North West Estuaries Processes Reports

Lune Estuary

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Lune Estuary

Sefton Council

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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.

Term	Definition
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.
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.

Term	Definition
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.
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.

Term	Definition
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.
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.

Term	Definition
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.
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 Lune Estuary is located on the eastern side of Morecambe Bay in sub-cell 11c. The River Lune has a large, largely rural catchment which extends northwards to the Howgill Fells, eastwards to Yorkshire Dales, and southwards to the Forest of Bowland. The northern and eastern parts of the catchment are relatively steep but there are significant areas of low ground in the lower part of the catchment around Lancaster, Morecambe and Garstang. The estuary length between the mouth and the normal tidal limit at Skerton Weir, east of Lancaster, is 12.8 km. The estuary mouth faces west towards Morecambe Bay but is constrained by the resistant sandstone outcrops at Sunderland Point and Plover Hill, both of which are capped by glacial till.

The outer reaches of the estuary are characterised by large intertidal areas and a meandering low water channel. Beyond the estuary entrance the low water channel crosses an extensive ebb-tidal delta and enters the Lune Deep in Morecambe Bay. Two large areas of saltmarsh occur in the middle to outer estuary at Glasson Marsh and Lades Marsh. These areas are of national and international conservation importance and form part of the Morecambe Bay SSSI, SAC, SPA and Ramsar site.

In common with Morecambe Bay, the Lune estuary experiences a macro-tidal regime and both flood and ebb flows are relatively strong. The estuary is flood dominant and tidal bores are common on the upper Lune. Wave action within the estuary is limited by rocky scars at the mouth. Outcrops of resistant rocky material also occur on the bed of the middle and inner estuary bed and creates shallow areas known locally as ‘fords’.

The estuary has been filling with sediment throughout the later Holocene. Morecambe Bay and the Irish Sea provide the main sources of sediment to the estuary, although some fine sediment is also supplied by the Lune and by localised cliff erosion near the mouth. The estuary had probably reached a condition of dynamic equilibrium by around 1838, but following the construction of training walls within the middle estuary to improve navigation access to Lancaster, this balance was disrupted, causing variable spatial patterns of accretion and erosion. A new equilibrium was believed to have been reached by 1955, although further accretion has occurred since, albeit at a slower rate. The training walls are now not maintained and the low water channel is likely to re-establish meandering behaviour in the future unless maintenance measures are re-implemented.

The long term SMP2 vision for the Lune is to continue to protect infrastructure and the historic city of Lancaster, but other areas will not be defended, allowing occasional inundation and natural evolution. There is uncertainty about the impact of continuing erosion at Sunderland Point on the wider Lune Estuary. The SMP2 concluded that it will be increasingly unjustifiable to maintain defences around the villages of Sunderland and to the south of Glasson Dock, and further studies are required to refine the shoreline management policies for these areas in the medium and longer terms. Within the middle reaches of the Lune, training walls which once constrained the channel are becoming increasingly ineffective. Consequently, where the channel is increasingly free to meander, saltmarsh erosion is occurring. However, as there are limited areas of land or property at risk, the SMP2 policy is No Active Intervention in the middle reaches. The city of Lancaster is located in the inner part of the estuary where there has been significant development on the flood plain. There are also large historical landfill sites on both banks of the estuary in the inner estuary. The SMP2 policy in the inner estuary is therefore Hold The Line in all three epochs.

Within the context of flood and coastal erosion risk management across the Cell 11, the Lune Estuary has relatively high risks in relation to assets on the flood plain of the estuary, mainly in the inner estuary. The previous Lune strategy studies were undertaken about 10 years ago, prior to implementation of flood defence schemes at Lower Lancaster and adaptation measures at Sunderland Village. Large lengths of the estuary now have a NAI policy in the SMP2, which recommends more detailed studies and development of an updated long term strategy to assess risks related to the polices and develop actions to put it into practice.

The outer part of the estuary is reasonably well monitored at present but there are major gaps in data coverage for the middle and inner parts of the estuary. Topographic, bathymetric and sediment monitoring needs to be extended in order to assess and predict the impacts of deterioration of the training walls and sea level rise. As the walls fail the estuary is likely to return toward a more natural meandering regime, with implications for saltmarsh erosion and stability of flood defences. There is a requirement to obtain a better understanding of the physical processes, sediment regime and likely long-term morphological evolution of the estuary as it returns to a more natural state. Due to the strong coastal process linkages between the Lune Estuary and the southern part of Morecambe Bay, it is recommended that some of the further studies should be progressed jointly with other studies in Morecambe Bay.

1 Introduction

This report summarises the existing understanding of the Lune 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.

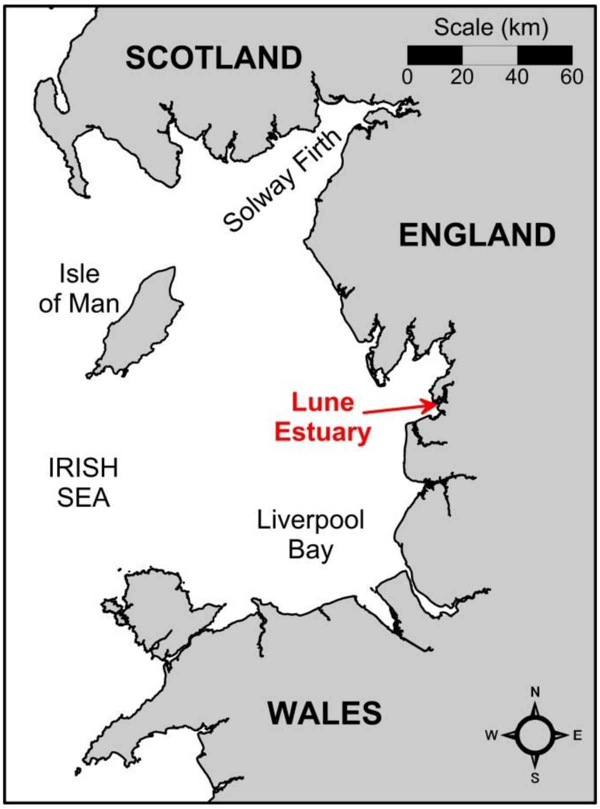

Figure 1.1 Location of the Lune Estuary

2 Coastal Setting

The Lune Estuary is located within Morecambe Bay in sub-cell 11c which extends from Rossall Point, Fleetwood to Hodbarrow Point on the west side of the Duddon estuary (Figure 2.1).

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

The River Lune has a large, largely rural catchment which extends northwards to the Howgill Fells, eastwards to Yorkshire Dales, and southwards to the Forest of Bowland (Figure 2.2). The northern and eastern parts of the catchment are relatively steep but there are significant areas of low ground in the lower part of the catchment around Lancaster, Morecambe and Garstang (Environment Agency, 2009).

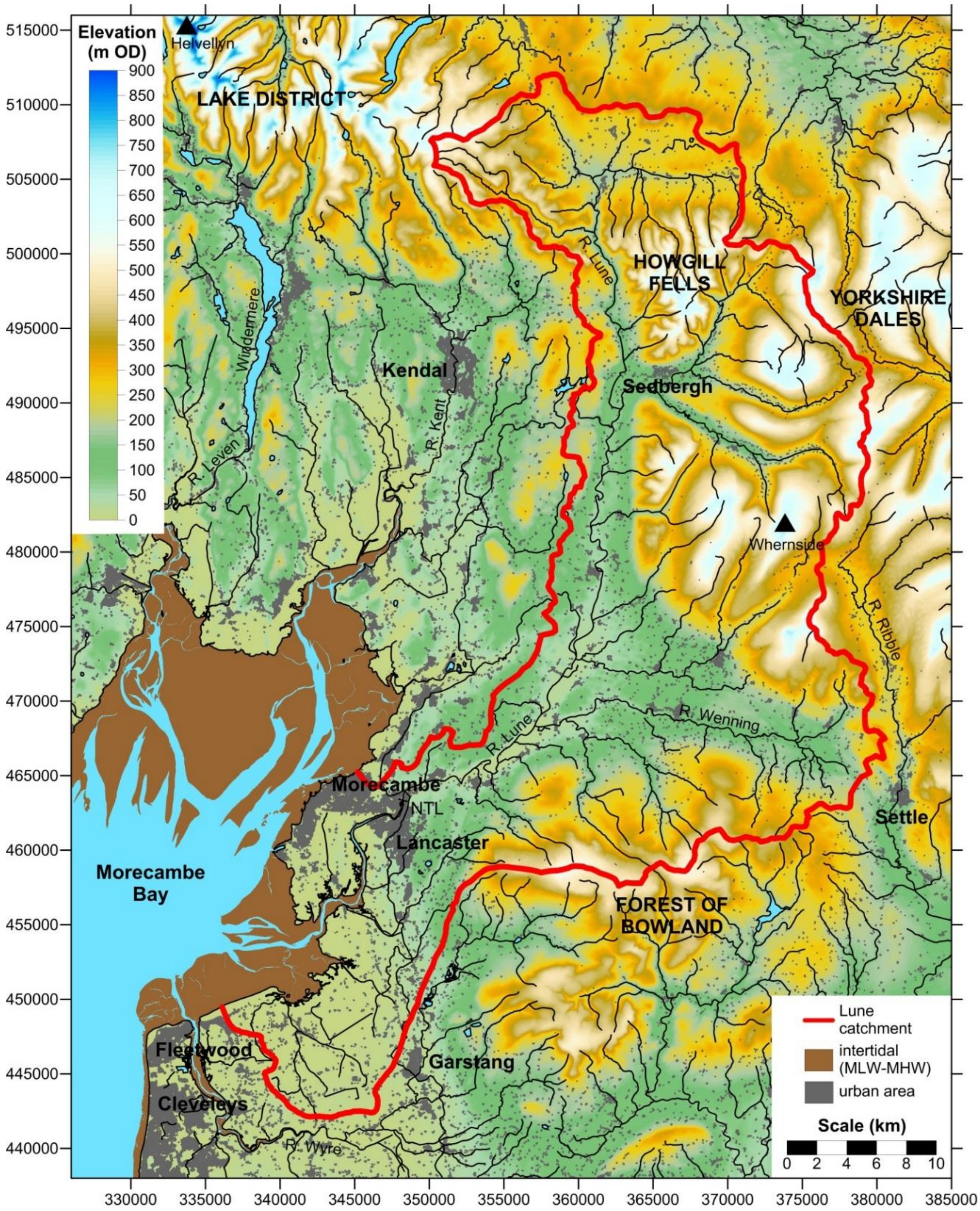

Figure 2.2 The River Lune catchment, showing the main urban areas and general extent of the intertidal zone. Source: modified from Ordnance Survey Open Data, after Pye & Blott (2013).

3 Estuary Review

3.1 Description

The Lune estuary (Figure 3.1) extends 12.8km through low hills, from the mouth to the normal tidal limit at Skerton Weir, east of Lancaster (Halcrow, 2004). The open estuary mouth, facing west into Morecambe Bay, is constrained by the resistant sandstone outcrops at Sunderland Point and Plover Hill, both of which are capped by low glacial till (boulder clay) cliffs and scars (Halcrow, 2010e).

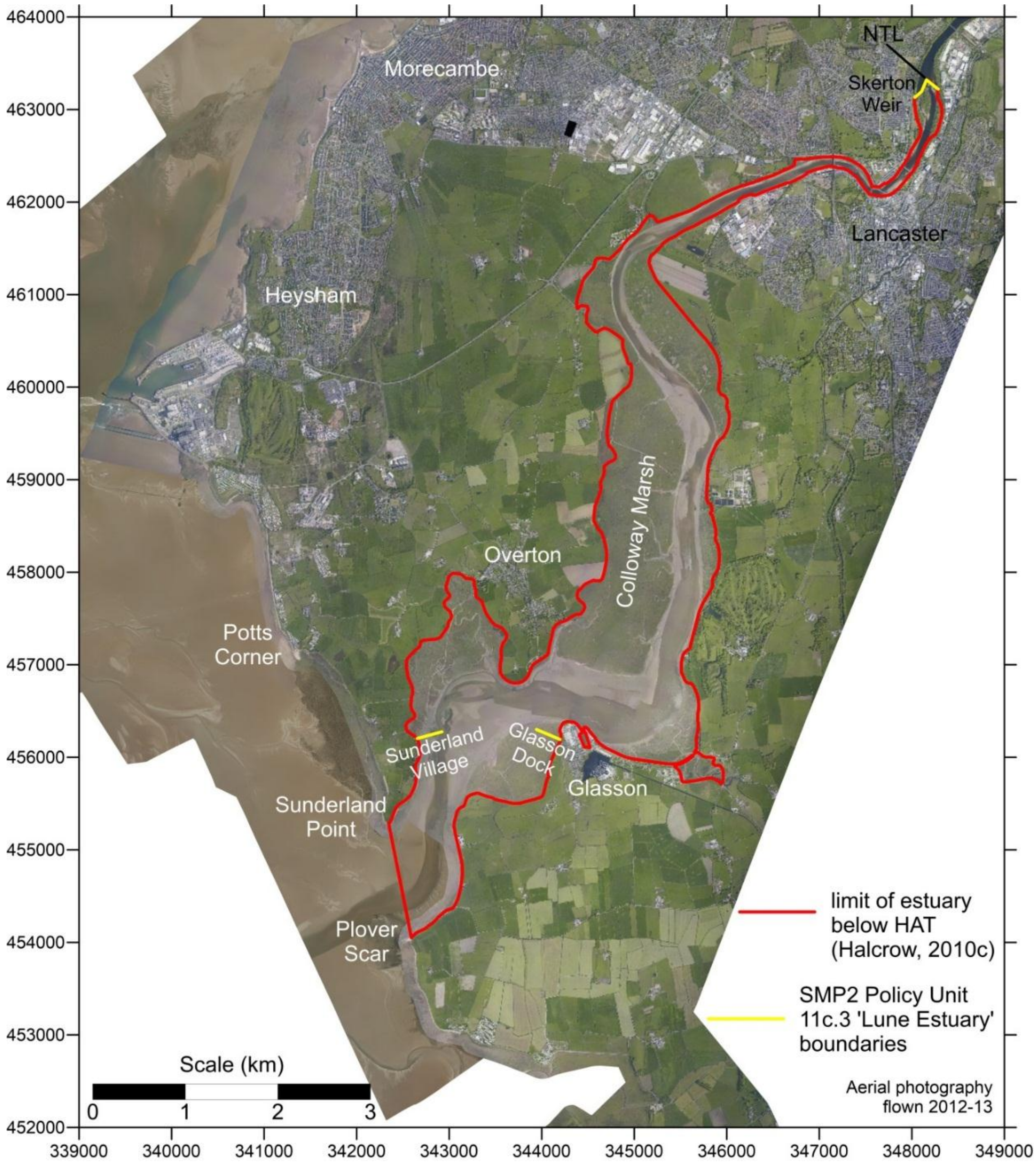

Figure 3.1 Limits of the Lune Estuary and SMP Policy Unit 11.c.3

The outer reaches of the Lune Estuary are characterised by large intertidal areas and a meandering low water channel. Two large areas of saltmarsh are located in the outer estuary, Glasson Marsh south of the channel and Lades Marsh to the north. A causeway road which floods at high tide has been built across Lades Marsh linking Overton and Sunderland. Bazil Point is an area of higher land, with till cliffs exposed at the estuary shore (Halcrow, 2010c). Beyond the entrance limits of the estuary (as defined in Figure 3.1), the low water channel of the Lune crosses an extensive ebb-tidal delta and enters the Lune Deep Channel in Morecambe Bay.

Within the middle reaches of the estuary, training walls constrain the channel and large areas of saltmarsh have formed. Within the inner reach, intertidal areas are more limited and the channel is confined. The intertidal flats and marshes located within the estuary were considered to be stable in terms of mudflat and saltmarsh areas (Halcrow, 2004). Resistant material located within the estuary bed creates shallow areas known as 'Fords' (Halcrow, 2010c).

The low water channel is sinuous and historically has shown unstable behaviour. In the mid estuary training walls have been constructed to constrain channel movements (Inglis and Kestner, 1958) and this has assisted the stability of marshes and mudflats in the system over the past century (O'Connor, 1987; Halcrow, 2010c). However, the training walls are not maintained and the low water channel is likely to re-establish meandering behaviour to trend towards its pre-training wall form in future (Halcrow, 2010c).

The middle and outer estuary, seawards of Freeman's Pools, is of national and international conservation importance and forms part of the Morecambe Bay SSSI, SAC, SPA and Ramsar site (Figure 3.2).

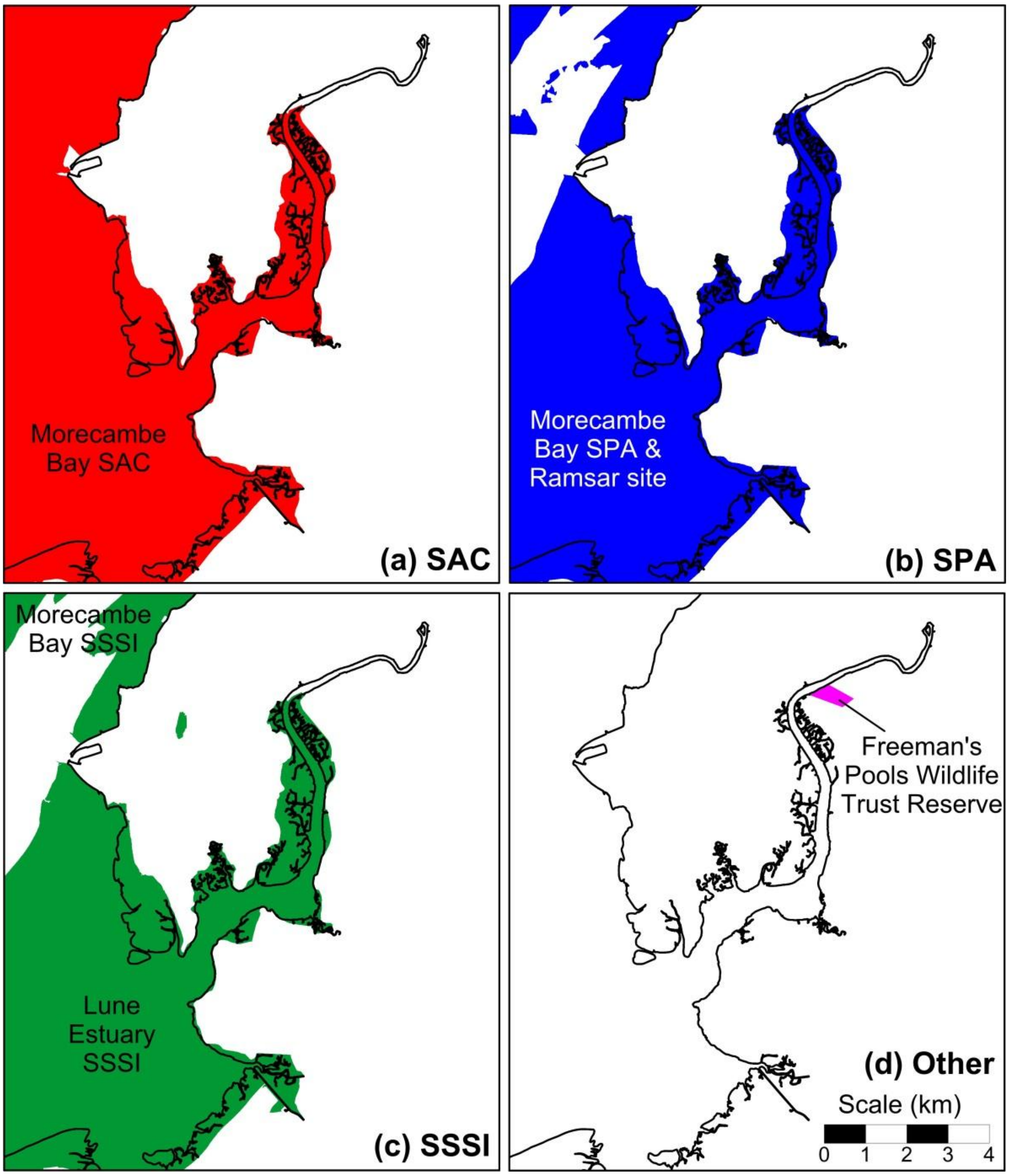

Figure 3.2 Nature conservation designations and reserves in and surrounding the Lune Estuary.

The shoreline management plan (SMP2) (Halcrow, 2010a) estimated that there would be about 8,800 residential and 1,000 non-residential properties along with around 1,800ha of agricultural land at risk in the long term if there were a No Active Intervention (Do Nothing) approach to flood and erosion risk management. Compared to the other North West Estuaries, the Lune estuary ranks third in terms of the numbers of properties at risk , after the Wyre and Ribble.

3.2 Coastal Processes

The estuary is macrotidal, well mixed and flood-dominated (Halcrow, 2004). Principal tidal levels based on the Admiralty Tide Tables are given in Table 3.1.

The estuary mouth is open to the southwest, allowing some penetration of waves from Morecambe Bay into the lower estuary, but wave action is not a major factor governing the morphology of the estuary (Shoreline Management Partnership, 1999). Freshwater input to the estuary from the River Lune is relatively small and constitutes only 1 - 16% of the tidal prism, depending on seasonal flow conditions (Halcrow, 2004). The influence of these fluvial flows is greater in the inner and middle reaches of the estuary. Morecambe Bay and the Irish Sea provide the main sources of sediment to the system (Halcrow, 2010c).

Table 3.1 Tidal levels at Secondary Ports in and near the Lune Estuary. Source: Admiralty Tide Tables (2012)

	LAT	MLWS	MLWN	MSL	MHWN	MHWS	HAT
Glasson Dock	nd	nd	nd	nd	2.40	4.60	5.70
Lancaster	nd	nd	nd	nd	3.05	4.85	5.75

Morecambe Bay and the Irish Sea provide the main sources of sediment to the estuary, which in turn acts as a sediment sink. On-going erosion at Sunderland Point also provides limited additional sediment to the estuary. Sediment transport, of fine sand and coarse silt, is dominated by tidal currents and is concentrated in the main low water channel where water depths and flows are the greatest (Halcrow, 2010c).

Littoral and subtidal potential sediment transport vectors, based on regional numerical modelling from the CETaSS study (Halcrow, 2010d), are shown in Figure 3.3 and demonstrate net potential sediment transport directed from Morecambe Bay into the outer Lune. 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 transport becomes increasingly flood dominated due to greater asymmetry of the tides producing stronger flood current speeds and a net import of sediment into the feeder estuaries. There is some supply of sediment (mainly mud) into the Lune Estuary from the River Lune, but its significance has not been quantified.

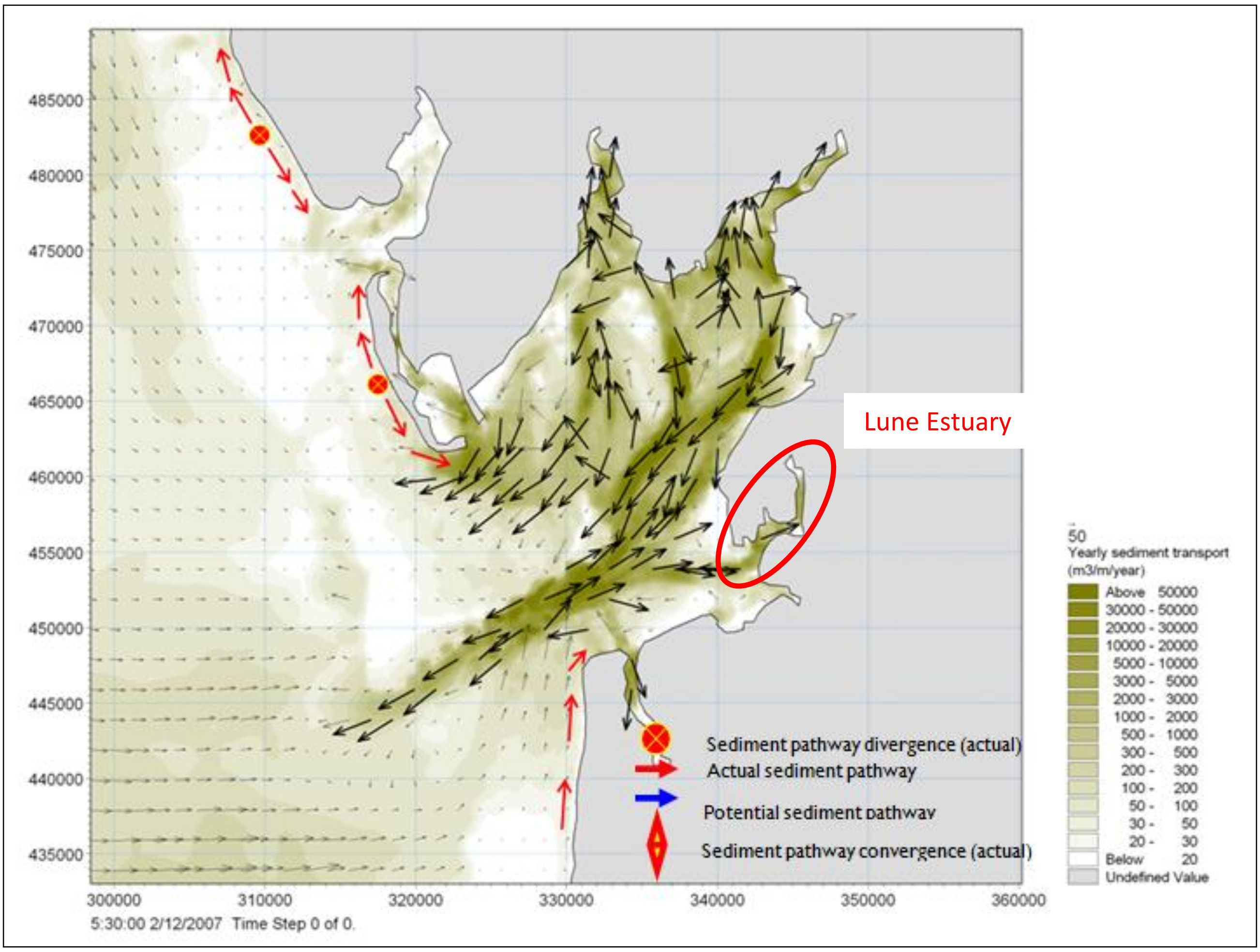

Figure 3.3 Map showing sediment transport in the vicinity of Lune Estuary (from Halcrow, 2010d).

Channel migration is facilitated by strong tidal currents, but within the middle estuary the Lune channel has historically been artificially constrained through the construction of training walls. 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 (Halcrow, 2010c).

Wave action is most significant in the outer estuary as the scars at the mouth act to govern the height of waves that progress up the estuary. The inherent geography of the estuary, combined with channel and bank configurations, causes attenuation of wave heights as they travel up the estuary; consequently, waves are not a principal factor governing shoreline evolution within the estuary (Shoreline Management Partnership, 1999).

Within the estuary, sediment transport, of fine sand and coarse silt, is dominated by tidal currents and is concentrated in the main low water channel where water depths and flows are the greatest (Halcrow, 2010c).

A sediment survey carried out as part of CERMS in 2009-10 indicated that the intertidal zone of the estuary is dominated by muddy sands and sandy muds. Very little gravel is present and the muds typically contain less than 10% clay (Figure 3.4) (Pye *et al*., 2010). However, the inner parts of the estuary and the low water channel were not sampled in this survey.

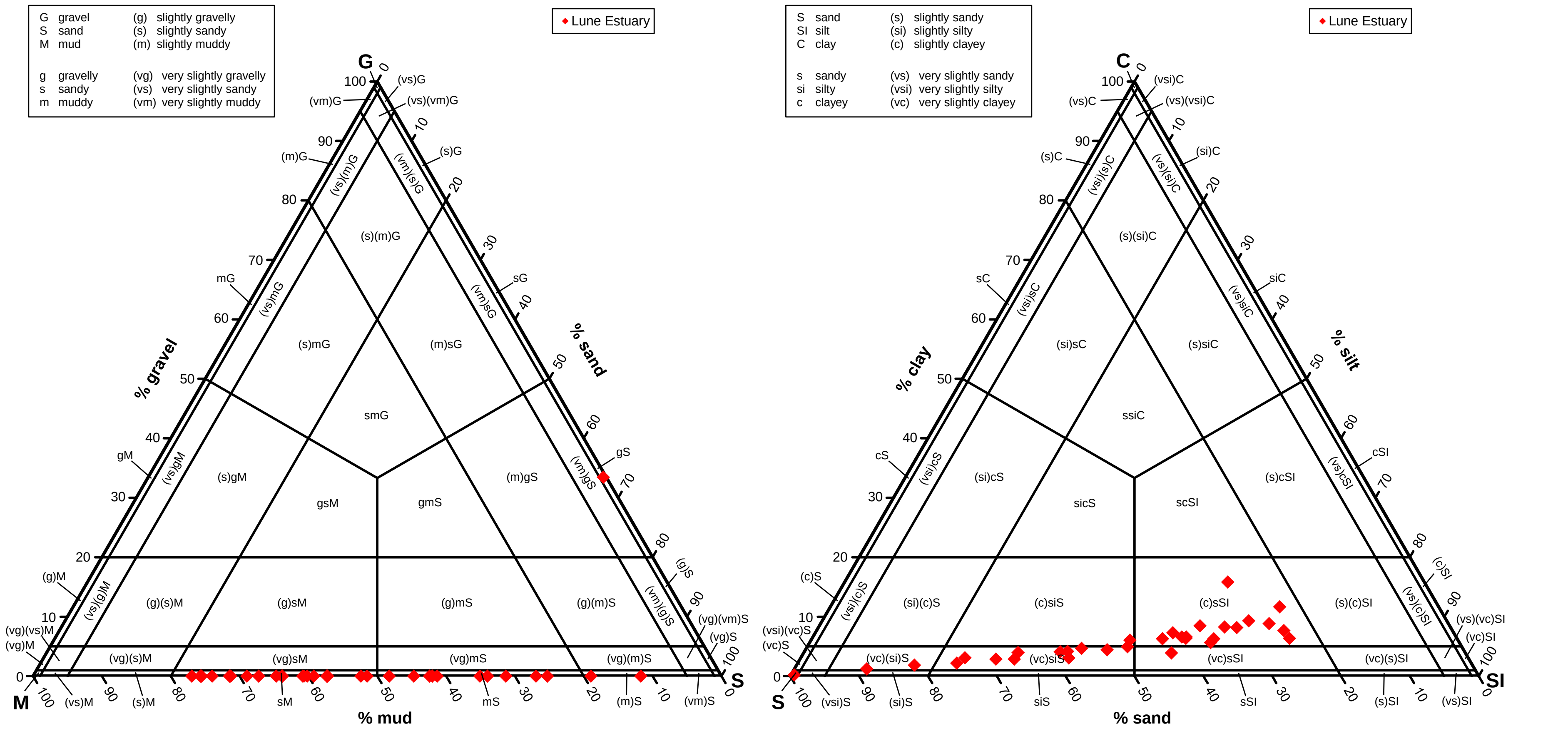

Figure 3.4 Gravel-Sand-Mud and Sand -Silt-Clay trigons, based on the classification of Blott & Pye (2012), for sediment samples collected within the Lune Estuary in 2009-10 (data from Pye et al., 2010).

3.3 Past Changes

Historically the estuary has been infilling throughout the Holocene, reaching equilibrium by around 1838 (Halcrow, 2004). Morecambe Bay and the Irish Sea provide the main sources of sediment to the Lune Estuary, which in turn acts as a sediment sink within the larger Morecambe Bay system (Halcrow, 2010e).

Following the installation of training walls within the middle estuary to improve navigation access to Lancaster, this balance was disrupted, causing variable spatial patterns of accretion and erosion. A new equilibrium was believed to have been reached by 1955; however, further accretion has occurred since this date, albeit at a slower rate (Inglis and Kestner, 1958; Patrick, 1978).

On individual spring tides the estuary has been shown by modelling to be flood dominant (Halcrow, 2004). However, over longer timescales it has been suggested that the estuary is in dynamic equilibrium at present, where the net import of sediment is keeping pace with sea level rise, allowing a stable form to be maintained (Halcrow, 2004).

Along the southern shoreline, Glasson Marsh has developed over the past 150 years, increasing in area in the sheltered lee between Chapel Hill and Glasson. Cyclical changes in the position of the low water channel at Glasson have been observed in the past where the channel moved laterally by approximately 400m within a 2 to 3 year period (Halcrow, 2004).

Along the northern shore, Lades Marsh has also increased in size between the middle of the 19th century and the 1960s. However, deep gullies have now formed in the saltmarsh (Halcrow, 2010c). Contemporary movement of the low water channel into Overton Marsh and towards Sunderland village has also been observed when comparing aerial surveys (ABPmer, 2006).

The high water mark at Sunderland Point has moved slowly over time; exposure to extreme waves and water levels and the close proximity of the Lune Channel has resulted in erosion of local till cliffs at the Point (Halcrow, 2004). Subsequent to the SMP2, which sets a managed realignment policy for Sunderland Point (See Figure 3.7), it is understood that local scale erosion protection measures are being planned by the landowners and residents of Sunderland Village to slow the process of erosion of the point.

3.4 Future Behaviour

There are a number of proximal potential sediment sources for the Lune Estuary, including erosion of short lengths of undefended soft cliff around Morecambe Bay, and erosion of the intertidal flats and saltmarshes which occur extensively in the southern and north-eastern parts of the Bay. The River Lune will continue to supply relatively small but significant quantities of (mainly) fine sediment, but the suspended sediment pool provided by Irish Sea waters is likely to remain the main source of mud. Given the relatively high levels of both active and reclaimed marshes with respect to the tidal frame, it is expected that vertical accretion of saltmarshes (including any managed realignment areas) would be able to keep pace with sea level rise (Halcrow, 2010e).

The training walls are not maintained and as they deteriorate the low water channel is likely to re-establish meandering behaviour reverting towards its pre-training wall form in future (Halcrow, 2010c). This may impact on the dynamic balance of saltmarsh and mudflat areas.

3.5 Conceptual Model of Estuary Behaviour

A conceptual model for the Morecambe Bay overall (from Halcrow, 2010f) is provided in Figure 3.5.

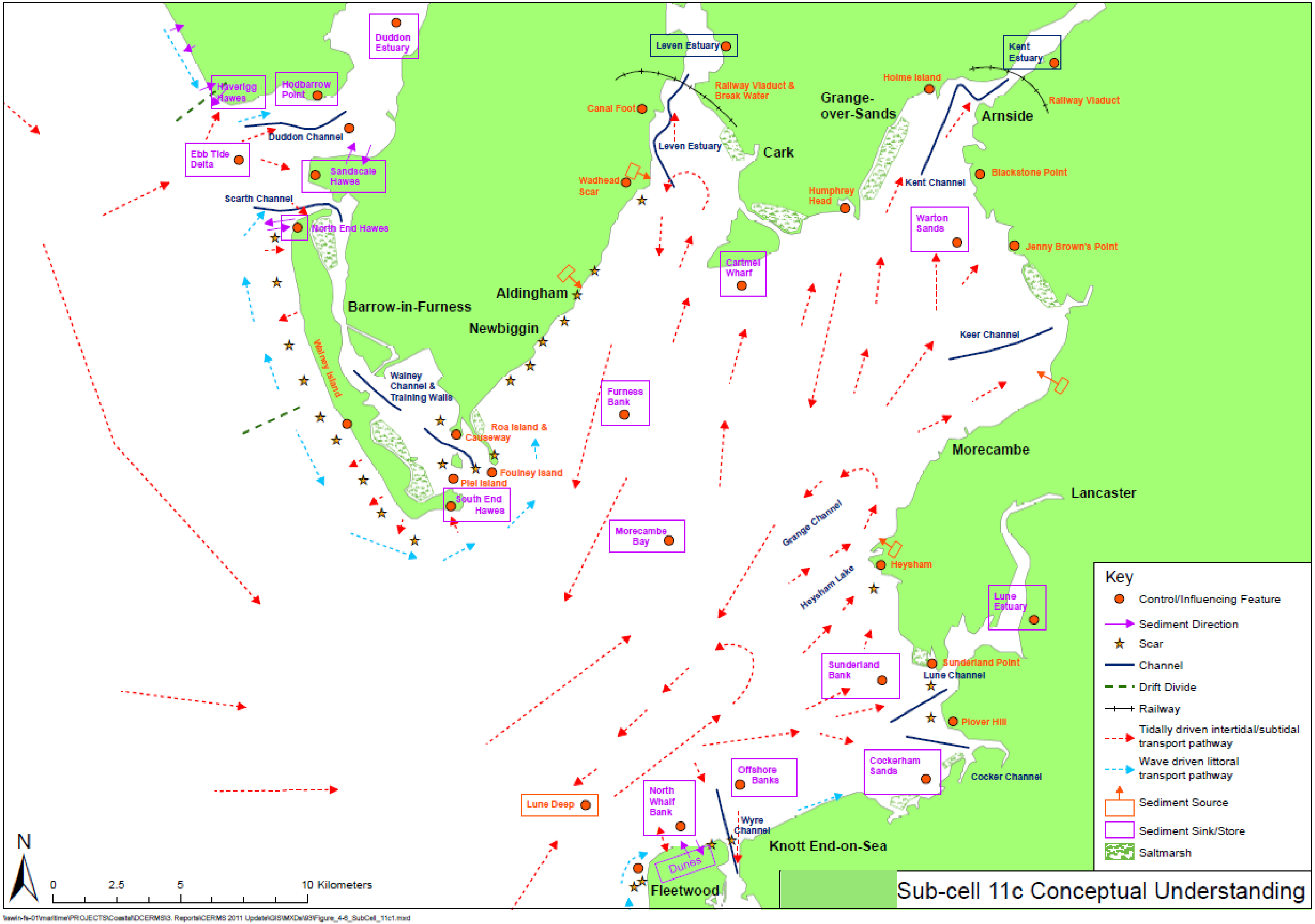

Figure 3.5 A simple conceptual model for Morecambe Bay and the Cell 11c area (source: Halcrow, 2010f)

A more detailed conceptual diagram has been developed specifically for the Lune estuary in Figure 3.6.

The overall morphology of the estuary is strongly controlled by natural rock outcrops on the banks and bed. Intertidal flat and saltmarsh deposits surround these rock outcrops, forming a wide plain between Lancaster Morecambe, and south of Glasson. This area formed a broad bay during the maximum marine transgression during the mid-Holocene period, since when relative mean sea level has fallen in this area by approximately 1 m. Embanking and land-claim since the 18th century has significantly reduced the size of the intertidal area (Grey & Adam, 1974). The construction of training walls in the 19th century restricted the free movement of the low water channel and has allowed the development of new saltmarsh on the seaward side of the embankments (Inglis & Kestner, 1958; O'Connor, 1987). The tidal capacity of the estuary has declined significantly since the early 19th century due to reclamation, training wall construction and the import of sediment from Morecambe Bay; this process is apparently continuing at the present day, although at a much reduced rate, as the estuary approaches a new equilibrium condition.

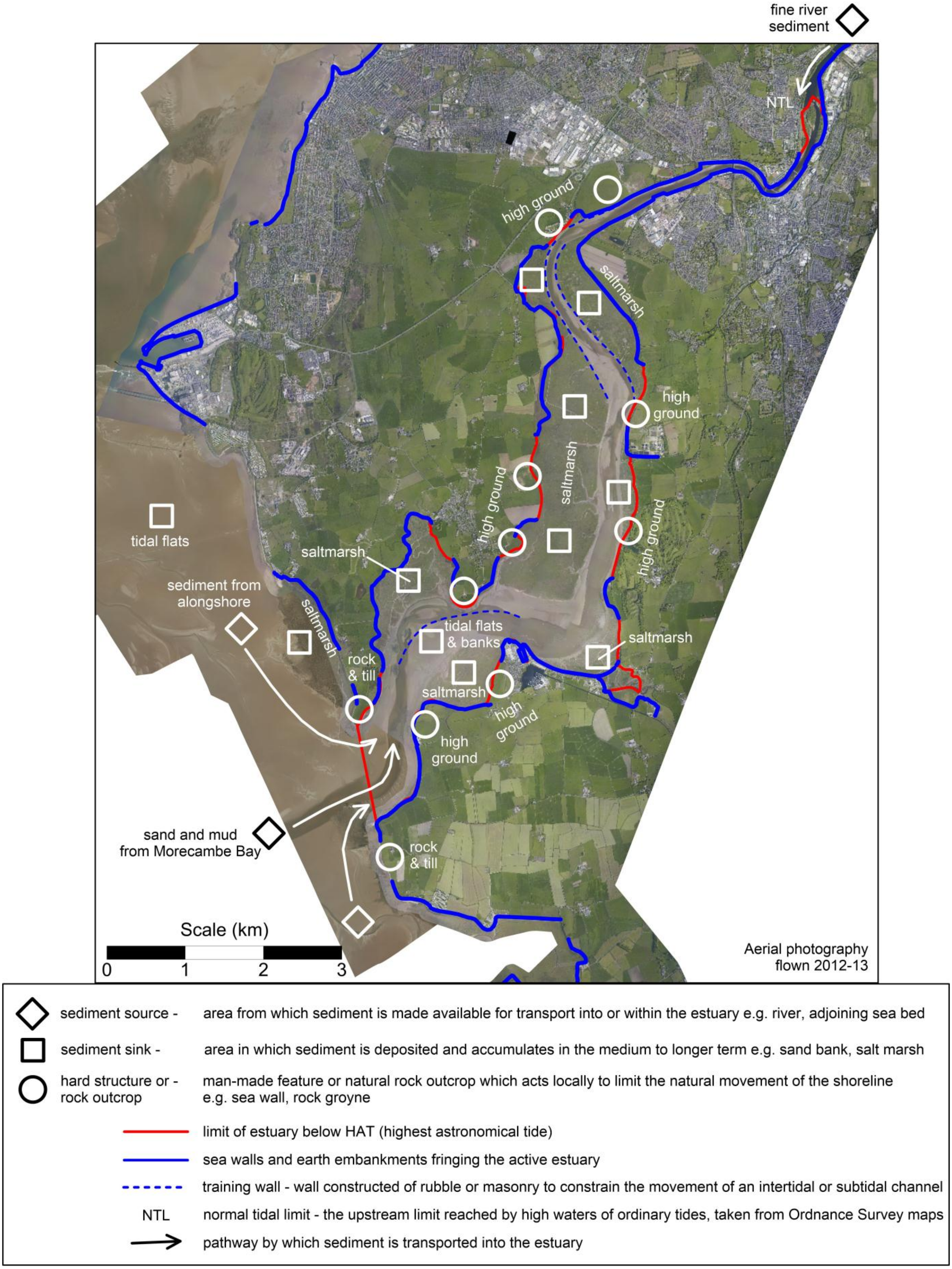

Figure 3.6 Conceptual diagram showing the main sediment sources, geomorphological features and engineering structures which influence the morphology of the Lune estuary.

3.6 Coastal Defences and SMP Policies

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

The long term SMP2 plan for the Lune is to continue to protect infrastructure and the historic city of Lancaster, but other areas would not be defended, allowing occasional inundation and natural evolution. The adopted policies are shown on Figure 3.7.

Both Hold the Line and No Active Intervention policies were assessed for Sunderland village during SMP2 development. A continued hold the line policy along this frontage would not be viable for public funding and as sea levels rise, would not be sustainable in the long term. The recommended no active intervention policy reflects the affordability issue but also allows for a continuation of existing practices to privately maintain local and individual property defences as long as sustainable. At present, the access route to Sunderland village across Lades marsh is cut off on large tides. This will worsen in the future and longer term viability of sustaining Sunderland village itself needs consideration (Halcrow, 2010b).

There is inherent uncertainty about the impact of erosion at Sunderland Point on the wider Lune Estuary, and as such, a Managed Realignment policy will allow the Point to behave as naturally as possible with only limited intervention to reduce the rate of erosion whilst further monitoring is undertaken (Halcrow, 2010b).

The defences south west of Glasson Dock form part of the protection to the extensive flood plain of Cockerham and Thurnham. The SMP2 found that it is going to become increasingly difficult to justify public affordability of maintenance and improvements to the defences to continue to hold the line in the long term. The SMP2 medium and long term policy for the coastal defence to this large flood cell south of the Lune was undecided and could be either Hold the Line or Managed Realignment, subject to further studies prior to the next SMP review. A range of significant realignment opportunities were identified at Cockerham and Thurnham, however, due to the potential extent of realignment and implications on property, heritage, agricultural output, ground water bodies and flows into/out of the Lune estuary, the SMP2 recommended that further studies need to take place to inform the management intent in the medium and long term along these frontages. The Environment Agency has been working closely with the Cockersands Forum Steering Group to progress more detailed assessments of options for the frontage since the SMP2 was published.

Within the middle reaches of the Lune, training walls which once constrained the channel are becoming increasingly ineffective. Consequently, where the channel is now able to meander freely, saltmarsh erosion is occurring. However, as there are limited areas of land or property at risk the SMP2 policy is No Active Intervention in the middle reaches.

The city of Lancaster is located in the inner part of the estuary where there has been significant development on the flood plain (Halcrow, 2010c). There are also large historical land fill sites on both banks of the estuary in the inner estuary. The SMP2 policy in the inner estuary is therefore Hold The Line in all three epochs.

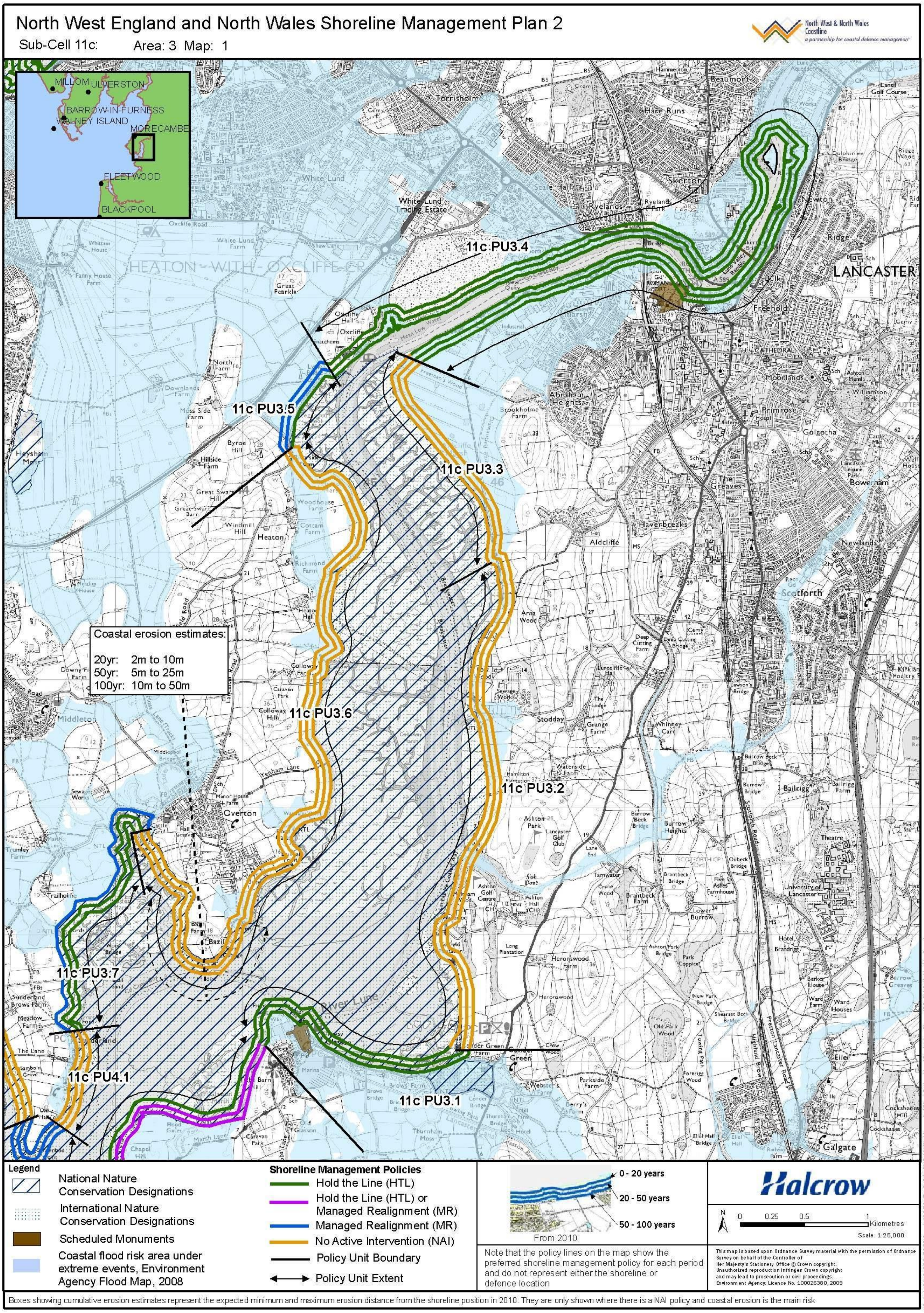

Figure 3.7 Shoreline management policy map for the Lune estuary, Policy Area 11c3. (Source: Halcrow 2010c)

3.7 Existing Monitoring Data

Details of the monitoring data being collected for the Lune 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 available beach profiles, sediment size data and tide gauge 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 north and south banks of the Lune 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).
Monitoring of the position of the seaward edge of saltmarsh areas of foreshore has been carried out bi-annually at five separate locations between the River Lune and Silverdale since 1997.	As above.	CERMS Update Report, Section 2.5.3 (Halcrow, 2010f).
Tide gauge 1 (Glasson Dock), located on the south bank of the estuary towards the mouth. Owned/maintained by EA NW. Data is available from March 2004 to present.	Gauge is part of the EA flood warning network. Gauge dries out so does not capture full tidal range. Useful for monitoring extreme tide levels and for calibrating / verifying models which can then be used for the purpose of modelling hydrodynamics or flood forecasting.	CERMS Update Report, Section 2.4.1 (Halcrow, 2010f). CERMS Tide Gauge Review (Halcrow, 2010g).
Tide gauge 2 (Glasson Saltmarshes, Condor Green), located on the south bank of the estuary towards the mouth. Pressure sensor level gauge operated by EA. The period for which data available is not specified in the CERMS Tide Gauge Review (Halcrow, 2010g).	This gauge is located near to the tidal limit on the Condor where it joins the Lune and is part of the EA flood warning network. Data not reviewed.	CERMS Tide Gauge Review (Halcrow, 2010g).
Tide gauge 3 (Lancaster Quay), located on the south bank of the estuary towards the head of the estuary. Pressure sensor level gauge operated by EA. Digital data is available from 11/2000 to 04/08/2009 (and ongoing).	Gauge is located at an EA flow measurement station and is part of the flood warning network. Flow and level data from selected events potentially useful for calibrating hydrodynamic models and for flood forecasting. Data not reviewed.	CERMS Tide Gauge Review (Halcrow, 2010g).
Tide gauge 4 (Skerton Weir), located towards the head of the estuary. Pressure sensor level gauge operated by EA. Digital data is available from 10/07/2003 06/07/2009 (and ongoing).	Due to location the gauge only records levels of higher tides. It is part of the EA flood warning network. Data from selected events potentially useful for calibrating extreme water levels in hydrodynamic models and for flood forecasting.	CERMS Tide Gauge Review (Halcrow, 2010g).

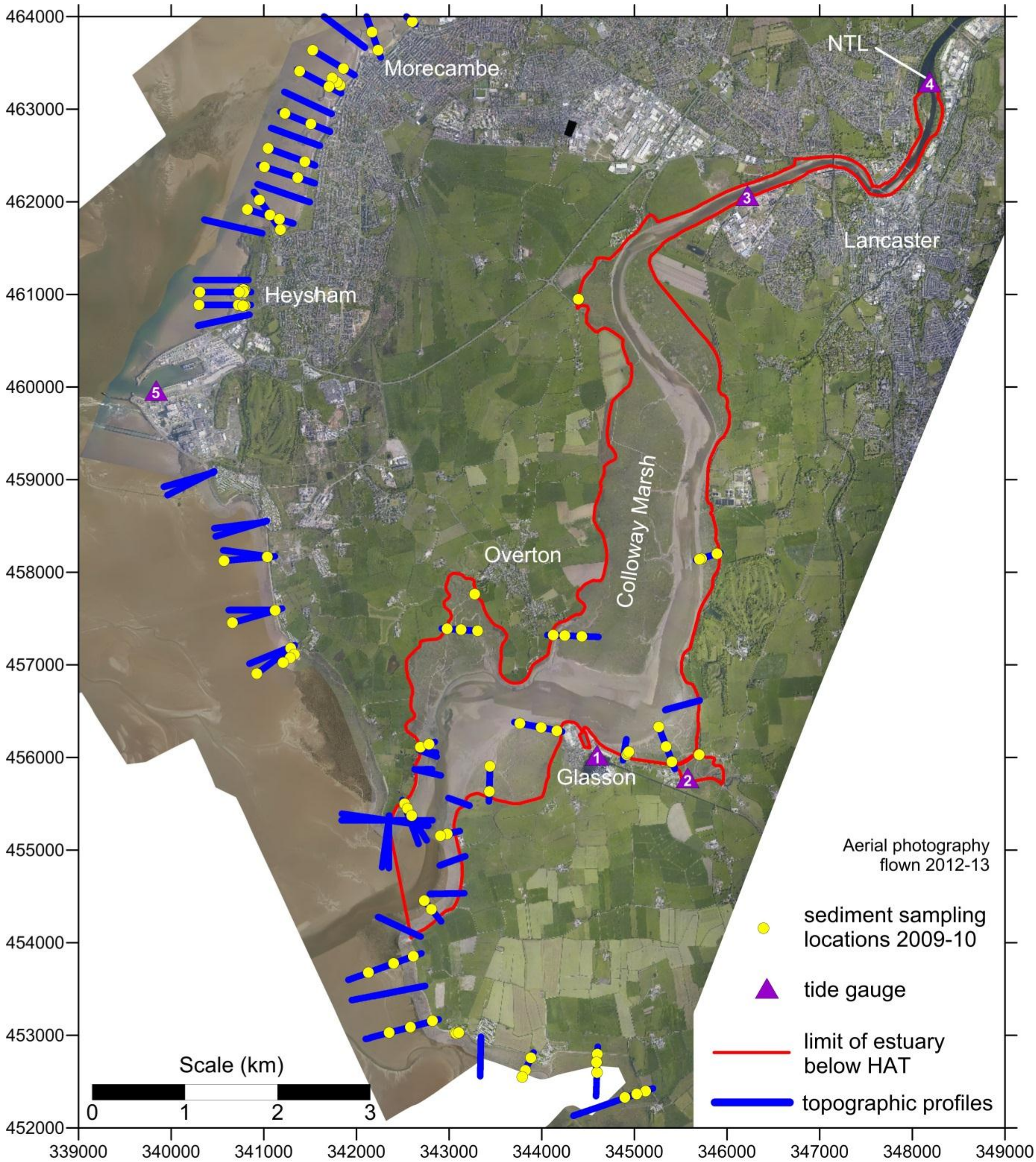

Figure 3.8 Summary of monitoring data available for the Lune Estuary. Water level gauges located at: (1) Glasson Dock (EA); (2) Glasson Saltmarshes, Condor Green; (3) Lancaster Quay; (4) Skerton Weir; and (5) Heysham (Class A Station).

3.8 Gaps in Understanding

A number of previous reports have been 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 Lune 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 Lune 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 Lune is a small estuary with a limited number 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, especially in the middle and inner parts of the estuary. Due to the strong linkages in processes and continuity of habitats between the Lune estuary and the wider Morecambe Bay, plans for studies and monitoring in the Lune should be developed in conjunction with the Leven, Kent and Wyre Estuaries 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; most is derived from records on NFCDD dated between 2005 and 2008, although some relies on oblique aerial imagery from 2008. Defences to the Cockersands flood cell were inspected by Halcrow in 2012 as part of EA work with the Cockersands Forum but have not been undated in the database.	1. Continue to monitor and manage defences on HTL frontages and update defence database to have a consistent data set prior to the next SMP review. (See item 1 in Appendix B). **Urgency – Low** **Importance – medium** **Difficulty – low** **Overall Priority - Low**
Habitat losses and creation The SMP2 has a MR policy in the inner estuary at PU 11c3.5.	(ii) 11c3.5	The SMP2 action plan recommends studies to review viability of MR in the medium or long term between Lythe Bridge and Riverside Farm, east of the A683. This viability study will need updated hydrodynamic and sediment transport modelling.	2. Develop updated or new hydrodynamic and sediment transport model for the Lune to inform viability studies for MR and inform updated strategy. (See item 2 in Appendix B). **Urgency – Low** **Importance – medium** **Difficulty – medium** **Overall Priority - Low**
Coastal and estuary morphodynamics Reliable bathymetry data is not available for setting up detailed models.	Whole estuary	The previous Lune modelling will need updating to inform new modelling to inform a strategy update recommended in the SMP2. This will require updated bathymetry data. There are a small number of topographic profiles in the outer estuary. There	3. Undertake bathymetry survey of channels and LiDAR survey of intertidal areas down to low water, including potential MR sites, e.g. 11c3.5. (required to feed into item 2 in Appendix B). **Urgency – medium** **Importance – medium** **Difficulty – medium** **Overall Priority - medium**
Coastal and estuary morphodynamics Impacts of deterioration of training walls on saltmarsh extent	11c3.7	Anecdotal evidence during SMP2 consultation suggested that the deterioration of the training wall may be related to marine traffic to Glasson Dock and is leading to erosion of Lades Marsh, with implications for nature conservation and the access causeway to Sunderland Village. The SMP2 action plan includes proposals to review the requirements for and responsibility for limited intervention to manage the training wall, which is not considered to be a coastal defence.	4. The previous geomorphological studies undertaken for the Lune strategy (Halcrow, 2004) should be updated to take into account more recent aerial photographic surveys and LiDAR data collection to monitor trends in intertidal habitat as the training walls deteriorate. (see item 3 in Appendix B). **Urgency – medium** **Importance – medium** **Difficulty – medium** **Overall Priority - medium**

Issue	Location	Comments	Recommendations
Coastal and estuary morphodynamics Impacts of deterioration of training walls on saltmarsh extent are uncertain.	11c3.2, 11c3.6	The SMP2 policy for the middle estuary is for NAI. There is extensive saltmarshes in this location that are stabilised by the training walls, which were formerly navigation structures but are disused. There are also isolated property and land at flood risk.	5. Consider risks in more detail including the contribution of the training walls to coastal defence and impacts of their loss on flood risks in the inner estuary and the need for intervention to adapt to the failing walls in a controlled way. (see item 3 in Appendix B) **Urgency – medium** **Importance – medium** **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 2 in Appendix B) **Urgency – medium** **Importance – medium** **Difficulty – low** **Overall Priority - medium**
Data Collection **Tide and current data**	EA tide gauges in Lune.	The CERMS tide gauge review in 2011 only obtained data from the Glasson Dock tide gauge and the level datum was uncertain. The latest data should be obtained. The data (current and sediment data) used for the previous modelling studies should also be collated into the CERMS database.	7. Data from all the EA tide gauges should be obtained and reviewed to ascertain data quality and if possible data for selected extreme events extracted for calibrating hydrodynamic models and improving tidal flood forecasting for Lancaster. New current data collection from at least one location in middle estuary is required to calibrate model. (see items 2, 3 and 4 in Appendix B) **Urgency – high** **Importance – medium** **Difficulty – medium** **Overall Priority - high**

4 Discussion and Conclusions

Within the context of flood and coastal erosion risk management across the Cell 11, the Lune estuary has relatively high risks in relation to assets on the flood plain of the estuary and these are mainly located in the inner estuary. The previous Lune strategy studies were undertaken about 10 years ago, prior to implementation of flood defence schemes at Lower Lancaster and adaptation measures at Sunderland Village. Large lengths of the estuary now have a NAI policy in the SMP2, which recommends more detailed studies and development of an updated long term strategy to assess risks related to the polices and develop actions to put it into practice.

The training walls were constructed for navigation but are now falling into disrepair. These walls stabilised the meandering river and encouraged the growth of saltmarsh. As the walls fail the estuary is likely to return toward a more natural meandering channel alignment, which may have implications for the important conservation sites with areas of saltmarsh erosion and mudflat or new saltmarsh growth. It is unclear if, other than stabilising the saltmarsh, the training walls have any significant FCERM benefits. The need for any intervention with the walls to manage the transition to a more natural state should be considered.

A number of additional studies are recommended to address the gaps in understanding which have been 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 Lune estuary and the south of Morecambe Bay it is recommended that some of the further studies in the Lune, such as sediment sampling and sediment transport modelling, are progressed jointly with other studies in Morecambe Bay.

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Appendix A
Coastal Defences in the Lune Estuary

Appendix A Coastal Defences in the Lune Estuary

This data has been sourced from the SMP2, Policy Areas 11c3 (Halcrow, 2010b)

Location	Defence History	Present Defences	Residual Life – (Do Nothing Scenario) Years	Natural Features	Source and Assumptions
Plover Hill (Plover Scar) National Grid: (342591E 454023N) to (342882E 454274N)	Constructed 1971	Earth embankment with rock facing.	11-20	Scar	NFCDD 2007.
Plover Hill to Abbey Lighthouse Gateway National Grid: (342882E 454274N) to (343040E 454360N)	Originally constructed 1975	Earth embankment.	6-10	Scar	NFCDD 2007.
Abbey Car park to Lighthouse cottage road National Grid: (343040E 454360N) to (343077E 454406N)	Originally constructed 1978	Earth embankment with masonry facing.	6-10	Saltmarsh	NFCDD 2007.
Road to Crook Cottage National Grid: (343077E 454406N) to (343139E 454616N)	Originally constructed 1958	Earth embankment with pre-cast concrete face with road forming a berm.	6-10	Saltmarsh	NFCDD 2007.
Crook Cottage to Crook Farm National Grid: (343139E 454616N) to (343096E 455035N)	Originally constructed 1958	Berm and embankment with masonry slopes, divided by road forming a berm.	6-10	Scar	NFCDD 2007.

Location	Defence History	Present Defences	Residual Life – (Do Nothing Scenario) Years	Natural Features	Source and Assumptions
Crook Farm to Chapel Hill National Grid: (343096E 455035N) to (343070E 455350N)	Original defences date from 1800	Sloping masonry embankment	6-10	Scar	NFCDD 2007 and EA oblique coastal area photos Cell 11.
Chapel Hill to Janson Pool embankment National Grid: (343070E 455350N) to (343140E 455450N)	Original defences date from 1800	Earth embankment	6-10	Scar	NFCDD 2007.
Janson Pool Embankment National Grid: (343140E 455450N) to (343237E 455585N)	Defences date from 1960s	Earth embankment with rock facing.	6-10	Saltmarsh	NFCDD 2007.
Janson Pool Embankment (2) National Grid: (343237E 455585N) to (344014E 455542N)	Defences date from 1960s	Earth embankment	6-10	Saltmarsh	NFCDD 2007.
Caravan park to Industrial estate National Grid: (344014E 455542N) to (344168E 456105N)	Defences date from 1960s	Natural embankment	6-10	Saltmarsh	NFCDD 2007.

Location	Defence History	Present Defences	Residual Life – (Do Nothing Scenario) Years	Natural Features	Source and Assumptions
Industrial estate to sailing club National Grid: (344168E 456105N) to (344194E 456280N)	Unknown	Earth embankment with trees on both faces.	6-10	Saltmarsh	NFCDD 2007.
Sailing club to grain store National Grid: (344194E 456280N) to (344352E 456332N)	Unknown	Stone revetment	6-10	Saltmarsh	NFCDD 2007.
Yacht club to dock gate National Grid: (344352E 456332N) to (344432E 456290N)	Dock and harbour built 1793. Flood wall added at unknown time.	Concrete flood wall	>20		NFCDD 2005.
Glasson dock flood gates National Grid: (344432E 456290N) to (344455E 456292N)	Dock and harbour built 1793. Flood wall added at unknown time.	Steel flood gates	20-50		NFCDD 2005. Residual life estimated from defence condition.
Glasson docks flood wall National Grid: (344455E 456292N) to (344615E 456153N)	Dock and harbour built 1793. Flood wall added at unknown time.	Concrete flood wall	>20		NFCDD 2005.
Glasson docks National Grid: (344615E 456153N) to (344686E 456099N)	Dock and harbour built 1793. Flood wall added at unknown time.	Concrete embankment and wall	>20		NFCDD 2005.

Location	Defence History	Present Defences	Residual Life – (Do Nothing Scenario) Years	Natural Features	Source and Assumptions
Glasson Basin and Lancaster Canal National Grid: (344686E 456099N) to (344969E 455981N)	Unknown	Earth embankment	20-50	Saltmarsh	NFCDD 2005. Residual life estimated from defence condition.
Brows Bridge to Caravan Park National Grid: (344969E 455981N) to (345444E 455928N)	Unknown	Concrete embankment and wall.	>20	Saltmarsh	NFCDD 2005.
Crossing Cottage to start of concrete gate National Grid: (345684E 456111N) to (345564E 456815N)	Unknown	Earth embankment with masonry.	11-20	Saltmarsh	NFCDD 2005.
Small wall to old railway National Grid: (345564E 456815N) to (345595E 457169N)	Unknown	Earth embankment with concrete cladding and masonry crest.	11-20	Saltmarsh	NFCDD 2005.
High Ground to Waterloo Cottage National Grid: (345595E 457169N) to (345711E 457572N)	Unknown	Earth embankment	11-20	Saltmarsh	NFCDD 2005.

Location	Defence History	Present Defences	Residual Life – (Do Nothing Scenario) Years	Natural Features	Source and Assumptions
Waterloo Cottage to Old Railway National Grid: (345711E 457572N) to (345842E 457823N)	Unknown	Earth embankment with masonry wall.	11-20	Saltmarsh	NFCDD 2005.
Old Railway to Aldcliffe Embankment National Grid: (345842E 457823N) to (345928E 460044N)	Unknown	Revetment with seawall	11-20	Saltmarsh	NFCDD 2005.
Railway Crossings Lane to Freemans Wood footpath National Grid: (345928E 460044N) to (345303E 461539N)	Embankment owned by Wildfowlers Association.	Earth embankment. Embankment is private with secondary embankment now built behind.	1-5	Saltmarsh	NFCDD 2005.
Freemans Wood footpath to Marsh Point National Grid: (345303E 461539N) to (345779E 461763N)	Embankment is new and part of Lancaster Quays Scheme	Earth embankment.	>20	Saltmarsh	NFCDD 2007.
Marsh Point depot National Grid: (345779E 461763N) to (345922E 461764N)	Wall is new and part of Lancaster Quays Scheme	Concrete steel piled flood wall	>20	Saltmarsh	NFCDD 2007.

Location	Defence History	Present Defences	Residual Life – (Do Nothing Scenario) Years	Natural Features	Source and Assumptions
Thetis Road, Lune Industrial Estate National Grid: (345922E 461764N) to (346084E 461947N)	Unknown	Concrete steel piled flood wall	>20	Saltmarsh	NFCDD 2007.
New Quay Road, Lune Industrial Estate National Grid: (346084E 461947N) to (346131E 462031N)	Unknown	Earth embankment with concrete wall.	>20	Saltmarsh	NFCDD 2007.
New Quay, Lune Industrial Estate National Grid: (346131E 462031N) to (346298E 462070N)	Unknown	Earth embankment with concrete wall	>20	Mudflats, river channel.	NFCDD 2007.
Factory, Lune Industrial Estate National Grid: (346298E 462070N) to (346653E 462195N)	Unknown	Earth embankment with concrete wall	>20	Saltmarsh	NFCDD 2007.
Marsh Cricket Ground National Grid: (346653E 462195N) to (346847E 462292N)	Unknown	Earth embankment with concrete wall	>20	Saltmarsh	NFCDD 2007.

Location	Defence History	Present Defences	Residual Life – (Do Nothing Scenario) Years	Natural Features	Source and Assumptions
Industrial estate National Grid: (346847E 462292N) to (347049E 462375N)	Unknown	Concrete wall	>20	Saltmarsh	NFCDD 2007.
Industrial estate to Carlisle Bridge National Grid: (347049E 462375N) to (347163E 462371N)	Unknown	Concrete wall	>20	Saltmarsh	NFCDD 2007.
St Georges Quay National Grid: (347163E 462371N) to (347532E 462090N)	Unknown	Earth channel bed with masonry wall lining channel side. Was has some vegetation growth through it. Debris in channel.	11-20	River channel	NFCDD 2007.
Under River Lune footbridge National Grid: (347532E 462090N) to (347566E 462066N)	Unknown	Masonry revetment topped by small vertical masonry wall.	11-20	River channel	NFCDD 2007.
River Lune footbridge to upstream of Skerton Bridge National Grid: (347566E 462066N) to (348039E 462377N)	Unknown	Earth channel bed with masonry wall lining channel side - sloped at toe, then vertical.	11-20	Some saltmarsh vegetation, river channel	NFCDD 2007.

Location	Defence History	Present Defences	Residual Life – (Do Nothing Scenario) Years	Natural Features	Source and Assumptions
Upstream Skerton Bridge to Skerton Weir National Grid: (348039E 462377N) to (348291E 463218N)	Unknown	Earth channel with tree lined embankments	11-20	River channel	NFCDD 2007.
Cow Shard footpath to Skerton Bridge National Grid: (347997E 462589N) to (347896E 462388N)	Unknown	Earth embankment with some masonry facing	11-20	River channel	NFCDD 2007.
Skerton Bridge to end of Earl Street National Grid: (347896E 462388N) to (347837E 462297N)	Unknown	Earth embankment with vertical masonry wall	11-20	River channel	NFCDD 2007.
Derby Road National Grid: (347837E 462297N) to (347631E 462186N)	Unknown	Earth channel bed with vertical masonry wall lining channel side. Was has some vegetation growth through it. Debris in channel.	11-20	River channel	NFCDD 2008.
Ramp under Morecambe Road National Grid: (347631E 462186N) to (347609E 462190N)	Unknown	Earth bed with embankment that runs under foot bridge. Some minor erosion but defence remaining stable.	11-20	River channel	NFCDD 2008.

Location	Defence History	Present Defences	Residual Life – (Do Nothing Scenario) Years	Natural Features	Source and Assumptions
Ramp under Morecambe Road to new footbridge National Grid: (347609E 462190N) to (347570E 462200N)	Unknown	Earth embankment with masonry side. Some erosion to earth bank and debris in channel side.	11-20	River channel and saltmarsh	NFCDD 2008.
New footbridge to Morecambe Road National Grid: (347570E 462200N) to (347208E 462497N)	Unknown	Earth channel with rock armour in places and earth embankment. Erosion to bank in places.	11-20	River channel and saltmarsh	NFCDD 2008.
Carlisle Bridge National Grid: (347208E 462497N) to (347149E 462491N)	Unknown	Earth channel side with vertical masonry wall. Debris in channel.	11-20	River channel and saltmarsh	NFCDD 2008.
Carlisle Bridge to end of Marshaw Road National Grid: (347149E 462491N) to (346866E 462476N)	Unknown	Earth channel with masonry wall	>20	River channel and saltmarsh	NFCDD 2008.
Morecambe Road to end of landfill at Oxcliffe Marsh National Grid: (346866E 462476N) to (345173E 461867N)	N/A	Natural channel	N/A	River channel and saltmarsh	NFCDD 2008.

Location	Defence History	Present Defences	Residual Life – (Do Nothing Scenario) Years	Natural Features	Source and Assumptions
Landfill to ramp on Lancaster Road National Grid: (345173E 461867N) to (345107E 461865N)	Unknown	Earth embankment	>20	River channel and saltmarsh	NFCDD 2007.
Lancaster Road, Oxcliffe Hall Farm National Grid: (345107E 461865N) to (345092E 461858N)	Unknown	Earth embankment with road on crest.	Unknown	River channel and saltmarsh	NFCDD 2007.
Caravan park to ramp on road National Grid: (345091E 461858N) to (344918E 461586N)	N/A	Natural high ground	N/A	Saltmarsh	NFCDD 2005.
Golden Ball pub car park to Riverside caravan park National Grid: (344918E 461586N) to (344857E 461511N)	Unknown	Earth embankment with masonry wall.	11-20	Saltmarsh	NFCDD 2007.
End of wall to Golden Pub car park National Grid: (344857E 461511N) to (344730E 461383N)	Unknown	Earth embankment with localised problem spots.	11-20	Saltmarsh	NFCDD 2007.

Location	Defence History	Present Defences	Residual Life – (Do Nothing Scenario) Years	Natural Features	Source and Assumptions
Moss Road embankment to high ground. National Grid: (344730E 461383N) to (344369E 460923N)	Unknown	Earth embankment with masonry face.	6-10	Saltmarsh	NFCDD 2007.
High Ground to Oxcliffe Embankment National Grid: (344369E 460923N) to (344467E 460753N)	N/A	Natural high ground	N/A	Saltmarsh	NFCDD 2007.
Start of walled embankment to high ground National Grid: (344467E 460753N) to (344682E 460639N)	Unknown	Masonry walled embankment. Some problems with wall integrity.	10-20	Saltmarsh	NFCDD 2007. Residual life estimated from defence condition.
High ground to start of walled embankment National Grid: (344682E 460639N) to (344751E 459855N)	N/A	Natural high ground.	N/A	Saltmarsh	NFCDD 2007.
Heaton Hall Farm Embankment to High Ground National Grid: (344751E 459855N) to (344695E 459468N)	Unknown	Earth embankment. Needs monitoring of crest problems.	6-10	Saltmarsh	NFCDD 2007.

Location	Defence History	Present Defences	Residual Life – (Do Nothing Scenario) Years	Natural Features	Source and Assumptions
High ground to start of Heaton Farm Embankment National Grid: (344695E 459468N) to (344597E 457915N)	Unknown	Earth embankment.	11-20	Saltmarsh	NFCDD 2007.
Start of Dunnal Point Embankment to High Ground National Grid: (344597E 457915N) to (344382E 457731N)	Unknown	Earth embankment. Some concerns about condition of embankment.	10-20	Saltmarsh	NFCDD 2007. Residual life estimated from defence condition.
60m upstream 2nd house to start of embankment Dunnal Point National Grid: (344382E 457731N) to (343955E 457037N)	Unknown	Earth embankment with rock facing. Some sections in poor condition.	10-20	Saltmarsh	NFCDD 2007. Residual life estimated from defence condition.
Ferry Cottage to end of wall National Grid: (343955E 457037N) to (343856E 456888N)	Unknown	Masonry wall with high ground behind.	11-20	Saltmarsh	NFCDD 2007.
Bazil Point to Ferry Cottage National Grid: (343856E 456888N) to (343551E 456951N)	N/A	Natural high ground. Some areas of deterioration.	N/A	Saltmarsh	NFCDD 2007.

Location	Defence History	Present Defences	Residual Life – (Do Nothing Scenario) Years	Natural Features	Source and Assumptions
Embankment National Grid: (343551E 456951N) to (343572E 457404N)	Unknown	Earth embankment	>20	Saltmarsh	NFCDD 2007.
Globe Hotel to start of embankment National Grid: (343572E 457404N) to (343279E 457892N)	Unknown	Earth embankment	6-10	Saltmarsh	NFCDD 2007.
Ramp of Globe Hotel to start of wall on backside of embankment National Grid: (343279E 457892N) to (343099E 457987N)	Unknown	Earth embankment supported by rock armour.	>20	Saltmarsh	NFCDD 2006.
Start of wall on bankside of embankment to end of wall National Grid: (343099E 457987N) to (342959E 457831N)	Unknown	Earth embankment with rock armour seaward face and masonry landward face.	>20	Saltmarsh	NFCDD 2006.
Start of secondary defence to Sunderland Point National Grid: (342959E 457831N) to (342632E 456229N)	Unknown	Earth embankment with concrete sea wall blocks on front face. Vegetation between blocks needs clearing.	11-20	Saltmarsh	NFCDD 2006.

Location	Defence History	Present Defences	Residual Life – (Do Nothing Scenario) Years	Natural Features	Source and Assumptions
Sunderland Village National Grid: (342632E 456229N) to (342640E 455700N)	Unknown	Vertical concrete/block wall	>5	Shingle/Cobble beach	Defences interpreted from EA oblique coastal area photos Cell 11.
Old Hall National Grid: (342640E 455700N) to (342460E 455500N)	Unknown defences look relatively new	Rock armour revetment with concrete groynes.	>20	Shingle/Cobble beach	Defences interpreted from EA oblique coastal area photos Cell 11.
Sunderland Point (Hall End Scar) National Grid: (342632E 456229N) to (342329E 455290N)	N/A	Natural high ground with lots of erosion.	N/A	Saltmarsh	NFCDD 2005.

Appendix B
Recommendations for further studies

Appendix B Recommended further studies for the Lune 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. Also collate data from inspections of the Cockersands defences undertaken by Halcrow in 2012. 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 / or AIMS.	Estimated cost £10 to £15k, assuming packaged with other similar work on defences in other estuaries or adjacent parts of Morecambe Bay. Priority – medium - needed to feed into MR viability studies and strategy.
2. Improve understanding of sediment pathways and linkages. [Combined study with other Morecambe bay estuaries]	Study to be led by Sefton or Lancaster CC or EA. Plan and implement a sediment sampling campaign, for the Lune 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 Lune estuary and include the flood plain to allow for future MR studies (or use / develop similar model). Calibrate model using water level data from EA tide gauges and current data collected under 4 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 - Sediment data collection and analysis £5 - 10k? Priority – medium in isolation, but High if a Bay or Cell- wide sediment provenance and transport pathway study is to be undertaken Estimated cost of model update, calibration and baseline runs £50k - £90k? Needs to be undertaken in combination with / before modelling in item 3. Priority – High. Needed before MR viability studies and for modelling in item 3.
3. Updated geomorphological study for Lune estuary. [Combine with or undertake after sediment pathway study in item 2.]	Study could be led by LCC, NE, EA or Sefton. The aim is to provide and updated coastal and estuary process study to inform future management of coastal defences and the strategy for implementing the policies in the SMP2. It will also inform a future Habitats Regulations Assessment for the strategy. Update previous studies of historical morphological change in the Lune using LiDAR data and aerial photography collected since 2004. Include estimates of rates of historical saltmarsh and intertidal mudflat growth and vertical accretion. Review changes to the training walls and the impacts on saltmarsh extent over the past 10 years.	Estimated cost £75k to £120k. Could be packaged with parts of pathways study in item 2 with combined modelling study. Priority – medium, SMP action plan recommends start on strategy in 2015/16.

Recommended study (See Table 3.3)	Outline scope	Outline cost estimate and priority
	Using updated model developed in item 2 above, undertake model runs and associated expert geomorphological assessment to assess impacts on the estuary of possible MR site at PU11c3.5 and failure of training walls. Develop new estimates of future change including gains and losses of habitats and assess implications of future estuary evolution related to the implementation of the NAI and MR policies in the SMP2 in combination with sea level rise. Assess implications of training wall deterioration on balance of habitats and erosion risks in the estuary to inform consideration in the strategy of the need for intervention to encourage controlled adaptation and any future monitoring requirements for the training walls.	
4. Tide and current data collection and review	Obtain and review data from all the EA tide gauges to ascertain data quality and if possible extract data for selected extreme events for calibrating hydrodynamic models. Review data that may be available from previous data collection campaigns, for previous model development for the earlier strategy and if suitable collate into CERMS database. Collect new tidal current data for at least a spring neap cycle, preferably concurrent with LiDAR and bathymetry surveys for at least one location in mid estuary.	Estimated cost of data review £5k to £10k Estimated cost of new data collection £5k to £10k, assuming undertaken in conjunction with other data collection. Priority – High – needed before modelling in item 3 above.