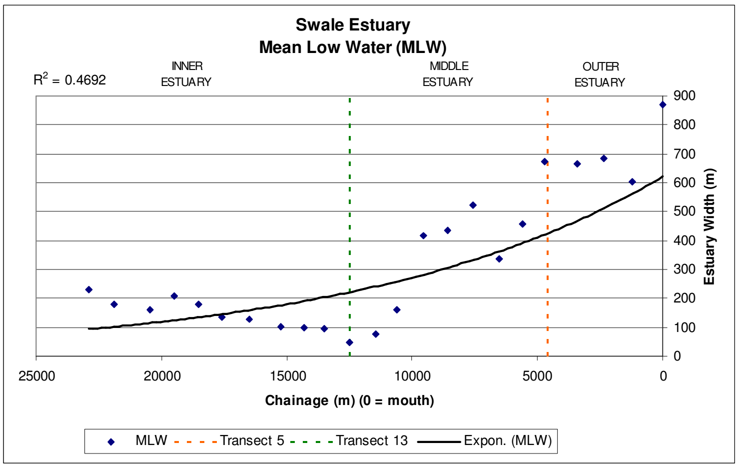


Figure C5.22: Width of Swale estuary for each transect location at Mean Low Water.

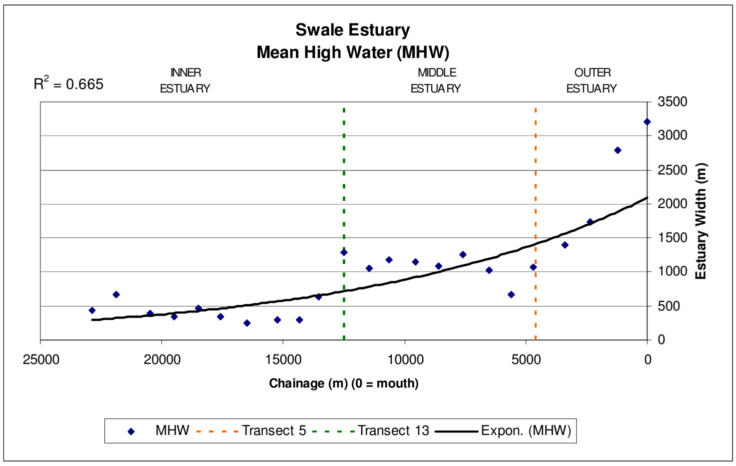


Figure C5.23: Width of Swale estuary for each transect location at Mean High Water.

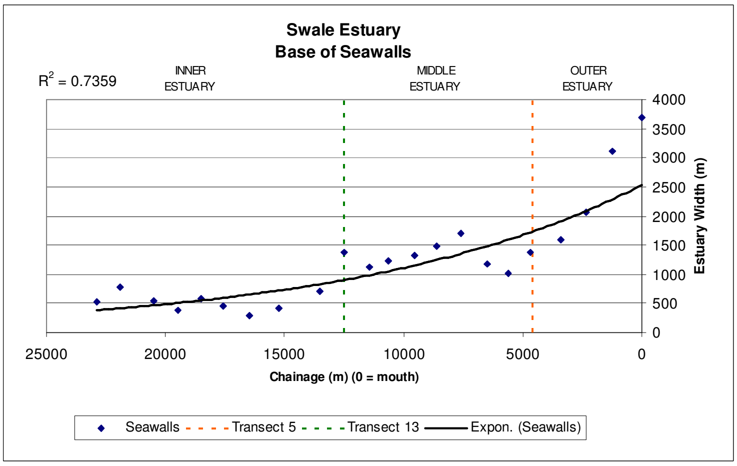


Figure C5.24: Width of Swale estuary for each transect location at the base of seawalls.

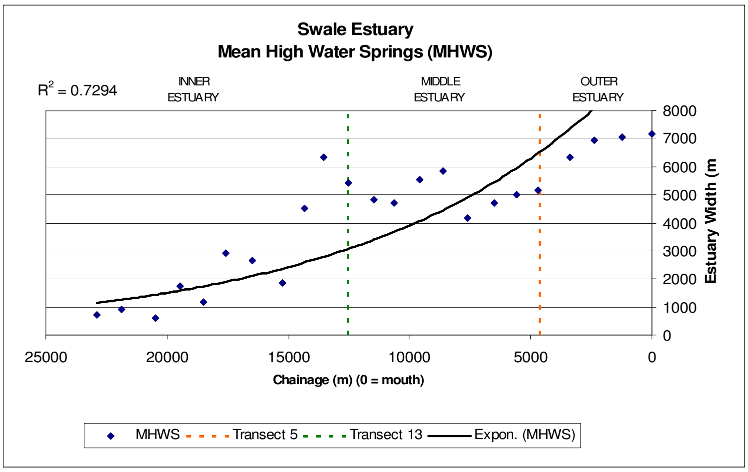


Figure C5.25: Width of the Swale valley for each transect location at Mean High Water Springs.

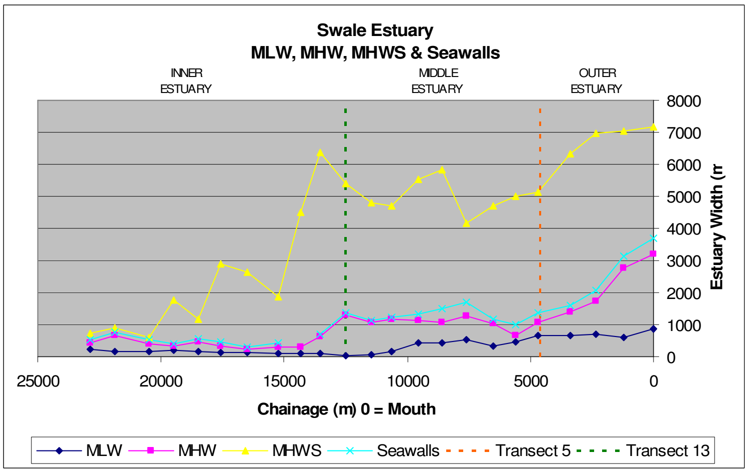


Figure C5.26: Width of Swale estuary and valley for each transect location at various levels.

Each estuary has been divided into three reaches as outlined in Section C1.4.1 For the Medway, these reaches correspond to:

- Outer-Sheerness to Chetney Marshes – which has a constrained ebb dominant channel bordered by mudflats that are relatively narrow and steep (Transects 1 to 5);
- Middle – Chetney Marshes to Gillingham – which is flood dominant, has overly wide central channel and has extensive intertidal areas (Transects 5 to 13); and,
- Inner – Gillingham to Allington Lock – which is ebb dominant and has a narrow meandering channel with limited intertidal areas (Transects 13 to 34).

For the Swale, these reaches correspond to:

- Outer – Whitstable to Nagden Marshes – which represents a wide mouth region (Transects 1 to 5);
- Middle – Nagden Marshes to Elmley Island (Transects 5 to 13); and,
- Inner – Long Reach/West Swale – which comprises a narrow canalised channel (Transects 13 to 23).

In order to compare the present estuary form at various levels with an ideal estuary form, exponential lines of best fit have been applied to the data (Figures C5.17 to C5.20 and C5.22 to C5.25). The maximum r^2 value is 1, so values closer to 1 indicate a closer conformity to an ideal estuary form. The consideration of equilibrium estuary form also needs to consider the cross-sectional area (CSA) of the estuary. In order to assess differences in the estuary form at different levels, combined graphs have been produced for each estuary (Figures C5.21 and C5.26). These graphs allow an assessment of the different widths of mudflat saltmarsh and reclaimed land along the estuaries.

Differences in the width of the estuary channel at MLW and MHW indicate the presence of intertidal mudflats. Differences in the width of the estuary channel at MHW and base of the seawalls indicate the presence of intertidal saltmarsh. Differences in the width of the estuary channel at the base of the seawalls and the width of the valley at a level MHWS indicate areas of low lying land outside the present day flood defences. These areas are likely to represent areas that were formerly intertidal and were reclaimed by the construction of embankments.

An assessment of the potential habitats that could be formed if the present day defences were to fail is presented in Figures C5.27 to C5.29 (Annex C1). These predictions are based on tidal levels from the mouth of the Medway and make no allowance for the variation in tidal levels along the length of each estuary (Table C5.1). Tidal levels for the Medway and Swale estuaries were obtained from the 2006 Admiralty Tide Tables and converted from Chart Datum (mCD) to Ordnance Datum (mOD). It has been assumed that Saltmarsh habitats would form between MHWN and MHWS and mudflats would form below MHWN. These predictions make no allowance for future rise in sea level or increases in land surface elevation to sedimentation.

Table C5.1: Present water levels adjusted from mCD to mOD, excluding sea level rise.

Port Name	OD Newlyn	MHWS	MHWN	MSL	MLWN	MLWS	LAT
Medway							
Sheerness	-2.9	2.9	1.8	0.1	-1.4	-2.3	-3
Bee Ness	-2.8	3.2	2	0.18	-1.3	-2.2	
Bartlett Creek	-2.8	3.1	1.9	no data	no data		
Chatham	-2.8	3.3	2	0.2	-1.4	-2.4	
Rochester (Strood Pier)	-2.74	3.26	2.16	0.17	-1.44	-2.44	
Wouldham	-2.11	3.49	2.29	0.58	-1.61	-1.81	
New Hythe	-0.65	3.55	2.35	1.38	-0.35	-0.35	
Allington Lock	-0.12	3.58	2.38	0.84	0.08	0.08	
Swale							
Chetney Marshes (using slope)		3.00	1.80	-0.89	-1.30	-2.30	
Grovehurst Jetty	-2.9	2.9	1.8	no data	-1.4	-2.4	
Faversham	-2.8	2.8	1.7	no data	no data		
Margate							
Whitstable Approaches	-2.74	2.66	1.76		-1.24	-2.24	

C5.2.3 Results

Medway

Figures C5.17 to C5.21 show that the three reaches of the Medway conform to the ideal estuary form to differing degrees. These differences generally occur at all levels MLW, MHW and seawall levels. At each level, the estuary is typified by:

- An outer region that is generally narrower than expected and lies below the exponential line of best fit;
- A middle region that is wider than expected and lies above the exponential line of best fit; and,
- An inner region that conforms closely to the expected exponential trend line.

With reference to Table C5.2, the maximum r^2 value is 1, so values closer to 1 indicate a closer conformity to an ideal estuary form. Comparison of the r^2 values for the exponential trend lines illustrates that the degree to which the estuary widths conform to an ideal form depends on the level being considered (Table C5.2).

Table C5.2: r^2 values for estuary width relationships in Medway and Swale estuaries.

	Medway	Swale
MHWS	0.6	0.7
Seawalls	0.7	0.7
MHW	0.8	0.7
MLW	0.9	0.5

Table C5.2 shows that in terms of estuary width, the Medway is most similar to an ideal exponential relationship at the MLW position (r^2 = 0.9). The width of the valley at MHWS shows the lowest conformance (r^2 = 0.6).

Comparison of the width of the estuary channel and valley widths for each of the transects allows the controls on present day estuary form to be assessed. Figure C5.21 shows that for Transects 1 and 2 (Grain to Sheerness) in the outer estuary, the present estuary channel is constrained by high land, however these areas are islands formed by the Isle of Grain on the west and the western part of Sheerness in the east. Beyond these high areas land elevations are lower, implying that large scale realignment would increase the width of the estuary channel in this location by forming secondary channels.

Transects 3 (Grain to Chetney Marshes) to 10 (Hoo St Werburg to Gillingham) in the middle estuary show substantial differences in width of estuary at MLW, MHW, seawalls and width of valley at MHWS. These differences arise due to presence of wide intertidal areas (both saltmarsh and mudflat) and wide areas of low lying land that is presumed to have been reclaimed from the estuary.

From Transects 10 (Hoo St Werburg to Gillingham) to 12 (Lower Upnor to St Mary’s Island) in the middle estuary there is less difference between the width of the estuary at MHW, at the base of seawalls and at MHWS illustrating the lack of saltmarshes and low lying areas behind seawalls. The difference between widths at MLW and MHW indicate that there are significant widths of intertidal mudflats in this area.

From Transect 12 (Lower Upnor to St Mary’s Island) to 34 (Allington) in the inner estuary, there is generally less difference in the width of the estuary or valley at different levels. This indicates a lack of intertidal habitats and low lying areas behind flood defences. The exception to this occurs between Transect 17 (Temple Marsh to Chatham) and 34 (Allington) where there are some limited areas of low lying land beyond the present day estuary extent, implying that reclamation has occurred here in the past.

Figure C5.1 shows variations in tidal prism (i.e. the volume of the channel at MHW – the volume of the channel at MLW) and Figure C5.2 shows variations in cross sectional area (CSA) along the length of the Medway. The variation of the tidal prism (Figure C5.1) and cross sectional area (CSA) of the estuary channel (Figure C5.2) follows a similar pattern to that of channel width. Both tidal prism and CSA show:

- The restricted dimensions of the estuary mouth at Transects 1 and 2 (Grain to Sheerness);
- The oversized dimensions of the middle estuary; and,
- The smooth decrease in estuary dimensions within the inner estuary.

Exponential lines of best fit for tidal prism and CSA show high r^2 values (0.9) suggesting that the estuary is close to equilibrium.

Swale

Figures C5.22 to C5.26 show how the three reaches of the Swale conform to an ideal estuary form as expressed by an exponential line of best fit. There is substantial scatter in the data, but the general trends are:

- A wide outer estuary, especially Transects 1 and 2 (Shell Ness to Graveney Marshes);
- A middle reach that lies around the ideal form; and,
- An inner reach that widens towards its confluence with the Medway.

Table C5.2 illustrates that in terms of estuary width, the Swale estuary is most similar to an ideal exponential relationship at the levels of the MHW, MHWS and the base of seawalls (r^2 = 0.7). The width of the estuary at MLW level shows a low conformance (r^2 = 0.5).

Figures C5.23, C5.24 and C5.26 show that there are two pinch points within the estuary around Transect 6 (Ferry Inn Public House (west) (Isle of Sheppey) to Uplees) and Transect 15 (Elmley Hills to the Kemsley Paper Mill). These transects have similar MHW and MLW widths, indicating that the MLW channel is likely to be deep at these locations. Widening of the estuary channel in these locations would move the estuary towards its equilibrium form.

Figure C5.26 shows that at Transect 15 (Elmley Hills to the Kemsley Paper Mill) there is little difference in the width of the estuary channel and the valley width, implying that land levels rise rapidly beyond the current estuary extent at this location.

Transects 1 (Shell Ness and Graveney Marshes) to 15 (Elmley Hills to the Kemsley Paper Mill) show differences in the width of the estuary at levels of MLW and seawalls, due to the presence of saltmarshes. From Transect 15 (Elmley Hills to the Kemsley Paper Mill) to 23 (Queenborough to west Point) marsh development is more limited.

The difference between widths of estuary at MLW and MHW is due to the presence of mudflats. These are present throughout the Swale, but the greatest widths occur in the outer and middle estuary between Transect 1 (Shellness to Gravemey Marshes) and 15 (Elmley Hills to Kemsley Paper Mill). An exception to this occurs at Transect 6 in the middle estuary where there is limited mudflat development.

The difference in width of the estuary at MHW and the width of the valley at MHWS indicates the presence of low lying land outside the present day flood defences. This implies that these areas of land have been reclaimed from the estuary in the past. Such areas exist in each of the three reaches of the Swale.

Figure C5.3 shows variations in tidal prism and Figure C5.4 shows variations in cross sectional area (CSA) along the length of the Swale. The variation of the tidal prism (Figure C5.3) and CSA of the estuary channel (Figure C5.4) follow a similar pattern to that of channel width.

C5.2.4 Discussion

Medway

The comparison of estuary widths in the Medway shows that although the original valley form (at MHWS level) deviated from the ideal estuary form, the infilling of this with marine sediment has produced an estuary form that more closely matches the ideal estuary form, characterised by an exponential decrease in width with increasing distance from the mouth. The greatest similarity exists at MLW where the highest degrees of sedimentation have occurred.

The constrained mouth of the Medway is primarily due to the inherited valley form at this location, with land levels rapidly rising above the level of MHWS (Transects 1 and 2 (Grain to Sheerness)). However, in the past the estuary mouth may have had a greater combined width, having connection with the sea behind both the Isle of Grain and the area occupied by Minster Marshes to the east of Sheerness.

Parts of the outer and middle estuary have substantial widths of intertidal mudflats, and low lying areas behind current sea defences (Transects 3 (Grain (south) to Deadmans Island) to 10 (Hoo St Werburg to Gillingham)). In these areas the valley form is wider than the ideal estuary form, and therefore does not constrain the present day estuary. The intertidal regions are dominated by mudflats with saltmarshes making up a lower proportion. Reference to the OS map indicates that these marshes are very fragmented in plan shape.

From Transect 12 (Lower Upnor to St Mary's Island) to 34 (Allington) the estuary is more constrained by the underlying valley form, although there are a number of low lying areas outside the present day estuary.

The implications of the above findings for future flood and coastal risk management within the Medway are:

- Transects 1 and 2 (Grain to Sheerness) – although the estuary width is narrower than its ideal form, this is primarily due to the underlying topographic constraint. Were sea defences to fail in this area, then there would be limited scope for expansion of the estuary channel due to the rising land. Intertidal erosion is likely to predominate this region in the future under the present day management scenario;
- From Transects 3 (Grain (south) to Deadmans island) to 12 (Lower Upnor to St Mary's Island), the estuary is wider than its ideal form, despite areas of reclamation. The wide expanses of mudflat and saltmarsh within this region can be considered as an attempt by the estuary channel to decrease in dimensions to more closely conform to an ideal estuary form. If sufficient sediment supply exists, then further accretion would be expected in this area in the future under the present day management scenario;

- Were sea defences to fail in this area, then the estuary channel could increase in size significantly. However, this would move the estuary away from its ideal form. Additionally, although realignment would create habitats, it would also increase the tidal prism of the estuary leading to an increase in flow speeds at the estuary mouth and a corresponding increase in the potential for erosion;
- A possible option to allow a realignment, whilst moving the estuary towards a more ideal estuary form, would be to create a second estuary mouth by connecting Yantlet Creek to the estuary to the west of the Isle of Grain. IECS (1993) report that this area represents a former second mouth of the estuary that was closed by reclamation in Roman times. This connection would have the potential to increase the width of the estuary mouth and create more saltmarsh habitat, albeit at the expense of the existing freshwater marshes to the west of the Isle of Grain; and,
- Landwards of Transect 12 (Lower Upnor to St Mary's Island) the estuary channel takes on a fluvial form with an almost constant width and limited area of intertidal flats. The channel shows a close correspondence to the ideal form in this region and any policy of realignment would perturb this. Examination of the OS map indicates that the failure of defences could create additional intertidal habitats in a number of areas landwards of Transect 17 (Temple Marsh to Chatham). However, at present many of the low lying areas that occur outside the present estuary channel are urbanised. One possible strategy for some of the non-urbanised areas would be to develop flood control areas that flooded under extreme events and reduced water levels in the main estuary channel. Hydrodynamic modelling would be required to assess the likely changes in water levels that could be generated.

At an estuary-wide scale, modelling work in the Humber estuary has indicated that schemes located in the inner reaches of estuaries may generate reductions in peak water levels, whilst those located in the outer reaches may generate slight increases (Townend and Pethick, 2002). These authors report that removing all the defences in the outer Humber would potentially raise high water levels throughout the estuary by 0.2m, whilst removing all the defences within the Rivers Trent and Ouse would potential reduce water levels by up to 2m within the rivers. It is not possible to simply transpose these findings to actual values of change in the Medway and Swale estuaries. However, taking the findings of Townend and Pethick (2002) at the most general level, suggests that large realignments near the estuary mouths could raise water levels in the inner reaches of the estuaries, whilst large realignments in the inner reaches of the estuaries could reduce water levels. It is recommended that the impacts of large realignments in the Medway or Swale needs to be modelled in order to assess the potential increases or decreases in tidal water levels.

Swale

The comparison of estuary widths in the Swale illustrates that the original valley form showed an exponential decrease in width with increasing distance from the mouth. The infilling of this form with marine sediment, coupled with large areas of reclamation has produced a smaller estuary channel that has a similar degree of conformance to the equilibrium form.

It is notable that the substantial amounts of reclamation around the Swale have produced an estuary outline (defined by seawalls) that approximates an ideal estuary form. Unlike the Medway, however, the low water channel does not show a close conformance to an ideal estuary form. This is due to the connection with the Medway at the eastern end. Additionally, it is possible that the low water channel has yet to adjust to the substantial amounts of reclamation that have taken place in the estuary.

The outer and middle reaches of the Swale have extensive mudflats. Mudflats are more restricted in the inner reach of the Swale. The estuary shows a constriction at MHW around Transects 5 (Ferry Inn Public House to Faversham Creek (west) and 15 (Elmley Hills to Kemsley Paper Mill), due to the underlying valley form. In contrast to the Medway, the Swale has an overly wide mouth with extensive mudflats (Transects 1 and 2 (Shell Ness to Graveney Marshes)). In the mouth region although further accretion is possible in terms of estuary form, this is likely to be offset by wave action under the present day management scenario.

In the middle estuary Transects 8 (Bells Creek to Luddenham Marshes) to 13 (Sharfleet Creek to Tonge Corner) all have widths at MHW that lie above the ideal form for the estuary, under the present day management scenario, given a suitable supply of sediment. Further intertidal accretion might therefore be expected within this reach under the present day management scenario.

The implications of the above findings for future flood and coastal risk management within the Swale are:

- There are only a limited number of locations (Transects 5 (Ferry Inn Public House to Faversham Creek (west)), 15 (Elmley Hills to Kemsley Paper Mill) and 19 (Rushenden (south) to Ferry Marshes)), where land levels rise rapidly beyond the present day estuary extent. Allowing defences to fail in these constricted areas alone would not lead to a significant expansion of the present day estuary channel unless areas landwards of the Isle of Harty and Elmley Island/ Elmley Hills were reconnected to the estuary forming secondary channels;
- The failure of present day defences has the potential to lead to large increases in the width of the estuary channel at most other locations. The present day estuary that is bounded by sea defences approximates an equilibrium form in these areas. R^2 values for the present day estuary widths at MHW, at the base of seawalls and at MHWS (Figures C5.23 to C5.25) are all very similar, at around 0.7, indicating that they show similar conformance to an ideal form. If defences were allowed to fail / be removed along the whole of the Swale, i.e. along the whole of the estuary east of Kingsferry Bridge (including Shell Ness), in terms of width, the estuary would conform to a new ideal form. It should be noted however that this would lead to large increases in tidal prism which would in turn lead to large changes in estuary form, i.e. there would be substantial erosion of the estuary channel below MHW as the estuary adjusts to the new equilibrium form; and,
- Allowing defences to fail would potentially move the estuary away from this form. This is most notable in the middle estuary, between Transects 8 (Bells Creek to Luddenham Marshes) to 13 (Sharfleet Creek to Tonge Corner), where the present day estuary channel is already larger than its equilibrium form. Increases in the size of the estuary channel at this point, due to the failure of defences, would increase the tidal prism of the estuary. This would lead to increased flows within the estuary, which would raise the potential for erosion in other regions of the estuary. This erosion would be most likely in areas where the channel is currently confined (Transects 5 (Ferry Inn Public House to Faversham Creek (west)), 15 (Elmley Hills to Kemsley Paper Mill) and 19 (Rushenden (south) to Ferry Marshes)).

At an estuary-wide scale, modelling work in the Humber estuary has indicated that schemes located in the inner reaches of estuaries may generate reductions in peak water levels, whilst those located in the outer reaches may generate slight increases (Townend and Pethick, 2002), as discussed in the Medway section. As stated previously, it is not possible to simply transpose these findings to actual values of change in the Medway and Swale estuaries. However, taking the findings of Townend and Pethick (2002) at the most general level, suggests that large realignments near the estuary mouths could raise water levels in the inner reaches of the estuaries, whilst large realignments in the inner reaches of the estuaries could reduce water levels. The fact that the Swale has two entrances is likely to lead to a more complicated relationship between the area of the realignments, their position in the estuary and the impact on water levels. It is recommended that the impacts of large realignments in the Medway or Swale needs to be modelled in order to assess the potential increases or decreases in tidal water levels.

C5.2.5 FUTURE MORPHOLOGICAL EVOLUTION

Assessing the morphological response of estuaries to rising sea level is not straight forward. Whilst on open coasts it is relatively simple to assess the position of future shorelines by extrapolating present day trends of erosion or accretion, the response of estuaries needs to consider the whole 3-dimensional form of the estuary. Importantly, it appears that difference estuaries can undergo different response to rising sea levels, including:

- Complete sedimentary infilling (e.g. Pontee, 2005);
- Insitu vertical accretion;
- Landward translation (rollover) (e.g. Townend and Pethick, 2002); and,
- Drowning (e.g. Bects *et al.*, 1992).

These responses are likely to be governed by a number of controls including geological inheritance, the rate of sea level rise, sediment supply, longshore sediment, transport, the hydrodynamic flushing capacity of the estuary and the degree of wave exposure. Changes in one part of the estuary can also bring about changes either upstream or downstream regions.

At present there is no one accepted morphological model capable of predicting future estuary morphology under different scenarios of sea level rise and management intervention. The EMPHASYS study recommended that in order to understand estuary morphodynamics it was necessary to synthesise the results from a number of approaches (EMPHASYS consortium, 2000; Defra, 2002).

C5.2.6 With Present Management

For the present study, the future evolution of the Medway and Swale estuaries under a ‘With Present Management Scenario’ has been assessed by combining the findings from Section C4.2, which identified areas of the Medway and Swale where erosion or accretion could occur in the future, with the results of previous workers who have analysed where the estuaries have shown accretion or erosion historically.

Section C1.5.3 summarised the analysis of the Medway carried out by IECS (1993). This analysis documented:

- A net decrease in the area of saltmarsh post 1840; and,
- A net increase in the area of salt marsh after 1972 in the Medway, and after 1961 in the Swale.

The initial period of erosion was attributed to mud mining, which reduced mudflat levels and increased the amount of wave and tidal energy reaching the saltmarshes. The subsequent phase of accretion was attributed to a return to flood dominance in the estuary.

CCM (2002) report that the majority of saltmarsh accretion in the Medway occurred in the Stoke Saltings within the middle reach of the estuary. Figure C5.30 illustrates the changes in salt marsh areas between 1988 and 2000 in the Medway. These changes were attributed to the expansion of the *Spartina* saltmarsh.

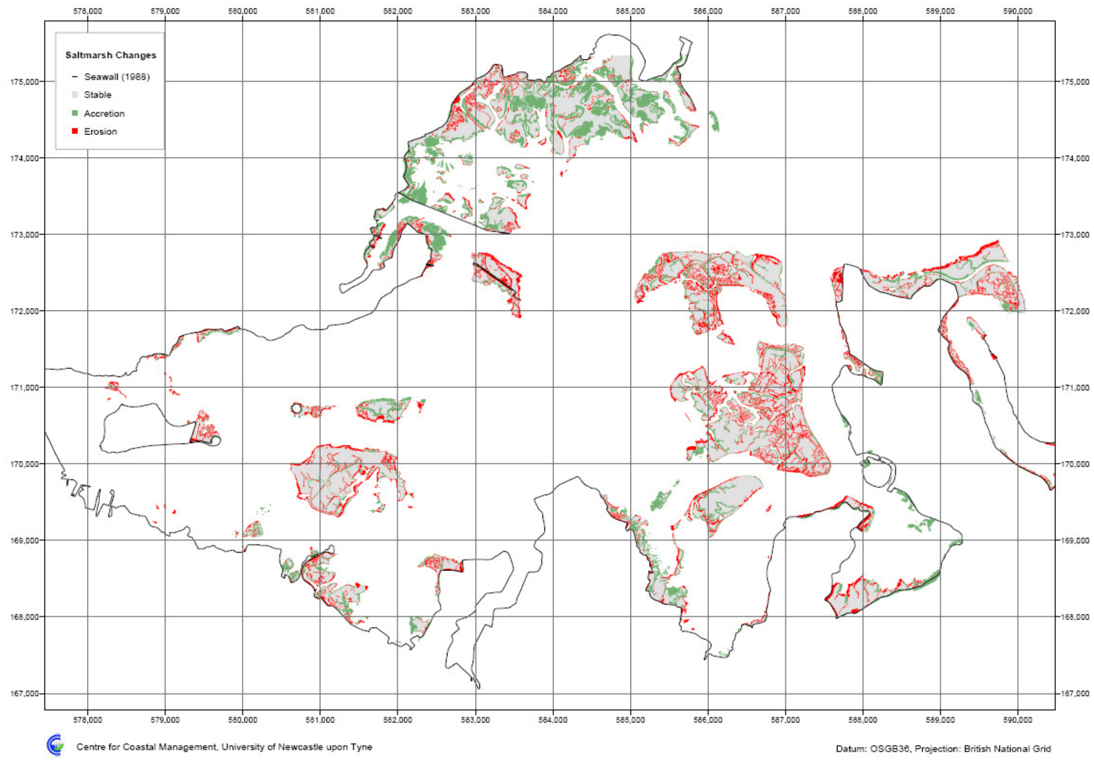


Figure C5.30: Saltmarsh changes in the Medway estuary 1988 – 2000 (from CCM, 2002).

CCM (2002) reported the majority of saltmarsh accretion in the Swale occurred on the north side of the outer and middle reaches estuary, between Shellness and Spitend Part. Figure C5.31 illustrates the changes in salt marsh areas between 1988 and 2000 in the Swale. These areas of saltmarsh growth lie within these reaches of the estuaries that were identified in Section C4.2 as being wider than an ideal estuary form and therefore as being likely to undergo further accretion in the future. Tables C5.3 and C5.4 summarise the likely future evolution of the Medway and Swale estuaries under a 'With Present Management Scenario'.

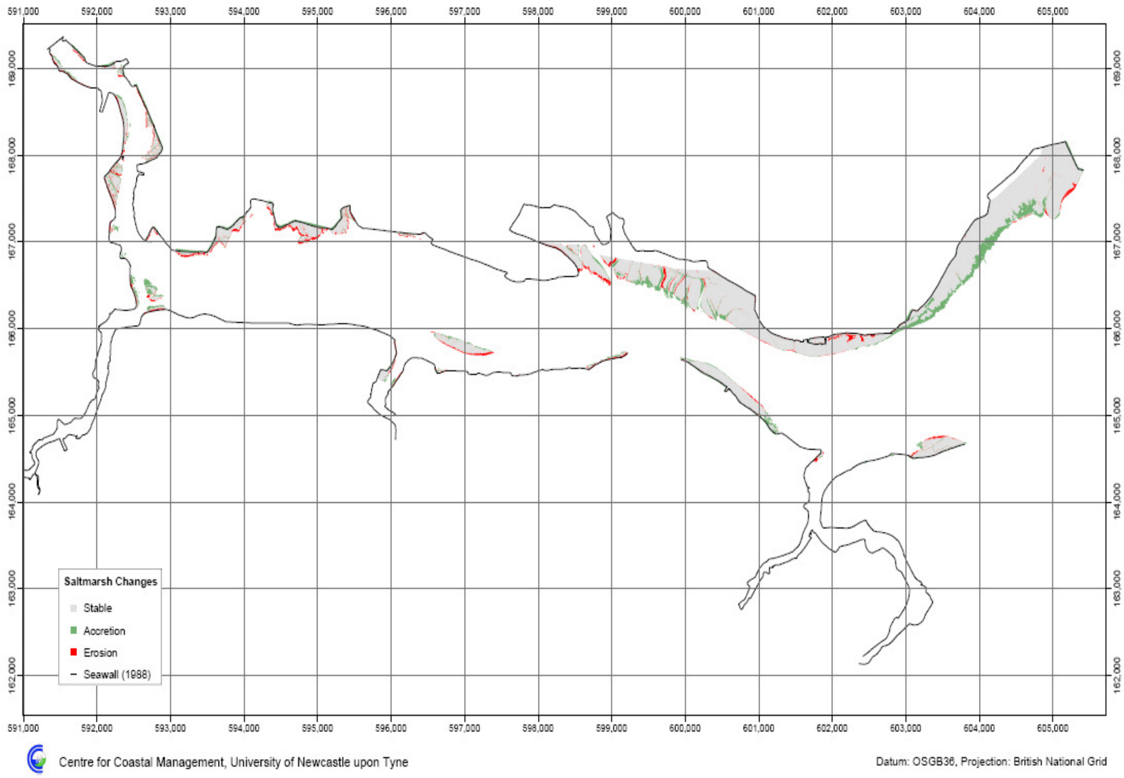


Figure C5.31: Saltmarsh changes in the Swale Estuary 1988 – 2000 (from CCM, 2002)

The likely future morphological trends are based on the form analysis plus the historical trend in salt marsh extent between 1988 and 2000. Where both lines of evidence suggest the same trend, then the predictions are considered to have moderate confidence. Where the two lines of evidence show opposite trends, the predictions are considered to have low confidence. Where opposite trends are suggested, then the future predictions have been based on the historical change in salt marsh.

Table C5.3: Likely future evolution of Medway estuary on basis of estuary form and historical analysis with present day management

Transect Number	Geographic Location	Estuary Reach	Comparison with ideal estuary form	Implication	Historical trend in saltmarsh 1988-2000*	Likely future morphological trend	Confidence
1	Grain to Sheerness	Outer	Narrower than ideal form at MLW	Erosion possible			
			Narrower than ideal form at MHW	Erosion possible		Mudflat & marsh erosion	Moderate
			Narrower than ideal form at seawalls	Erosion possible			
			CSA less than ideal	Erosion possible			
2	South Grain to South Sheerness	Outer	Close to ideal form at MLW	Stability			
			Narrower than ideal form at MHW	Erosion possible		Mudflat erosion	Moderate
			Narrower than ideal form at seawalls	Erosion possible			
			CSA less than ideal	Erosion possible			
3	South Grain to Deadmans Island	Outer	Narrower than ideal form at MLW	Erosion possible			
			Narrower than ideal form at MHW	Erosion possible	Erosion	Mudflat & marsh erosion	Moderate
			Close to ideal form at seawalls	Stability			

Transect Number	Geographic Location	Estuary Reach	Comparison with ideal estuary form	Implication	Historical trend in saltmarsh 1988-2000*	Likely future morphological trend	Confidence
			CSA less than ideal	Erosion possible			
4	Grain Power Station to Barkshore Marshes	Outer	Wider than ideal form at MLW	Accretion possible			
			Narrower than ideal form at MHW	Erosion possible	Erosion	Mudflat & marsh erosion	Moderate
			Wider than ideal form at seawalls	Accretion possible			
			CSA close to ideal	Stability			
5	Colemouth Creek to Lower Halstow	Outer	Close to ideal form at MLW	Stability			
			Wider than ideal form at MHW	Accretion possible	Accretion and erosion	Marsh accretion	Moderate
			Wider than ideal form at seawalls	Accretion possible			
			CSA close to ideal	Stability			
6	Stoke Marshes to Ham Green	Middle	Wider than ideal form at MLW	Accretion possible			
			Wider than ideal form at MHW	Accretion possible	Erosion	Marsh erosion	Low
			Wider than ideal form at seawalls	Accretion possible			

Transect Number	Geographic Location	Estuary Reach	Comparison with ideal estuary form	Implication	Historical trend in saltmarsh 1988-2000*	Likely future morphological trend	Confidence
			CSA greater than ideal	Accretion possible			
7	Stoke to Motney Hill	Middle	Wider than ideal form at MLW	Accretion possible			
			Wider than ideal form at MHW	Accretion possible	Accretion	Marsh accretion	Moderate
			Wider than ideal form at seawalls	Accretion possible			
			CSA greater than ideal	Accretion possible			
8	East Kingsnorth Power Station to Bloors Wharf (Lower Rainham)	Middle	Wider than ideal form at MLW	Accretion possible			
			Wider than ideal form at MHW	Accretion possible	Accretion and erosion	Marsh accretion	Moderate
			Wider than ideal form at seawalls	Accretion possible			
			CSA close to ideal	Stability			
9	West Kingsnorth Power Station to Lower Twydall	Middle	Wider than ideal form at MLW	Accretion possible			
			Wider than ideal form at MHW	Accretion possible	Erosion	Marsh erosion	Low

Transect Number	Geographic Location	Estuary Reach	Comparison with ideal estuary form	Implication	Historical trend in saltmarsh 1988-2000*	Likely future morphological trend	Confidence
			Wider than ideal form at seawalls	Accretion possible			
			CSA greater than ideal	Accretion possible			
10	Hoo St Werburg to Gillingham	Middle	Close to ideal form at MLW	Stability			
			Wider than ideal form at MHW	Accretion possible	Erosion	Marsh erosion	Low
			Wider than ideal form at seawalls	Accretion possible			
			CSA close to ideal	Stability			
11	Hoo St Werburg Marina to Gillingham	Middle	Wider than ideal form at MLW	Accretion possible			
			Wider than ideal form at MHW	Accretion possible		Marsh accretion	Low
			Narrower than ideal form at seawalls	Erosion possible			
			CSA greater than ideal	Accretion possible			
12	Lower Upnor to St Mary's Island	Middle	Close to ideal form at MLW	Stability			
			Close to ideal form at MHW	Stability		Mudflat erosion	Low
			Narrower than ideal form at seawalls	Erosion possible			

Transect Number	Geographic Location	Estuary Reach	Comparison with ideal estuary form	Implication	Historical trend in saltmarsh 1988-2000*	Likely future morphological trend	Confidence
			CSA close to ideal	Stability			
13	Upper Upnor to Medway Tunnel	Inner	Close to ideal form at MLW	Stability			
			Close to ideal form at MHW	Stability		Stability	Low
			Narrower than ideal form at seawalls	Erosion possible			
			CSA close to ideal	Stability			
14	Medway City Industrial Estate to chatham Historic Dockyard (Chatham Reach)	Inner	Close to ideal form at MLW	Stability			
			Close to ideal form at MHW	Stability		Stability	Low
			Close to ideal form at seawalls	Stability			
			CSA close to ideal	Stability			
15	Medway City Industrial Estate to chatham Historic Dockyard (Limehouse Reach)	Inner	Close to ideal form at MLW	Stability			

Transect Number	Geographic Location	Estuary Reach	Comparison with ideal estuary form	Implication	Historical trend in saltmarsh 1988-2000*	Likely future morphological trend	Confidence
			Close to ideal form at MHW	Stability		Stability	Low
			Close to ideal form at seawalls	Stability			
			CSA close to ideal	Stability			
16	Temple Manor (Rochester) to Chatham Castle (Bridge Reach)	Inner	Close to ideal form at MLW	Stability			
			Close to ideal form at MHW	Stability		Stability	Low
			Close to ideal form at seawalls	Stability			
			CSA close to ideal	Stability			
17	Temple Marsh to Chatham (North of the Medway Bridge)	Inner	Close to ideal form at MLW	Stability			
			Close to ideal form at MHW	Stability		Stability	Low
			Close to ideal form at seawalls	Stability			
			CSA close to ideal	Stability			
18	South of Medway Bridge	Inner	Close to ideal form at MLW	Stability			
			Close to ideal form at MHW	Stability		Stability	Low

Transect Number	Geographic Location	Estuary Reach	Comparison with ideal estuary form	Implication	Historical trend in saltmarsh 1988-2000*	Likely future morphological trend	Confidence
			Close to ideal form at seawalls	Stability			
			CSA close to ideal	Stability			
19	Cuxton to Wouldham marshes	Inner	Close to ideal form at MLW	Stability			
			Close to ideal form at MHW	Stability		Stability	Low
			Close to ideal form at seawalls	Stability			
			CSA close to ideal	Stability			
20	North Halling to Wouldham Marshes	Inner	Close to ideal form at MLW	Stability			
			Close to ideal form at MHW	Stability		Stability	Low
			Close to ideal form at seawalls	Stability			
			CSA close to ideal	Stability			
21	Halling Marshes (North) to Wouldham Marshes (South)	Inner	Close to ideal form at MLW	Stability			
			Close to ideal form at MHW	Stability		Stability	Low

Transect Number	Geographic Location	Estuary Reach	Comparison with ideal estuary form	Implication	Historical trend in saltmarsh 1988-2000*	Likely future morphological trend	Confidence
			Close to ideal form at seawalls	Stability			
			CSA close to ideal	Stability			
22	Halling Marshes (South) to Wouldham	Inner	Close to ideal form at MLW	Stability			
			Close to ideal form at MHW	Stability		Stability	Low
			CSA close to ideal	Stability			
23	Holborough (North) to Wouldham (South)	Inner	Close to ideal form at MLW	Stability			
			Close to ideal form at MHW	Stability		Stability	Low
			CSA close to ideal	Stability			
24	Holborough (South)	Inner	Close to ideal form at MLW	Stability			
			Close to ideal form at MHW	Stability		Stability	Low
			CSA close to ideal	Stability			
25	Snodland	Inner	Close to ideal form at MLW	Stability			

Transect Number	Geographic Location	Estuary Reach	Comparison with ideal estuary form	Implication	Historical trend in saltmarsh 1988-2000*	Likely future morphological trend	Confidence
	(North)						
			Close to ideal form at MHW	Stability		Stability	Low
			CSA close to ideal	Stability			
26	Burham Court	Inner	Close to ideal form at MLW	Stability			
			Close to ideal form at MHW	Stability		Stability	Low
			CSA close to ideal	Stability			
27	Laybourne Lakes	Inner	Close to ideal form at MLW	Stability			
			Close to ideal form at MHW	Stability		Stability	Low
			CSA close to ideal	Stability			
28	Laybourne Lakes	Inner	Wider than ideal form at MLW	Accretion possible			
			Wider than ideal form at MHW	Accretion possible		Stability	Low
			CSA close to ideal	Stability			
29	New Hythe (North)	Inner	Close to ideal form at MLW	Stability			
			Close to ideal form at MHW	Stability		Stability	Low

Transect Number	Geographic Location	Estuary Reach	Comparison with ideal estuary form	Implication	Historical trend in saltmarsh 1988-2000*	Likely future morphological trend	Confidence
			CSA close to ideal	Stability			
30	Aylesford Paper Mill to Sand Pit	Inner	Close to ideal form at MLW	Stability			
			Close to ideal form at MHW	Stability		Stability	Low
			CSA close to ideal	Stability			
31	Millhall	Inner	Close to ideal form at MLW	Stability			
			Close to ideal form at MHW	Stability		Stability	Low
			CSA close to ideal	Stability			
32	Aylesford	Inner	Close to ideal form at MLW	Stability			
			Close to ideal form at MHW	Stability		Stability	Low
			CSA close to ideal	Stability			
33	Forstall	Inner	Close to ideal form at MLW	Stability			
			Close to ideal form at MHW	Stability		Stability	Low
			CSA close to ideal	Stability			
34	Allington	Inner	Close to ideal form at MLW	Stability			

Transect Number	Geographic Location	Estuary Reach	Comparison with ideal estuary form	Implication	Historical trend in saltmarsh 1988-2000*	Likely future morphological trend	Confidence
			Close to ideal form at MHW	Stability		Stability	Low
			CSA close to ideal	Stability			

(* from CCM, 2002).

Table C5.4 : Likely future evolution of Swale estuary on basis of estuary form and historical analysis with present day management

Transect Number	Geographic Location	Estuary Reach	Comparison with ideal estuary form	Implication	Historical trend in saltmarsh 1988-2000*	Likely future morphological trend	Confidence
1	Shell Ness (Isle of Sheppey) to Graveney Marshes	Outer	Wider than ideal form at MLW	Accretion possible			
			Wider than ideal form at MHW	Accretion possible	Accretion	Mudflat & marsh accretion	Moderate
			Wider than ideal form at seawalls	Accretion possible			
			CSA greater than ideal				
2	Shell Ness (West) (Isle of Sheppey) to Graveney Marshes (West)	Outer	Close to ideal form at MLW	Stability			
			Wider than ideal form at MHW	Accretion possible		Mudflat & marsh accretion	Moderate
			Wider than ideal form at seawalls	Accretion possible			
			CSA greater than ideal				
3	Sayes Court (East) (Isle of Sheppey) to Cleve Marshes	Outer	Wider than ideal form at MLW	Accretion possible			

Transect Number	Geographic Location	Estuary Reach	Comparison with ideal estuary form	Implication	Historical trend in saltmarsh 1988-2000*	Likely future morphological trend	Confidence
			Close to ideal form at MHW	Stability	Accretion	Marsh accretion	Moderate
			Close to ideal form at seawalls	Stability			
			CSA greater than ideal	Accretion possible			
4	Sayes Court (Isle of Sheppey) to Graveney Marshes Nature Reserve	Outer	Wider than ideal form at MLW	Accretion possible			
			Close to ideal form at MHW	Stability	Erosion	Marsh erosion	Moderate
			Narrower than ideal form at seawalls	Erosion possible			
			CSA close to ideal	Stability			
5	Ferry Inn Public house (Isle of Sheppey) to Faversham Creek (West Bank)	Outer	Wider than ideal form at MLW	Accretion possible			
			Narrower than ideal form at MHW	Erosion possible	Erosion	Marsh erosion	Moderate

Transect Number	Geographic Location	Estuary Reach	Comparison with ideal estuary form	Implication	Historical trend in saltmarsh 1988-2000*	Likely future morphological trend	Confidence
			Narrower than ideal form at seawalls	Erosion possible			
			CSA close to ideal	Stability			
6	Ferry Inn Public House (West) (Isle of Sheppey) to Uplees	Middle	Close to ideal form at MLW	Stability			
			Narrower than ideal form at MHW	Erosion possible	Erosion	Marsh erosion	Moderate
			Narrower than ideal form at seawalls	Erosion possible			
			CSA close to ideal	Stability			
7	Bells Creek (East) (Isle of Sheppey) to Uplees (West)	Middle	Close to ideal form at MLW	Stability			
			Close to ideal form at MHW	Stability	Accretion	Marsh accretion	Low
			Narrower than ideal form at seawalls	Erosion possible			
			CSA close to ideal	Stability			
8	Bells Creek (Isle of	Middle	Wider than ideal form at MLW	Accretion possible			

Transect Number	Geographic Location	Estuary Reach	Comparison with ideal estuary form	Implication	Historical trend in saltmarsh 1988-2000*	Likely future morphological trend	Confidence
	Sheppey) to Luddenham Marshes						
			Close to ideal form at MHW	Stability	Erosion	Marsh erosion	Low
			Wider than ideal form at seawalls	Accretion possible			
			CSA close to ideal	Stability			
9	Spitend Point (Isle of Sheppey) to Luddenham Marshes	Middle	Wider than ideal form at MLW	Accretion possible			
			Close to ideal form at MHW	Stability	Stability	Marsh stability	Moderate
			Close to ideal form at seawalls	Stability			
			CSA close to ideal	Stability			
10	Spitend Marshes (Isle of Sheppey) to Conyer (East)	Middle	Wider than ideal form at MLW	Accretion possible			
			Wider than ideal form at MHW	Accretion possible	Erosion & accretion	Marsh stability	Moderate
			Close to ideal form at seawalls	Stability			
			CSA close to ideal	Stability			
11	Wellmarsh Creek (East) (Isle of	Middle	Narrower than ideal form at MLW	Erosion possible			

Transect Number	Geographic Location	Estuary Reach	Comparison with ideal estuary form	Implication	Historical trend in saltmarsh 1988-2000*	Likely future morphological trend	Confidence
	Sheppey) to Conyer Creek (West)						
			Wider than ideal form at MHW	Accretion possible	Erosion	Marsh erosion	Low
			Close to ideal form at seawalls	Stability			
			CSA close to ideal	Stability			
12	Wellmarsh Creek (Isle of Sheppey) to Blacketts	Middle	Narrower than ideal form at MLW	Erosion possible			
			Wider than ideal form at MHW	Accretion possible	Erosion	Marsh erosion	Low
			Close to ideal form at seawalls	Stability			
			CSA close to ideal	Stability			
13	Sharfleet Creek (Isle of Sheppey) to Tonge Corner	Middle	Narrower than ideal form at MLW	Erosion possible			
			Wider than ideal form at MHW	Accretion possible	Erosion	Marsh erosion	Low
			Wider than ideal form at seawalls	Accretion possible			
			CSA less than ideal	Erosion possible			
14	Elmley Island (Isle of Sheppey) to Sittingbourne	Inner	Narrower than ideal form at MLW	Erosion possible			

Transect Number	Geographic Location	Estuary Reach	Comparison with ideal estuary form	Implication	Historical trend in saltmarsh 1988-2000*	Likely future morphological trend	Confidence
	Lakes						
			Close to ideal form at MHW	Stability			
			Close to ideal form at seawalls	Stability	Erosion and accretion	Marsh stability	Moderate
			CSA close to ideal	Stability			
15	Elmley Hills (Isle of Sheppey) to Kemsley Paper Mill	Inner	Narrower than ideal form at MLW	Erosion possible			
			Narrower than ideal form at MHW	Erosion possible		Marsh and mudflat erosion	Low
			Narrower than ideal form at seawalls	Erosion possible			
			CSA less than ideal	Erosion possible			
16	Elmley Hills (North))Isle of Sheppey) to Ridham Dock (South)	Inner	Narrower than ideal form at MLW	Erosion possible			
			Narrower than ideal form at MHW	Erosion possible	Erosion	Marsh and mudflat erosion	Moderate
			Narrower than ideal form at seawalls	Erosion possible			
			CSA less than ideal	Erosion possible			

Transect Number	Geographic Location	Estuary Reach	Comparison with ideal estuary form	Implication	Historical trend in saltmarsh 1988-2000*	Likely future morphological trend	Confidence
17	Kingsferry Bridge (South)	Inner	Close to ideal form at MLW	Stability			
			Narrower than ideal form at MHW	Erosion possible	Erosion	Marsh erosion	Moderate
			Close to ideal form at seawalls	Stability			
			CSA close to ideal	Stability			
18	Knigsferry Bridge (North)	Inner	Close to ideal form at MLW	Stability			
			Close to ideal form at MHW	Stability		Stability	Low
			Close to ideal form at seawalls	Stability			
			CSA close to ideal	Stability			
19	Rushenden (South) (Isle of Sheppey) to Ferry Marshes	Inner	Wider than ideal form at MLW	Accretion possible			
			Close to ideal form at MHW	Stability		Stability	Low
			Close to ideal form at seawalls	Stability			
			CSA close to ideal	Stability			
20	Rushenden dredging disposal site (Isle of Sheppey) to Chetney	Inner	Wider than ideal form at MLW	Accretion possible			

Transect Number	Geographic Location	Estuary Reach	Comparison with ideal estuary form	Implication	Historical trend in saltmarsh 1988-2000*	Likely future morphological trend	Confidence
	Marshes						
			Close to ideal form at MHW	Stability		Stability	Low
			Close to ideal form at seawalls	Stability			
			CSA close to ideal	Stability			
21	Rushenden dredging disposal site (North) (Isle of Sheppey) to Chetney Marshes	Inner	Wider than ideal form at MLW	Accretion possible			
			Close to ideal form at MHW	Stability		Accretion	Low
			Wider than ideal form at seawalls	Accretion possible			
			CSA close to ideal	Stability			
22	Rushenden to west Point	Inner	Wider than ideal form at MLW	Accretion possible			
			Wider than ideal form at MHW	Accretion possible		Accretion	Low
			Close to ideal form at seawalls	Stability			
			CSA greater than ideal	Stability			
23	Queenborough to west Point	Inner	Wider than ideal form at MLW	Accretion possible			
			Close to ideal form at MTL	Stability		Stability	Low
			CSA greater than ideal	Accretion possible			

Transect Number	Geographic Location	Estuary Reach	Comparison with ideal estuary form	Implication	Historical trend in saltmarsh 1988-2000*	Likely future morphological trend	Confidence

(* from CCM, 2002).

C5.2.7 No Active Intervention

Under a management scenario of ‘No Active Intervention’ sea defences are anticipated to fail gradually over time (see Defences Table – Table C2.1 for details of residual life). In low lying areas this will lead to the creation of new intertidal regions and commensurate increases in the estuary tidal prism. Experience in other estuaries, where managed realignment schemes have been planned or implemented, has shown that increases in tidal prism lead to increases in flood and ebb velocities in the estuary channel downstream of the realignment area. The changes tend to be larger on the ebb tide, due to the increased volume of water draining out of the realigned areas. These changes have the potential to cause erosion of the estuary channel downstream of the realigned area. Hydrodynamic modelling also indicates that the creation of realigned areas can lead to a slight decrease in flow speeds upstream of the realigned areas. This has the potential to raise siltation rates in these areas, although this has not been observed in the field. Experience with managed realignment schemes also shows that if flows into and out of the realigned areas are confined to localised breaches, then the high flow speeds tends to erode channels in the fronting intertidal area.

The changes in flow speeds will be proportional to the tidal prisms of the realigned areas. Since the land is generally low lying then these prisms are likely to be mainly controlled by the area of land that is inundated, Figures C5.11, C5.12 and C5.16 indicate the areas that lie below the present day level of MHWS within the Medway and Swale estuaries. It can be seen that large areas surrounding the Medway and Swale could be inundated under a ‘No Active Intervention’ scenario. In the Medway, realignment in the middle reaches of the estuary has the capacity to increase erosion in the constrained estuary mouth (Transects 1 and 2 (Grain to Sheerness)). Realignment in Yantlet Creek however would essentially form a second estuary mouth. This would allow the confined mouth area to increase in width, moving the estuary towards its equilibrium form. In the Swale, realignment in the middle reaches would have the capacity to increase erosion in the more constrained parts of the estuary (Transects 5 (Ferry Inn Public House to Faversham Creek (west)), 15 (Elmley Hills to Kemsley Paper Mill) and 19 (Rushenden (south) to Ferry Marshes)). Realignment around the constrained regions of the Swale would however increase the estuary width at these points by forming secondary channels landwards of the high land, essentially moving the estuary towards an equilibrium form at these locations.

The future evolution of the Medway and Swale estuaries under a scenario of ‘No Active Intervention’ will depend on the timing of failure of defences in different areas of the estuary. The defences likely to fail first are those with the lowest residual life: Table C2.1 summarises the condition of the existing sea defences in the Medway and Swale estuaries. In the Medway, the defences with the lowest residual life (<5 years) are located in the inner estuary between Medway Bridge and Halling, Halling and Aylesford Paper Mills, and between Allington Lock (right bank) and Aylesford Paper Mills (opposite). In the Swale, the defences with the lowest residual life (<20 years) are located between Shell Ness and the Isle of Harty in the outer estuary, between the Isle of Harty and Sheerness Docks in the middle and inner estuary, and between Chetney Marshes and Ferry Marshes in the inner estuary.

Considering the future of the realigned areas themselves, evolution depends on the initial elevations with regard to the tidal frame, the levels of sedimentation and the colonisation of the area with salt marsh vegetation. Figures C5.27, C5.28 and C5.29 show the potential intertidal habitats that could form in the Medway and Swale were the defences to fail under present day sea levels. These predictions are based on the elevation of the land with respect to present day sea levels: mudflat habitats are predicted to form between MLWS and MHWN levels, saltmarsh habitats are predicted to form between MHWN and MHWS levels. High rates of sedimentation can lead to the expansion of Saltmarsh habitats, whilst low rates of sedimentation can lead to reductions in saltmarsh area as marshes 'drown' under rising sea levels. The amount of sedimentation that occurs is dependent on the availability of sediment.

In the Medway, the defences with the lowest residual life (<5 years) are located between Medway Bridge and Halling, Halling and Aylesford Paper Mills, and between Allington Lock (right bank) and Aylesford Paper Mills (opposite). In the Swale, those defences with the lowest residual life (<20 years) are located between Shell Ness and the Isle of Harty, between the Isle of Harty and Sheerness Docks and between Chetney Marshes and Ferry Marshes.

C5.3 CONCLUSIONS

This section has assessed the likely future morphological evolution of the Medway and Swale estuaries under two management scenarios:

- No Active Intervention; and,
- With Present Management.

At present there is no one accepted morphological model that predicts the evolution of estuaries over the long term. Present guidance (Defra, 2002) recommends that the results from a number of different modelling approaches are synthesised to generate a robust conceptual model. Detailed modelling is beyond the scope of the present report and future evolutionary trends have been based on:

- Understanding of physical processes provided by previous workers (see Halcrow 2006);
- A re-analysis of the morphological form of the estuary and valley forms; and,
- Previous analysis of recent salt marsh evolution.

Under a scenario of 'No Active Intervention' the present day defences are assumed to fail at some point in the future. This has the potential to inundate large areas of land surrounding the present day estuaries. This would create intertidal habitat within the realigned areas. The type of habitat would depend on the elevation of the land, future sedimentation rates and the colonisation of the areas by salt marsh vegetation.

The exact nature of morphological change within the estuaries will depend on how and when the defences fail. In the Medway, under a scenario of 'No Active Intervention' existing defences are likely to fail first between Medway Bridge and Halling, Halling and Aylesford Paper Mills, and between Allington Lock (right bank) and Aylesford Paper Mills. In the Swale, existing defences are likely to fail first between Shell Ness and the Isle of Harty, between the Isle of Harty and Sheerness Docks and between Chetney Marshes and Ferry Marshes.

The analysis of estuary form suggests that realignment will move the esturaries away from their equilibrium morphological forms. In general terms, the creation of realigned areas would increase the tidal prism and flow speeds downstream of the realignment areas. Such changes would increase the potential for erosion in confined areas of the estuary channel. Such areas include Transects 1 and 2 (Grain to Sheerness) in the mouth of the Medway and Transects 5 (Ferry Inn Public House to Faversham Creek (west)), 15 (Elmley Hills to Kemsley Paper Mill) and 19 (Rushenden (south) to Ferry Marshes) in the Swale. Flows into and out of the realigned areas would also lead to the localised erosion of channels in the vicinity of breaches in the defences.

Under the scenario of 'With Present Management' the present day defences are assumed to remain in place. Under this scenario the future morphological evolution of the Medway and Swale has been assessed by considering:

- The concordance of the present estuary form with an ideal estuary form; and,
- Recent trends in salt marsh evolution.

In the Medway, the main expected trends are:

- Erosion in the confined mouth region;
- Continued accretion on marshes that are presently accreting within the middle estuary; and,
- Relative stability in the inner estuary.

In the Swale, the main expected trends are:

- Possible accretion in the mouth region, although this may be offset by increases in wave action;
- Accretion within parts of the middle estuary; and,
- Erosion in confined parts of the middle and inner estuary.

These predictions of future geomorphological changes are subject to varying levels of confidence. Whilst the trends described in the previous sections would be expected to continue over the next 20 years, their extrapolation of longer timescales is more uncertain. Further studies are recommended to improve these levels of confidence before works are undertaken on the ground. Further studies include:

- Initiation of a monitoring programme to assess present and future trends in estuary morphology and habitats;
- Comparison of previous and present trends in estuary morphology and habitats; and,
- Assessment of sediment budgets under future sea level scenarios in order to better inform predictions of future estuary morphology and habitats.

Consideration of the requirement for the application of modelling techniques to further inform predictions of future estuary morphology and habitats.

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Annex C1 Figures

Annex C2 No Active Intervention Maps

Erosion Mapping Methodology

EROSION ZONES

Within the Medway and Swale estuaries there are only a limited number of areas that are potentially at risk from erosion under a NAI scenario (see Table C3.1). There is uncertainty however, regarding erosion rates in these areas. Erosion rates used in the following NAI maps have been adapted from Futurecoast (Defra, 2002), i.e. using rates from comparable locations with a similar geology (see Table C3.1).

In the following NAI maps, erosion has been illustrated over the 100 year period using three erosion 'zones' (one for each epoch) i.e. 0-20 years, 20-50 years and 50-100 years. The following table contains the methodology used to calculate the amount of erosion for each epoch, for each area of erosion.

Erosion zones have also been calculated using the following assumptions:

- If the defence residual life < 5 years then assume failure in year 0.
- If the defence residual life > 20 years then assume failure in year 30.
- If the defence residual life < 20 years then assume failure in year 10.

NAI Mapping: Methodology for calculating erosion zones.				
Frontage	***0-20yrs***	***20-50yrs***	***50-100yrs***	***Notes***
Hoo Marina to Lower Upnor (Cockham Wood)	**Undefended sections:** Cockham wood Average erosion rate per annum = 0.5m/yr & 20 yrs of erosion assumed **Total erosion in epoch 1: 10m**	**Undefended sections:** Cockham wood Average erosion rate per annum = 0.5m/yr & 30 yrs of erosion assumed **Total erosion in epoch 2: 15m**	**Undefended sections:** Cockham wood Average erosion rate per annum = 0.5m/yr & 50 yrs of erosion assumed **Total erosion in epoch 3: 25m**	Cockham Wood currently undefended
Lower Upnor to Upper Upnor	**Defended sections** = no erosion	**Assume Defences fail in yr 30** Lower Upnor to Upper Upnor Average erosion rate = 0.5m/yr & 20 yrs of erosion assumed **Total erosion in epoch 2: 10m**	**Undefended sections:** Lower Upnor to Upper Upnor Average erosion rate = 0.5m/yr & 50 yrs of erosion assumed **Total erosion in epoch 3: 25m**	Defences fail > 20 years but calculate erosion as if defences fail in year 30.
Rochester Bridge to Medway Bridge	**Defences fail in yr 15** Flooding predicted Temple Marsh Average erosion rate per annum = 0.5m/yr & 10 years of erosion assumed **Total erosion in epoch 1: 5m**	**Undefended sections:** Flooding predicted Temple Marsh Average erosion rate per annum = 0.5m/yr & 30 years of erosion assumed **Total erosion in epoch 2: 15m**	**Undefended sections:** Flooding predicted Temple Marsh Average erosion rate per annum = 0.5m/yr & 50 years of erosion assumed **Total erosion in epoch 3: 25m**	Defences fail < 20 years therefore calculate erosion as if defences fail in year 10.
Medway Bridge to Halling	**Defences fail in this epoch (<5yrs)** Flooding predicted Cuxton and North Halling	**Undefended sections:** Flooding predicted Cuxton and North Halling Average erosion rate per annum	**Undefended sections:** Flooding predicted Cuxton and North Halling Average erosion rate per annum =	Defences fail < 5 years therefore calculate erosion as if defences fail in year 0, to allow for uncertainty in erosion rates.

NAI Mapping: Methodology for calculating erosion zones.				
Frontage	***0-20yrs***	***20-50yrs***	***50-100yrs***	***Notes***
	Average erosion rate per annum = 0.5m/yr & 20 years of erosion assumed **Total erosion in epoch 1: 10m**	= 0.5m/yr & 30 years of erosion assumed **Total erosion in epoch 2: 15m**	0.5m/yr & 50 years of erosion assumed **Total erosion in epoch 3: 25m**	
Halling	**Defended sections** = no erosion	**Defences fail in yr 35** Halling Average erosion rate per annum = 0.5m/yr & 15 years of erosion assumed **Total erosion in epoch 2: 7.5m**	**Undefended sections:** Halling Average erosion rate per annum = 0.5m/yr & 50 years of erosion assumed **Total erosion in epoch 3: 25m**	Defences fail > 20 years but calculate erosion as if defences fail in year 35, to allow for uncertainty in erosion rates.
Halling to New Hythe	**Defences fail in this epoch (<5yrs)** Flooding predicted Snodland Average erosion rate per annum = 0.5m/yr & 20 years of erosion assumed **Total erosion in epoch 1: 10m**	**Undefended sections:** Flooding predicted Snodland Average erosion rate per annum = 0.5m/yr & 30 years of erosion assumed **Total erosion in epoch 2: 15m**	**Undefended sections:** Flooding predicted Snodland Average erosion rate per annum = 0.5m/yr & 50 years of erosion assumed **Total erosion in epoch 3: 25m**	Defences fail < 5 years therefore calculate erosion as if defences fail in year 0, to allow for uncertainty in erosion rates.
Allington Lock to Medway Bridge	**Defences fail** Flooding predicted **Defences fail in yr 10** North Burham Court & Wouldham Average erosion rate per annum = 0.5m/yr & 10 years of erosion	**Undefended sections:** Flooding predicted North Burham Court & Wouldham Average erosion rate per annum = 0.5m/yr & 30 years of erosion assumed	**Undefended sections:** Flooding predicted North Burham Court & Wouldham Average erosion rate per annum = 0.5m/yr &50 years of erosion assumed **Total erosion in epoch 3: 25m**	Defences fail < 20 years therefore calculate erosion as if defences fail in year 10, to allow for uncertainty in erosion rates.

NAI Mapping: Methodology for calculating erosion zones.				
Frontage	***0-20yrs***	***20-50yrs***	***50-100yrs***	***Notes***
	assumed **Total erosion in epoch 1: 5m**	**Total erosion in epoch 2: 15m**		
Medway Bridge to Otterham Quay	**<u>Defended sections</u>** = no erosion	**<u>Defences fail in yr 30</u>** Flooding predicted Rochester & Limestone Reach Chatham Average erosion rate per annum = 0.1m/yr & 20 years of erosion assumed **Total erosion in epoch 2: 2m**	**<u>Undefended sections:</u>** Flooding predicted Rochester & Limestone Reach Chatham Average erosion rate per annum = 0.1m/yr & 50 years of erosion assumed **Total erosion in epoch 3: 5m**	Defences fail > 20 years but calculate erosion as if defences fail in year 30, to allow for uncertainty in erosion rates.
Otterham Quay to north Lower Halstow	**<u>Defended sections</u>** = no erosion	**<u>Defences fail in yr 30</u>** Flooding predicted Ham Green to east of Upchurch Average erosion rate per annum = 0.5m/yr & 20 years of erosion assumed **Total erosion in epoch 2: 10m**	**<u>Undefended sections:</u>** Flooding predicted Ham Green to east of Upchurch Average erosion rate per annum = 0.5m/yr & 50 years of erosion assumed **Total erosion in epoch 3: 25m**	Defences fail > 20 years but calculate erosion as if defences fail in year 30, to allow for uncertainty in erosion rates.
Funton to Raspberry Hill	**<u>Defended sections</u>** = no erosion	**<u>Defences fail in yr 30</u>** Funton to Raspberry Hill Average erosion rate per annum = 0.5m/yr & 20 years of erosion assumed **Total erosion in epoch 2: 10m**	**<u>Undefended sections:</u>** Funton to Halling Average erosion rate per annum = 0.5m/yr & 50 years of erosion assumed **Total erosion in epoch 3: 25m**	Defences fail > 20 years but calculate erosion as if defences fail in year 30, to allow for uncertainty in erosion rates.
Kingsferry Bridge to	**<u>Defended sections</u>** = no erosion	**<u>Defences fail in yr 30</u>**	**<u>Undefended sections:</u>**	Defences fail > 20 years but

NAI Mapping: Methodology for calculating erosion zones.				
Frontage	***0-20yrs***	***20-50yrs***	***50-100yrs***	***Notes***
Nagden		Flooding predicted Kemsley Down Average erosion rate per annum = 0.5m/yr & 20 yrs of erosion assumed **Total erosion in epoch 2: 10m**	Flooding predicted Kemsley Down Average erosion rate per annum = 0.5m/yr & 50 yrs of erosion assumed **Total erosion in epoch 3: 25m**	calculate erosion as if defences fail in year 30, to allow for uncertainty in erosion rates.
Shell Ness to Kingsferry Bridge	**Defences fail** Flooding predicted **No defences at present:** Isle of Harty & Elmley Hills Average erosion rate per annum = 0.5m/yr & 20 yrs of erosion assumed **Total erosion in epoch 1: 10m**	**Undefended sections:** Flooding predicted Isle of Harty & Elmley Hills Average erosion rate per annum = 0.5m/yr & 30 yrs of erosion assumed **Total erosion in epoch 2: 15m**	**Undefended sections:** Flooding predicted Isle of Harty & Elmley Hills Average erosion rate per annum = 0.5m/yr & 50 yrs of erosion assumed **Total erosion in epoch 3: 25m**	Defences fail < 20 years, however calculate erosion as if defences fail in year 0, as no defences as present in these locations and to allow for uncertainty in erosion rates.
Kingsferry Bridge to Sheerness	**Defences fail in this epoch** Flooding predicted Rushenden Average erosion rate per annum = 0.5m/yr & 10 yrs of erosion assumed **Total erosion in epoch 1: 54m**	**Undefended sections:** Flooding predicted Rushenden Average erosion rate per annum = 0.5m/yr & 30 yrs of erosion assumed **Total erosion in epoch 2: 15m**	**Undefended sections:** Flooding predicted Rushenden Average erosion rate per annum = 0.5m/yr & 50 yrs of erosion assumed **Total erosion in epoch 3: 25m**	Defences fail < 20 years therefore calculate erosion as if defences fail in year 10, to allow for uncertainty in erosion rates