North West Estuaries Processes Reports

Kent Estuary

Prepared for

Sefton Council

November 2013

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Metadata

Addressee	Sefton Council
Audience	Coastal/Environmental Engineers
Contributor(s)	CH2M HILL, Kenneth Pye Associates Ltd
Coverage	North West estuaries
Creator	Halcrow Group Ltd, a CH2M Hill Company
Date	November 2013
Description	Review of coastal processes knowledge and issues in Kent Estuary
Format	Text
Identifier	V3.0 November 2013
Keyword	Estuary, Strategic, Coastal, Processes
Language	English
Location	Kent Estuary
Mandate	CERMS Regional Monitoring Framework
Publisher	Sefton Council
Status	Final
Subject	Coastal and estuarine processes
Title	North West Estuaries Processes Reports – Kent Estuary
Type	Text/report
Date of metadata update	18 November 2013

Document History

North West Estuaries Processes Report

Kent Estuary

Sefton Council

This document has been issued and amended as follows:

version	Date	Description	Created By	Verified By	Approved By
1.0	28/03/13	Internal Draft	Emma Allan, Nigel Pontee, Ken Pye	A Parsons	N/A
2.0	15/10/13	Draft for client comment	A Parsons,	K Pye	A Parsons
3.0	18/11/13	Finalised following client comments and internal review	A Parsons	K Pye	A Parsons

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Glossary

Term	Definition
Accretion	Accumulation of sediment due to the natural action of waves, currents and wind.
Advance the Line (ATL)	Advance the Line. A Shoreline Management Plan policy to build new defences on the seaward side of the existing defence line to reclaim land.
AIMS	Asset Information Management System. National database being developed by Environment Agency to replace NFCDD.
Bathymetry	The seabed elevation and depth of water in relation to it.
Coastal Change	Physical change to the shoreline, i.e. erosion, coastal landslip, permanent inundation and coastal accretion.
CD	Chart Datum.
Clay	Sediment particles smaller than 0.002 mm.
Cell Eleven Regional Monitoring Strategy (CERMS)	Regional Monitoring Strategy for the area known as Cell 11, which extends from Llandudno to Solway Firth.
Cell Eleven Tide and Sediment Study (CETaSS)	Regional sediment transport study for coastal Cell 11, undertaken in two main stages to support the development and implementation of the second round shoreline management plan (SMP2). The study included modelling of tides, waves and sediment transport alongside desk based studies with a focus on issues and uncertainties identified in the SMP1s and the initial scoping phase.
Coastal Erosion	A natural process that occurs as a result of waves, tides or currents – in other words, the sea – striking the shore. Sediment or rocks are washed away (but can be a sediment source for elsewhere), and our coastline changes shape as a result. This may include cliff instability, where coastal processes result in landslides or rock falls.
Coastal Landsliding/Instability	Process that involves slope failure and mass movement of a coastal slope or cliff and may result in deposition of debris on the beach and foreshore. Some landslides are very large and extend a considerable distance inland, offshore and deep below beach level and care must be taken to ensure their true extent is recognised. Cliff instability and erosion is a four stage process involving detachment of particles or blocks of material, transport of this material through the cliff system, its deposition on the foreshore and its removal by wave and tidal action.
Coastal Narrowing (including Coastal Squeeze)	The process whereby rising sea levels and other factors such as increased storminess push the coastal habitats landwards. At the same time in areas where land claim or coastal defence has created a static, artificial margin between land and sea or where the land rises relative to the coastal plain, habitats become squeezed into a narrowing zone. Manifestation of this process is most obvious along the seaward margins of coastal habitats, especially salt marshes, when erosion takes place.

Term	Definition
Coastal processes	A collective term covering the action of natural forces on the shoreline and nearshore seabed. Includes such processes as wave action tidal flows and sediment transport.
D_{50}	Median particle/ grain size in sediments; the 50th percentile size of a distribution.
EA	Environment Agency.
Ebb dominant	Stronger current on ebb tide than flood tide. Coarser sediments may be moved more by ebb direction currents than flood. The balance of net sediment transport depends on the relative strength and duration of ebb and flood currents.
Ebb-tide	The falling tide. Part of the tidal cycle between high water and the next low water.
Estuary	A semi-enclosed coastal body of water which has a free connection to the open sea and where freshwater mixes with saltwater.
Fetch	Distance over which a wind acts to produce waves - also termed fetch length.
Flood and Coastal Erosion Risk Management (FCERM)	Flood and coastal erosion risk management addresses the scientific and engineering issues of rainfall, runoff, rivers and flood inundation, and coastal erosion, as well as the human and socio-economic issues of planning, development and management.
Flood Defence Grant in Aid (FDGiA)	The mechanism by which most of the funding for flood and coastal defence works in England is provided by the Government. The grants are used to cover our operating costs and to fund capital projects.
Flood dominant	Stronger current on flood tide than ebb tide. Coarser sediments may be moved more by flood direction currents than ebb. The balance of net sediment transport depends on the relative strength and duration of ebb and flood currents.
Fluvial	Belonging to rivers streams or ponds. e.g. Fluvial flooding, fluvial plants.
Geomorphology/ Morphology	The form of the earth's surface including the distribution of the land and water and the processes responsible for their movement.
Hard structure of rock outcrop (Hard point)	Man-made feature or natural rock outcrop which acts to locally limit the natural movement of the shoreline e.g. sea wall, rock groyne.
HAT	Highest Astronomical Tide. See Tide Levels.
Headland	Hard feature (natural or artificial) forming local limit of longshore extent of a beach.
Hinterland	The area landward of flood or coastal defences.
Hold the Line (HTL)	Hold the Line. A Shoreline Management Plan policy to maintain or change the level of protection provided by defences in their present location.
Holocene	An epoch of the Quaternary period, spanning the time from the end of the Pleistocene (10,000 years ago) to the present.

Term	Definition
Hydrographic Survey	A field survey carried out to map the sea bed features which affect maritime navigation, marine construction, dredging, offshore oil exploration/drilling and related disciplines.
Infrastructure	The basic facilities and equipment for the functioning of the country or area, such as roads, rail lines, pipelines and power lines.
Intertidal zone	The zone between the high and low water marks.
LAT	Lowest Astronomical Tide. See Tide Levels.
LiDAR	Light Detection and Ranging – a method of measuring land elevations using a laser, often from a light aeroplane.
Littoral transport (drift)	The movement of beach material in the littoral zone by waves and currents. Includes movement parallel (longshore drift) and perpendicular (cross-shore transport) to the shore.
LLFA	Lead Local Flood Authority. Responsible body for local flood risk management in accordance with the Flood and Water Management Act (FWMA) (2010).
Managed Realignment (MR)	A Shoreline Management Plan policy that allows the shoreline position to move backwards (or forwards) with management to control or limit movement.
MHWS	Mean High Water Springs. See Tide Levels.
MHWN	Mean High Water Neaps. See Tide Levels.
MLWN	Mean Low Water Neaps. See Tide Levels.
MLWS	Mean Low Water Springs. See Tide Levels.
MSL	Mean Sea Level. See Tide Levels.
Mud	A type of sediment containing more than 50% silt and clay size particles; may also contain sand and/or gravel and be described as sandy mud, gravelly mud etc.
Mudflats	Expanses of mud which are periodically exposed at low tide, often found adjacent to saltmarshes.
NFCDD	National Flood and Costal Defence Database. Database of flood defence assets developed by EA. Now being superseded by AIMS.
NTL	Normal Tidal Limit. The point to which the tide reaches in an estuary, under normal conditions i.e. in absence of storm surge and with typical river flow.
Neap tide	Tides over a 14 day period with lowest tidal range between high and low water.
No Active Intervention (NAI)	A Shoreline Management Plan policy that assumes that existing defences are no longer maintained and will fail over time or undefended frontages will be allowed to evolve naturally.
OD	Ordnance Datum - the standard reference level for Ordnance Survey maps throughout the UK from which the height of the land is measured. Currently based on mean sea level at Newlyn in Cornwall.

Term	Definition
Partnership Funding	Funding contributions for flood and coastal erosion risk management from beyond traditional flood and coastal erosion risk management budgets (e.g. Flood Defence Grant in Aid (FDGiA); the grant by which government funds its share of the costs of FCERM projects in England).
Policy Unit (PU)	Sections of coastline for which a certain coastal defence management policy has been defined in the Shoreline Management Plan – see SMP.
Progradation	Seaward movement of the shoreline (mean high water mark) due to sediment accumulation on a beach, dunes, delta etc.
Ramsar	Ramsar sites are wetlands of international importance, designated under the Ramsar Convention of 1971.
Regression	A seaward movement of the shoreline due to a fall in sea level.
Risk	A combination of both the probability of an event occurring and the expected consequences if it does occur. In the case of coastal change adaptation planning, risk relates to the impact and consequences of a hazard, which may be coastal erosion, coastal landsliding, coastal accretion or coastal flooding resulting in regular or permanent inundation.
Risk Management Authorities	Organisations that have a key role in flood and coastal erosion risk management as defined by the Flood and Water Management Act (2010). These are the Environment Agency, lead local flood authorities, district councils where there is no unitary authority, internal drainage boards, water companies, and highways authorities.
SAC	Special Area of Conservation. An area which has been given special protection under the European Union's Habitats Directive.
Sand	Sediment particles, often mainly of quartz, with a diameter of between 0.063mm and 2mm, generally classified as `fine', `medium', `coarse' or `very coarse'.
Saltmarshes	An ecosystem in the mid- to high intertidal zone which is vegetated by salt-tolerant plants.
Sediment sink	An area in which transported sediment is deposited and accumulates over time.
Sediment source	An area from which sediment is derived and becomes available for transport to a sediment sink.
Shoreline Management Plan (SMP)	A plan providing a large-scale assessment of the risk to people and to the developed, historic and natural environment associated with coastal processes. SMP2 refers specifically to the second generation SMP.
Silt	Sediment particles with a grain size between 0.002mm and 0.063mm, i.e. coarser than clay particles but finer than sand.
SPA	Special Protection Area. An area of land, water or sea which has been identified as being of international importance for the breeding, feeding, wintering or the migration of rare and vulnerable species of birds found within the European Union.
Spring tide	Tides over a 14 day period with highest tidal range between high and low water.

Term	Definition
SSSI	Site of Special Scientific Interest (SSSI) National conservation designation given to sites of biological or geological interest in England, Wales and Scotland.
Storm surge	The local change in sea level associated with a change in atmospheric pressure and/ or onshore winds. Surges may be either positive (higher than predicted astronomical sea level) or negative (lower than predicted), and typically have a duration of a few hours to a few days.
Strategy Plan	A long term documented plan for coastal management, including all necessary work to meet defined flood or coastal defence objectives for the target area. It is designed to provide the basis for decision making and action related to the provision and management of flood or coastal defences. Strategy Plans develop the policies recommended in SMPs by defining the preferred approach to shoreline management requirements over a 100 year period.
Tidal range	Microtidal < 2m; Mesotidal 2m - 4m; Macrotidal >4m; Hypertidal > 8m.
Tide	The rise and fall of the sea caused by the gravitational pull of the moon and sun.
Tide levels	(1) High astronomical tide (HAT), lowest astronomical tide (LAT): the highest and lowest tidal levels, respectively, which can be predicted to occur under average meteorological conditions. (2) Mean high water springs (MHWS): the height of mean high water springs is the average throughout a year of the heights of two successive high waters during those periods of 24 hours (approximately once a fortnight) when the range of the tide is greatest. (3) Mean low water springs (MLWS): the height of mean low water springs is the average height obtained by the two successive low waters during the same periods. (4) Mean high water neaps (MHWN): the height of mean high water neaps is the average of the heights throughout the year of two successive high waters during those periods of 24 hours (approximately once a fortnight) when the range of the tide is least. (5) Mean low water neaps (MLWN): the height of mean low water neaps is the average height obtained by the two successive low waters during the same periods. (6) Mean high water (MHW), mean low water (MLW): mean high/low water, as shown on Ordnance Survey Maps, is defined as the arithmetic mean of the published values of mean high/low water springs and mean high/low water neaps.
Tidal prism	Volume of water entering and leaving an estuary during each tide, i.e. the difference between low water volume and high water volume.
Training walls	A wall typically constructed of rubble or masonry to constrain or guide the movement of an intertidal or sub-tidal channel.
Transgression	A rise in mean sea level responsible for landward movement of the shoreline.
Turbidity maximum	Location of high concentration of suspended sediment in an estuary; associated with fresh / seawater mixing with vertical and horizontal salinity gradient resulting in residual vertical circulation and flocculation of suspended sediment. Location varies during the tide and with variations in river flow.

Term	Definition
Up-drift	Longshore drift is the movement of beach materials along the shore, if a location is described as up-drift; it is located further up the sediment pathway (closer to the sediment source) than an alternative area; the opposite of down-drift.
Wave Height	The vertical distance between a wave crest and the next trough.

Executive summary

The Kent Estuary is a small estuary located on the north-eastern side of Morecambe Bay in sub-cell 11c. It drains into Morecambe Bay via the Grange Channel which converges with the Ulverston and Lancaster Channels before flowing out of the Bay though the 'Lune Deep'. The River Kent drains a large part of the southeastern Lake District and the western Howgill Fells.The catchment is largely rural and contains only one significant town, Kendal.

The estuary can be considered to extend from a line between Blackstone Point and Holme Island to the normal tidal limits at Waterside on the River Kent and Sampool Bridge on the River Gilpin. It is constrained by man-made embankments on the northern side and by naturally rising ground on the southern side. The estuary is constrained at Arnside by the Kent Railway Viaduct and 2km further inland at Sandside by high ground. The southern bank of the outer estuary, between Arnside and Blackstone Point, is backed by limestone cliffs and pocket shingle beaches, fronted by intertidal sandflats. On the northern bank there is a large tidal flood plain protected by embankments, including the railway, extending north east from high ground to the west of Holme Island and including Meathop and Foulshaw Marshes.

The whole of the estuary is of national and international conservation importance and forms part of the Morecambe Bay SSSI, SAC, SPA and Ramsar site.

The estuary experiences a macrotidal regime with MHWN and MHWS levels at Arnside of 2.7m and 4.9m OD, respectively. Ebb dominant flows are experienced in the Grange Channel, reinforced at low tidal stage by river discharge. The orientation of the estuary means that wave exposure is limited to waves penetrating up the Kent Channel under storm conditions.

The estuary is sand dominated, although sandy mud and muddy sediments occur in the high intertidal zone around the estuary fringes, and near the estuary head. The majority of sediment supplied to the Kent Estuary is sourced from Morecambe Bay. Sediment is transported in a net northerly direction into the estuary during storms and is deposited on banks within the estuary. Localised sediment input, from erosion of cliffs at Arnside, may also occur under extreme conditions but is likely to represent only a small contribution to the estuary sediment budget. The River Kent also provides some fluvial sediment to the system, but the relative amount is poorly quantified.

Tidal channels exert a significant influence on the exposure of the shoreline to wave energy and resulting erosion and accretion patterns within the estuary. Channel migration is facilitated by strong tidal currents and the channels are highly mobile. Saltmarsh erosion and accretion patterns within the estuary are highly dependent on the channel and bank positions.

Originally, the estuary had a much larger plan-shape, confined by the steeply sloping sides of the valley. Key modifications within the estuary include construction of the Arnside Kent Railway Viaduct (1857), reclamation of Meathop Marsh (1930s), training of the River Winster (1970s) and construction of alternative channel throughways under the Kent Viaduct (1950s).The area of the estuary basin has changed significantly due both to natural infilling and human intervention, which has been ongoing since at least the 18th century, with the channel now confined by saltmarshes and reclaimed land. The defences have effectively fixed the estuary shoreline and the Kent Viaduct effectively constrains the channel with its extensive 'lead-in' embankments and deepened spans to locate channels on either side of the estuary.

A comparison of EA LiDAR data surveys from 2000 to 2004 and 2009/10 showed that, although there were significant changes in the low water channel, leading to localised saltmarsh erosion and accretion, changes in overall intertidal area was small, indicating redistribution of sediment rather than major net losses or gains. The estuary presently appears to be in a state of dynamic equilibrium in terms of the extent of mudflat and saltmarsh area.

Erosion of small outcrops of soft cliffs, saltmarshes and tidal flats around the margins of Morecambe Bay will continue to provide some sediment input to the estuarine sediment system, as will fluvial transport from the

River Kent, but the main source of sediment is likely to continue to be from Morecambe Bay and the wider Irish Sea. The sediment balance of the estuary is considered unlikely to be constrained by sediment supply, although the relative importance of different sources, present fluxes, and the potential effects of large-scale managed realignment are presently poorly quantified. The low water channel is expected to continue to meander where not restricted by defences or surrounding topography, potentially causing the erosion of saltmarshes and undermining of defence structures in some areas but creating new areas of saltmarsh in areas of sediment accretion.

The SMP2 estimated that there would be less than 100 residential properties, along with around 3,600ha of agricultural land, at risk in the long term for a No Active Intervention (Do Nothing) approach to flood and erosion risk management. Compared to the other NW estuaries, the number of properties at risk around the Kent Estuary ranks lowest alongside the Ravenglass estuary. However the extensive rural flood plain has the fourth highest area of agricultural land at risk.

The vision for the long term identified in the SMP2 is that inland of the Kent viaduct (Policy Unit 11c 9) there is considerable scope to set back defences to higher ground, to return parts of the estuary to a more natural state, and to create additional habitat. The SMP2 recommends a policy of MR in the medium and long term for most of the defences inland of the viaduct. However, any realignment needs to be considered in combination with impacts on flows in and out of the estuary and possible consequences elsewhere, including economic losses resulting from loss of productive agricultural land. The long term plan in the outer estuary, seaward of the viaduct (11c 8), is to continue to manage flood and erosion risks to property and infrastructure, although some local opportunities for habitat creation to mitigate future coastal squeeze exist through realignment or habitat creation through regulated tidal exchange east of Grange-over-Sands. The proposed policies manage risk to people, property and infrastructure in a sustainable manner whilst maintaining the natural character of this section of the estuary and Morecambe Bay shore. In the long term, opportunities for additional habitat creation exist, if required, for compensatory habitat creation for areas experiencing coastal squeeze elsewhere in the region.

A number of additional studies are recommended to address the gaps in understanding identified, including a re-evaluation of assets at risk, acquisition of better topographic and bathymetric data, collection of process data to allow validation and testing of models, and studies to quantify sediment sources, transport pathways and fluxes to the estuary, including changes which might arise from climate change and large-scale managed realignment. Due to the strong coastal process linkages between the Kent Estuary and the rest of Morecambe Bay it is recommended that further studies in the Kent are progressed jointly with other Morecambe Bay monitoring, especially for the Leven estuary.

1 Introduction

This report summarises the existing understanding of the Kent Estuary (Figure 1.1). It draws on information from the second round SMP, the Cell Eleven Tidal and Sediment Transport Study (CETaSS) and other more recent studies. It provides a summary of:

- The physical processes and evolution of the estuary;
- The SMP policies for the estuary;
- The existing monitoring data;
- Gaps in understanding; and
- Recommendations for further monitoring, additional studies and review of flood risk ratings and SMP policies.

This report forms one of a series of similar reports for the major estuaries on the coast of North West England.

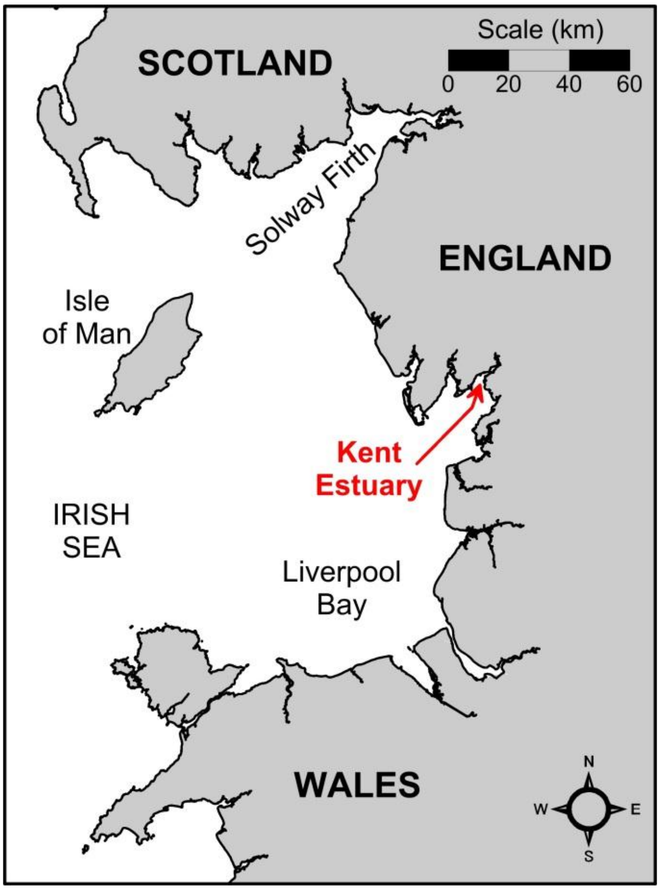


Figure 1.1 Location of the Kent Estuary.

2 Coastal Setting

The Kent Estuary is a small estuary located along the north-eastern side of Morecambe Bay in sub-cell 11c which extends from Rossall Point, Fleetwood to Hodbarrow Point on the Duddon Estuary (Figure 2.1). The Kent Estuary drains into Morecambe Bay via the Grange Channel and converges with the Ulverston and Lancaster Channels before flowing out of the Bay though the 'Lune Deep', a steep-sided channel that can reach up to 100m deep (Halcrow, 2010b).

Figure 2.1 Overview of Cell 11 study area, showing SMP2 sub-cell frontages (source: Halcrow, 2010c)

The River Kent drains a large part of the southeastern Lake District and the western Howgill Fells (Figure 2.2).The catchment is largely rural and contains only one significant town, Kendal.

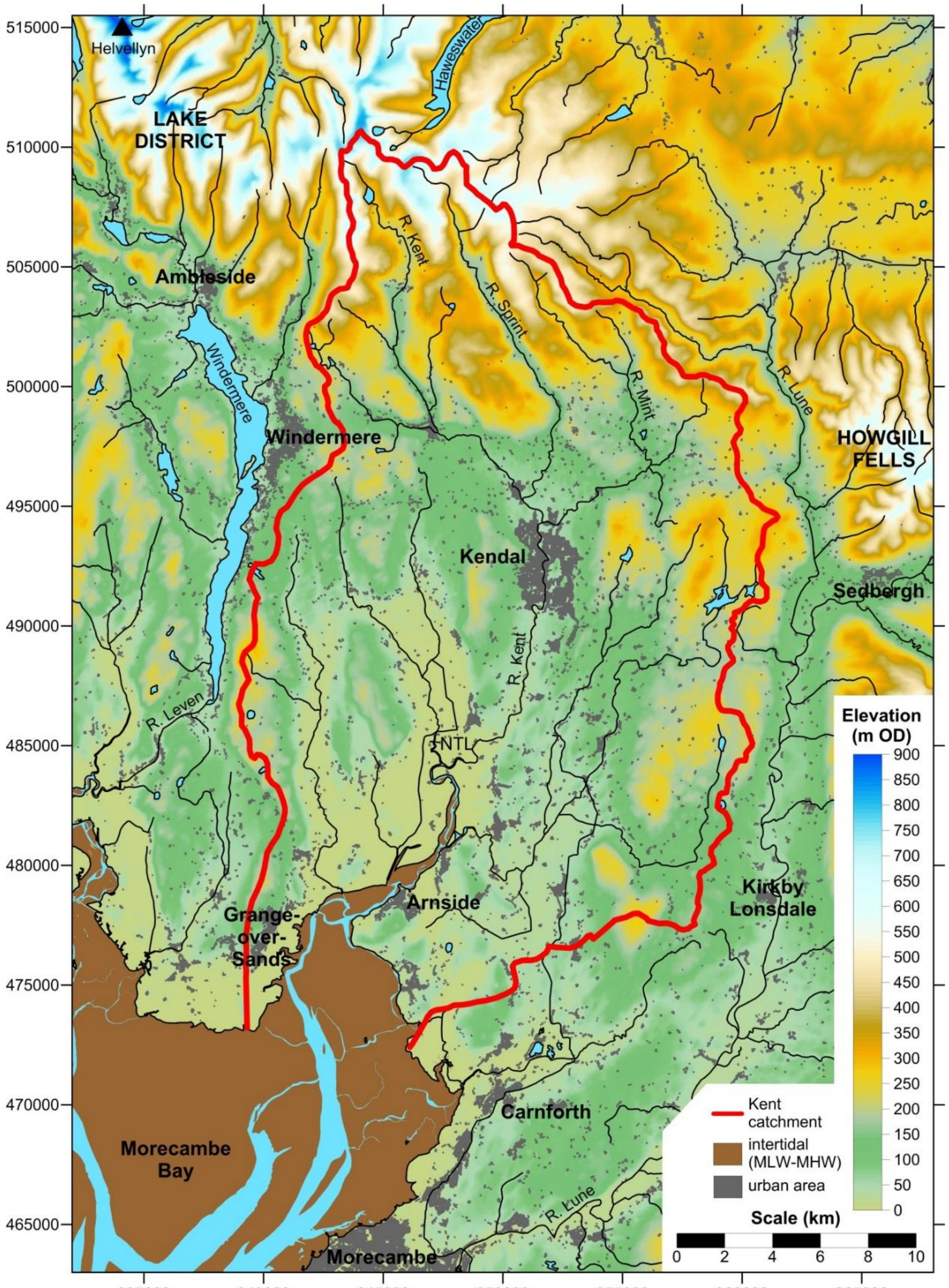


Figure 2.2 The River Kent catchment, showing the main urban areas and general extent of the intertidal zone. Source: adapted from Ordnance Survey Open Data, after Pye & Blott (2013).

3 Estuary Review

3.1 Description

The Kent Estuary (Figure 3.1) can be considered to extend from its mouth, defined by a line between Blackstone Point and Holme Island, to the normal tidal limits at Waterside on the River Kent and Sampool Bridge on the River Gilpin (Halcrow, 2010c). The estuary is constrained by man-made embankments on the northern side and by naturally rising ground on the southern side (Halcrow, 2010c). The SMP2 split the Kent Estuary between two Policy Areas: 11c8 includes the outer Kent Estuary seaward of the Kent railway viaduct between Heald Brow and Humphrey Head, whilst 11c9 is the Kent Estuary inland of the Kent Viaduct.

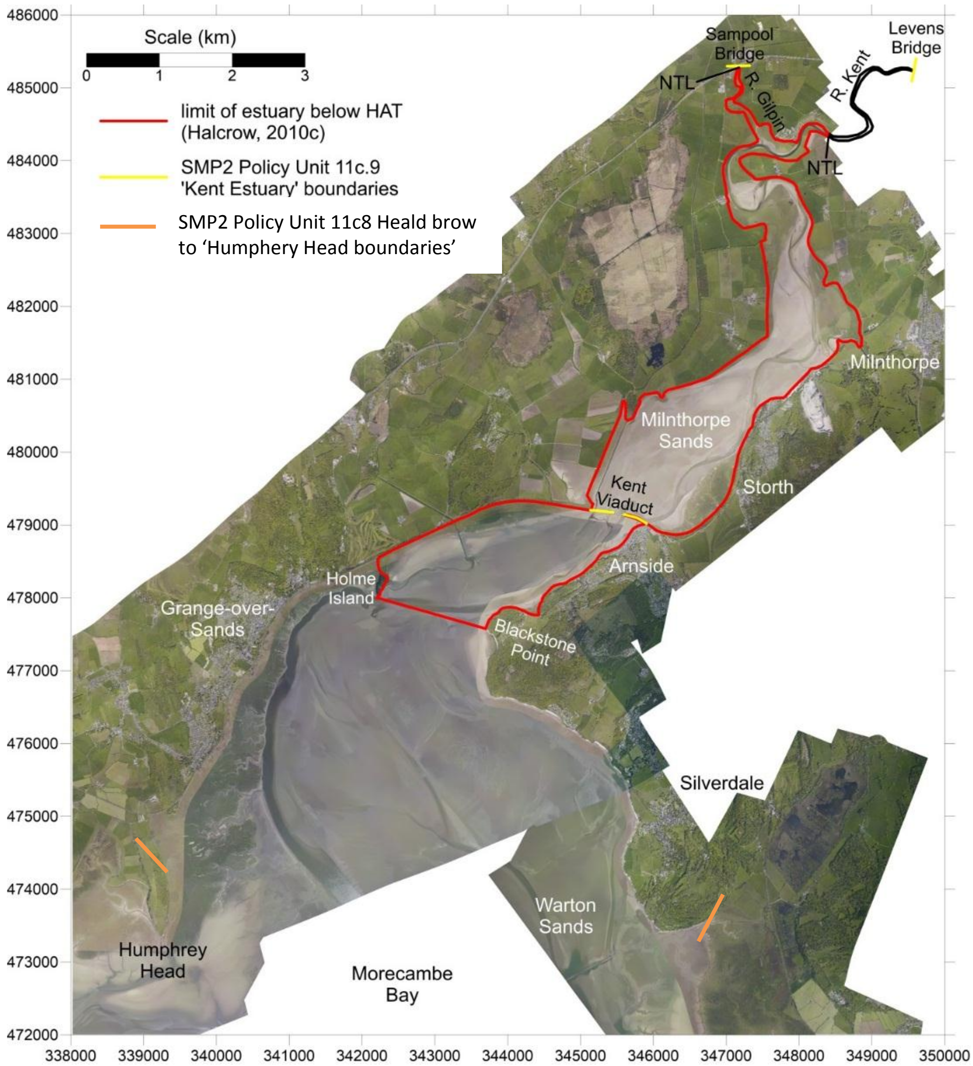


Figure 3.1. Limits of the Kent Estuary and SMP2 Policy Units 11c.8 and 11c9.

The estuary is generally funnel shaped, although it is constrained in width at two locations: Arnside, where it is constrained by the Kent Railway Viaduct, and about 2km inland the high land at Sandside. North of Milnthorpe Marsh, the estuary narrows to a single meandering channel. The south bank of the outer estuary, between Arnside and Blackstone Point, is characterised by limestone cliffs and pocket shingle beaches, fronted by intertidal sandflats. In places, irregular shore platforms which extend seaward are thought to have formed following erosion of the limestone cliffs (Halcrow, 2010b). On the north bank of the estuary there is a large tidal flood plain protected by embankments including the railway, extending north east from high ground to the west of Holme Island and including Meathop and Foulshaw Marshes.

The whole of the estuary is of national and international conservation importance and forms part of the Morecambe Bay SSSI, SAC, SPA and Ramsar site (Figure 3.2)

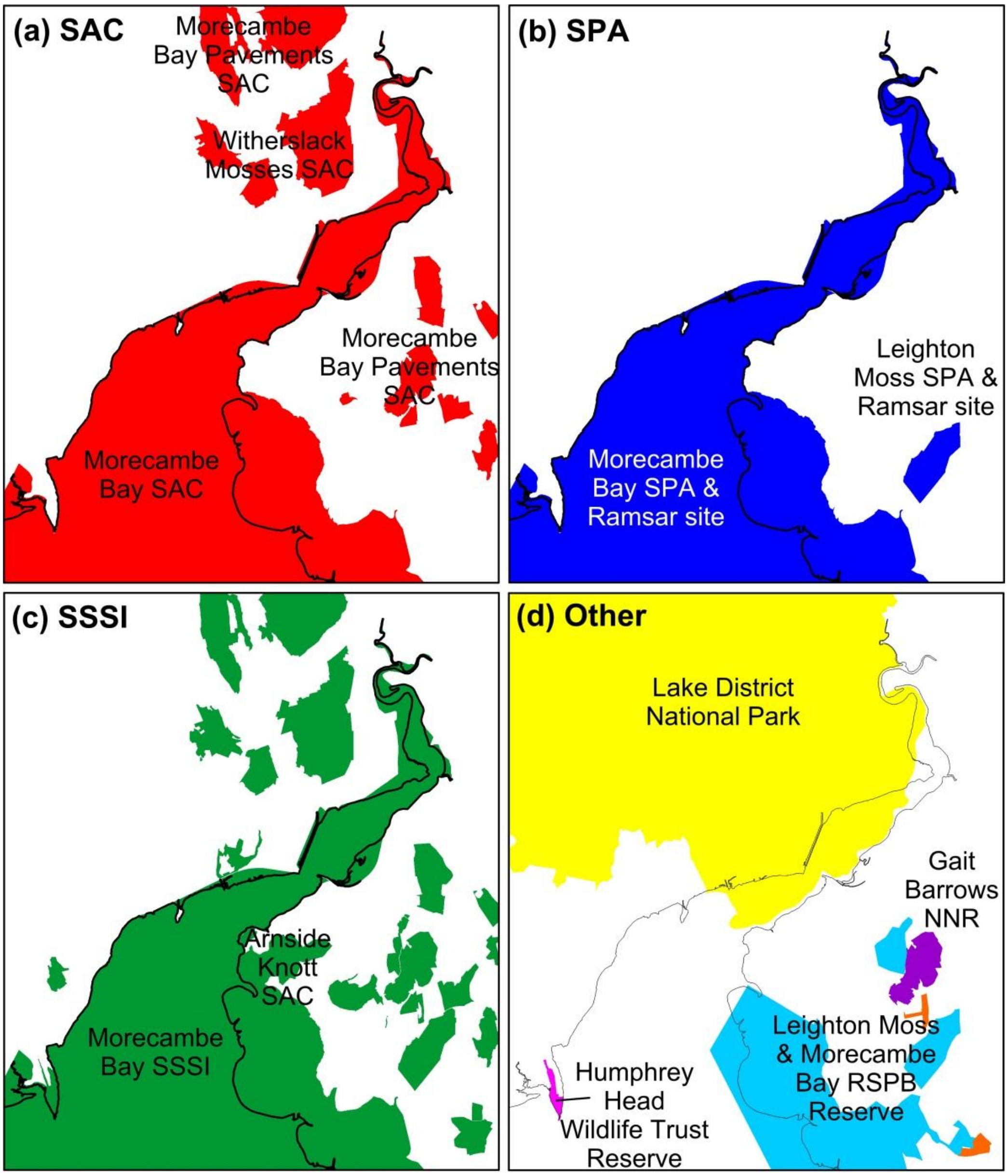


Figure 3.2 Nature conservation designations and reserves in and surrounding the Kent Estuary.

The shoreline management plan (SMP2) (Halcrow, 2010a) estimated that there would be less than 100 residential properties, along with around 3,600ha of agricultural land, at risk in the long term for a No Active Intervention (Do Nothing) approach to flood and erosion risk management. Compared to the other North West estuaries, the number of properties at risk around the Kent Estuary rank lowest alongside the Ravenglass estuary complex. However the extensive rural flood plain has the fourth highest area of agricultural land at risk (CH2M HILL, 2013).

3.2 Coastal Processes

A macro-tidal regime operates in Morecambe Bay and the Kent Estuary, with a spring tidal range along this frontage of around 8.40m (Shoreline Management Partnership 1999). According to Admiralty Tide Tables, MHWN and MHWS at Arnside 2.7m and 4.9m , respectively (Table 3.1).

Table 3.1 Tidal levels at Arnside, at the mouth of the Kent Estuary. Source: Admiralty Tide Tables (2012)

	LAT	MLWS	MLWN	MSL	MHWN	MHWS	HAT
Arnside	nd	nd	nd	nd	2.70	4.90	6.00

Ebb dominant flows are experienced in the Grange Channel, reinforced at low tidal stage by the river discharge (Pringle, 1987). The orientation of the Kent Estuary means that it is relatively sheltered and therefore, in general, wave exposure will be limited to waves penetrating up the Kent Channel under storm conditions (Shoreline Management Partnership, 1999). Upstream of the viaduct, waves will also be attenuated by the bank and channel alignments (Halcrow, 2010b).

The majority of sediment supplied to the Kent Estuary is sourced from offshore within Morecambe Bay. Sediment is transported in a net northerly direction (Shoreline Management Partnership, 1999) into the estuary during storms and is deposited on banks within the estuary. Localised sediment input, from erosion of cliffs at Arnside, may occur under extreme conditions (Shoreline Management Partnership, 1999) but is likely to represent only a small contribution to the estuary sediment budget. The River Kent also provides some fluvial sediment to the Morecambe Bay system (Halcrow, 2010b).

Tidal channels exert an influence on the degree of exposure of the shoreline to wave energy and control erosion and accretion patterns within the estuary. Channel migration is facilitated by strong tidal currents and within this estuary the channels are highly mobile, being known to move significant distances within a few days. The saltmarsh erosion and accretion patterns within the estuary are highly dependent on the channel and bank positions: when the main channel of the Kent River lies close to the shore, it allows larger, higher, energy waves to erode the marsh cliff, whereas areas of sand banks in front of the shore will act to attenuate wave energy. The railway viaduct at Arnside constrains channel movements in this location and therefore has a significant effect on shoreline evolution in the outer estuary (Halcrow, 2010b).

Littoral and subtidal transport vectors based on numerical modelling from the CETaSS study (Halcrow, 2010d) are shown in Figure 3.3. Morecambe Bay itself is a net sink for sediment, receiving material from north and south by littoral transport and from the Irish Sea.

Inside Morecambe Bay the sediment pathways are complex; east of the Lune Deep on the southern part of the Bay's mouth, transport is flood dominated, whereas towards the northern two-thirds of the mouth, the potential sediment transport is ebb dominated out of the Bay. A little way into the Bay, analysis across a transect from Newbiggin to Pilling indicates overall flood dominance. Further into Morecambe Bay and particularly in the Kent and Leven estuaries the transport becomes flood dominated due to increased asymmetry of the tides producing stronger flood current speeds and a net import of sediment into the feeder estuaries.

Within Morecambe Bay the strong tidal currents and plentiful sediment availability have led to the formation of a shifting system of banks and channels, (Halcrow, 2010b). The Kent Estuary exerts a significant control on the adjacent shorelines within Morecambe Bay since changes in its channel configuration influences the exposure of adjacent shoreline therefore erosion and accretion patterns (Pringle, 1995; 2006).

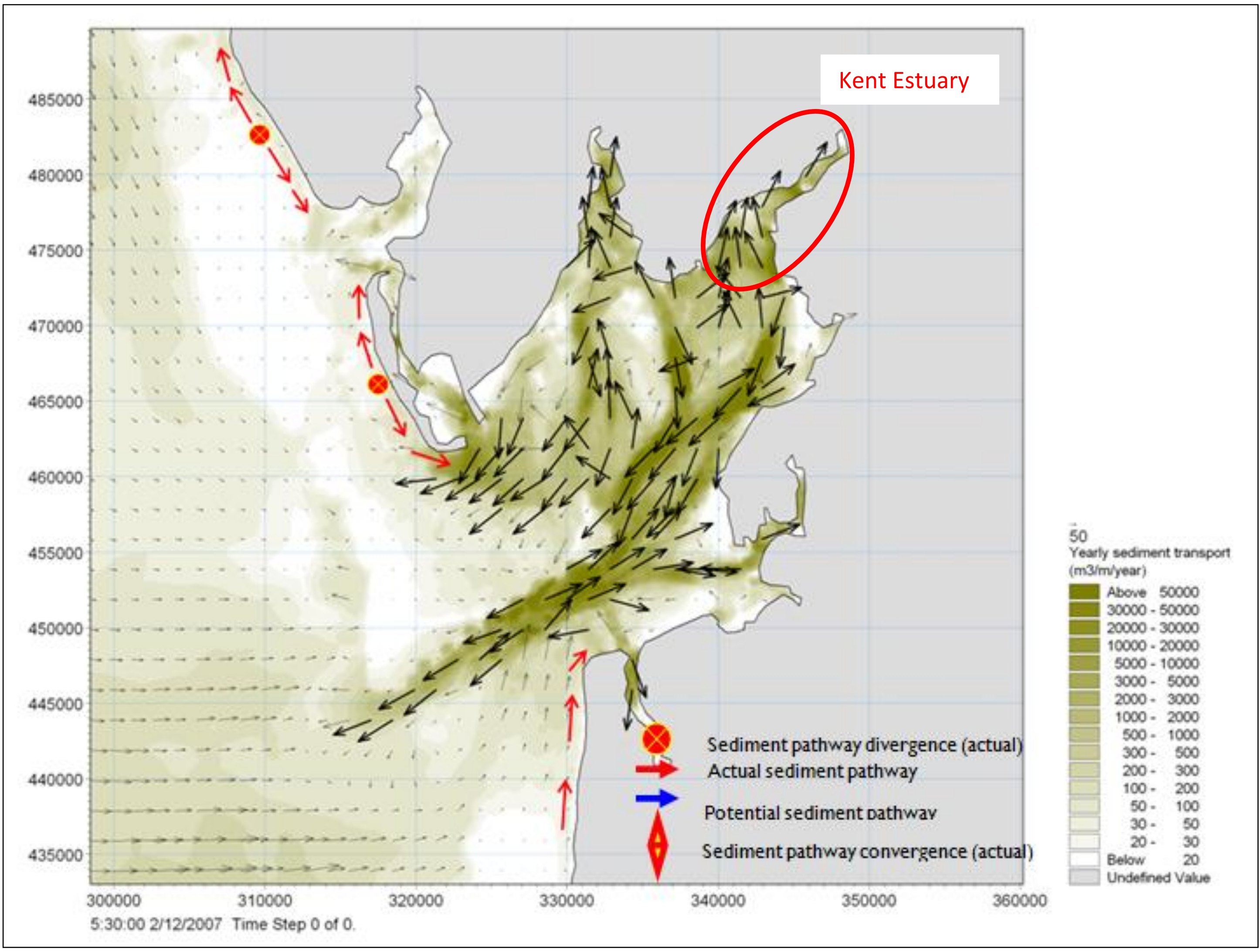


Figure 3.3 Map showing sediment transport in the vicinity of Lune Estuary (from Halcrow, 2010d).

The Rivers Winster, Bela, Kent and Gilpin drain into the Kent Estuary and freshwater flows from the Bela, and to a lesser extent the Gilpin, contribute to lateral movement of the main channel within the estuary. The influence of the Gilpin is less significant as the river is more constrained at this location (Halcrow, 2010b).

Downstream of Foulshawthe main low water channel is highly mobile and it moves position over very short periods of time, relocating from one side of the estuary to another. At times the main channel flows along the western side of the estuary, south of Foulshaw, following the shoreline closely along the Foulshaw Main Drain training embankment, but at other times it follows close to the shoreline at Sandside, before entering the outer estuary and Morecambe Bay via the Kent Viaduct.

The estuary is sand dominated, although sandy mud and muddy sediments occur in the high intertidal zone around the estuary fringes, and near the estuary head. Samples collected from the outer estuary as part of the 209-10 CERMS survey campaign varied from slightly muddy sands to slightly sandy muds (Pye *et al.*, 2010; Figure 3.4)

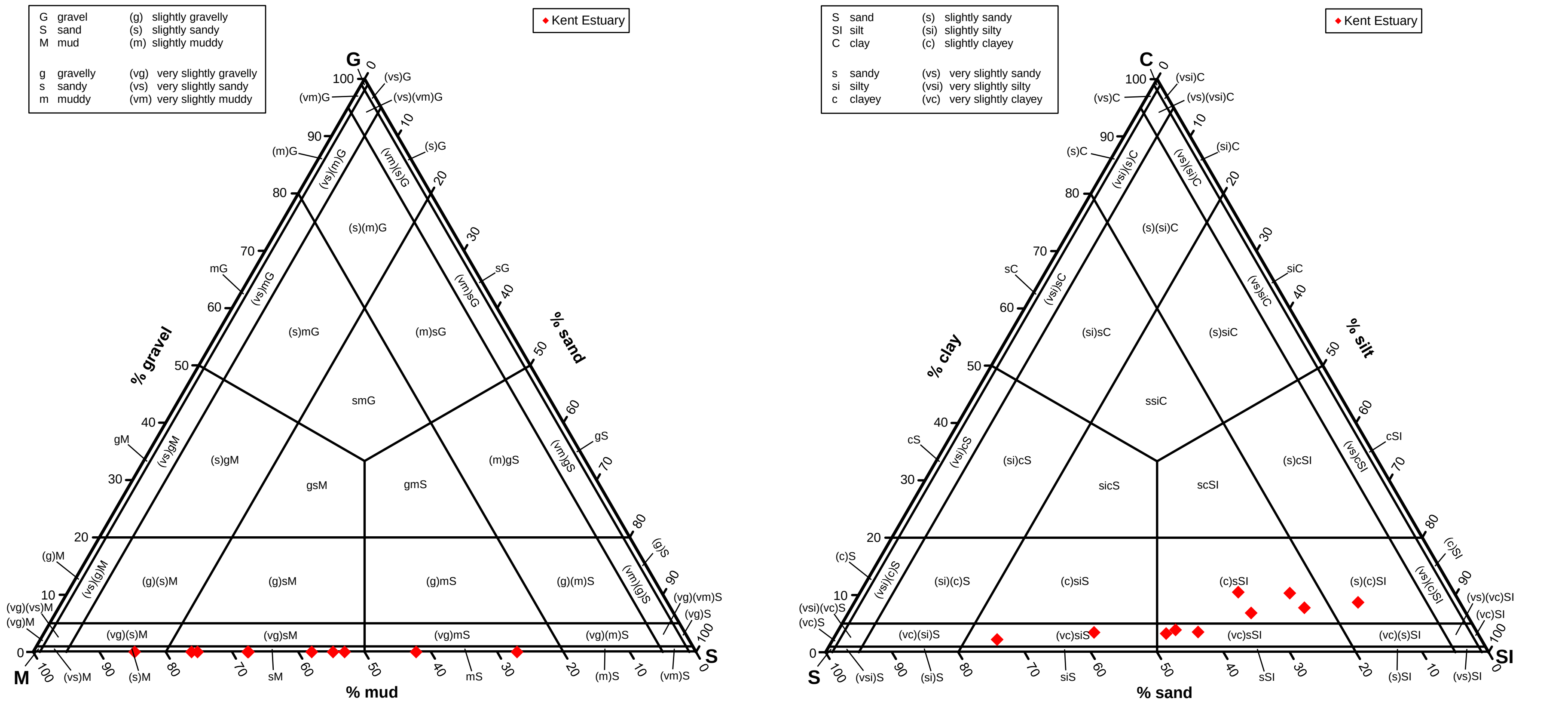


Figure 3.4 Gravel-Sand-Mud and Sand-Silt-Clay trigons, based on the classification of Blott & Pye (2012), for sediment samples collected within the Kent Estuary in 2009-10 (data from Pye et al., 2010).

3.3 Past Changes

The Kent Estuary lies within the larger estuarine environment of Morecambe Bay, which is a shallow open embayment created by the post-glacial submergence of a network of valleys over 10,000 years BP. Within the inner part of Morecambe Bay, a net north-easterly transport pattern has been documented with a net import of fine sand into the Bay. Morecambe Bay provides the main source of fine sediment to the Kent Estuary which acts as a sediment sink within the larger Morecambe Bay system (Halcrow, 2010b).

Originally, the estuary had a much larger plan-shape, confined by the steeply sloping sides of the valley. Key modifications within the estuary include:

- Construction of the Arnside Kent Railway Viaduct (1857);
- Reclamation of Meathop Marsh (1930s);
- Training of the River Winster (1970s); and
- Construction of alternative channel throughways under the Kent Viaduct (1950s).

The area of the estuary basin has changed significantly both due to natural infilling and human intervention, which has been ongoing since at least the 18th century, with the channel now confined by saltmarshes and reclaimed land. The defences have effectively fixed the estuary shoreline along the majority of its shoreline. The Kent Viaduct effectively fixes the mouth of the estuary and significantly constrains the channel with its extensive 'lead-in' embankments and deepened spans to locate channels on either side of the estuary (Halcrow, 2010b).

During the 18th century piecemeal attempts were made to drain and reclaim the more northerly banks of the study area for use as agricultural land. During and after the construction of the railway in the 1850s, reclamation of land was more intensive (Gray & Adam, 1974; Dixon-Gough, 2006). Construction of railway embankments at the estuary mouth meant that the low water channel became anchored in this location and the railway viaduct caused tidal flows in the estuary to be directed along the Arnside frontage. The associated reclamation of the Mosses and the area around the railway also reduced the cross-sectional area of the estuary and slowed the ebb tide. Subsequently this led to increased deposition in the estuary leading to the formation of greater areas of saltmarsh (Halcrow, 2010b).

Between the late 1800s and 1940/50 the main channel was located on the eastern side of the estuary. In the Arnside area the channel moved to the west side of the estuary after 1940/50, but then moved back to the east side after the mid 1960s (Comber *et al*., 1993b; Shoreline Management Partnership, 1999b). Such changes have altered the exposure conditions along the estuary shorelines (and along the adjacent stretches of coast) and therefore initiated changes in the foreshore, with development and subsequent erosion of saltmarshes. Similar oscillations of the Kent low water channel have occurred in the outer estuary and have a greater influence on fluctuating conditions of the shore at Grange Over-Sands and Silverdale (Pringle, 1995; Dixon-Gough, 2006; Halcrow, 2010b). On the western bank the saltmarshes associated with Grange-Over-Sands grew significantly from the 1970s (Dixon-Gough, 2006): the sheltering nature of both the Holme Island embankment and the River Winster training walls, together with the configuration of the Kent Channel on the eastern side of the estuary, has resulted in greater accretion in these areas. Conversely, the saltmarshes on the eastern side of the outer estuary, along the Arnside frontage narrowed from about 1,000m in 1975 to about 150m in 1992 (Halcrow 2002).

A comparison of EA LiDAR data surveys in the Kent Estuary using a mosaic of data from 2000 to 2004 and another from 2009/10 is reported in (Halcrow and KPAL, 2011). Although there were significant changes in the low water channel location between the two surveys changes in intertidal areas were small, indicating redistribution of sediment rather than major losses and gains.

Today the Kent Estuary appears to be in a state of dynamic equilibrium in terms of the extent of mudflat and saltmarsh area, although there are rapid changes in the local extent and position of saltmarsh and tidal flat in response to changes in low water channel position (Halcrow, 2010b).

3.4 Future Behaviour

Erosion of small outcrops of soft cliffs, saltmarshes and tidal flats around the margins of Morecambe Bay is likely to continue to provide some sediment input to the estuarine sediment system, as is fluvial transport from the River Kent. However, the main source of sediment supply is likely to continue to be from Morecambe Bay and the wider Irish Sea. There is a large store of mobile sand on the floor of Morecambe Bay, and the banks and channels experience significant movement on decadal to centennial timescales (Kestner, 1970). The tidal waters of Morecambe Bay have a relatively high load of suspended fine sand and silt, especially during storm tides and periods of high wave action. The sediment balance of the estuary is therefore unlikely to be constrained by limited sediment supply (Halcrow, 2010cd). The low water channel is expected to continue to meander where not restricted by defences or surrounding topography, which has the potential to cause the erosion of saltmarshes and undermining of defence structures, however, these marshes would be expected to re-establish over time due to redistribution of any eroded sediment within the estuary (Halcrow, 2010d; Halcrow and KPAL, 2011).

3.5 Conceptual Model of Estuary Behaviour

A conceptual model for the Cell 11c area, showing regional sediment transport pathways, control features and sediment sources and stores is provided in Figure 3.5. A more detailed diagram has been developed for the Kent Estuary in Figure 3.6.

The present Kent Estuary is a relic of a once much larger feature which has been reduced in size following embanking and reclamation. A number of rock outcrops and engineering structures now act as hard points which control the morphology of the estuary. Although natural movements of the low water channel are now more constrained, they continue to display a relatively high degree of mobility which results in spatial and temporal variations in saltmarsh and tidal flat erosion and accretion along the length of the estuary. Following major disturbances in the 19th century, the estuary now seems to have approached a new condition of dynamic equilibrium.

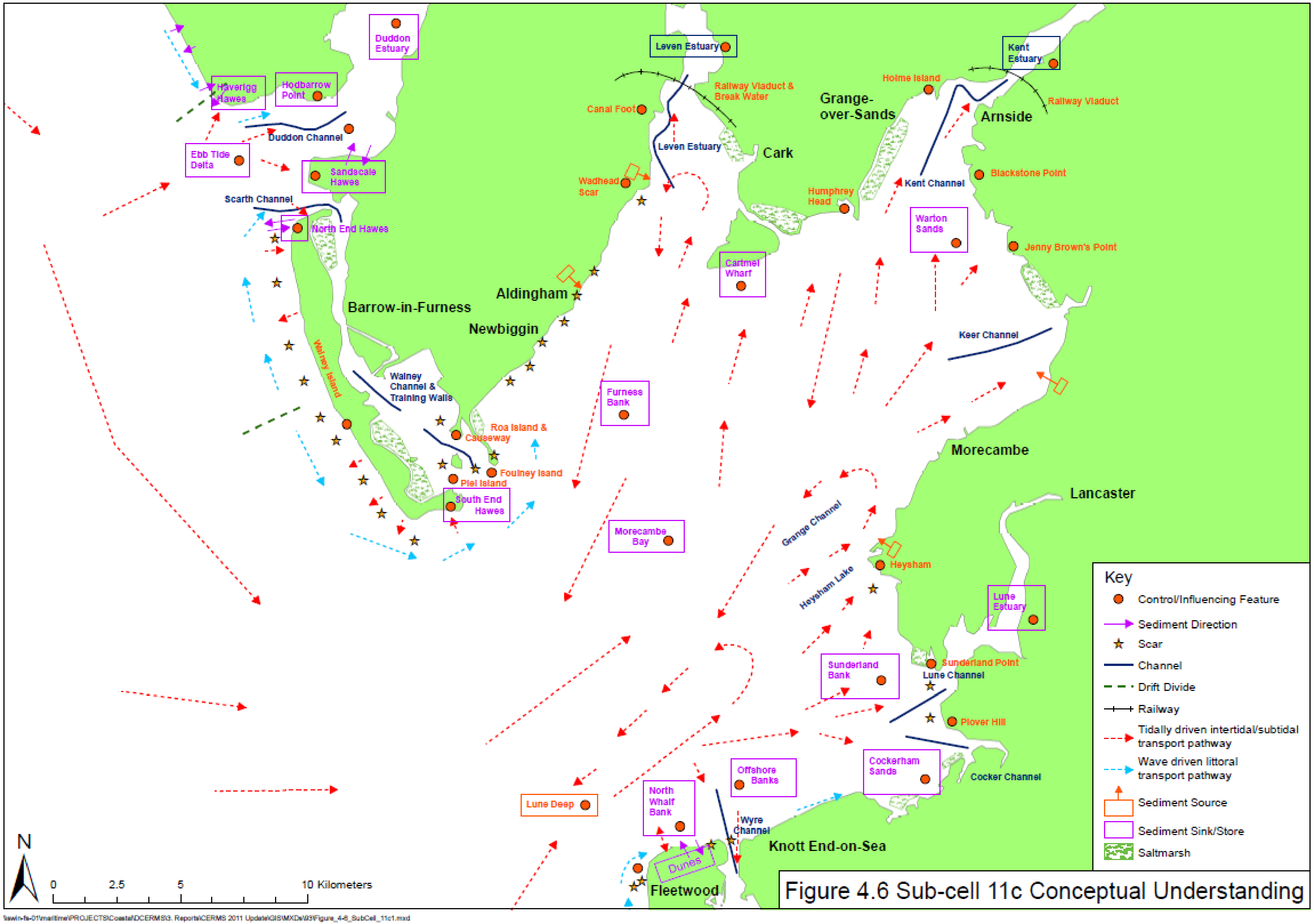


Figure 3.5 A simple conceptual model for Morecambe Bay and the Cell 11c area (source: Halcrow, 2010f

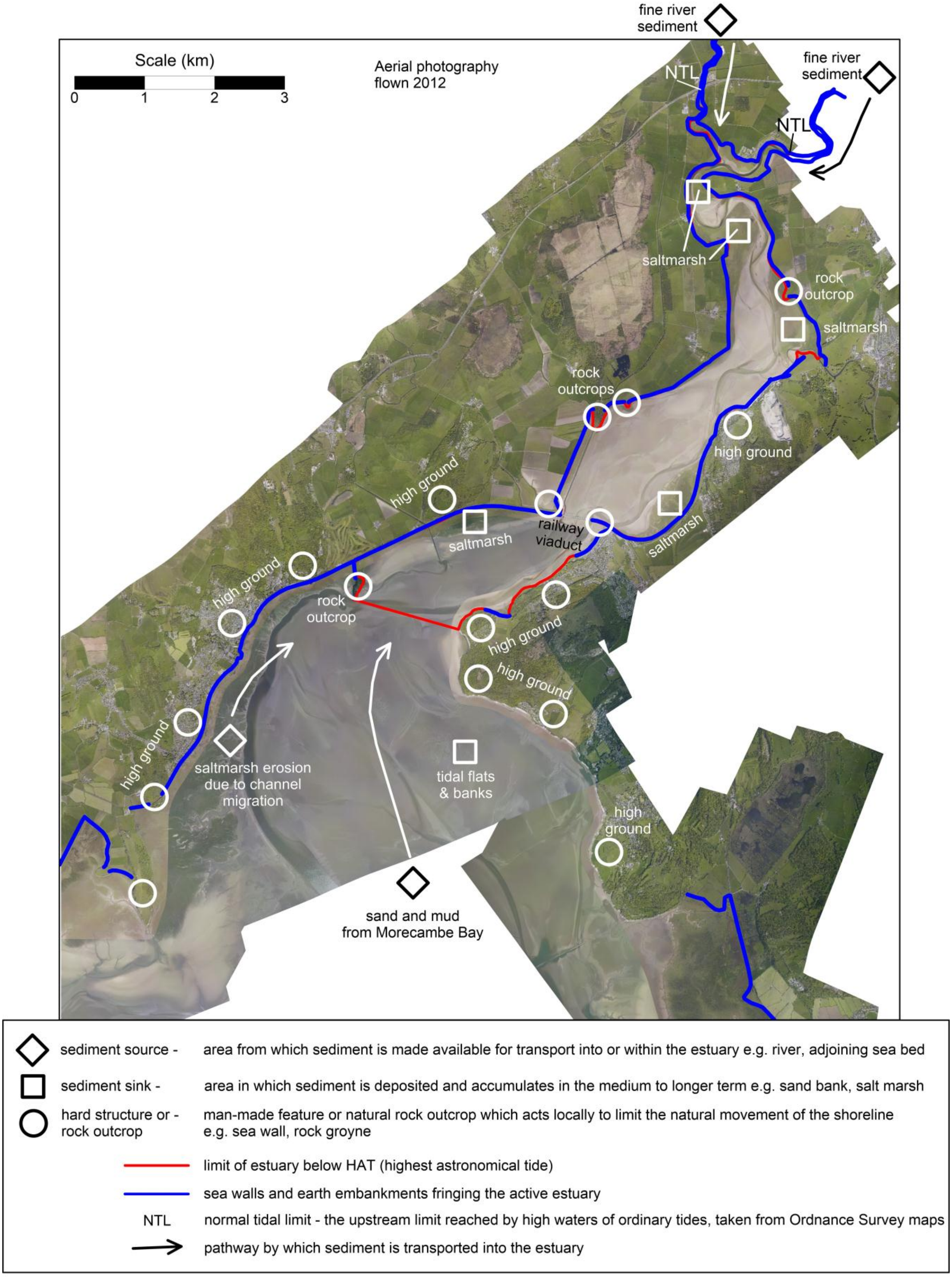


Figure 3.6. Conceptual diagram showing the main sediment sources, geomorphological features and engineering structures within the Kent Estuary.

3.6 Coastal Defences and SMP policies.

A list of the coastal defences in the Kent Estuary from the SMP2 is provided in Appendix A (Halcrow, 2010a).

Inland of the Kent viaduct (11c 9) there is considerable scope to set back to higher ground and return parts of the Kent Estuary to a more natural state and create additional habitat, and this is to be considered in planning the vision for the longer term. The SMP2 sets a policy of MR in the medium and long term for most of the defences inland of the viaduct. However, any realignment needs to be considered in combination with impacts upon flows into and out of the estuary and with possible consequences elsewhere, as well as economic losses resulting from reduction in the area of agricultural land. Managed flood risk under a policy of managed realignment meets social objectives whilst also achieving a greater number of the natural environmental objectives, but in doing so, areas of agricultural land will be more regularly inundated and reduced in quality (Halcrow, 2010a).

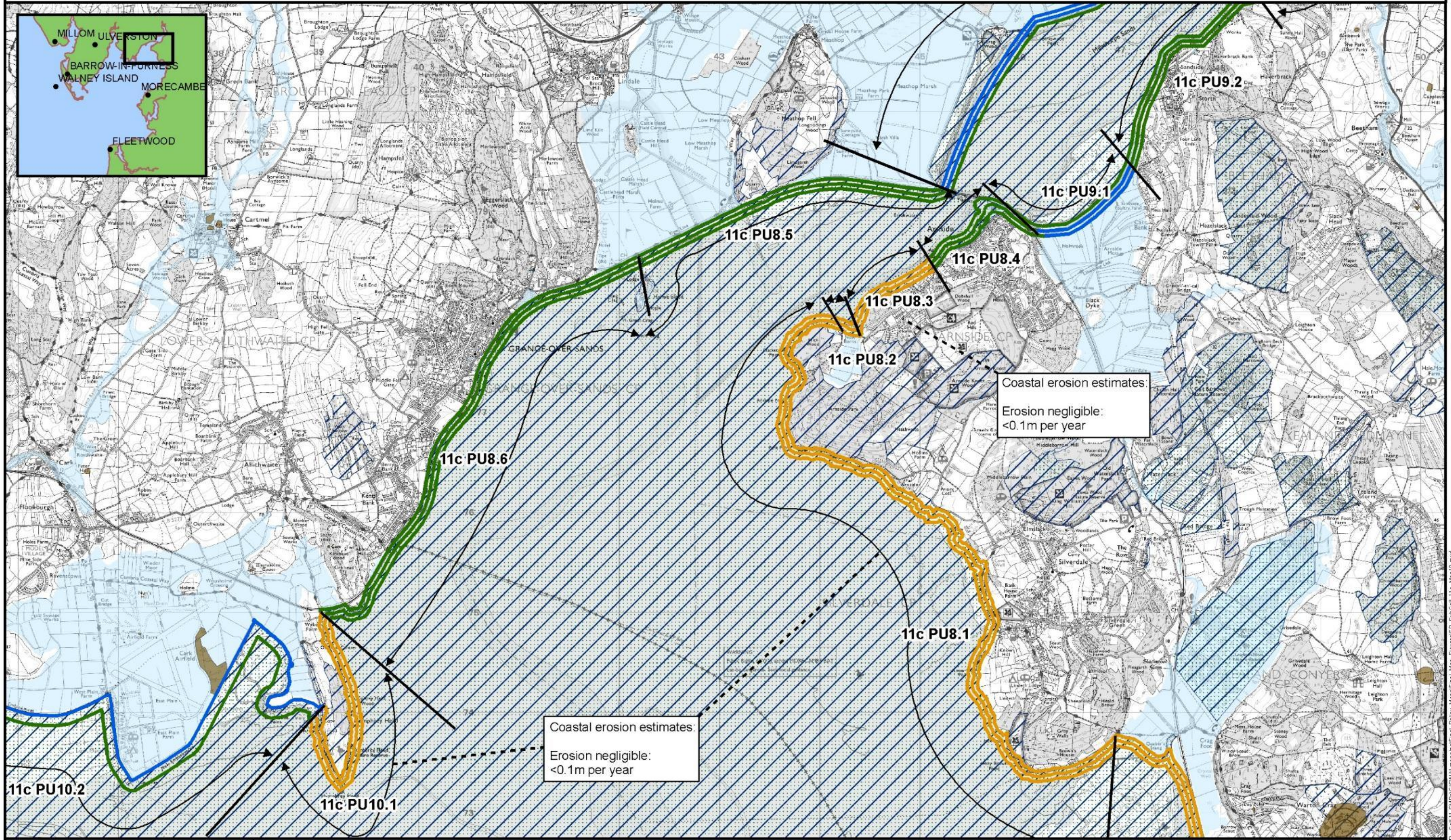
The long term plan in the outer estuary, seaward of the viaduct (11c 8), is to continue to manage flood and erosion risks to property and infrastructure, although some local opportunities for habitat creation to mitigate future coastal squeeze exist through realignment or habitat creation through regulated tidal exchange east of Grange-over-Sands. The proposed policies manage risk to people, property and infrastructure in a sustainable manner whilst maintaining the natural character of the section. In the long term opportunities for additional habitat creation exist, if required, for compensatory habitat creation for areas experiencing coastal squeeze elsewhere in the Shoreline Management Plan region (Halcrow, 2010a).

The adopted SMP2 policies are shown on the maps in Figure 3.7.

North West England and North Wales Shoreline Management Plan 2

Sub-Cell 11c: Area: 8 Map: 2

North West & North Wales Coastline
a partnership for coastal defence management



N

0 0.25 0.5 1 Kilometres

Scale: 1:35,000

Legend

- National Nature Conservation Designations
- International Nature Conservation Designations
- Scheduled Monuments
- Coastal flood risk area under extreme events, Environment Agency Flood Map, 2008
- Policy Unit Boundary
- Policy Unit Extent

Shoreline Management Policies

- Hold the Line (HTL)
- Managed Realignment (MR)
- No Active Intervention (NAI)

0 - 20 years
20 - 50 years
50 - 100 years
From 2010

Note that the policy lines on the map show the preferred shoreline management policy for each period and do not represent either the shoreline or defence location

Halcrow

Boxes showing cumulative erosion estimates represent the expected minimum and maximum erosion distance from the shoreline position in 2010. They are only shown where there is a NAI policy and coastal erosion is the main risk

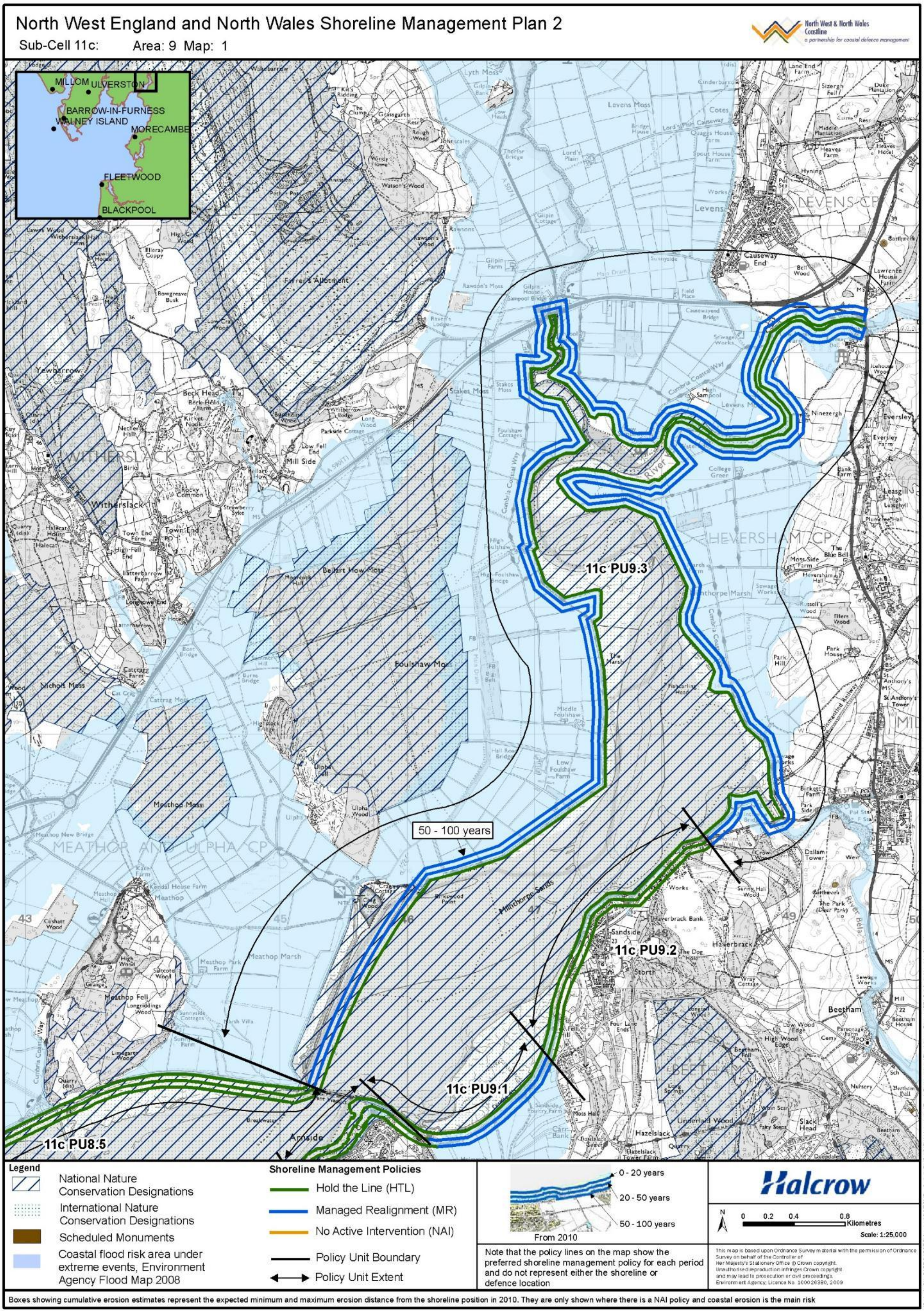


Figure 3.7 SMP2 Policy maps for the Kent Estuary (from Halcrow, 2010a).

3.7 Existing Monitoring Data

Details of the monitoring data being collected for the Kent Estuary and an assessment of the value that these data bring are summarised in Table 3.2. The map in Figure 3.8 shows the location of beach profiles and data collection stations with available data.

Table 3.2 Existing monitoring data collected and value assessment.

Description of monitoring data collected	Assessment of value of data collection	Source of information / reference to further information
Beach profile data. A small coverage of beach profiles on the north and south banks of the Kent Estuary in the vicinity of the mouth.	Beach monitoring ensures that coastal managers have an understanding of the changes occurring on the coastline and can take pro-active rather than re-active approaches to management.	CERMS Update Report, Section 2.4.3 (Halcrow, 2010e).
Tide gauge 1 (Leighton Beck (at Arnside), located at on the south bank of the estuary. Owned/maintained by the Environment Agency NW. Captures water level. Data available from August 2003 to present.	Useful for monitoring long-term trends in water level (particularly extreme water levels and any sea level rise) and use in hydrodynamic modelling and overtopping calculations, which can then be used for the purpose of flood forecasting.	CERMS Update Report, Section 2.4.3 (Halcrow, 2010e). CERMS Tide Gauge Review (Halcrow, 2010f).
Tide gauge 2 (Winster Sluice), located towards the head of the estuary. Owned/maintained by the Environment Agency NW. Captures water level. Analogue/hard-copy data available from 10/01/1958 to 02/09/2003. Digital data available from 02/09/2003 to 12/05/2009.	Useful for monitoring long-term trends in water level (particularly extreme water levels and any sea level rise) and use in hydrodynamic modelling.	CERMS Tide Gauge Review (Halcrow, 2010f).

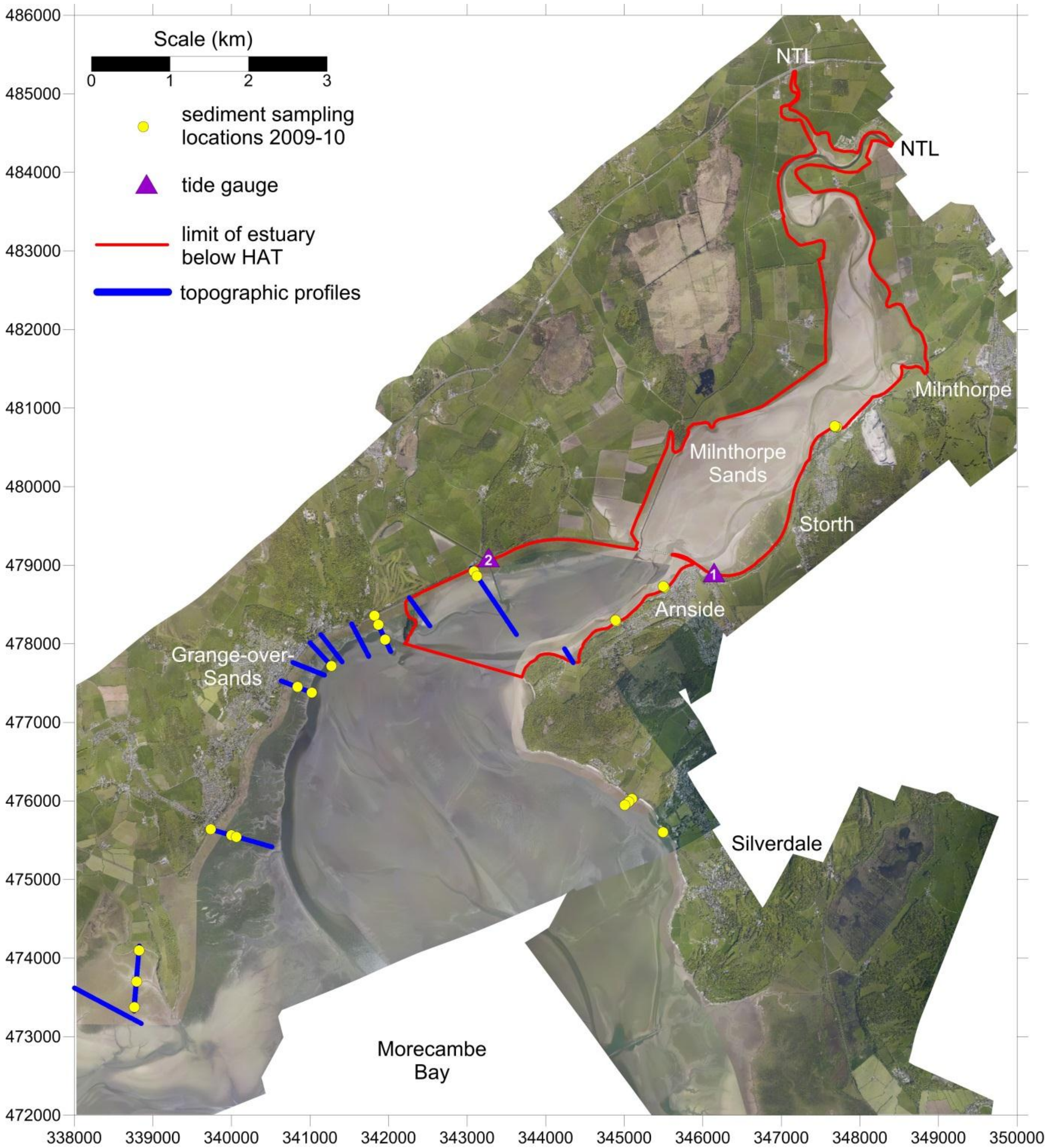


Figure 3.8 Summary of available data available for the Kent Estuary. Tide gauges located at: (1) Leighton Beck, Arnside; and (2) Winster Sluice (both operated by the EA).

3.8 Gaps in Understanding

A number of previous reports have identified gaps in understanding, including issues and uncertainties related to coastal and estuarine processes and shoreline management within Cell 11. Some of the uncertainties identified in the earlier studies (e.g. SMP1, Futurecoast) were subsequently addressed by the later studies (e.g. CETaSS, SMP2, CERMS; EA, 2011). The CERMS regional baseline understanding report (Halcrow, 2010e) provided a full listing of previous uncertainties in the Cell 11 area.

For the present report we have reviewed the list of uncertainties previously identified for the Kent Estuary and have identified the most important areas where future studies/monitoring are required (Table 3.3). We have organised these by thematic areas:

- Flood and coastal defences
- Habitat losses and creation
- Coastal and estuary morphodynamics
- Data collation

Further details for the recommended further studies and data collection are given in Appendix B.

Due to the strong linkages between coastal processes in the whole of Morecambe Bay and the Kent Estuary, the issues and recommendations listed below should be considered alongside the wider issues and generic recommendations for the other Cell 11 estuaries. This is considered within the main overview report (CH2M Hill, 2013). Likewise, the generic gaps and recommendations considered in the overview report (CH2M Hill, 2013) should also be considered alongside those described below.

In the context of the other estuaries in Cell 11, the Kent is a small estuary with limited numbers of properties at risk. It has therefore been studied less than most of the others in Cell 11 and there is currently very little ongoing monitoring. There are no topographic monitoring profiles upstream of the railway viaduct and no sediment sampling has been undertaken to characterise the bed and bank sediments in this area. Due to the strong linkages in processes and continuity of habitats between the Kent Estuary and the wider Morecambe Bay, plans for studies and monitoring in the Kent should be developed in conjunction with the Leven and Morecambe Bay in general.

Table 3.3 Data gaps and recommendations

Issue	Location	Comments	Recommendations
Flood and coastal defences Defence condition, ownership condition and maintenance data require review.	Whole estuary	The defence data in Appendix A is taken from the SMP2; some is based on interpretation from aerial photography, some from NFCDD and / or previous studies of the estuary and is over 10 years old.	1. Update defence database to have a consistent data set prior to the next SMP review. Also needed to inform consultations with stakeholders regarding potential for managed realignment and or withdrawal from maintenance and adaptation in the upper estuary. Continue to monitor and manage defences on HTL frontages. (See item 1 in Appendix B). **Urgency – medium** **Importance – medium** **Difficulty – low** **Overall Priority - medium**
Flood and coastal defences Management of defences and delivery of SMP2 policies.	Whole estuary	The SMP2 action plan recommends several studies to investigate the viability of options for future managed realignment in the inner estuary and to develop a long term strategy. There could potentially be significant impacts from changes to the defences on the overall estuary morphology, on flows and scour at the viaduct and low water channel movements in the outer estuary, for example at Grange and Arnside. There are also potential wider impacts for FCERM in the rest of Morecambe Bay, for example at Hest Bank and Morecambe where channel migration can have major consequences for the coastal defences and there are large numbers of properties at risk of coastal flooding. Consideration of impacts requires an evidence base of good quality data to develop and test models and understand existing processes.	2. Collect baseline data and undertake studies to improve understanding of past changes and their causes. This is needed in advance of the viability studies and strategy development recommended in the SMP2 Action Plan. (See item 2 in Appendix B). **Urgency – medium** **Importance – medium** **Difficulty – high** **Overall Priority - medium**
Habitat losses and creation An improved estimate is needed of future losses and gains of habitats due to the impacts of sea level rise and coastal defences on designated sites.	Whole estuary (and wider Morecambe Bay as the sites are continuous)	The SMP2 policy development assumes that the estuaries and Bay will continue to accrete and that sediment supply is sufficient to keep pace with sea level rise over the short to medium term, but there are large uncertainties, particularly in the longer term. The SMP2 therefore allows for MR in medium or longer term, but recognises	3a. Sediment supply and sediment transport study including data collection and analysis and modelling for Morecambe Bay, including adjoining estuaries. (See item 3 in Appendix B). 3b. Develop a more detailed assessment of losses and gains of habitat for the Morecambe Bay SPA / SAC / Ramsar sites from the qualitative assessment that supported the SMP2

Issue	Location	Comments	Recommendations
		there would be significant risks to the wider bay related to large scale MR in the inner Kent. More detailed studies of sediment supply options for MR and an improved estimate of losses and gains of habitats are therefore required before the next SMP review. The LiDAR change analysis and coastal squeeze assessment for the Kent Estuary in Halcrow and KPAL (2011) estimates volumes of sediment required to allow the estuary to accrete and keep pace with SLR. However the analysis has uncertainties due to lack of synoptic topographic and bathymetric data, and poor information relating to sediment sources and fluxes.	HRA (SMP Appendix J) using the approach in Halcrow and KPA, 2011, and informed by the sediment study above. (See item 4 in Appendix B) **Urgency – medium** **Importance – high** **Difficulty – high** **Overall Priority – medium**
Coastal and estuary morphodynamics Reliable bathymetry data is not available for setting up detailed models	Inner and outer estuary	There are a small number of topographic monitoring profiles on the north shore to the east of Grange, and a single profile on the south shore. Previous LiDAR surveys have failed to cover the entire estuary in a single flight, and no bathymetric surveys of the low water channels have been undertaken.	4. Undertake a combined LiDAR and swath bathymetry survey (see item 5 in Appendix B). **Urgency – medium** **Importance – medium** **Difficulty – medium** **Overall Priority - medium**
Coastal and estuary morphodynamics Uncertainty over causes for channel migration / switching	Inner and outer estuary and wider bay	There is limited present understanding of the drivers for and risks related to channel migration and in particular the implications for management of the defences. For example the channel may in future return to the Grange side and erode the large area of saltmarsh, but this may or may not be related to changes to the defences, river flows and drainage outfalls.	5. Undertake a study to investigate and improve understanding of historical channel movements. (See item 2 in Appendix B). **Urgency – medium** **Importance – high** **Difficulty – medium** **Overall Priority - medium**
Data Collection **Sediment data**	Whole estuary	A small number of sediment samples was collected from the outer part of the estuary as part of the CERMS sampling programme in 2009-10, but the major part of the estuary remains un-sampled	6. In combination with a wider scale sampling programme across other estuaries further sediment samples should be collected and analysed. (See item 3 in Appendix B). **Urgency – medium** **Importance – medium** **Difficulty – low** **Overall Priority - medium**

Issue	Location	Comments	Recommendations
Data Collection **Tide and current data**	Mid-estuary	The data from the two tide gauges could be useful for calibrating and verifying hydrodynamic models for use in managed realignment and sediment transport studies. Such studies would need to consider wider scale impacts across Morecambe Bay and with hydrodynamic modelling studies would need to cover the whole bay, not just the Kent Estuary. A key potential impact of realignment in the inner estuary would be changes to current speeds and potential for scour / deepening of the channel in the constriction at the railway viaduct. Some current data for present day conditions should be collected in order to allow calibration of models in future.	7. As part of a wider hydrodynamic data gathering campaign or study the available data from the two EA gauges in the Kent should be obtained and quality reviewed for use in modelling. Current speed data should be gathered over selected tidal events, e.g. a spring - neap tidal cycle in the region of the viaduct. Tidal level data and river flow data would need to be collected over the same period, either using existing EA gauges, or additional instruments if the data from EA gauges is not adequate. (See item 6 in Appendix B). **Urgency – medium** **Importance – high** **Difficulty – medium** **Overall Priority - medium**

4 Discussion and Conclusions

Within the context of flood and coastal erosion risk management across the Cell 11, the Kent Estuary has relatively low risks in relation to assets on the flood plain of the estuary itself. Due to this the Kent Estuary has in the past been given low priority for additional monitoring and further studies. However, movements of the low water channel from the Kent across the north-eastern part of Morecambe Bay is highly important to the management of tidal flood and erosion risks at Morecambe, where large parts of the town and over 6,000 properties are at tidal flood risk.

The SMP2 policy proposes managed realignment to large lengths of defence in the Kent, but recognises that implementation will require detailed assessment of the risks to infrastructure such as the railway embankments and viaducts and risks to wider scale channel movements in Morecambe Bay, such as at Morecambe. The effects of large scale realignment on the regional sediment demand and supply balance have not been considered in detail.

A number of additional studies are recommended to address the gaps in understanding identified. Details of the issue/ uncertainty, recommendations for further study and an assessment of the study priority are presented in Table 3.3, with further details on scope given in Appendix B. Due to the strong coastal process linkages between the Kent Estuary and the rest of Morecambe Bay it is recommended that further studies in the Kent are progressed jointly with other Morecambe Bay monitoring, especially for the Leven.

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Appendix A
Coastal Defences in the Kent Estuary

Appendix A Coastal Defences in the Kent Estuary

This data has been sourced from the SMP2, Policy Areas 11c8 (part) and 11c9 (Halcrow, 2010b)

Location	Defence History	Present Defences	Residual Life – (Do Nothing Scenario) Years	Natural Features	Source and Assumptions
End of EA embankment to Shore Road National Grid: (346966E 473797N) to (345786E 474864N)	N/A	Natural high ground	N/A	Saltmarsh and sand beach, rock outcrop	NFCDD
Shore Road (access to Shore Cottages) National Grid: (345786E 474864N) to (345751E 475022N)	N/A	Natural high ground	N/A	Saltmarsh; sand and shingle beach, rock outcrop	NFCDD
Shore Cottages to edge of Lancaster Boundary National Grid: (345751E 475022N) to (345453E 475696N)	N/A	Natural high ground	N/A	Sand and shingle beach, rock outcrop	NFCDD
Wall End to Park Point National Grid: (345453E 475696N) to (343740E 476658N)	N/A	Natural high ground	N/A	Sand and shingle beach, rock outcrop	NFCDD

Location	Defence History	Present Defences	Residual Life – (Do Nothing Scenario) Years	Natural Features	Source and Assumptions
Park Point to Blackstone Point National Grid: (343740E 476658N) to (343708E 477641)	N/A	Natural high ground	N/A	Sand and shingle beach, rock outcrop	NFCDD
Blackstone Point to New Barns National Grid: (343708E 477641) to (344222E 477821N)	N/A	Natural high ground	N/A	Sand and shingle beach, rock outcrop	NFCDD
New Barns to high ground at foot of wood National Grid: (344222E 477821N) to (344421E 477783N)	Unknown	Wall faced embankment with road on crest. Some sections missing wall and two flood gates which would leak.	1-5	Saltmarsh/ sand beach	NFCDD 2005
New Barns to North of Grubbins Wood National Grid: (344421E 477783N) to (344752E 478202N)	N/A	Natural high ground	N/A	Saltmarsh/ sand beach	NFCDD
North of Grubbins Wood to Beachwood National Grid: (344752E 478202N) to (344930E 478288N)	N/A	Natural high ground	N/A	Saltmarsh/ sand beach	NFCDD

Location	Defence History	Present Defences	Residual Life – (Do Nothing Scenario) Years	Natural Features	Source and Assumptions
Beachwood House to Coastguard Lookout National Grid: (344930E 478288N) to (345208E 478511N)	Constructed 1930	Wall and apron	>5	Saltmarsh/ sand beach	NFCDD. Defences interpreted from EA oblique coastal area photos Cell 11. Residual life based on SMP 1 and photos
Coastguard lookout to start of prom National Grid: (345208E 478511N) to (345385E 478639N)	Constructed 1930	Small vertical wall, backed by sloping masonry revetment and dry stone wall on crest.	>5	Some shingle and green beach	NFCDD. Defences interpreted from EA oblique coastal area photos Cell 11. Residual life based on SMP 1 and photos
Start of promenade to Silverdale Road National Grid: (345385E 478639N) to (345589E 478768N)	Constructed 1983	Vertical masonry wall	>5	Some shingle and green beach	NFCDD. Defences interpreted from EA oblique coastal area photos Cell 11. Residual life based on SMP 1 and photos
Silverdale Road to past Arnside Pier National Grid: (345589E 478768N) to (345651E 478840N)	Constructed 1983	Sloping concrete revetment	>5	Some shingle and green beach	NFCDD. Defences interpreted from EA oblique coastal area photos Cell 11. Residual life based on SMP 1 and photos
Past Pier to EA defence National Grid: (345651E 478840N) to (345712E 478931N)	Constructed 1983	Sloping concrete revetment	>5	Some saltmarsh, sand beach	NFCDD. Defences interpreted from EA oblique coastal area photos Cell 11. Residual life based on SMP 1 and photos

Location	Defence History	Present Defences	Residual Life – (Do Nothing Scenario) Years	Natural Features	Source and Assumptions
Arnside promenade to railway viaduct National Grid: (345712E 478931N) to (345893E 479013N)	Unknown	Masonry flood wall with stop logs and flood gate.	11-20	Saltmarsh	NFCDD
Arnside Embankment National Grid: (347293E 480239N) to (346115E 478896N)	Unknown	Embankment with some rock facing at Storth end.	11-20	Estuarine mudflats.	NFCDD 2005
Sandside National Grid: (348100E 481100N) to (347300E 480300N)	Unknown	Concrete/masonry seawall with rock revetment.	>5	Estuarine mudflats.	Kent Estuary SMP 2001.
Heversham Embankment (Minthorpe Bridge) National Grid: (348200E 482800N) to (348800E 481500N)	Unknown	Embankment	11-20	Estuarine mudflats.	Kent Estuary SMP 2001. Residual life from NFCDD 2007.
Heversham Embankment (Minthorpe Marsh) National Grid: (347400E 483800N) to (348200E 482800N)	Unknown	Embankment with rip-rap revetment.	11-20	Estuarine mudflats.	Kent Estuary SMP 2001. Residual life from NFCDD 2007.

Location	Defence History	Present Defences	Residual Life – (Do Nothing Scenario) Years	Natural Features	Source and Assumptions
Heversham Embankment (Halforth) National Grid: (349000E 484500N) to (347400E 483800N)	Unknown	Embankment	11-20	Estuarine mudflats.	Kent Estuary SMP 2001. Residual life from NFCDD 2007.
Sampool Embankment National Grid: (347200E 485300N) to (348700E 484900N)	Unknown	Embankment	11-20	Estuarine mudflats.	Kent Estuary SMP 2001. Residual life from NFCDD 2007.
Levens Bridge to Ninezergh National Grid: (349600E 485200N) to (349023E 484529N)	N/A	Natural defence	N/A	Estuarine mudflats.	Kent Estuary SMP 2001.
Levens Bridge to Floodgates at Levens Moss National Grid: (348700E 484900N) to (349598E 485242N)	N/A	Natural defence	N/A	Estuarine mudflats.	Kent Estuary SMP 2001.
River Gilpin West Bank National Grid: (347400E 484200N) to (347200E 485300N)	Unknown	Earth embankment with rip rap embankment in places.	11-20	Estuarine mudflats.	Kent Estuary SMP 2001. Residual life from NFCDD 2007.

Location	Defence History	Present Defences	Residual Life – (Do Nothing Scenario) Years	Natural Features	Source and Assumptions
Foulshaw Embankment (Birkswood Point to Low Sampool) National Grid: (346100E 480800N) to (347400E 484200N)	Unknown	Earth embankment with outer rock facing in places.	11-20	Estuarine mudflats.	Kent Estuary SMP 2001. Residual life from NFCDD 2007.
Foulshaw Embankment (Birkswood Point) National Grid: (346000E 480800N) to (346100E 480800N)	Unknown	Earth embankment with outer rock facing.	>20	Estuarine mudflats.	Kent Estuary SMP 2001. Residual life from NFCDD 2007.
Milnthorpe Embankment National Grid: (345100E 479200N) to (345600E 480700N)	Unknown	Earth embankment	11-20	Estuarine mudflats.	Kent Estuary SMP 2001. Residual life from NFCDD 2007.
River Kent railway viaduct (east) National Grid: (345893E 479013N) to (345604E 479151N)	Original construction 1850s. Upstream face refurbished 2007	Railway embankment with rock facing topped by vertical post and plank wall on upstream side and pitched block revetment and crest wall on downstream side.	>20	Saltmarsh (downstream side); Estuarine mudflat and river channel (upstream).	NFCDD. Defences interpreted from EA oblique coastal area photos Cell 11.
Kent Channel to South of Sunnyside Farm National Grid: (345140E 479220N) to (344295E 479322N)	Original construction 1850s.	Sloped masonry revetment topped by vertical wall. Rock breakwater.	>5	Saltmarsh, sand	NFCDD. Defences interpreted from EA oblique coastal area photos Cell 11. Residual life based on SMP 1 and photos.

Location	Defence History	Present Defences	Residual Life – (Do Nothing Scenario) Years	Natural Features	Source and Assumptions
South of Sunnyside Farm to Limegarth Wood National Grid: (344295E 479322N) to (343630E 479224N)	Original construction 1850s.	Sloped masonry revetment topped by vertical wall.	>5	Estuarine mudflat	NFCDD. Defences interpreted from EA oblique coastal area photos Cell 11. Defence to railway. NR Defence Survey 2002. RL estimated.
Limegarth Wood to River Winster National Grid: (343630E 479224N) to (343239E 479042N)	Unknown	Training walls for River Winster, otherwise natural defence.	N/A	Saltmarsh, sand, rock outcrop	NFCDD. Defences interpreted from EA oblique coastal area photos Cell 11.
River Winster to Lindale Road National Grid: (343239E 479042N) to (341625E 478271N)	Original construction 1850s.	Sloped masonry revetment topped by vertical wall. Wall protecting causeway to Holme Island.	>5	Saltmarsh and mudflat	NFCDD. Defences interpreted from EA oblique coastal area photos Cell 11. Defence to railway. NR Defence Survey 2002. RL estimated.
Lindale Road to swimming pool, Grange-over-Sands National Grid: (341625E 478271N) to (340579E 477170N)	Original construction 1850s.	Near Vertical wall with crest recurve and lower sloping block apron (partially covered by marsh).	>5	Saltmarsh	NFCDD. Defences interpreted from EA oblique coastal area photos Cell 11. Defence to railway. NR Defence Survey 2002. RL estimated.
Swimming pool to subway, Grange-over-Sands National Grid: (340579E 477170N) to (340391E 476959N)	Unknown	Vertical wall	>5	Saltmarsh	NFCDD. Defences interpreted from EA oblique coastal area photos Cell 11.

Location	Defence History	Present Defences	Residual Life – (Do Nothing Scenario) Years	Natural Features	Source and Assumptions
Subway to Guides Farm Slipway National Grid: (340391E 476959N) to (340124E 476506N)	Original construction 1850s.	Sloped masonry revetment topped by vertical wall.	>5	Saltmarsh	NFCDD. Defences interpreted from EA oblique coastal area photos Cell 11. Defence to railway. NR Defence Survey 2002. RL estimated
Guides Farm Slipway to Kentsford Road National Grid: (340124E 476506N) to (339974E 475949N)	Original construction 1850s. Wall repaired.	Pitched stone embankment topped by vertical masonry wall built over and round natural outcrops.	>5	Saltmarsh	NFCDD. Defences interpreted from EA oblique coastal area photos Cell 11.
Kentsford Road to Kirkhead End National Grid: (339974E 475949N) to (339450E 475200N)	Original construction 1850s.	Pitched stone embankment topped by vertical masonry wall built over and round natural outcrops.	>5	Saltmarsh	NFCDD. Defences interpreted from EA oblique coastal area photos Cell 11.
Kirkhead End National Grid: (339450E 475200N) to (339275E 475040N)	N/A	Natural shoreline	N/A	Rock outcrop, saltmarsh	NFCDD. Defences interpreted from EA oblique coastal area photos Cell 11.
Wyke Farm to EA defences National Grid: (339012E 475021N) to (339020E 474042N)	N/A	Natural high ground	N/A	Saltmarsh	NFCDD. Defences interpreted from EA oblique coastal area photos Cell 11.

Location	Defence History	Present Defences	Residual Life – (Do Nothing Scenario) Years	Natural Features	Source and Assumptions
Humphrey Head Embankment National Grid: (339020E 474042N) to (338708E 474113N)	Unknown	Earth embankment with rock armour pitching on face.	11-20	Saltmarsh, sand	NFCDD.

Appendix B
Recommendations for further studies

Appendix B Recommended further studies for the Kent Estuary

Recommended study (See Table 3.3)	Outline scope	Outline cost estimate and priority
1. Update of flood and coastal defence database.	Study assumed to be led by EA, Lancaster CC or Sefton. Review data in Appendix A against latest held by EA on their Asset Information Management System (AIMS) or the LLFA in their FWMA S21 register to check for any updates to information available through the SMP2. Compile latest data including mapping and undertake initial quality review using latest aerial photography from coastal group. Undertake walkover inspections / selected visits including photographs of each defence length and significant defects. Update database and make available on SANDS and AIMS.	Estimated cost £10 to £15k, if packaged with other similar work for other defences in nearby estuaries on Morecambe bay coast. Priority – medium - needed to feed into MR viability studies and strategy.
2. Develop improved understanding of historical changes to the low water channel of the Kent Estuary.	Study to be led by Sefton or Lancaster CC or EA. Review data and previous reports on channel migration held by LCC. Review previous studies and research, e.g. Lancaster University. Develop an updated database with additional info from historical maps and photography. Obtain historical river flow data for Kent and Leven from EA / CEH. Transform JPS 18 year wave and water level time series data to selected points in the outer Kent channel using model developed by Halcrow for Cockersands study or similar. Analyse storm wind / wave / surge data from JPS together with river discharge data and investigate correlation with channel movements Develop database of historical changes to defences, land drainage outfalls, channel training works etc from analysis of historical maps, aerial imagery and EA records. Prepare a report on findings with updated conceptual model and accompanying database.	Estimated cost £30k to £50k? Priority – high – needed to better understand implications of potential MR in Kent Estuary on coastal defence in wider Morecambe Bay.
3. Improve understanding of sediment pathways and linkages.	Study to be led by Sefton or Lancaster CC or EA. Plan and implement a sediment sampling campaign, for the Kent and wider Morecambe Bay. Undertake sample analysis including particle sizing, minearalogy and chemical fingerprinting. Using updated bathymetry and LiDAR data update existing hydrodynamic and sediment transport model of Morecambe Bay developed by Halcrow and Lancaster University for the Fylde coast study to have a finer resolution	Estimated cost – Additional sediment sample collection £10 - 15K, analysis of new and previously collected samples and analysis £20 - £25k Priority – high: essential to understand present and likely future sediment pathways to and within Morecambe Bay, and between the Bay and surrounding estuaries

Recommended study (See Table 3.3)	Outline scope	Outline cost estimate and priority
	in the Kent Estuary and include the flood plain to allow for future MR studies. Calibrate model using water level data from EA tide gauges and current data collected under 5 below. Undertake baseline modelling of cohesive and non-cohesive sediment movements for selected typical tide cases (e.g. mean spring and neap tide and a selected storm surge such as the 2007 surge modelled in CETaSS).	Estimated cost of model update, calibration and baseline runs £30k - £50k, assuming undertaken in combination with the other similar studies in the other estuaries of Morecambe Bay Priority – High. Needed before MR viability studies.
4. Improved assessment of future habitat gains and losses in the Kent Estuary.	Study to be led by Sefton or Lancaster CC or EA. This study should be undertaken in combination with similar study for the other Morecambe bay estuaries as HRA would need to cover whole site – see overview report and Leven Estuary report.	See overview report Priority: medium Estimated cost ~£15k if packaged together with the other Morecambe Bay estuaries.
5. LiDAR and bathymetric survey for the Kent Estuary	Study to be led by Sefton or EA. High level LiDAR survey of whole estuary and surrounding area of Morecambe Bay on spring tide low water. Low water swath bathymetry survey of LW channel to overlap with LiDAR data.	Estimated cost: ~£50k to £75k; depends if packaged with others. Priority – High. Needed before study 3 above.
6. Tide and current data collection and review	Study to be led by Sefton, LCC or EA. Obtain available tide data from EA gauges in Kent Estuary and wider Morecambe Bay (Heysham, Glasson, Fleetwood). Undertaken quality review of data and site comparison for selected surge tides, preparing dataset for model calibration (see item 3 above). Collect tidal current data from selected location(s) such as at / near the Kent viaduct for a spring neap cycle, preferably concurrent with the LiDAR and bathymetry survey (see item 5).	Priority – High. Needed before study 3 above. Estimated cost £5k to £10k – could be undertaken as part of model development in item 3. Estimated cost: £10 to £15k (to be undertaken in combination with bathy survey).