North West Estuaries Processes Reports

Leven Estuary

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North West Estuaries Processes Report
Leven Estuary
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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.
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 50^{th} 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.

Term	Definition
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.
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).

Term	Definition
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.
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.

Term	Definition
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.
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.

Term	Definition
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.
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 Leven Estuary is a small macro-tidal estuary located on the north side of Morecambe Bay. It lies within SMP2 Subcell 11c which extends from Rossall Point, Fleetwood to Hodbarrow Point on the west side of the Duddon Estuary. The estuary receives freshwater flow from the River Leven and the River Crake, which are fed by Lake Windermere and Coniston Water, respectively. The catchment comprises the largely rural area south of Helvellyn. The entire estuary is designated as a SSSI, SAC, SPA and Ramsar site, forming part of the larger Morecambe Bay site.

The estuary mouth is defined by hard rock outcrops and the morphology of the mid and inner estuary is also strongly influenced by 'hard points' composed of bedrock and/ or glacial till. Scars, present along the western shoreline in the outer estuary, fix the shoreline position, provide local stability and protection to the frontage and control the proximity of the Leven channel to the shore. The margins of the estuary are flanked by raised terraces which consist mainly of former tidal flat and marsh deposits which became emergent as a result of a slight fall in sea level following a high-stand in the mid Holocene.

The estuary is macro-tidal with mean spring and neap tidal ranges of approximately 8.4m and 5.2 m, respectively. The estuary is flood dominant, with the flood tide being both shorter in duration and having higher velocities than the ebb tide. The freshwater input to the estuary is small compared to the tidal prism. Extreme high water levels are predominantly caused by tidal surges although flooding can also occur due to runoff becoming trapped behind sea defences during high tides. The northerly orientation of the estuary, combined with the obstructive effect of the railway viaduct and breakwater, reduces any wave penetration into the estuary.

Erosion of low glacial till cliffs in the outer estuary provides some sand and shingle to the littoral system, and there is some fluvial supply during floods, but the main source of sediment to the estuary is provided from Morecambe Bay. The estuary is sand-dominated although there are areas of sandy mud accumulation in the high intertidal zone around the fringes of the inner estuary and the upper intertidal zone closer to the mouth contains mixtures of gravel and sand, reflecting the higher energy environment.

Historically, the low water channels of the Leven have varied in their position, especially upstream of the viaduct, and this has had a major effect on patterns of saltmarsh accretion and erosion. There have been significant human interventions in the estuary, notably construction of the Leven railway viaduct and associated infrastructure in the mid 19th century and construction of a breakwater in 1860, south of the viaduct, to stabilise the main channel. The breakwater has acted to redirect the Leven channel westwards through the viaduct and consequently has encouraged saltmarsh development along the western side of the Cartmel Peninsula. At present, the viaduct acts to deflect the channel south-east downstream of the structure, before dividing into two channels.

Historical analyses indicate that saltmarsh has been present along the eastern outer estuary frontage since the late 1600s. Land reclamation has taken place at various locations along the Cartmel Peninsula, leading to reduced tidal prism and enhanced accretion within the estuary. Since the early 1900s there has been little change in the plan-form of the outer estuary, where defences exist, but both erosion and accretion of the backshore has occurred along the undefended sections. The estuary presently appears to be in a state of relative equilibrium.

Over the next 100 years there is likely to be relatively minor sediment supply to the estuary from erosion of soft cliffs and raised marine terraces in northern Morecambe Bay, but the main source of sediment is likely to continue to be Morecambe Bay and the wider Irish Sea. There is no evidence to suggest that the general landward movement of sea-bed sediment in Morecambe Bay will change, or that concentrations of suspended sediment will diminish. The future evolution of the estuary is therefore unlikely to be sediment supply-limited. The low water channel is expected to continue to meander, where not restricted by defences or surrounding topography, creating the potential to erode saltmarshes and undermine defence structures. However, development of new marshes is also expected due to redistribution of eroded sediment within the estuary.

The SMP2 estimated that there would be less than 300 residential and 100 non-residential properties, along with around 1,700ha 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 3rd lowest after the Ravenglass and Kent estuaries.

The long term vision in the SMP2 for the outer Leven is to manage risks to the railway and agricultural land where economically justifiable, but to generally to allow the shoreline to adjust from the present alignment and respond to coastal change by allowing the development of additional saltmarsh habitat. By maintaining defence to the major assets and population whilst also allowing sections of the frontage to behave naturally and erode, most of the SMP objectives will be met. However, there are locations where the potential erosion resulting from a naturally functioning shoreline could have negative impacts, such as the release of contaminants into the estuary, and in these locations the impacts will need careful monitoring to inform future defence policy. The long term vision of the SMP2 for the inner Leven is to continue to manage flood and erosion risks to property and infrastructure where economically justifiable. However, there are significant areas where shoreline defence is considered not viable, leading to opportunities to realign flood defences. This will result in reduction in quality or loss of agricultural land but will allow room for landward expansion of saltmarsh and tidal flats in response sea level rise in the longer term.

The outer estuary and adjoining Morecambe Bay frontages are relatively well covered by topographic and bathymetric survey lines, but there is no coverage in the inner estuary and sub-tidal areas generally are poorly covered. The physical character of the sediments in the upper intertidal zone of the outer estuary is relatively well known but there are major gaps in coverage of the inner estuary and sub-tidal zone which need to be addressed. Better quantification is needed regarding the contributions of sediment to the estuary from different sources, and how these might change with climate change and sea level rise.

1 Introduction

This report summarises the existing understanding of the Leven 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.

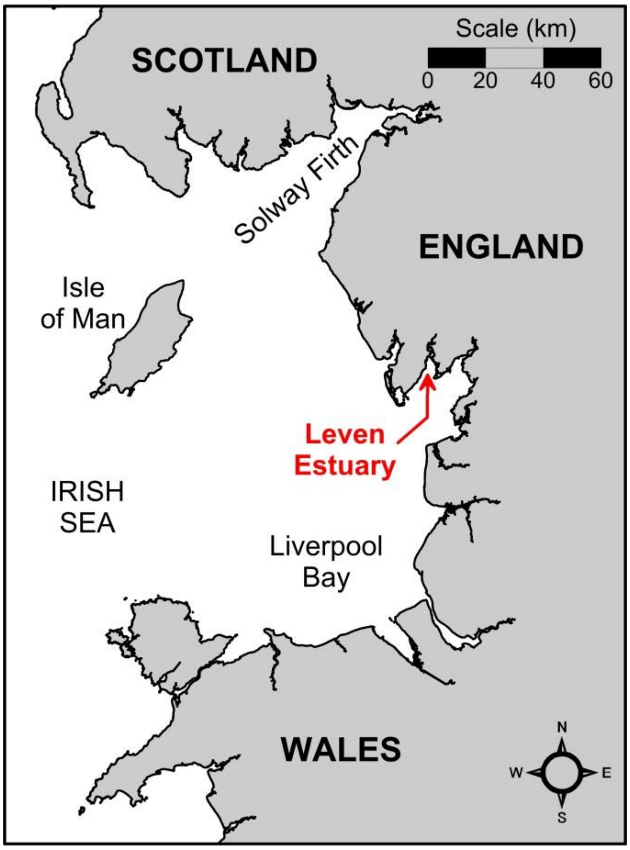


Figure 1.1 Location of the Leven Estuary.

2 Coastal Setting

The Leven Estuary is a small macro-tidal estuary located on the north side of Morecambe Bay. It lies within Sub-cell 11c of the second generation Shoreline Management Plan (SMP2) which extends from Rossall Point, Fleetwood to Hodbarrow Point on the west side of the Duddon Estuary, see Figure 2.1.

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

The Leven Estuary receives freshwater flow from the River Leven and the River Crake, which drain into the estuary from Lake Windermere and Coniston Water respectively. Smaller flows are also received through Russland Pool, draining the area between Coniston and Windermere. The catchment is the largely rural area south of Helvellyn (Figure 2.2).

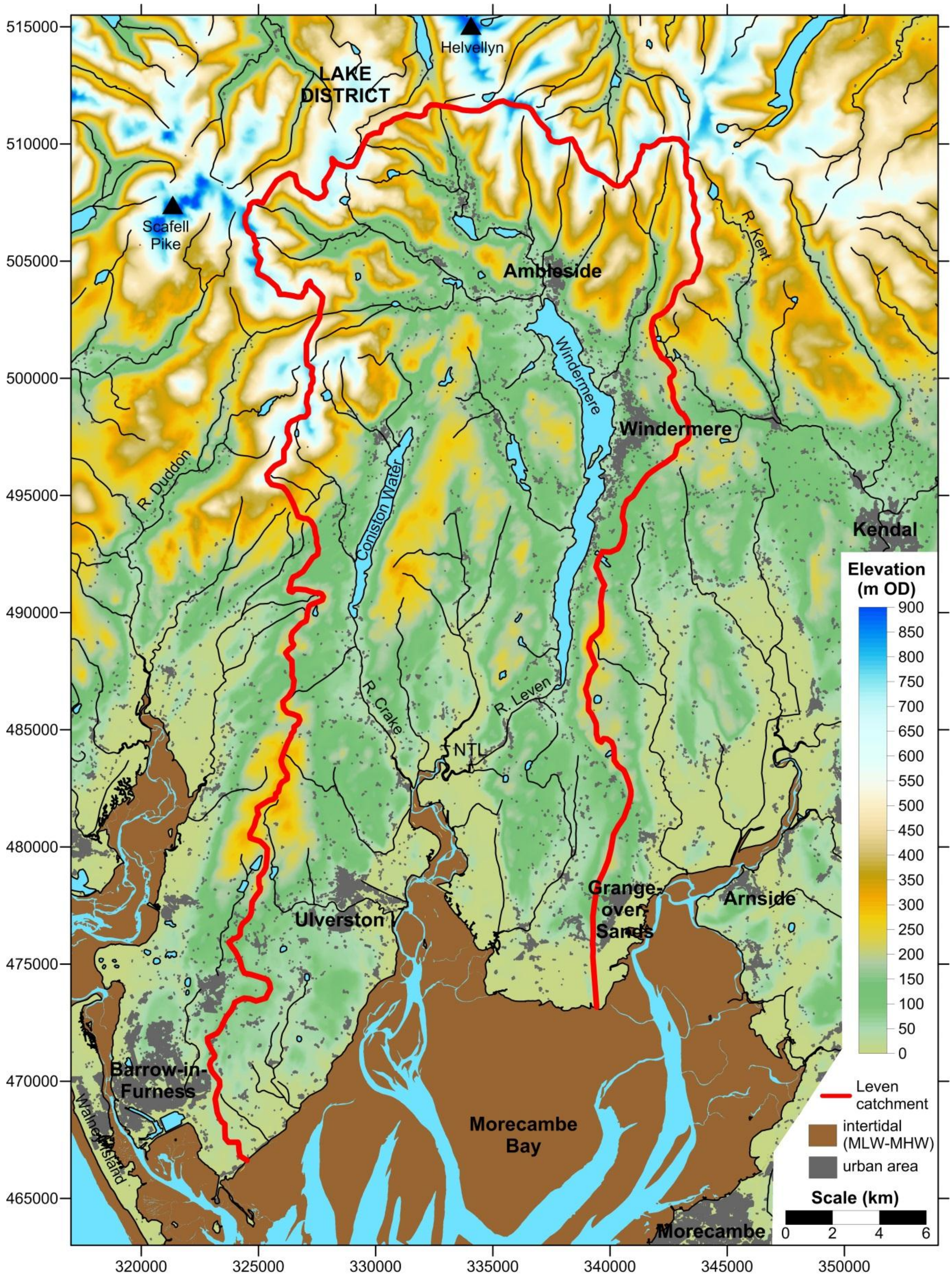


Figure 2.2 The Leven Estuary catchment, showing the main urban areas and general extent of the intertidal zone. Source: adapted from Ordnance Survey Open Data, after Pye and Blott (2013).

3 Estuary Review

3.1 Description

The Leven Estuary is a relatively wide-mouthed but short estuary on the northern side of Morecambe Bay. The estuary meanders through low hills and low-lying land, from the mouth between Wadhead Scar and the Cartmel Peninsula, to the normal tidal limit at Haverthwaite (Halcrow, 2010e). The funnel shaped estuary is sinuous, decreasing in width as the estuary extends inland (Figure 3.1).

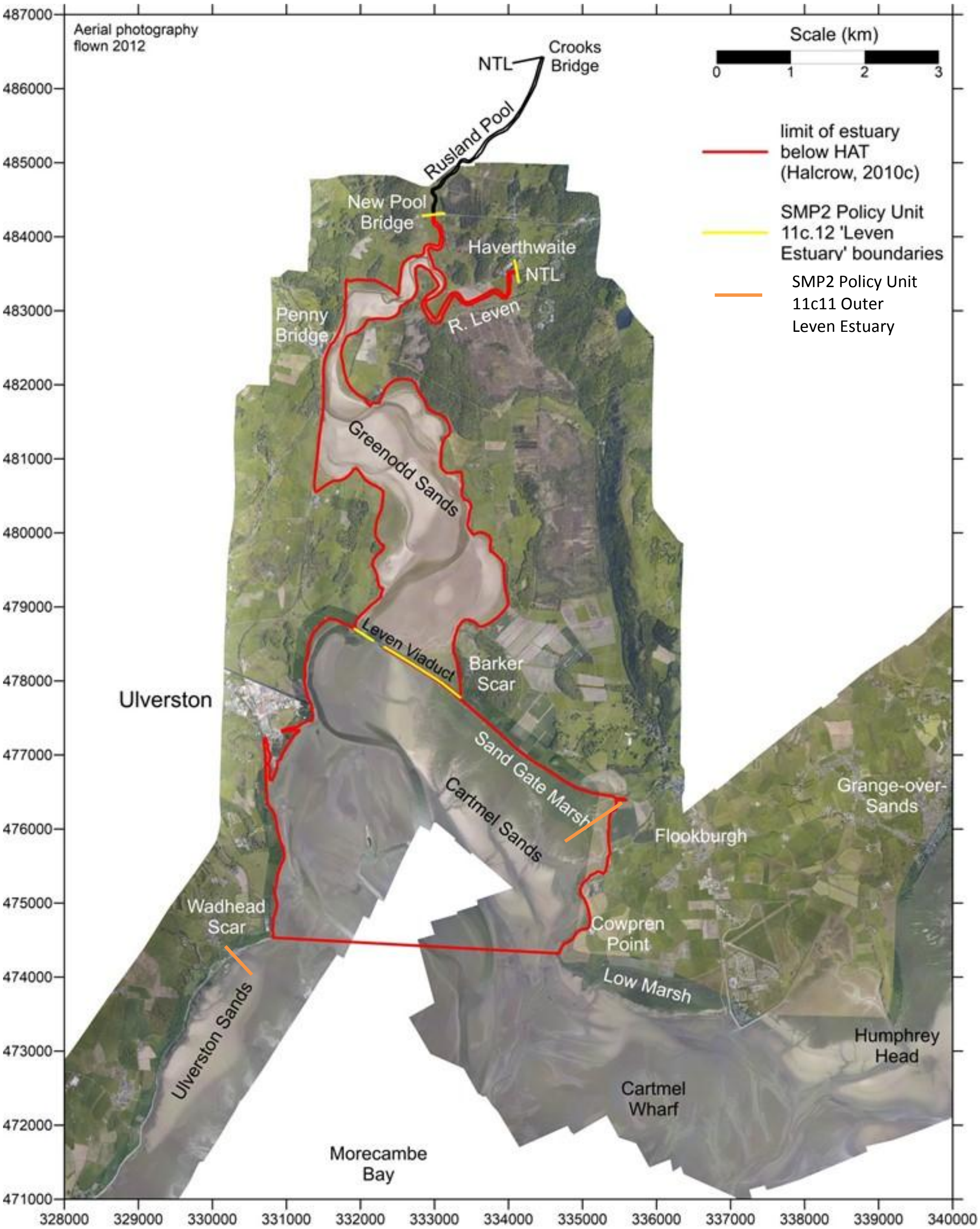


Figure 3.1 Limits of the Leven Estuary and SMP2 Policy Unit 11c.11 and 11c.12.

The estuary mouth is defined by hard rock outcrops and the morphology of the mid and inner estuary is also strongly influenced by 'hard points' composed of bedrock and/ or glacial till (Johnson *et al*., 2001). Scars, present along the western shoreline in the outer estuary, fix the shoreline position, provide local stability and protection to the frontage and control the proximity of the Leven channel to the shore (Halcrow, 2010c).

The margins of the estuary are flanked by raised terraces which consist mainly of former tidal flat and marsh deposits which became emergent as a result of a slight fall in sea level following a high-stand in the mid Holocene (Halcrow, 2010e).

The entire estuary is designated as a SSSI, SAC, SPA and Ramsar site, forming part of the larger Morecambe Bay site (Figure 3.2).

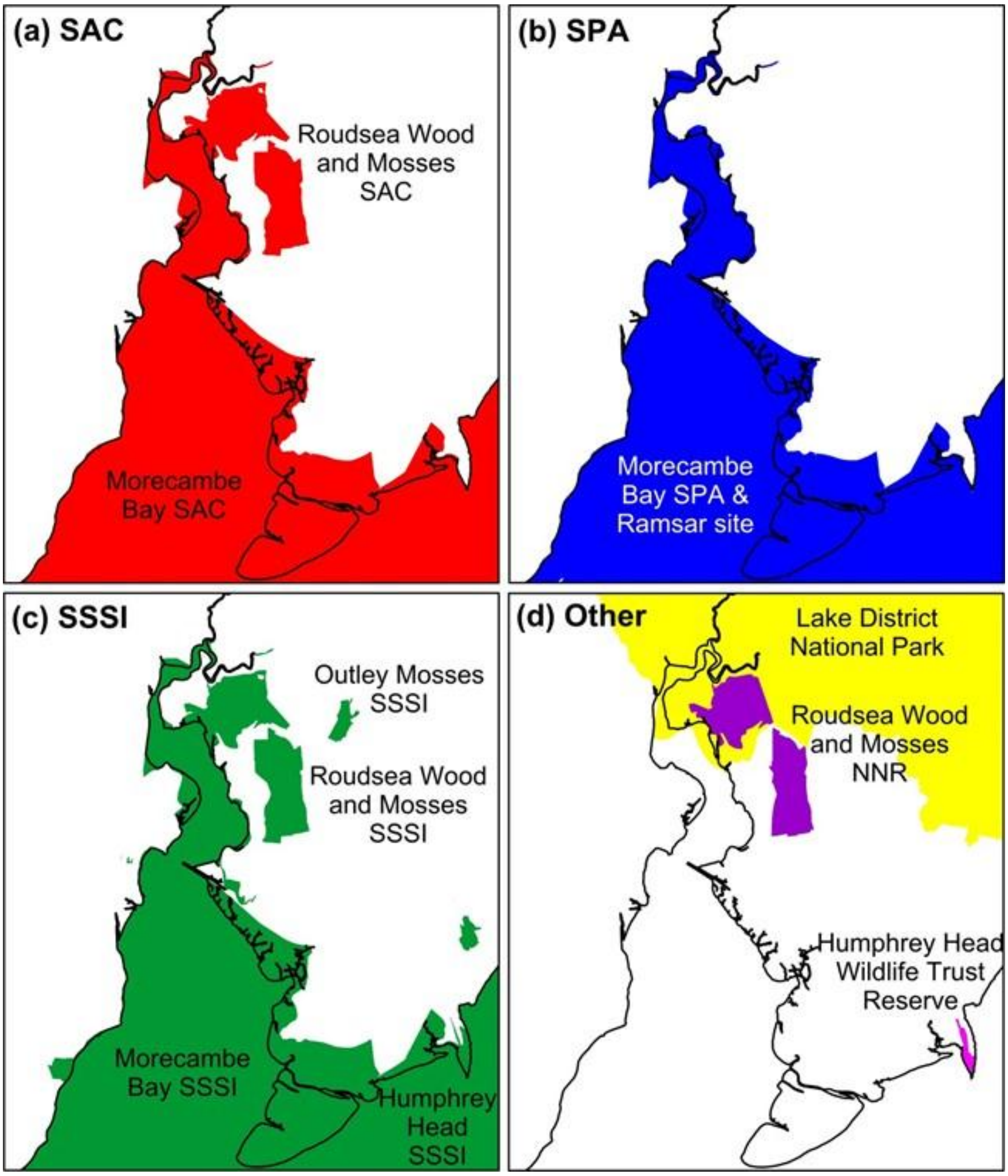


Figure 3.2 Nature conservation designations and reserves in and surrounding the Leven Estuary.

The shoreline management plan (SMP2) (Halcrow, 2010a) estimated that there would be less than 300 residential and 100 non-residential properties, along with around 1,700ha 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 Leven Estuary rank 3rd lowest after the Ravenglass Estuary complex and Kent Estuary (CH2M HILL, 2013).

3.2 Coastal Processes

A macro-tidal regime operates in Morecambe Bay and the Leven Estuary, with a spring tidal range along this frontage of around 8.40m (Shoreline Management Partnership 1999). Principal tidal levels at Ulverston, based on Admiralty Tide Tables, are shown in Table 3.1.

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

	LAT	MLWS	MLWN	MSL	MHWN	MHWS	HAT
Ulverston	nd	nd	nd	nd	2.60	4.60	5.60

Comparison with other west coast estuaries would suggest that the Leven Estuary is likely to be flood dominant, with the flood tide being both shorter in duration and having higher velocities than the ebb tide (Halcrow, 2010e).

The volumes of freshwater inputs to the Leven Estuary are expected to be very small compared to the total volumes of marine water exchanged on each tide, as Lake Windermere on the Leven and Coniston Water on the Crake have a strong attenuating impact on flows downstream. Extreme high water levels throughout the estuary are therefore predominantly caused by marine surges and high tidal levels. However, runoff can also become trapped behind sea defences during high tides (Environment Agency, 2008).

The northerly orientation of the estuary mouth, combined with the construction of the railway viaduct and breakwater, reduces any wave penetration into the estuary. Upstream of the viaduct, waves will also be attenuated by the bank and channel alignments (Halcrow, 2010e).

Low glacial till (boulder clay) cliffs within the outer estuary provide some sand and shingle to the littoral system, however, due to low rates of alongshore drift in this sheltered area, any sediment released will most likely be retained on local beaches. Some material may be transported into the estuary from erosion to the south; however, this again is likely to be negligible (Halcrow, 2010e).

The inner estuary experiences a low energy regime where little or no movement of sediment is likely, except under storm conditions. The estuary therefore acts as a sediment sink within the larger Morecambe Bay system (Halcrow, 2010e). Morecambe Bay provides the main source of sediment to the Leven Estuary which acts as a sediment sink (Halcrow, 2010c). Morecambe Bay itself is a net sink for sediment receiving material from north and south by littoral transport, and from the Irish Sea by tidal current transport. Littoral and subtidal transport vectors, based on numerical modelling from the CETaSS study (Halcrow, 2010d), are shown in Figure 3.3.

Inside Morecambe Bay the sediment pathways are complex; east of the Lune Deep in 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 transport becomes flood increasingly dominated, due to increased asymmetry of the tides producing stronger flood current speeds and a net import of sediment into the feeder estuaries.

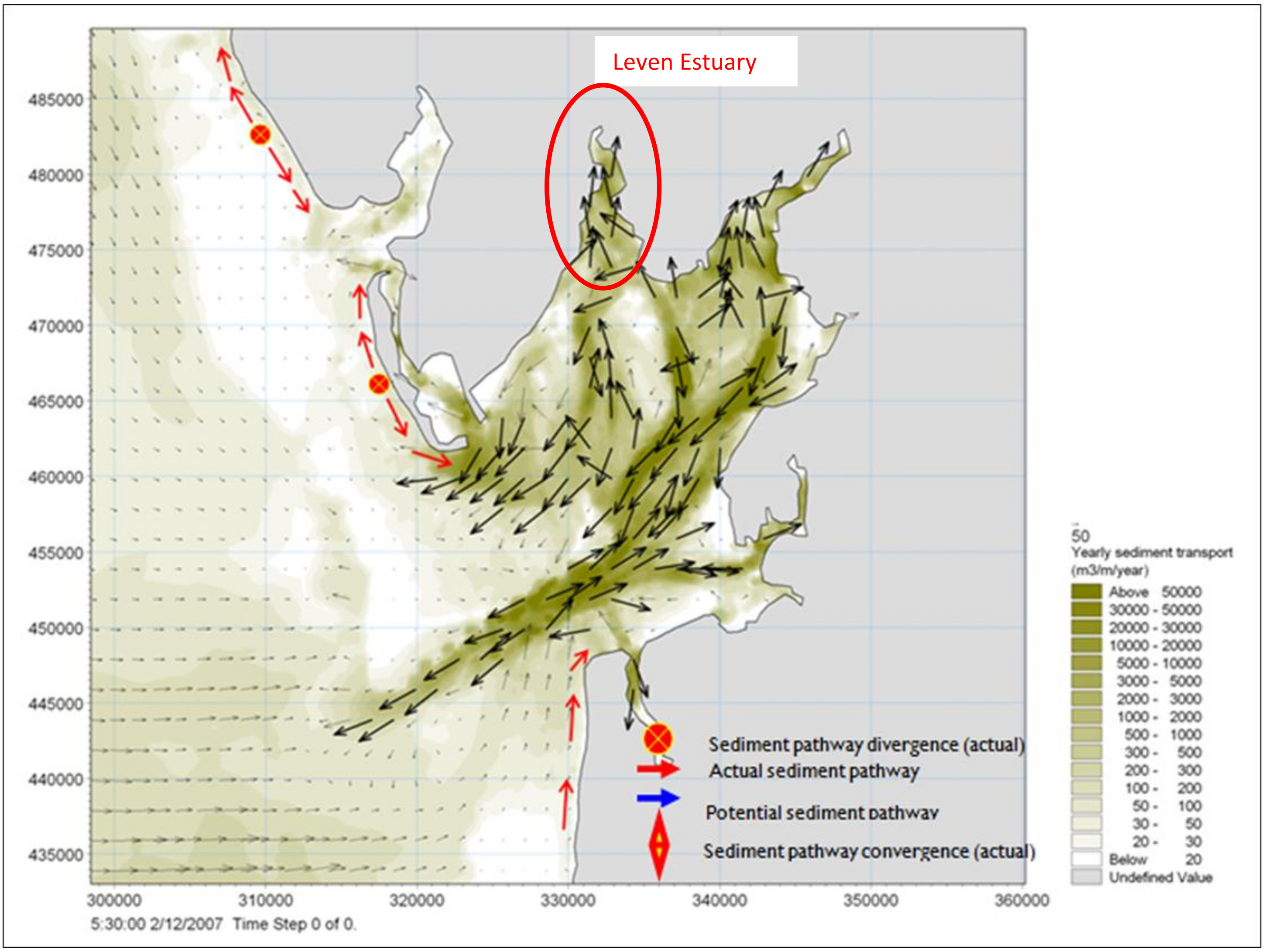


Figure 3.3 Annual sediment transport vectors in the vicinity of the Leven Estuary (from Halcrow 2010d)

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, 2010c). The Leven Estuary exerts a significant control on the adjacent shorelines within Morecambe Bay since changes in its channel configuration influence the exposure of adjacent shore (Halcrow, 2010c).

The Leven is a sand-dominated estuary although there are areas of sandy mud accumulation in the high intertidal zone around the fringes of the inner estuary and the upper intertidal zone closer to the mouth contains mixtures of gravel and sand, reflecting the higher energy environment. A survey carried out as part of CERMS in 2009-10 showed a wide range of sediment textural types ranging from gravel to silty sand and sandy silt. Only a very small number of samples (from the saltmarshes in the inner estuary) were found to contain more than 10% clay (Pye *et al*., 2010; Figure 3.4).

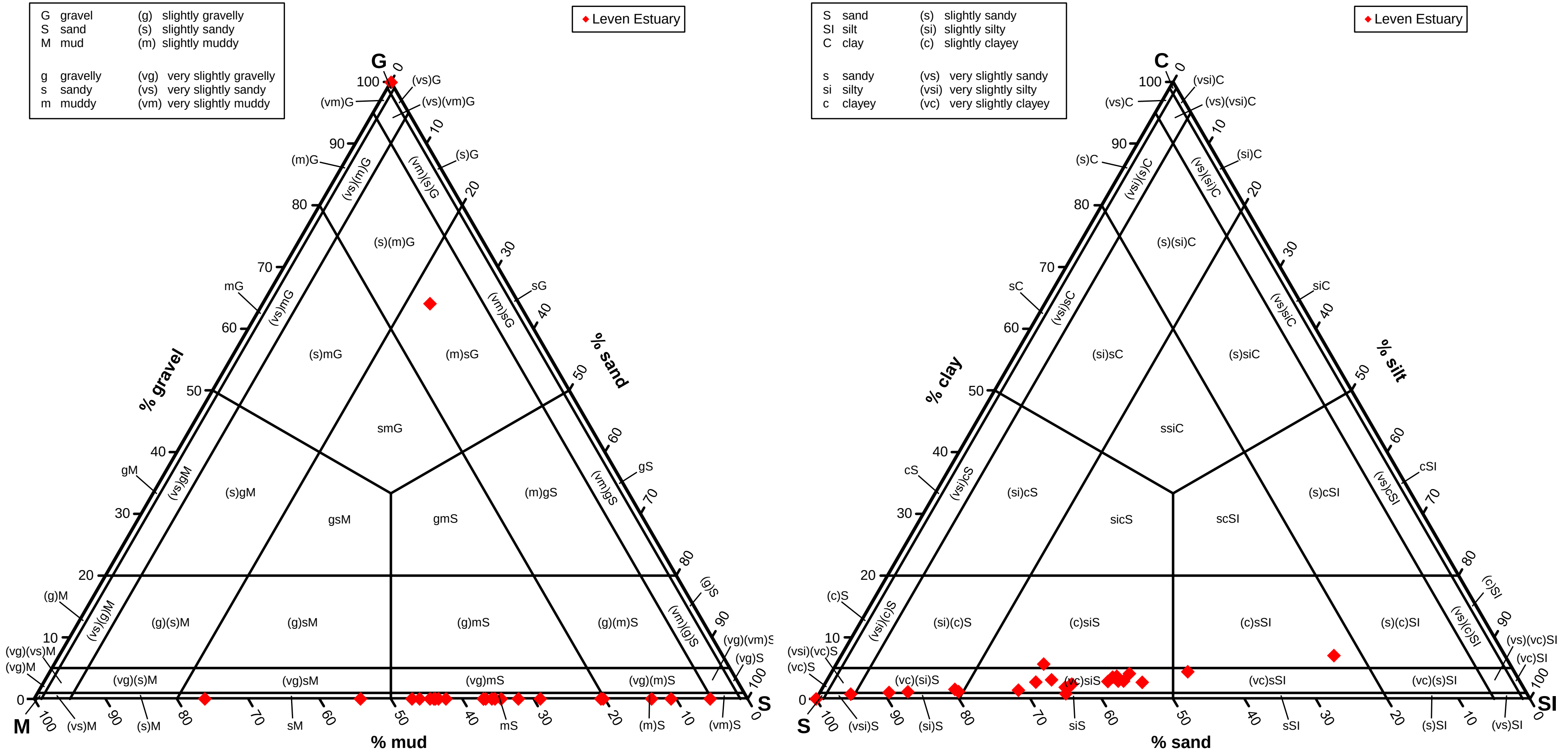


Figure 3.4 Gravel-Sand-Mud and Sand-Silt-Clay trigons, based on the classification of Blott and Pye (2012), for sediment samples collected within the Leven Estuary in 2009-10 (data from Pye et al., 2010).

3.3 Past Changes

Historically, the low water channels of the Leven have varied in their position, especially upstream of the viaduct (Halcrow, 2010c). An analysis of outer estuary channel positions between 1847 and 1980 has been made previously (Shoreline Management Partnership, 1999). The work observed variations in the east - west position of the channels and the alternation between one and two low water channels in parts of the estuary (Halcrow, 2010c).

The main form of human intervention within the Leven Estuary has been the construction of the Leven railway viaduct and associated infrastructure in the mid 1800s. A breakwater was constructed in 1860, south of the viaduct, in an attempt to stabilise the main channel of the Leven (Robinson and Pringle, 1987). These structures have affected the tidal regime within the Leven Estuary and have influenced channel configurations and patterns of saltmarsh development. The breakwater has acted to redirect the Leven channel westwards through the viaduct and consequently has encouraged saltmarsh development along the western side of the Cartmel Peninsula. At present, the viaduct acts to deflect the channel south-east downstream of the structure, before dividing into two channels.

The construction of a footbridge across the estuary at Greenodd impacted on the low water channel and bank regime downstream (Shoreline Management Partnership, 1999). Localised sections of embankment have been built throughout the middle and inner estuary, providing protection to low-lying agricultural land against tidal flooding. Within the outer estuary, defences have been constructed along the railway embankment landward of Sand Gate Marsh and to the west at Canal Foot, Conishead Bank and Bardsea (Halcrow, 2010c).

Historical analyses indicate that saltmarsh has been present along the eastern outer estuary frontage since the late 1600s. Since this time, land reclamation has taken place at various locations along the Cartmel Peninsula. Historical reclamation has reduced tidal prism and consequently increased accretion within the estuary. Although the estuary appears to be experiencing overall accretion, erosion is occurring to eastern shore marsh areas within the inner estuary, where the channel runs close to the shore (Shoreline Management Partnership, 1999). Since the early 1900s, there has been little change in the plan-form of the outer estuary, where defences exist, but both erosion and accretion of the backshore has occurred along the undefended sections. Cliff erosion has been relatively insignificant along the western frontage, due to the sheltered orientation of the shore (Halcrow, 2010c)

Today the Leven Estuary appears to be relatively stable in terms of the extent of mudflat and saltmarsh area, suggesting a relative state of equilibrium has been achieved (Halcrow, 2010c).

3.4 Future Behaviour

Over the next 100 years there is likely to be some relatively minor supply of sediment to the estuary provided by erosion of short lengths of soft cliffs and older sedimentary formations (raised marine terraces) in northern Morecambe Bay, but the main source of sediment is likely to continue to be Morecambe Bay and the wider Irish Sea. There is no evidence to suggest that the general landward movement of sea-bed sediment in Morecambe Bay will change, or that concentrations of suspended sediment will diminish. The future evolution of the estuary is therefore unlikely to be sediment supply-limited (Halcrow, 2010e). 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, 2010c).

3.5 Conceptual Model of Estuary Behaviour

A conceptual model for the Cell 11c area, showing 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 Leven Estuary in

Figure 3.6.

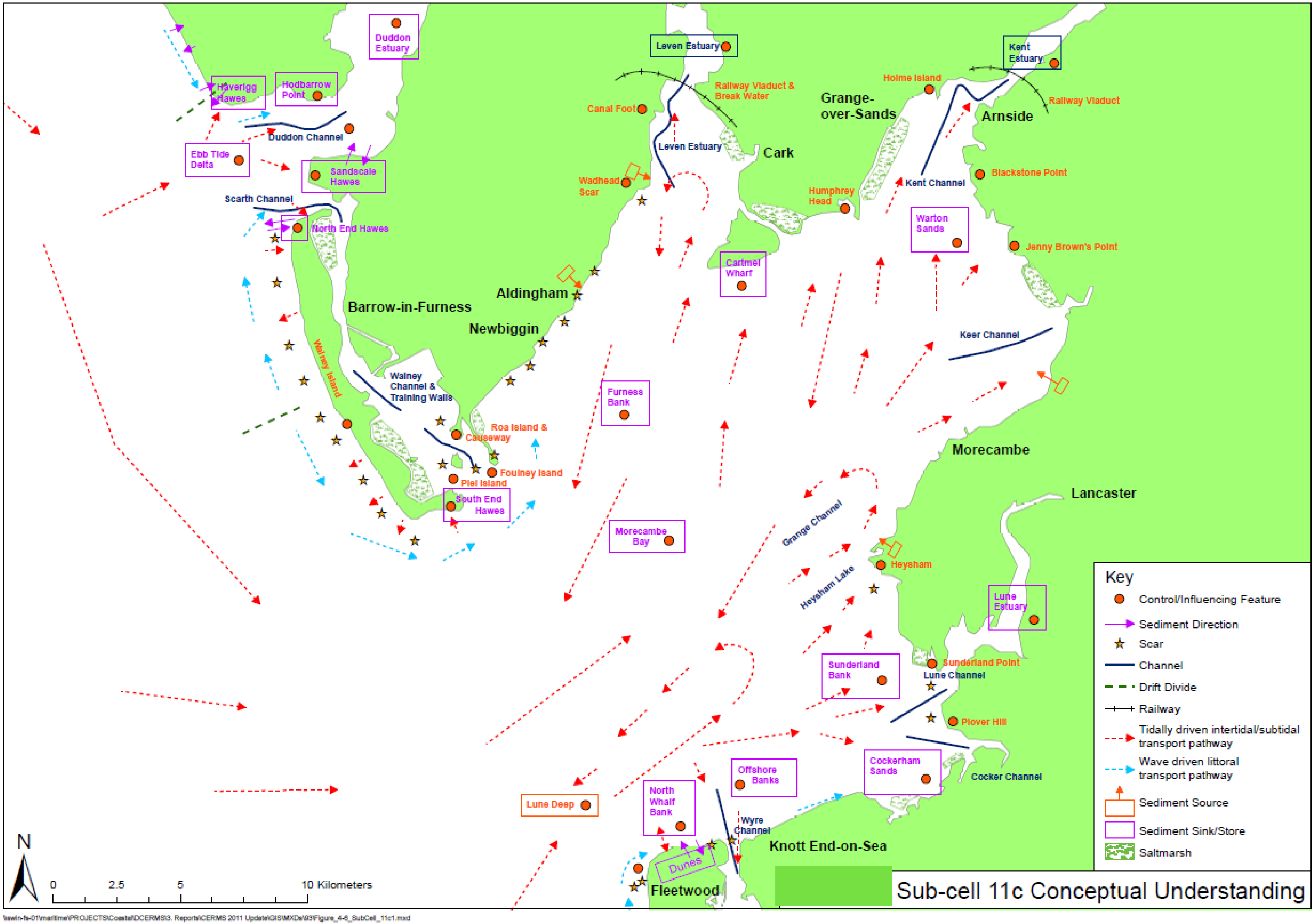


Figure 3.5 A simple conceptual model for Morecambe Bay and the Cell 11c area (source: Halcrow, 2010f)

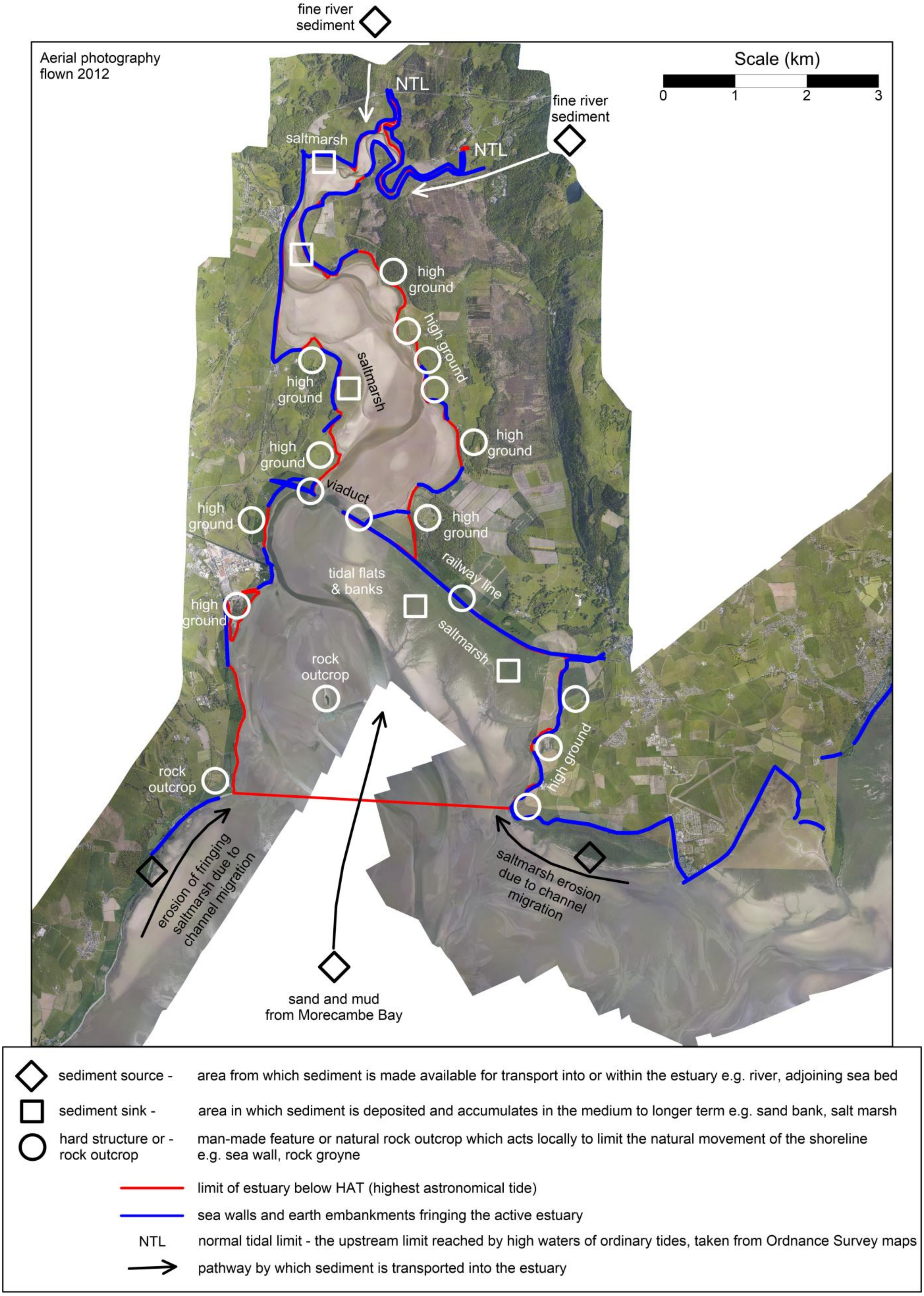


Figure 3.6 Conceptual diagram showing the main sediment sources, geomorphological features and engineering structures which influence the morphology of the Leven Estuary.

3.6 Coastal Defences and SMP Policies

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

The long term vision provided of the SMP2 for the outer Leven is to manage risks to the railway and agricultural land where economically justifiable, but to generally allow the shoreline to set back from the present alignment and respond to coastal change, by allowing additional saltmarsh development and habitat creation. By maintaining defence to the major assets and population whilst also allowing sections of the frontage to behave naturally and erode, most of the SMP objectives will be met. However, there are locations where the potential erosion resulting from a naturally functioning shoreline could have negative impacts, such as the release of contaminants into the estuary; in these locations the impacts will need careful monitoring or investigation in order to inform future defence policy (Halcrow, 2010a).

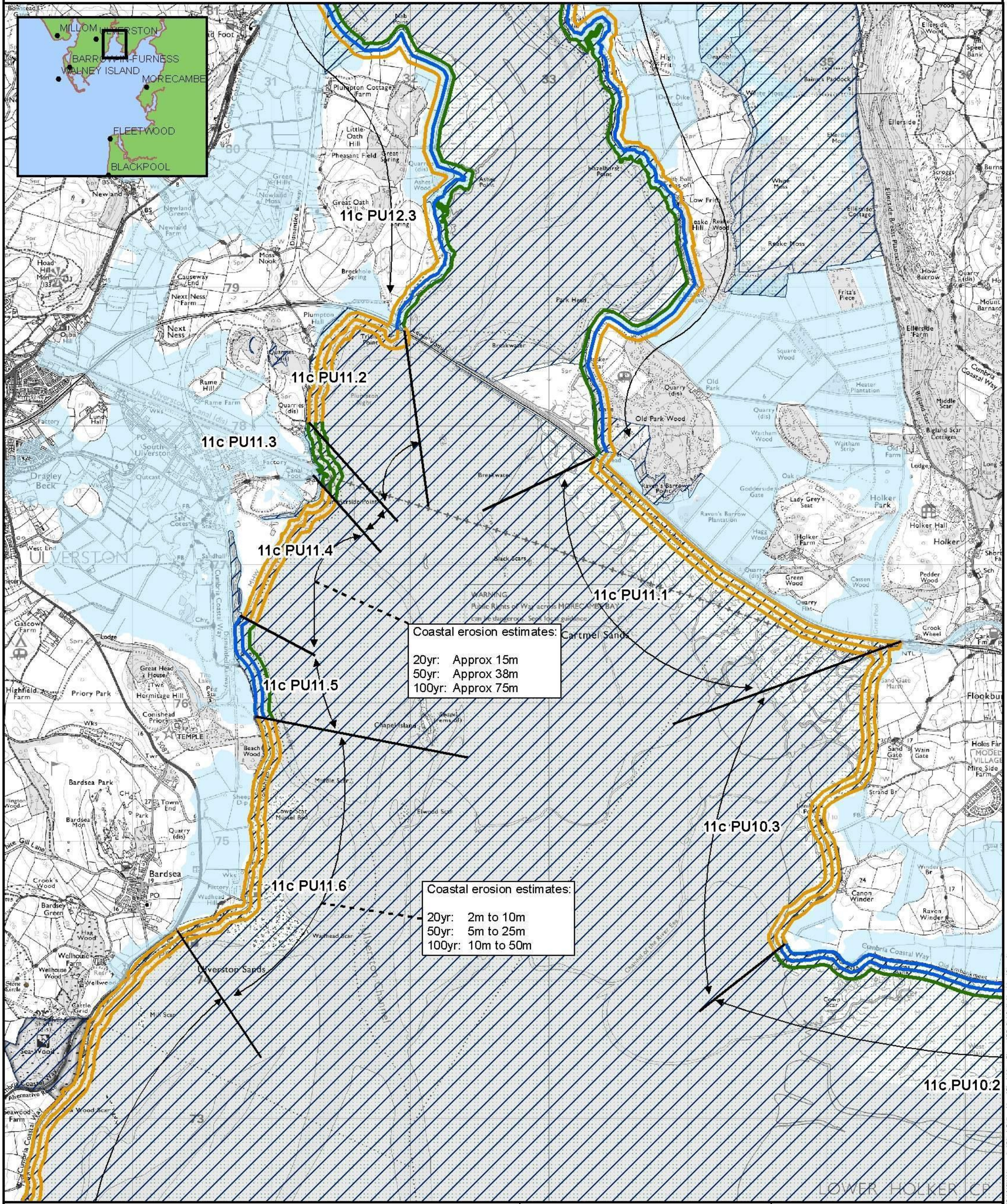
The long term vision for the inner Leven is to continue to manage flood and erosion risks to property and infrastructure where economically justifiable. However, there are significant areas where shoreline defence is considered not viable, leading to several opportunities to realign flood defences to higher ground. This will result in reduction in quality or loss of areas of agricultural land but will allow for expansion of the saltmarsh and tidal flats with future sea level rise in the long term (Halcrow, 2010b).

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

North West England and North Wales Shoreline Management Plan 2

Sub-Cell 11c: Area: 11 Map: 1

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



Legend

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

Shoreline Management Policies

- Hold the Line (HTL)
- Managed Realignment (MR)
- No Active Intervention (NAI)
- Policy Unit Boundary
- Policy Unit Extent

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

0 0.25 0.5 1 Kilometres
Scale: 1:25,000

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

(Swin-5-01) S:\PROJECTS\Coastal\DCESMP - Cell 11 SMP\GIS\Final mapping\Final_Policy_Maps\Final_Map_Figures\FP_SubCell_11c_Map12.mxd

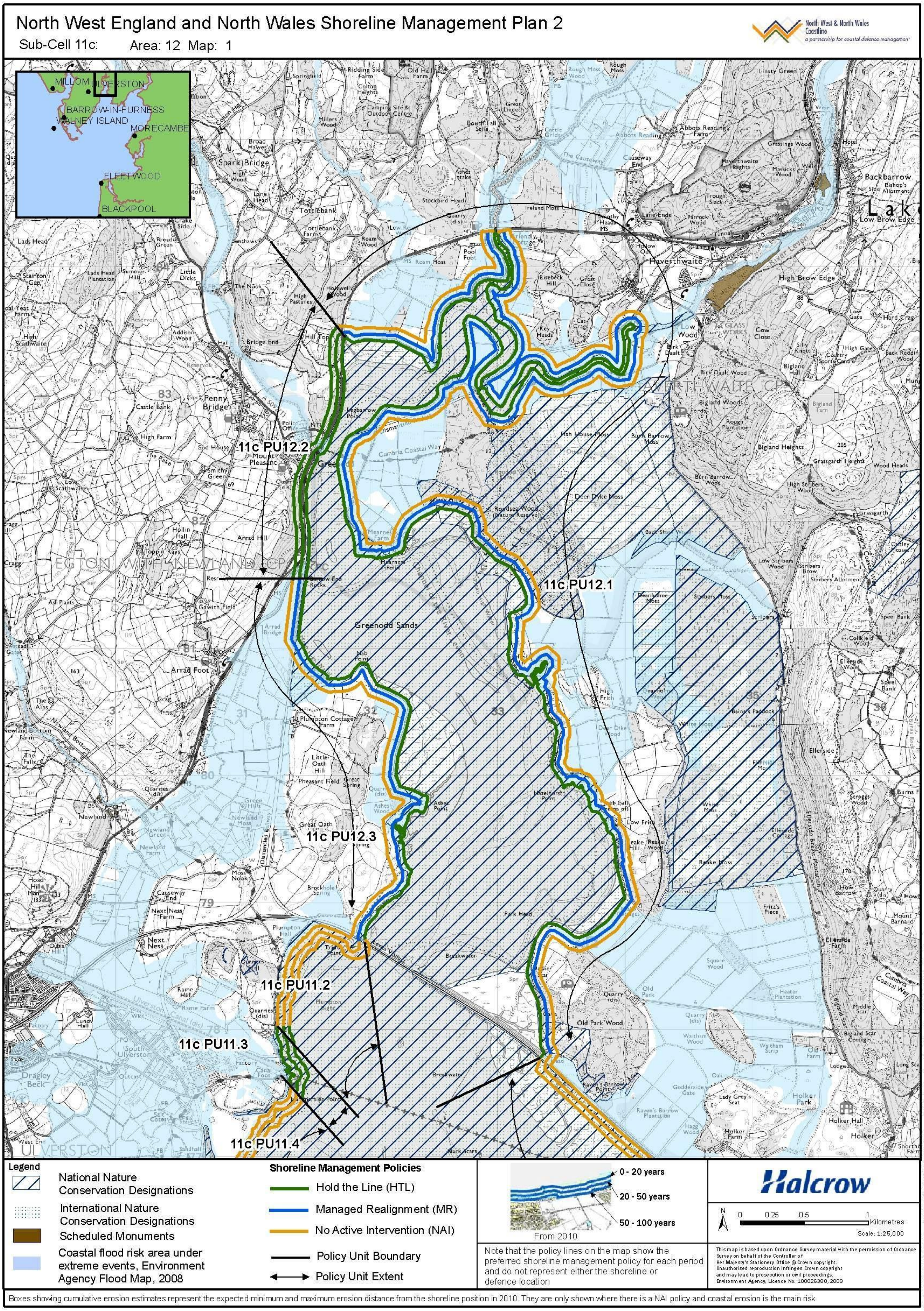


Figure 3.7 Policy maps for the Leven (from Halcrow, 2010a).

3.7 Existing Monitoring Data

Details of the monitoring data being collected for the Leven Estuary and an assessment of the value that this data brings is summarised in Table 3.2. The map in Figure 3.8 shows the location of beach profiles and data collection stations.

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. Beach profiles cover the east and west banks of the Leven 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, 2010f).
Tide gauge 1 (Canal Foot) located at Canal Foot (near Ulverston) on the west bank of the estuary. Captures water level. Owned/maintained by Environment Agency NW. Captures water level. Data is available from July 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, 2010f). CERMS Tide Gauge Review (Halcrow, 2010g).
Vertical aerial photography. March 2002 Strategic Survey.	Record of major channel and bank movements to contribute to the ongoing assessment of shoreline exposure changes and to provide information on the saltmarsh changes to supplement the marsh perimeter survey data.	Lancaster City Council (2011)
Vertical aerial photography and LiDAR surveys (surveyed on 1/3/2013, 1m resolution)	As above.	EA NW
Satellite imagery – feasibility study completed by LCC & BNSC for wider Morecambe Bay	Monitoring of major channel positions and saltmarsh gains and losses.	Lancaster City Council

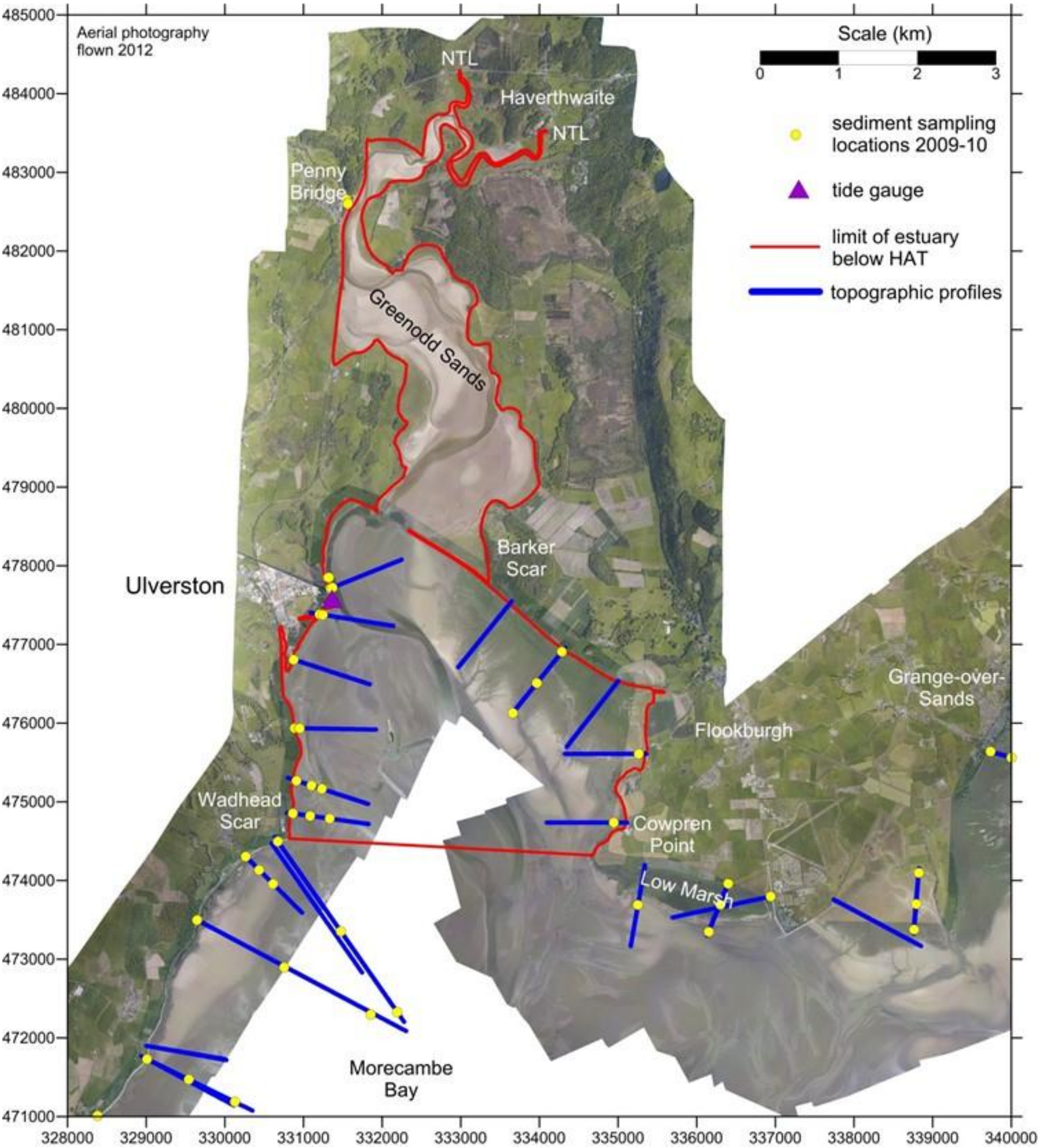


Figure 3.8 Summary of available monitoring data for the Leven Estuary. The tide gauge is located at Canal Foot, Ulverston (operated by the EA).

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, 2010f) 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 Leven 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.

The outer estuary and adjoining open coastal frontages are relatively well covered by topographic and bathymetric survey lines, but there is no coverage in the inner estuary. New LiDAR data coverage of the Leven was obtained in March 2013 but the data has not yet been made available for examination. No survey data appear to have been obtained for the subtidal channel areas, and this should be seen as a priority to be near-contemporaneous with the LIDAR and to allow a synoptic composite DEM to be constructed. It is a general recommendation for the NW estuaries that hydrographic profile extension surveys should be replaced by multi-beam / swath bathymetry surveys that give full coverage.

Sediment samples were collected as part of the 2009-10 CERMS programme from the intertidal zone along topographic survey lines in the outer estuary (Figure 3.8); however there are gaps where no topographic survey lines exist, and the lower intertidal and sub-tidal zones have not been sampled. This gap in coverage should be rectified. The generic gaps and recommendations considered in the accompanying overall report for the NW estuaries (CH2M Hill, 2013) should also be considered alongside those described below.

In the context of the other estuaries in Cell 11, the Leven 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 Leven Estuary and the wider Morecambe Bay, plans for studies and monitoring in the Leven should be developed in conjunction with the Kent 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 and based on a range of sources.	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 in medium term and withdrawal from maintenance and adaptation in the upper estuary in the long term. 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.	Outer Leven Policy Unit 11c 11.1	SMP2 Action Plan recommends studies and consultation to investigate viability of regulated exchange habitat creation landward of railway in conjunction with wider scale assessment of long term coastal squeeze of the internationally designated sites in relation to the railway. This could be undertaken in combination with studies in the other estuaries where the railway constrains future morphological change, e.g. Kent, Leven, Duddon, Ravenglass.	2. Undertake modelling and assessment of potential options using updated model of Morecambe bay and Leven Estuary developed under other actions below. (See item 2 in Appendix B) **Urgency – medium** **Importance – medium** **Difficulty – medium** **Overall Priority - medium**
Habitat losses and creation Management of defences and delivery of SMP2 policies	Leven Estuary in combination with rest of Morecambe Bay	SMP2 Action Plan recommends quantification of potential coastal narrowing / squeeze losses and gains of intertidal habitat within and adjacent to the internationally designated sites, taking account of SMP policies. This is needed to inform development of a Leven Strategy also recommended in the SMP2. SMP2 Action Plan recommends to undertake studies & consultation to investigate managed realignment viability and associated effects on the Leven Estuary and adjacent bay and infrastructure such as the Leven Viaduct. This is needed to inform development of a Leven Strategy also recommended in the SMP2. **T**he above actions will require an improved understanding of sediment transport and estimates of future morphological change in response to sea level rise. A more detailed model of the estuary is required, also covering wider Morecambe Bay. This will require up to date bathymetry and new sediment and hydrodynamic data collection (see actions below).	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 HRA (SMP Appendix J) using the approach in Halcrow and KPAL, 2011. (See item 4 in Appendix B) **Urgency – medium** **Importance – medium** **Difficulty – high** **Overall Priority - medium**

Issue	Location	Comments	Recommendations
Coastal and estuary morphodynamics Uncertainty over the future sediment supply to the estuary and Morecambe Bay as a whole; response to climate change and impacts of proposed large scale management policy changes.	Estuary and adjacent Bay	Although the CETaSS work identified sediment transport pathways it did not quantify the availability of sediment or transport rates. Furthermore it did not investigate feasibility of the proposed realignments, withdrawal from defences or potential for habitat creation through regulated tidal exchange. All of these issues need to be considered together in a Strategy study for the Leven Estuary, and also in combination with the other estuaries and defences surrounding l Morecambe Bay Need to gather additional information for calibration of a new model including suspended sediment under selected events and distribution of bed sediment sizes	4. Undertaken estuary processes and modelling studies (see item 4 in Appendix B) **Urgency – medium** **Importance – medium** **Difficulty – medium** **Overall Priority - medium**
Coastal and estuary morphodynamics Uncertainty over future evolution of banks and channels. Bathymetry at the mouth may be important for hydrodynamics and impacts water levels in the estuary and thus flood risk.	Whole estuary below MSL and adjacent coast.	A new LiDAR survey was flown in March 2013. In order to develop a full bathymetry grid for modelling the estuary the low water channels needed to be surveyed concurrently, preferably with a multi-beam swath bathymetry survey. As this was not done at the time it is recommended to be done as soon as possible afterwards with sufficient overlap to create a full high resolution digital terrain model. The data collection needs to include the low water channel across Morecambe Bay.	5. Undertake detailed swath bathymetric surveys as soon as possible to overlap with the recent LiDAR surveys of the intertidal areas. **Urgency – high** **Importance – medium** **Difficulty – medium** **Overall Priority - high**
Data Collection Tide and current data	Mid estuary	The data from the EA tide gauge at Canal Foot, in combination with others around the Bay 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 Leven Estuary. A key potential impact of the SMP2 policy in the inner estuary to change from HTL to MR in medium term and NAI in long term 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.	6. As part of a wider hydrodynamic data gathering campaign or study the available data from the EA gauges in the Leven 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. **Urgency – medium** **Importance – high** **Difficulty – medium** **Overall Priority - medium**

4 Discussion and Conclusions

The Leven Estuary is relatively small in the context of the other NW estuaries and there is limited development and infrastructure at risk in the tidal flood plain. Due to this the Leven is considered to be of lower priority than several of the other estuaries (CH2M HILL, 2013).

Although an estuary in its own right, the Leven also forms a significant component of the wider Morecambe Bay, system. The Leven Estuary influences flood and coastal erosion risks in the neighbouring areas in Morecambe Bay due to the influence of the meandering low water channel that drains across the tidal flats. In addition to the recommendations specifically for the Leven presented in Section 3 and Appendix B, the generic actions in the Overview report (CH2M HILL, 2013) should also be considered.

The SMP2 policy for most of the shoreline inland of the viaduct is a transition from current practice of Hold the Line through Managed Realignment in the medium term to No Active Intervention in the long term. The transition in policy is staged in order to allow time for adaptation measures to be put in place if necessary. In addition to impacts within the estuary itself the change in policy could have wider impacts on Morecambe Bay due to increasing tidal volume and sediment demand as accretion takes place in the expanded intertidal zones. There is a need to improve understanding of these potential impacts. There are also potential risks to infrastructure such as the railway viaduct that may be subject to greater tidal flows as tidal volumes increase. The impacts of the changes in policy require more detailed investigation through data collection to build a reliable evidence base and improve understanding, along with modelling and geomorphological assessments.

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Appendix A Coastal Defences in the Leven Estuary

Appendix A: Coastal Defences in the Leven Estuary

This data has been sourced from the SMP2 (Halcrow, 2010c).

Location	**Defence History**	**Present Defences**	**Residual Life – (Do Nothing Scenario)** **Years**	**Natural Features**	**Source and Assumptions**
River Eea to Leven Viaduct (Capeshead Embankment) National Grid: (335516E 476400N) to (332330E 478452N)	Original construction 1850s.	Pitched stone embankment topped by vertical masonry wall on either side.	>5	Saltmarsh, sand	NFCDD. Defences interpreted from EA oblique coastal area photos Cell 11.
Leven Viaduct to Barker Scar National Grid: (332700E 478300N) to (333200E 478500N)	N/A	Natural Shore	N/A	Estuarine sand and mudflats, saltmarsh.	Defences & RL interpreted from EA oblique coastal area photos Cell 11.
Park Head National Grid: (333200E 478500N) to (333600E 478700N)	Unknown	Vertical Walls	>5	Estuarine sand and mudflats, saltmarsh.	Defences & RL interpreted from EA oblique coastal area photos Cell 11.
Park Head to Reake Cottage National Grid: (334000E 479100N) to (334000E 478700N)	Unknown	Embankment	5-10	Estuarine sand and mudflats, saltmarsh	Defences & RL interpreted from EA oblique coastal area photos Cell 11.
Reake Cottages to Frith Hall National Grid: (334000E 478700N) to (333800E 479900N)	N/A	Natural Shore	N/A	Estuarine sand and mudflats, saltmarsh	Defences & RL 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
Frith Hall to Hazelhurst Point National Grid: (333800E 479900N) to (333500E 480000N)	Unknown	Embankment	Unknown	Estuarine sand and mudflats, saltmarsh	Defences & RL interpreted from EA oblique coastal area photos Cell 11.
Upstream and downstream Greenodd Bridge National Grid: (332093E 482834N) to (331817E 482066N)	Unknown	Earth embankment, front face reinforced with large stones. Defends pasture.	>20	Estuarine sand and mudflats	NFCDD 2007.
North edge of Greenodd Sands National Grid: (332501E 483249N) to (331805E 483463N)	Unknown	Vegetated earth embankment	5-10	Estuarine sand and mudflats	NFCDD 2007.
Greenodd Embankment National Grid: (331524E 482639N) to (331564E 482547N)	Unknown	Embankment	5-10	Estuarine sand and mudflats	NFCDD 2007.
Greenodd to Barrow End Rocks National Grid: (331564E 482547N) to (331480E 481600N)	Unknown	Embankment	Unknown	Estuarine sand and mudflats	Defences interpreted from EA oblique coastal area photos Cell 11 & OS plans.
Barrow End Rocks to Arrad Marsh National Grid: (331480E 481600N) to (331360E 480600N)	Unknown	Embankment	Unknown	Estuarine sand and mudflats, saltmarsh	Defences interpreted from EA oblique coastal area photos Cell 11 & OS plans.

Location	Defence History	Present Defences	Residual Life – (Do Nothing Scenario) Years	Natural Features	Source and Assumptions
Arrad Marsh National Grid: (331360E 480600N) to (332062E 480705N)	N/A	Natural Shore	N/A	Estuarine sand and mudflats	Defence interpreted from EA oblique coastal area photos Cell 11 & OS plans.
Nab Point to Ashes Wood National Grid: (332062E 480705N) to (332231E 479891N)	Unknown	Earth embankment	20-50	Estuarine sand and mudflats, saltmarsh	NFCDD 2007.
Ashes Wood National Grid: (332231E 479891N) to (331950E 478700N)	N/A	Natural Shore	N/A	Estuarine sand and mudflats	SMP1. Residual life assumed from condition.
River Leven West (Threadlow) Embankment National Grid: (331944E 478693N) to (331534E 478859N)	Original construction 1850s. Downstream face refurbished 2007.	Pitched stone embankment. Downstream facing supplemented/repaired with concrete rock and gabion baskets .	>5	Saltmarsh, sand	NFCDD. Defences interpreted from EA oblique coastal area photos Cell 11.
Start of high ground to North of Canal Foot National Grid: (331534E 478859N) to (331252E 477980N)	N/A	Natural defence	N/A	Saltmarsh, sand	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
North of Canal Foot to Ulverston Canal Foot National Grid: (331252E 477980N) to (331335E 477685N)	Constructed in 1970s	Vertical wall	>5	Saltmarsh, sand, mudflats	NFCDD. Defences interpreted from EA oblique coastal area photos Cell 11.
Lock to Hammerside Point National Grid: (331332E 477677N) to (331325E 477481N)	Unknown	Vertical masonry wall and revetment.	>5	Mudflats	NFCDD. Defences interpreted from EA oblique coastal area photos Cell 11.
Hammerside Point to Priory View National Grid: (331325E 477481N) to (330864E 476068N)	Foreshore reclaimed by tipping of waste in late 1800's.	Tipped shoreline defence to seaward edge supplemented with rock armour in places. Masonry revetment along dismantled railway to landward.	>5	Cobble and shingle shore; river channel	NFCDD. Defences interpreted from EA oblique coastal area photos Cell 11.
Prior View to Red Lane National Grid: (330864E 476068N) to (330844E 475101N)	N/A	Natural defence	N/A	Sand and shingle beach	NFCDD. Defences interpreted from EA oblique coastal area photos Cell 11.
Red Lane to non main watercourse National Grid: (330844E 475101N) to (330817E 474801N)	Erected in 1950s/1960s	Masonry revetment in places, some rubble armour. Revetment is falling apart, rubble is randomly placed and the bank is eroding.	<5	Sand and shingle beach	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
Non main watercourse to Coopers Lane National Grid: (330817E 474801N) to (330782E 474537N)	Erected in 1950s/1960s	Sloped concrete revetment backed by vertical wall. Holes in the concrete.	<5	Sand and shingle beach with some marsh vegetation.	NFCDD. Defences interpreted from EA oblique coastal area photos Cell 11.

Appendix B
Recommendations for further studies

Appendix B Recommended further studies for the Leven 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, South Lakeland 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 on other defences. Priority – medium - needed to feed into MR viability studies and strategy.
2. Modelling and assessment of potential regulated tidal exchange scheme options behind railway	Study assumed to be led by EA, South Lakeland, Lancaster or Sefton with contributions from Network Rail; or could be led by NR. Undertake preliminary modelling and assessment of potential options using updated model of Morecambe bay and Leven Estuary developed under other actions below to inform a viability study of options for coastal habitat creation scheme in medium or long term.	Estimated cost - £15k to £30k (depends on number of sites) The work could be packaged together with similar studies for other sites in the NW to develop compensatory habitat for future coastal squeeze related to NR defences. Priority – Medium to low – needed to inform next review of SMP
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 Leven 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 in the Leven 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 6 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 – 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 Estimated cost of model update, calibration and baseline runs £15k if undertaken in combination with similar work in Kent and Lune estuaries. Priority – High. Needed before MR viability studies. Data collection in items 5 and 6 needed before this is progressed.
4. Improved assessment of future habitat gains and losses in the Leven 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 Priority: medium - relies on outputs of item 3 above and will

Recommended study (See Table 3.3)	Outline scope	Outline cost estimate and priority
and wider Morecambe Bay.	see overview report. In accordance with SMP2 action plan, undertake estuary wide modelling, geomorphology and environmental studies to inform consultation and strategy development by considering implications of changes in policy and managed realignment at estuary wide scale. Estimate losses and gains and provide information to the estuary strategy and HRA. Confirm potential extent of managed realignment areas. Make a preliminary assessment of potential habitat gains by type, depending on technical approach and an indicative programme for phased implementation. Inform RHCP of programme of gains and losses by habitat type. Also link to proposed detailed studies in the SMP2 action plan for specific policy units on regulated tidal exchange and defence realignment. Study should be delivered in combination with modelling and geomorphological studies for the other Morecambe Bay estuaries.	use the same model. Estimated cost £20k to £35k per estuary, assuming delivered in combination with other Morecambe Bay estuaries.
5. LiDAR and bathymetric survey for the Leven Estuary	Study to be led by Sefton or EA. Assess data from most recent (March 2013) LiDAR survey including checking coverage to low water. Possibly undertake new 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. Preferably combine surveys with survey of the channel and intertidal flats across adjacent areas of Morecambe Bay.	Estimated cost: £70k to £100k. Priority – High for bathy survey. Data 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 at Canal Foot and wider Morecambe Bay (Heysham, Glasson, Fleetwood and in the Kent). 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 Leven 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).