North West Estuaries Processes Reports

Ravenglass Estuary Complex

Prepared for
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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.

Term	Definition
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 Ravenglass Estuary Complex is located on the Cumbrian coast in sub-cell 11d which extends from Hodbarrow Point, Haverigg to St Bees Head. The Estuary encompasses Policy Units 11d PU2.2 though to 11d PU4.1, including the spits to the north and south, and forms part of the Drigg coast SSSI and the Drigg Coast SAC. The limits of the estuary can be defined by a line between northern end of Eskmeals dunes and Drigg Point and the normal tidal limits at Hinning House Bridge on the River Esk, Muncaster Mill on the Mite and Drigg Holme on the Irt. All three rivers drain rural highland areas around Scafell Pike.

The mouth of the composite estuary is now relatively narrow (c. 500 m) owing to southward extension of the Drigg Spit and northwards extension of the Eskmeals Dunes spit since Roman times, when Ravenglass was an important staging post.

The SMP2 estimated that there would be less than 100 residential and around 10 non-residential properties along with nearly 500ha of agricultural land at risk in the long term for a No Active Intervention (Do Nothing) approach to flood and erosion risk management. There is also the coastal railway line infrastructure within the long term risk area and the Drigg low level waste respository is located adjacent to the estuary.

The Estuary is macro-tidal, with a mean spring tidal range of over 7m. The estuary has relatively high tidal discharges and velocities relative to its size, but the rivers that feed into it have relatively small discharges. There is a gradation from sandy sediments at the mouth of the estuary to muds near the limits of tidal influence. Most shorelines within the estuary are sheltered from wave action due to the protection afforded by the two spits.

Littoral sediment transport on the open coast to the south of the estuary is northerly, while on the northern side of the estuary it is southerly. The estuary entrance is therefore a zone of sediment convergence. A small ebb-tide delta at the mouth of the estuary affords some protection to the shore and provides a source of aeolian sand for the dune systems on either side of the mouth. However, sediment supply from offshore is limited and the estuary acts only as a weak sediment sink (mainly for fine-grained sediment). The estuary contains significant areas of saltmarsh which experienced a significant increase in area following construction of the railway viaducts in the 19th century. At the present time there are localised areas of marsh edge erosion and accretion which reflect patterns of change in the low water channels. The estuary at present is close to a state of dynamic equilibrium. Its future evolution will depend upon the balance between sea level rise and sediment availability. There are significant lengths of unprotected glacial till cliffs and sand dunes on the coast both to the north and south of the estuary mouth, although rates of cliff recession and longshore sediment drift have been low in recent decades. An acceleration in the rate of erosion in future years would be likely to provide sufficient sediment to allow the estuary to keep pace with sea level rise.

The long term plan in the SMP2 is to allow the natural behaviour of Rivers Esk, Mite and Irt to continue without further intervention and to promote a naturally functioning system which will maintain natural habitats. Management of flood risk to Ravenglass village will continue although a limited number of properties, access roads and tourism assets will be at increased risk of flooding in future and may need to be abandoned in the long term.

Existing monitoring within CERMS mainly involves beach and bathymetric profiles around the estuary mouth and near Ravenglass village, aerial photography and LiDAR. No bathymetric surveys of the sub-tidal area within the estuary have been undertaken, and sediment sampling has been limited. No tide gauge or other water level data are currently available for the estuary.

It is recommended that steps should be taken to incorporate the results of Drigg Low Level Waste Repository coastal change monitoring within CERMS, and that future monitoring should aim to fill remaining gaps. However, in view of the small size of the estuary, the steeply sloping hinterland and limited built assets at risk in terms of flood and coastal erosion risk management, the Ravenglass complex is rated as lowest priority of the NW estuaries for additional monitoring and further studies.

1 Introduction

This report summarises the existing understanding of the Ravenglass Estuary Complex, see Figure 1.1 for location. It draws on information from the second round Shoreline Management Plan (SMP2), 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. The location of the SMP sub-cells is shown on Figure 2.1.

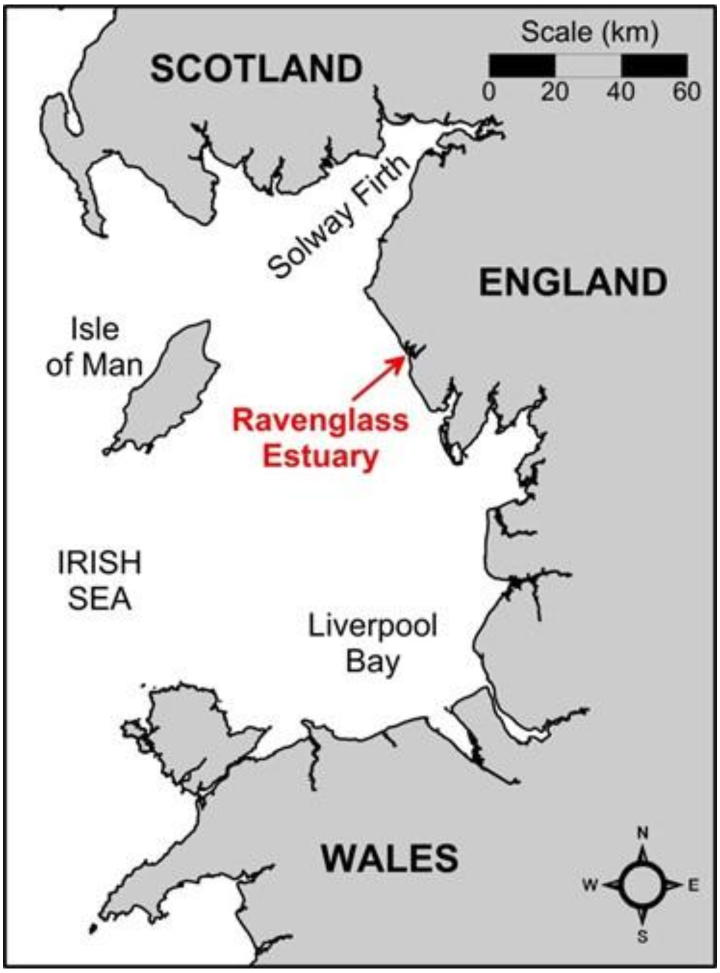

Figure 1.1 Location of the Ravenglass Estuary

2 Coastal Setting

The Ravenglass Estuary Complex is located on the Cumbrian coast in sub-cell 11d of the SMP2. Subcell 11d extends from Hodbarrow Point, Haverigg to St Bees Head, see Figure 2.1. The Ravenglass Estuary encompassing Policy Units 11d PU2.2 though to 11d PU4.1, including the spits to the north and south.

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

Three rivers flow into the estuary, the Irt, Mite and Esk. All three rivers drain rural highland areas around Scafell Pike, see Figure 2.2.

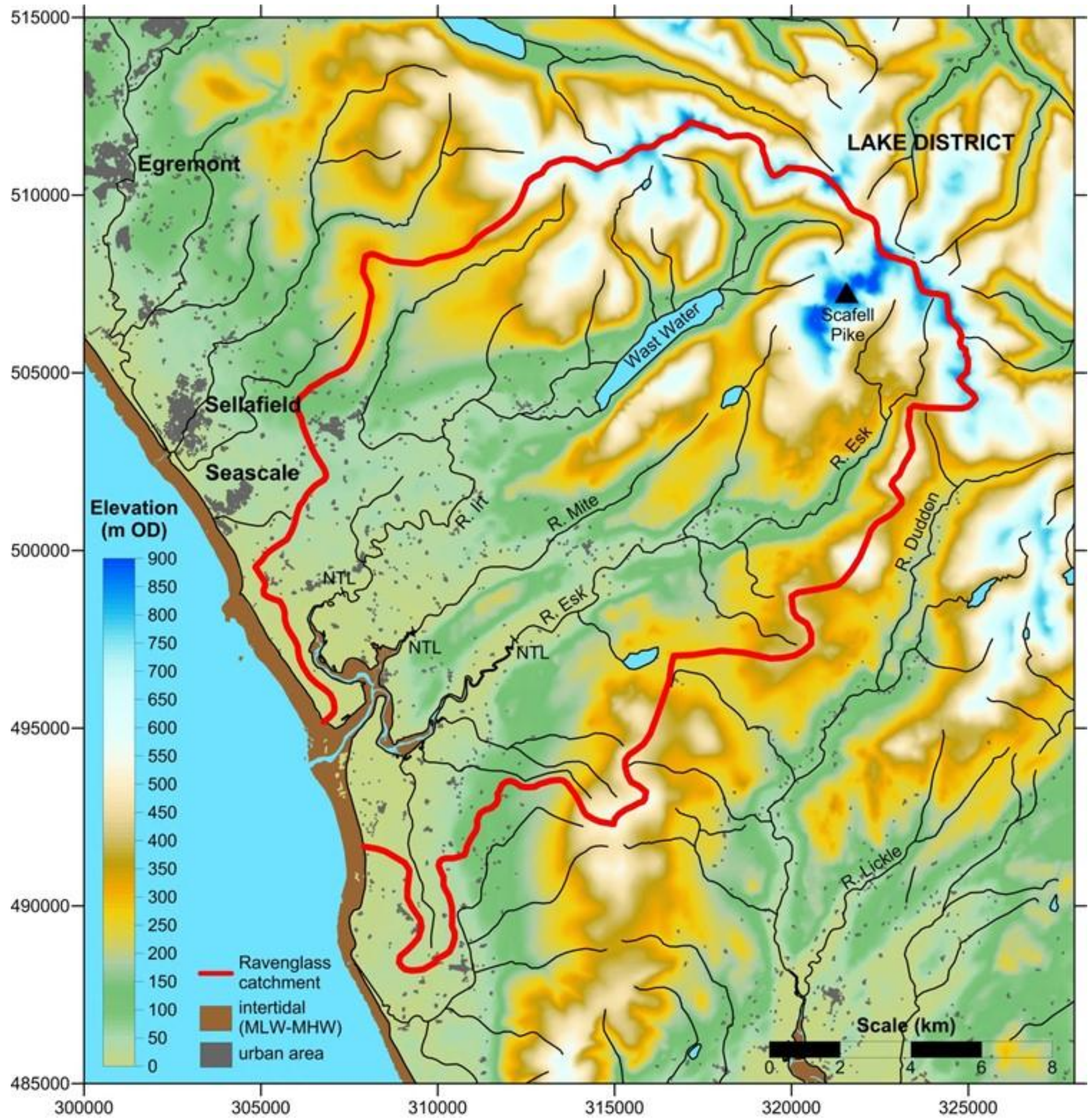

Figure 2.2 The catchment of the Rivers Irt, Mite and Esk rivers which flow into the Ravenglass Estuary, showing the main urban areas and general extent of the intertidal zone. Source: adapted from Ordnance Survey Open Data, after Pye and Blott, 2013).

3 Estuary Review

3.1 Description

The estuary can be considered to extend from its mouth, defined by a line between northern end of Eskmeals dunes and Drigg Point to the normal tidal limit at Hinning House Bridge on the River Esk, Muncaster Mill on the Mite and Drigg Holme on the Irt (Halcrow, 2010d; Figure 3.1).

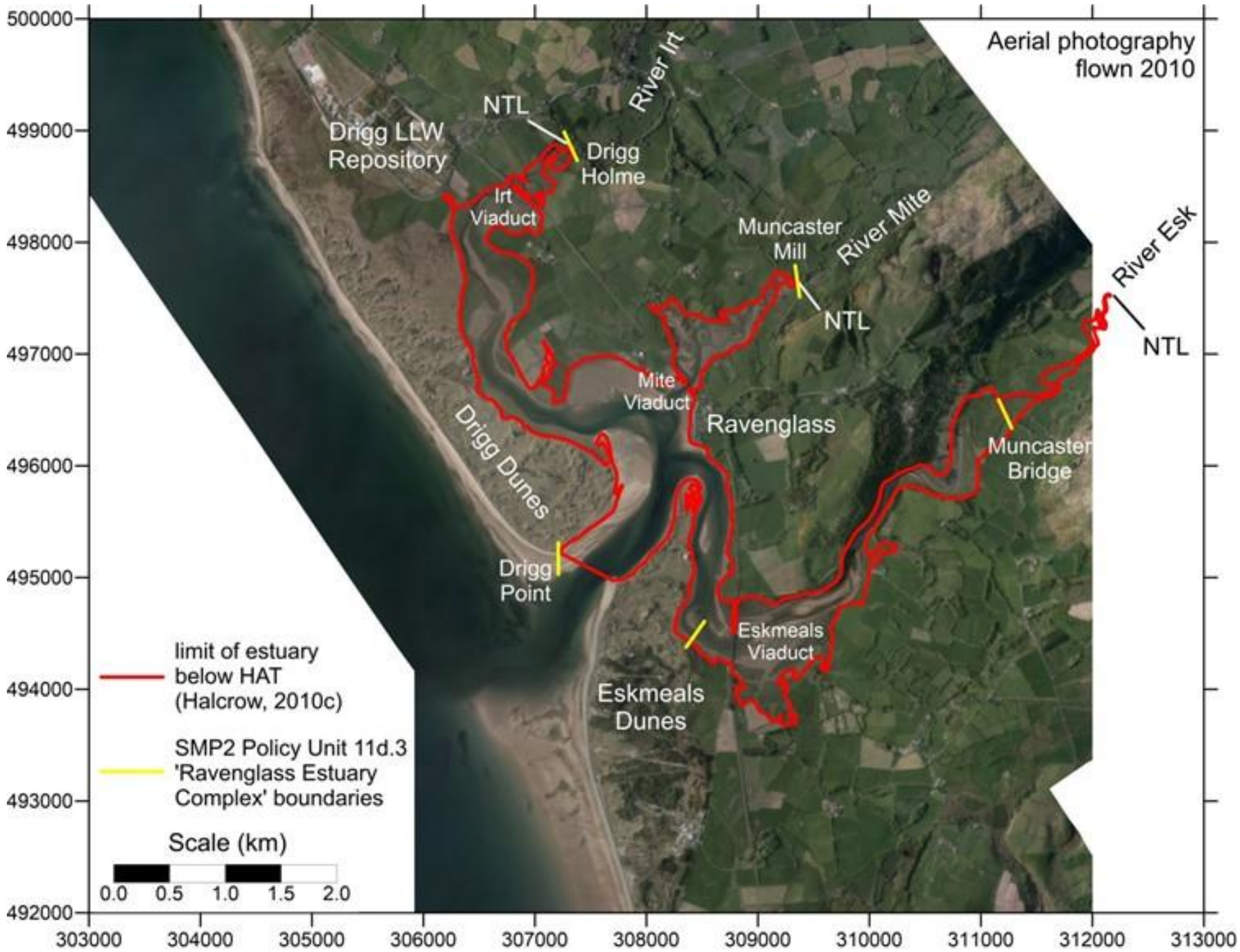

Figure 3.1. Limits of the Ravenglass Estuary and SMP2 Policy Unit 11d.3.

The Ravenglass Estuary Complex incorporates three rivers; the Mite, the Irt and the Esk. These three rivers join at a single point of confluence, which currently lies just offshore of Ravenglass village. A single channel then connects the confluence of the three rivers to the sea. The rivers flow into the estuary across a steep hinterland, which limits the tidal intrusion into these rivers and therefore reduces the tidal power of the estuary complex (Halcrow, 2010b).

The mouth of the composite estuary is now relatively narrow (c. 500 m) owing to southward extension of the Drigg Spit and northwards extension of the Eskmeals Dunes spit since Roman times, when Ravenglass was an important staging post. Today the village of Ravenglass is fronted by an erosional glacial till platform (Halcrow, 2010d).

The estuary forms part of the Drigg coast SSSI and the Drigg Coast SAC (Figure 3.2).

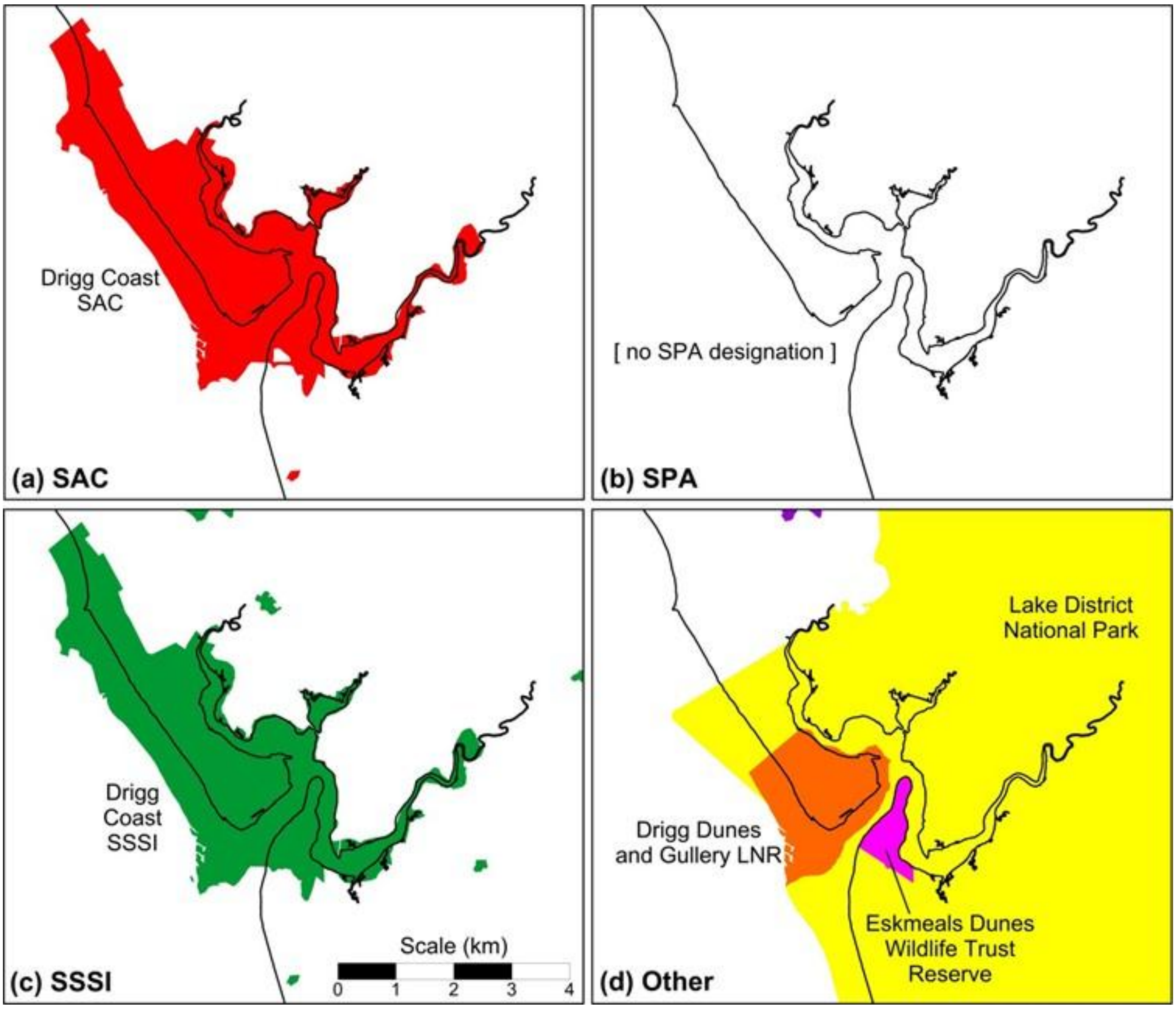

Figure 3.2. Nature conservation designations and reserves in and surrounding the Ravenglass Estuary.

The shoreline management plan (SMP2) estimated that there would be less than 100 residential and around 10 non-residential properties along with nearly 500ha of agricultural land at risk in the long term for a No Active Intervention (Do Nothing) approach to flood and erosion risk management. There is also the coastal railway line infrastructure within the long term risk area and the Drigg disposal site is in the dune system adjacent to the estuary.

3.2 Coastal Processes

The Ravenglass Estuary is a macro-tidal estuary, with a tidal range of over 7m on spring tides. According to Admiralty tidal tables for Tarn Point, south of Eskmeals, MHWN tides reach 2.1m, MHWS tides reach 4.0m and HAT tides reach 5.1m (Halcrow, 2010d), see Table 3.2.

Table 3.1 Tidal levels at Tarn Point, near the mouth of the Ravenglass Estuary. Chart Datum conversions have been taken from St Bees Head to Earnse Point SMP (1998). Source: Admiralty Tide Tables (2012)

	LAT	MLWS	MLWN	MSL	MHWN	MHWS	HAT
Tarn Point	nd	-3.40	-1.80	nd	2.10	4.00	5.00

The estuary has relatively high tidal discharges and velocities relative to its size (Junk-Suk, 1999), but the rivers that feed into it have relatively low discharges (Assinder *et al.,* 1985). The estuary largely empties of water at low tide. There is a gradation from sandy sediments at the mouth of the estuary to fine muds at the limit of tidal influence within the estuary. Relatively coarse sediments (sands and gravels) dominate the surface sediments in the lower reaches, extending upstream as far as the Newbiggin viaduct on the Esk, the Mite viaduct and Saltcoats on the Irt. In the middle reaches, coarse sediments in and adjacent to the low water mark are bordered by broad lateral banks of fine grained deposits. In the upper reaches, these fine grained sediments occupy most of the area (Bousher, 1999; Halcrow, 2010b). Samples taken from the upper and mid intertidal zone in the mid part of the estuary as part of a CERMS survey in 2009-10 (see monitoring figure for locations) were mainly sandy gravels, sands and muddy sands (Pye *et al*., 2010 – Figure 3.4).

Littoral and subtidal net annual sediment transport vectors based on numerical modelling are shown in Figure 3.3 (Halcrow, 2010c). Transport in this region is dominated by net tidal transport from the northwest towards the southeast. This transport is stronger offshore and diminishes in magnitude towards the Cumbrian coast. The littoral sediment transport on the northern side of the Duddon Estuary is towards the south and towards the estuary mouth. Further north, the transport direction changes and is in a northerly direction all the way to the Ravenglass Estuary Complex. On the northern side of this estuary there is southerly directed transport towards the estuary along a spit, which is a zone of sediment convergence.

The average net potential transport rate along the coastline from Seascale to Braystones is variable in terms of directionality, see Figure 3.3 (Halcrow, 2010c), which is probably due to this coast being aligned nearly perpendicular to the mean wave direction. Moving towards St Bees Head the transport rates increase in a northerly direction although St Bees Head will act as a littoral boundary. Further north the transport is in a northerly direction and therefore St Bees Head acts as a littoral boundary rather a sediment convergence zone (Halcrow, 2010c).

There is a small ebb-tide delta at the mouth of the estuary which affords some protection to the shorelines immediately on either side of the mouth. The area of influence is believed to span up to approximately 3km, protecting both the Drigg and Eskmeal dune systems. The delta is also likely to provide a source of sand for aeolian transport into the dune systems (Halcrow, 2010b). The 2010 aerial photograph shows a larger intertidal 'spit' opposite the southern and central parts of Eskmeals dunes, and a smaller intertidal 'spit' opposite Drigg Point. - see estuary limits figure. Sediment therefore seems to converge on the estuary mouth from both directions, but most importantly from the south, as also indicated from the littoral transport modelling undertaken during the CETaSS work, see Figure 3.3.

The characteristics of the Ravenglass Estuary suggest that it is a weak sink for sand and mud (Halcrow, 2002). The rivers are not a significant contributor of sediment to the estuary system (Bousher, 1999). There is also not thought to be a general onshore movement of sand or coarser sediment from further offshore, therefore reworking of the cliff and beach deposits along the open coast is likely to be the primary supply of sediment. The modelling of sediment transport under storm surge conditions undertaken in CETaSS (Halcrow 2010h) showed local onshore transport at Tarn Point to the south with an anticlockwise gyre in the bay to the north in front of the Eskmeals dunes. At a larger scale, open coast littoral transport within the North Eastern Irish Sea tends to be northwards but at low rates, although at the mouth of the Ravenglass Estuary the growth of the two spits illustrates that littoral drift is towards the estuary, probably as a result of sediment circulation within the outer banks (Halcrow, 2010b, see Figure 3.3).

A survey carried out as part of CERMS in 2009-10 showed a wide range of sediment textural types ranging from sandy gravel to silty sand (Pye *et al*., 2010; Figure 3.4).

Most shorelines within the estuary are sheltered from wave action. The estuary is also only exposed to storms from the south-west due to the orientation of the mouth and the protection afforded by the two spits (Halcrow, 2010b).

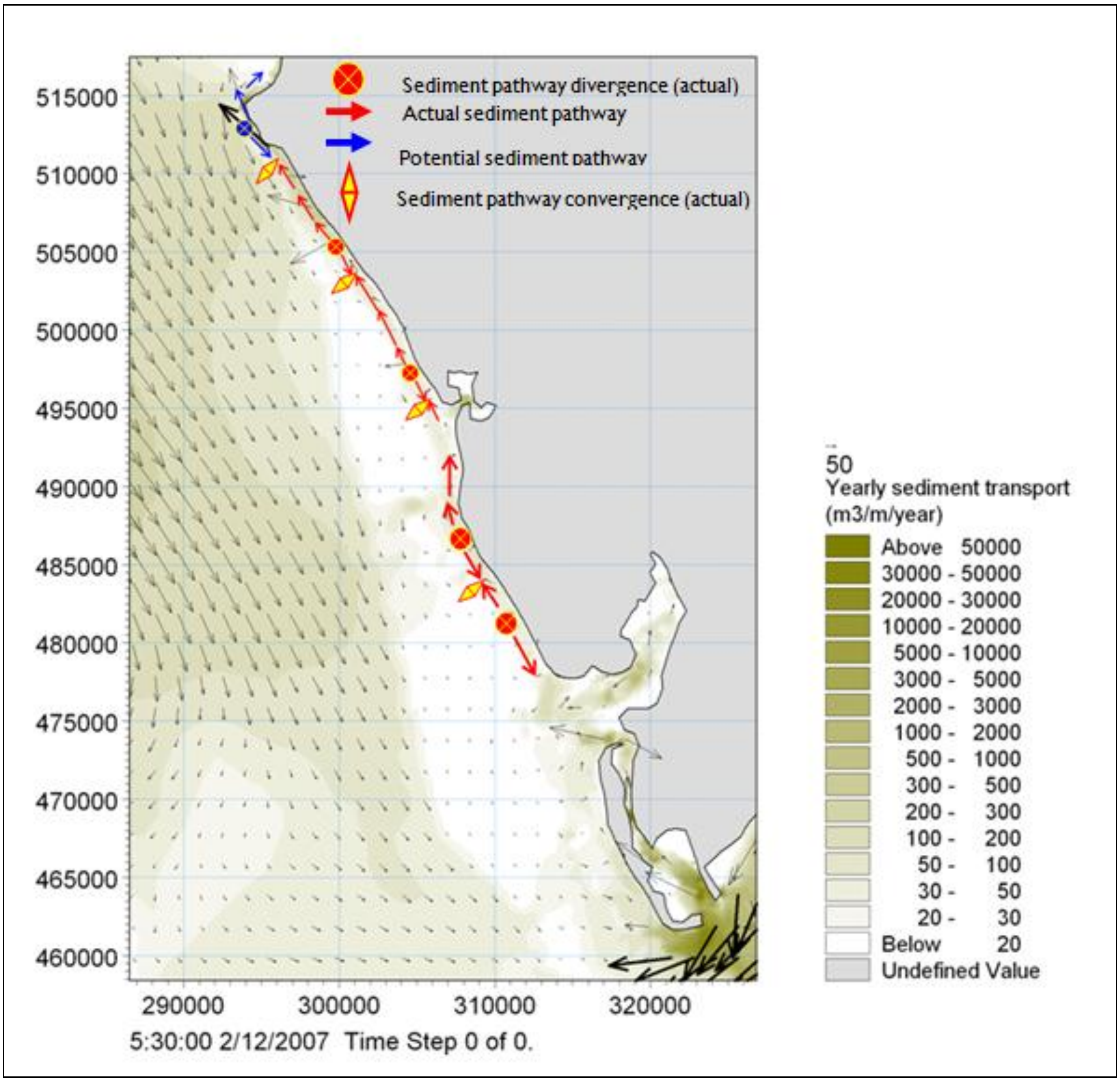

Figure 3.3 Map showing sediment transport in the vicinity of Ravenglass Estuary Complex (from Halcrow, 2010c).

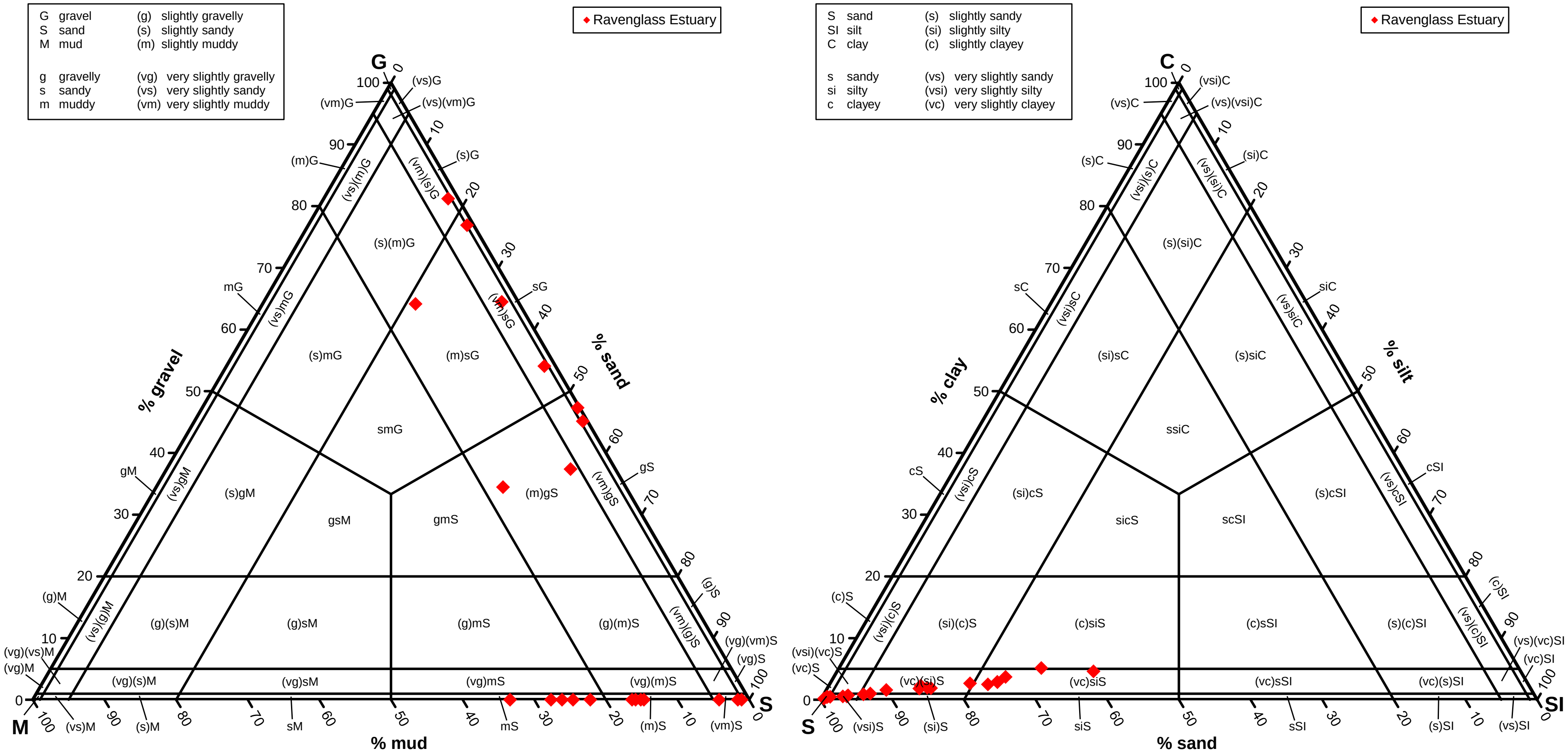

Figure 3.4 Gravel-Sand-Mud and Sand-Silt-Clay trigons, based on the classification of Blott and Pye (2012), for sediment samples collected within the Ravenglass Estuary in 2009-10 (data from Pye et al., 2010).

3.3 Past changes

The very long term evolution of the Cumbrian coastline has been dominated by glacial processes and the post-glaciation changes in relative sea levels. As the glaciers retreated, a complex suite of sediment was laid down in vast quantities, both onshore and offshore which has subsequently been reworked (Halcrow, 2010b). A recent paper by Lloyd *et al.* (2012) investigated sea level changes in the Ravenglass estuary and identified the following pattern:

- Lateglacial sea-level high-stand of approximately 2.3 m OD around 15–17,000 BP,
- a rapid relative sea level fall to -5 m OD to the start of the Holocene,
- a rapid rise during the early Holocene culminating in a mid-Holocene high-stand of about 1 m OD around 6,000 BP and
- a gradual fall in relative sea level to the present day.

The Ravenglass Estuary was formed through the submergence of the Irt, Mite and Esk channels, following the over-deepening of these valleys during the last glaciation. A map dating from the 1600s (Speed, 1995) suggests that at this time the rivers discharged separately, although there is some doubt about the accuracy of this information. Subsurface investigations recently undertaken along Drigg spit suggest that all of the northern half of the Drigg promontory is underlain by a ridge of till that determines the path of the Irt; only the southern half is a true spit, formed from prograding gravel ridges capped with dunes (Fish et al., 2010). Similarly, based on undated erosion surfaces, it has been postulated that the position of the coast during the Holocene lay over a kilometre seaward of its current position, with the three rivers discharging separately to the sea (Kelly and Emptage, 1992). Reworking of the glacial sediments resulted in the development of opposing spits, which led to the diversion of the Esk and affected the route of the Irt, resulting in the three rivers combining. However, based on the information presented in Lloyd et al. (2012), the timing of this is uncertain. It is thought that a more recent period of aeolian activity that occurred in the last c. 1,000 years resulted in the development of the Drigg and Eskmeal dune systems that sit on top of the two spits (Lloyd et al, 2012, 2005).

Ravenglass was for centuries a significant port. The Romans settled in the area in 78 AD, and for three centuries 'Glennaventa' was garrisoned by upwards of 500 Roman soldiers. It remained a significant port up until the industrial age, shipping out the copper, iron ore, slate and granite mined in the area. As the port gradually silted up, it became less important (Halcrow, 2010b). Recent radiocarbon dating of the saltmarshes in the Ravenglass Estuary complex by Lloyd et al (2012) suggests they formed through the Holocene, as sea-levels rose to reach near-present levels. The data indicates sea-level has been close to present for c. 6,000 years (ie. since the mid-Holocene highstand), suggesting the marshes have developed progressively since that time. In more recent times, it is thougt that the construction of the railway viaducts has led to localised increases in the area of marsh (Kelly and Emptage, 1992).

More recently there has been a slow increase in elevation of the saltmarshes and mudflats within the Ravenglass Estuary (Halcrow, 2010b).

Bousher (1999) estimated that about 18% of the estuary was undergoing erosion and reworking (based on work by Kelly and Emptage, 1992). The report concluded that reworking of the lower banks took place on time-scales of tens of years, whereas the upper banks tended to be reworked on timescales of hundreds of years. This study also concluded that at the time of reporting, bank erosion was very localised, although rates of bank retreat in these areas could be high, e.g. 14 m over 14 years. Bousher (1999) reported that sediments are accumulating in parts of the upper intertidal around the estuary (Halcrow, 2010b).

Following construction of the railway, there was accretion and subsequent reclamation in the inner reaches of the estuary. Changes to the cross-sectional area of the estuary may have influenced tidal exchange velocities passing in and out of the estuary and thus resulted in changes along the shoreline along the Drigg and Eskmeal frontages (Halcrow, 2010b).

3.4 Future Behaviour

The estuary is in a state of dynamic equilibrium with the import of sediment on flood tides being balanced by the export on ebb tides (Futurecoast, 2010b). The evolution of the estuary complex as a whole over the next century will depend upon the balance between sea level rise and sediment availability. There are significant lengths of unprotected glacial till cliffs and sand dunes both to the north and south of the estuary mouth, although rates of cliff recession and longshore sediment drift have been low in recent decades (Merrit and Auton, 2000; Moore *et al*., 2003). However, any acceleration in the rate of erosion in future years would be likely to provide sufficient sediment to allow the estuary to keep pace with sea level rise. Local differences in saltmarsh accretion and erosion patterns are likely within the estuary due to the effects of engineering structures on local hydrodynamics (Halcrow, 2010d).

3.5 Conceptual Model of Estuary Behaviour

A conceptual model for the Cell 11d 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 Ravenglass estuary complex and is shown in Figure 3.6 below.

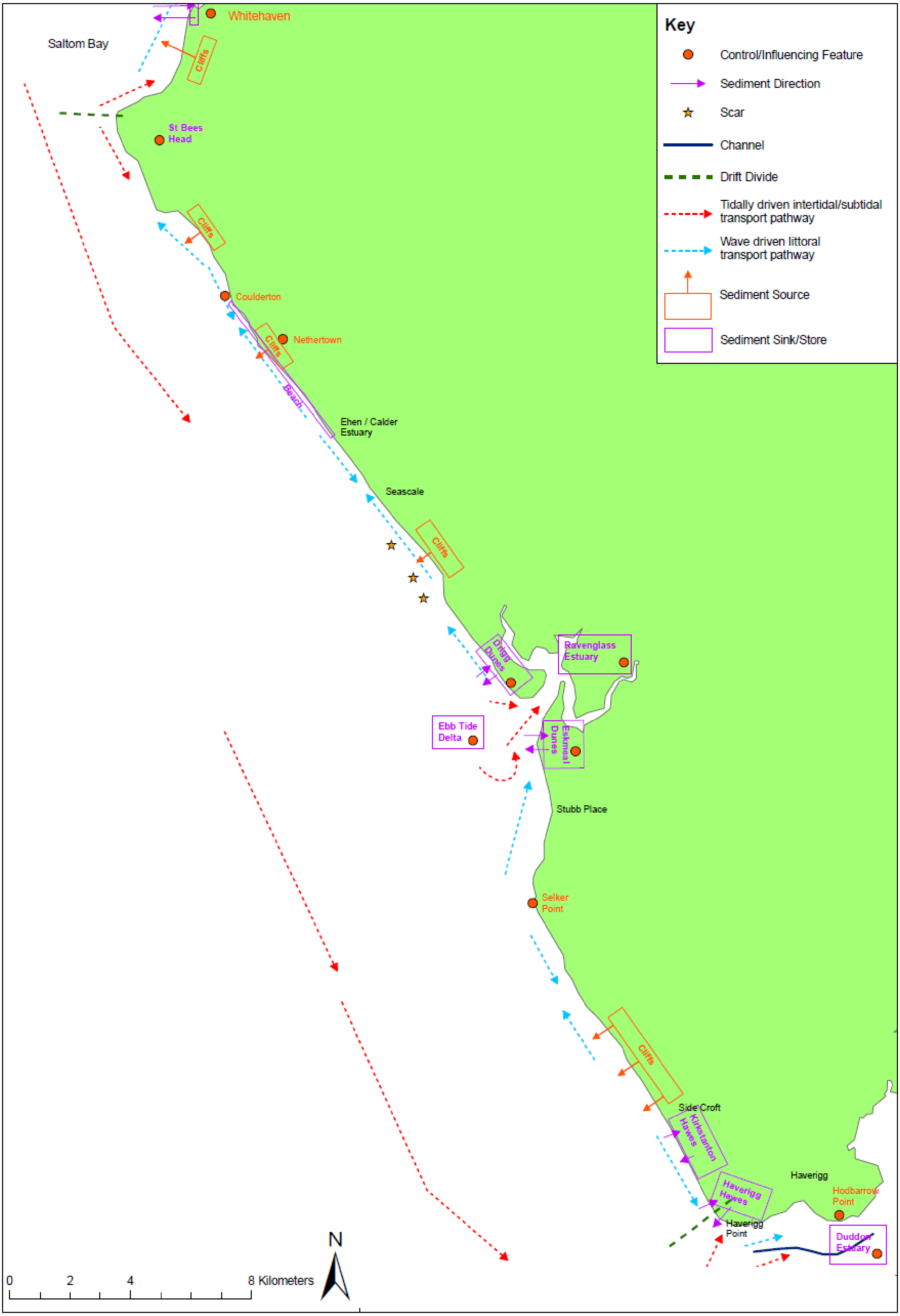

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Figure 3.5 A simple conceptual model for Sub Cell 11d (Halcrow, 2010f)

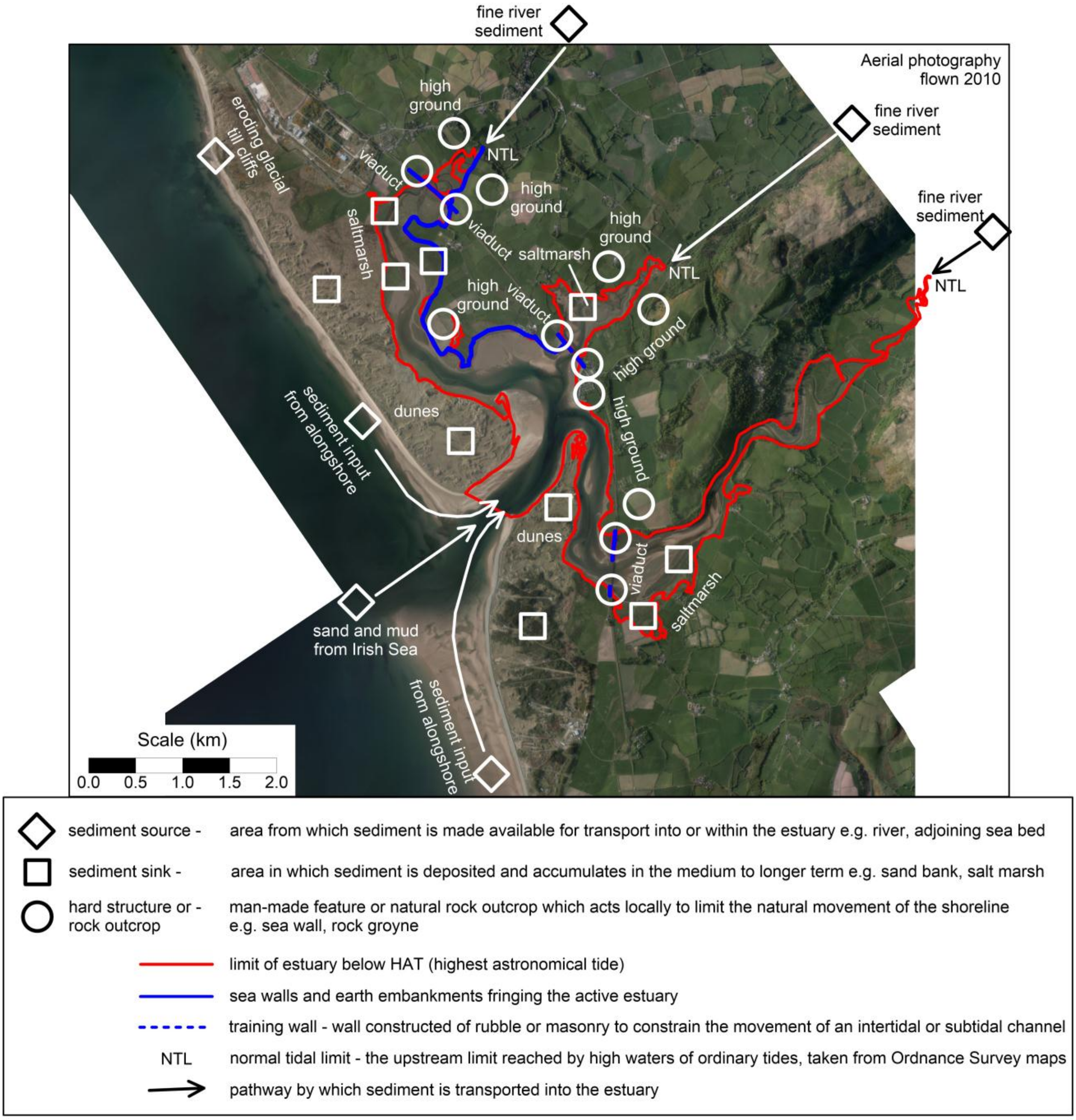

Figure 3.6. Conceptual diagram showing the main sediment sources, geomorphological features and engineering structures which influence the morphology of the Ravenglass Estuary.

3.6 Coastal Defences and SMP Policies

A list of the coastal defences in the Ravenglass Estuary from the SMP2 is provided in Appendix A (Halcrow, 2010a). The adopted shoreline management policies in the SMP are shown on the map in Figure 3.7.

The long term plan in the SMP2 is to allow the natural behaviour of Rivers Esk, Mite and Irt to continue without further intervention. Localised defence of the Cumbrian railway is not expected to have any significant detrimental effects upon these. Managed risk to Ravenglass village will continue; it is located on an area of higher land in the estuary so there are no advantages to surrounding coastal processes or environmental interests in not continuing to hold this. The recommended long term plan will promote a naturally functioning system helping to maintain a number of habitats and SSSI's. A limited number of properties and access roads will be at increasing risk of flooding in future and could need to be abandoned in the long term epoch. Some local tourism assets such as the Ravenglass and Eskdale Railway, the Cumbrian Coastal Way and small parts of Muncaster Castle Registered Park and Gardens may also be at an increasing risk of flooding in the long term. The implementation of this plan will need to manage residual risks to isolated properties, assets and infrastructure (Halcrow, 2010a).

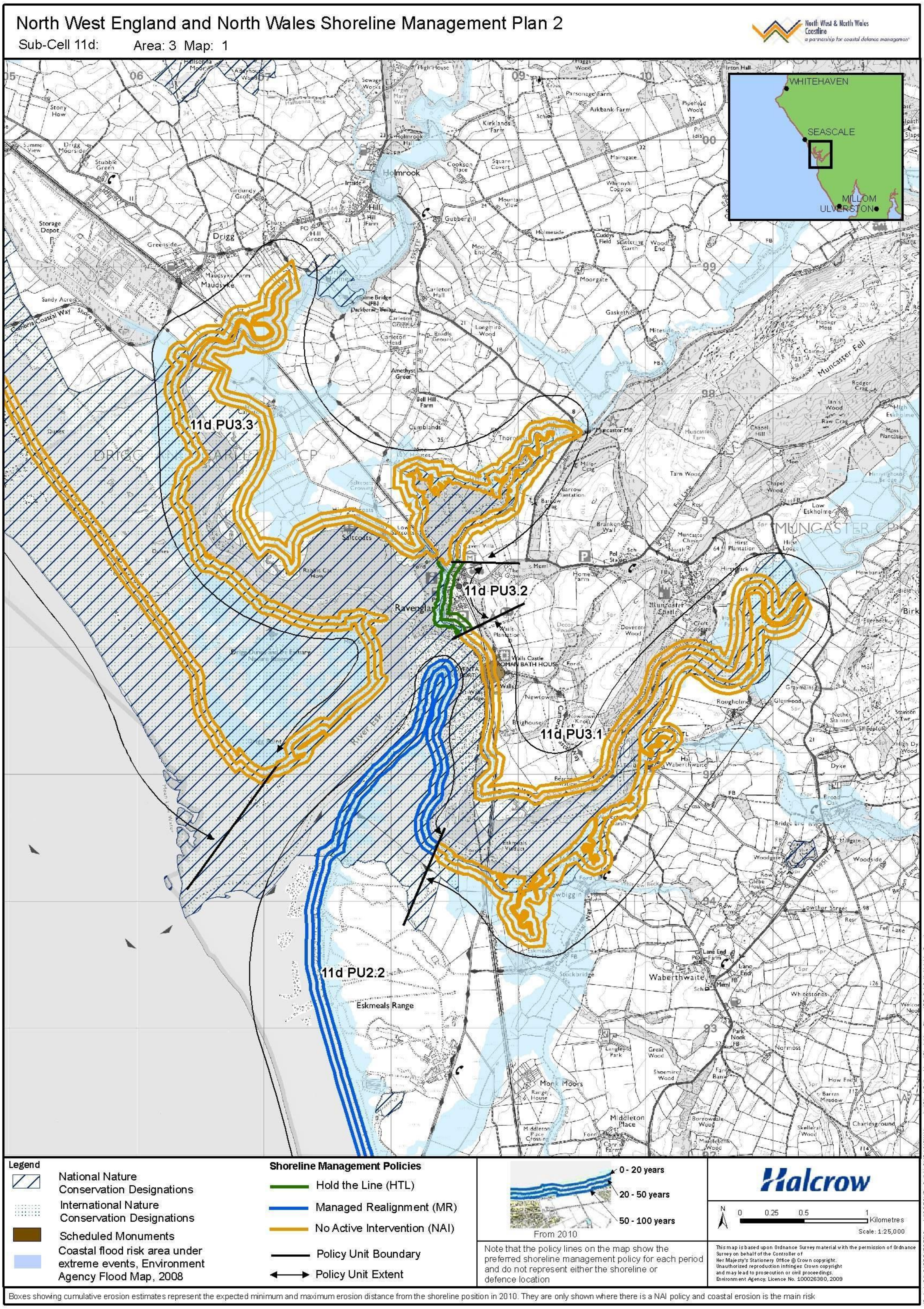

Figure 3.7 SMP2 Policy map for the Ravenglass (from Halcrow, 2010a).

3.7 Existing Monitoring Data

Details of the monitoring data being collected for the Ravenglass Estuary Complex 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 data collection stations and beach profiles that are available through CERMS and stored within the SANDS coastal monitoring database system used by a number of Local Authorities within the Cell 11 region.

It is understood that Drigg Low Level Waste Repository Ltd (LLWR) hold an archive of monitoring data for their site and surrounding area including photos, LiDAR and bathy going back to 2002 (Halcrow, 2009). Monitoring currently undertaken by LLWR is limited to an annual visual inspection of the coastline from St Bees to Ravenglass to identify erosion hotspots and changes in beach sediments. They also plan to capture aerial photos and LiDAR on a 5 to 10 year basis if these data are not available from CERMS.

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 a small section of coastline at Ravenglass and in the vicinity of the mouth of the Ravenglass Estuary Complex. Recorded in SANDS.	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 2.4.4 (Halcrow, 2010g). Annual Local Monitoring Report 2011 (CBC, 2012).

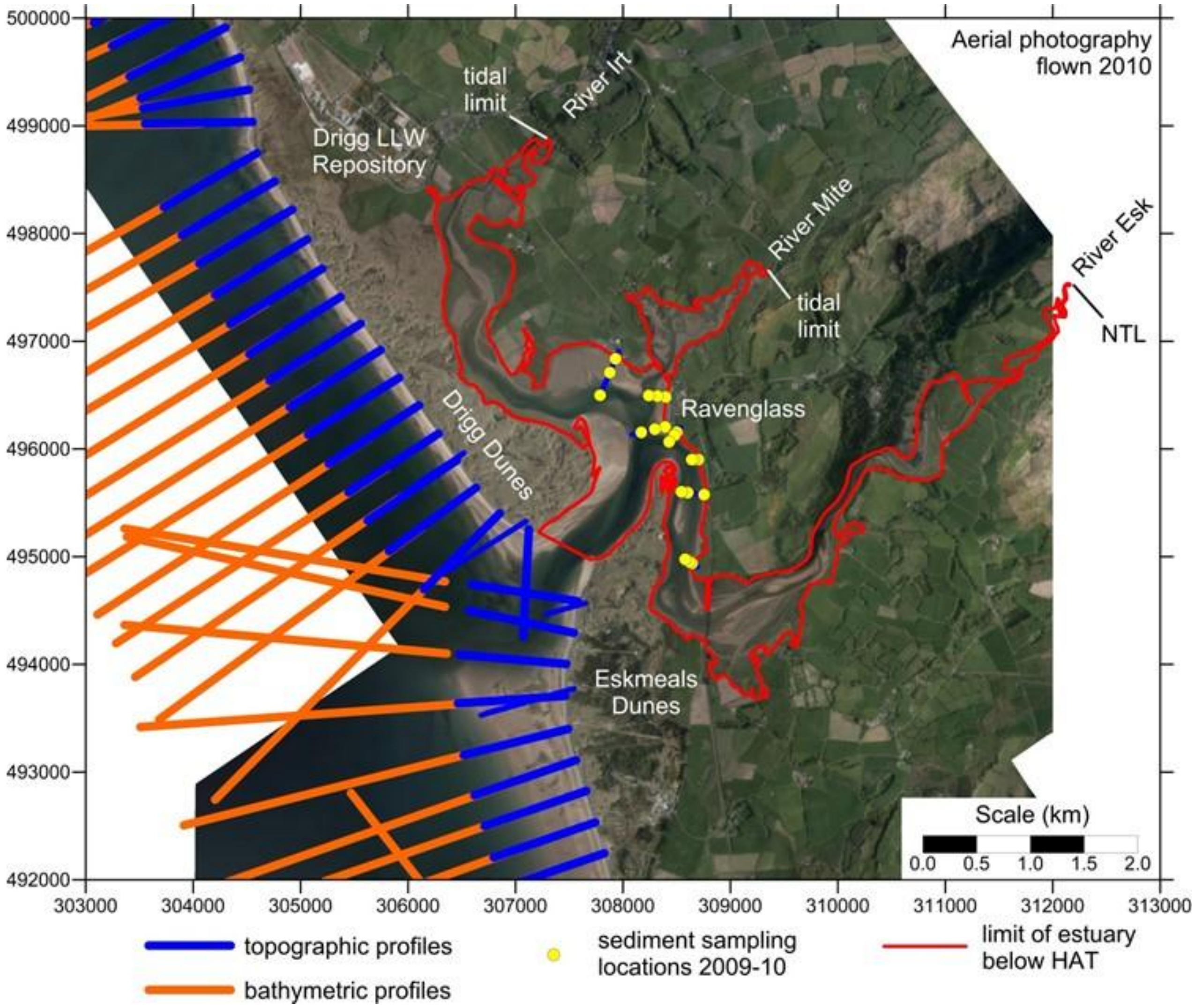

Figure 3.8 Summary of monitoring data available for the Ravenglass Estuary Complex

3.8 Data gaps and recommendations

In Cell 11 a number of previous reports have been identified gaps in understanding, including issues and uncertainties related to coastal and estuarine processes and shoreline management. 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, 2010b) 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 Ravenglass 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
- Port developments
- Water quality
- Data collation

We have noted where these actions might be best undertaken by the CERMS group or by other parties.

In the context of the other estuaries in Cell 11, the Ravenglass has had limited study.

The open coastal frontage around the mouth of the estuary is relatively well covered by topographic and bathymetric survey lines (although no sediment samples were collected as part of the CERMS survey in 2009-10). Existing LiDAR data coverage of the estuary is incomplete although it is understood it may be flown in its entirety during 2013/14. There are no existing bathymetric data for the low water channel areas, so a complete composite DEM cannot be created for modelling purposes.

The intertidal zone around Ravenglass has been sampled for sediment analysis but no data are available for the inner and outer parts of the estuary, or for the sub-tidal channel areas.

No tide gauge or other water level data are available for the estuary.

Table 3.3 Recommendations for studies and monitoring in Ravenglass estuary complex

Issue	Location	Comments	Recommendations
Flood and coastal defences Defence condition, ownership condition and maintenance data require review. A number of morphodynamic issues have relevance to defence provision, see below	Whole estuary	The defence data in Appendix A is taken from the SMP2 and based on a range of sources.	1. Update defence database. See item 1 in Appendix B. Continue ongoing maintenance and monitoring. **Urgency – medium** **Importance – medium** **Difficulty – low** **Overall Priority - medium**
Flood and coastal defences SMP2 Policy at Scheduled Monument	SMP2 Policy unit 11 d3.1 - at Ravenglass Fort Scheduled Monument	The SMP2 policy for the undefended frontage at the Scheduled monument is No Active Intervention, as is present practice. A study was recommended to investigate the likely longer term impacts of SMP2 policy on Ravenglass Fort Scheduled Monument, in order to determine the need and appropriateness of providing protection from erosion and / or appropriate mitigation or adaptation such as recording. In order to inform the future study better information is required on recent and historical change. Consider this location for inclusion in future combined aerial survey / LiDAR data capture. SMP policy to be reconsidered during next SMP review.	2. Monitoring of shoreline change at the site to inform policy review. 3. Study to assess longer term change. Review policy during SMP3 development. See item 2 in Appendix B. **Urgency – low** **Importance – medium** **Difficulty – low** **Overall Priority - medium**
Coastal and estuary morphodynamics Baseline bathymetric survey data is not available.	Whole estuary and adjacent coast	Surveys could be undertaken in conjunction with monitoring of adjacent coast.	4. Recommend synoptic swath bathymetry survey and inter-tidal LiDAR survey. (see generic recommendations for all estuaries) **Urgency – low** **Importance – low** **Difficulty – low** **Overall Priority - low**
Coastal and estuary morphodynamics Sediment supply to the estuaries is largely from reworking of material along the adjacent	Whole estuary	Linkage between open coast and estuary is only understood qualitatively.	5. Ongoing monitoring of beaches and cliffs on adjacent open coast. (no change). **Urgency – low** **Importance – medium**

Issue	Location	Comments	Recommendations
shorelines, particular to the south.			**Difficulty – low** **Overall Priority - low**
Data collation Data exchange and sharing between parties.	Estuary complex / adjacent coast	Monitoring and coastal change assessments undertaken for the Drigg frontage could be used to inform future estuary studies, if data can be brought into the programme.	6. Sefton and Copeland to contact Drigg landowners / operators to seek to share information. **Urgency – low** **Importance – medium** **Difficulty – medium** **Overall Priority - low**

4 Discussion and Conclusions

Within the context of flood and coastal erosion risk management across the Cell 11, the Ravenglass estuary complex has the lowest risks. This is because the estuary is relatively small, the hinterland is fairly steeply sloping and there are limited built assets at risk. Although the Drigg LLWR site is located clese to the Irt estuary it has been shown to be at very low long term risk of erosion from the estuary. Due to this the Ravenglass complex is rated as lowest priority for additional monitoring and further studies.

A number of additional studies are recommended to address the gaps in understanding identified in Section 4 of this report. Details of the issue/ uncertainty, the source of the recommended study, recommended study and purpose, and an assessment of the study priority are presented in Table 3.3.

The SMP policy at Ravenglass Fort, which is within 11d PU3.1 and has a NAI policy in all 3 epochs, should be reviewed in accordance with the recommendations of the SMP2 Action Plan, with consideration given to the erosion risks and possible justification to extend the HTL policy for Ravenglass village to include the Scheduled Monument.

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Appendix A
Coastal Defences in the Ravenglass Estuary Complex

Appendix A: Coastal Defences in the Ravenglass Estuary Complex

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

Location	Defence History	Present Defences	Residual Life – (Do Nothing Scenario) Years	Natural Features	Source and Assumptions
Eskmeals Dunes to Eskmeals Viaduct National Grid: (307467E 493945N) to (308750E 494257N)	N/A	Natural defence	N/A	Eskmeal Dunes. Foreshore of sand and gravel.	NFCDD. Defences interpreted from EA oblique coastal area photos Cell 11.
Eskmeals Viaduct to Muncaster Bridge National Grid: (308761E 494533N) to (311251E 496401N)	N/A	Natural defence	N/A	Marshland with muddy foreshore.	NFCDD. Defences interpreted from EA oblique coastal area photos Cell 11.
Muncaster Bridge to Eskmeals Viaduct National Grid: (311238E 496418N) to (308761E 494533N)	N/A	Natural defence	N/A	Vegetated river banks and saltmarsh	Defences interpreted from Google Earth (accessed 08/08/2008).
Eskmeals Viaduct to Brighouse National Grid: (308761E 494533N) to (308718E 495266N)	N/A	Natural defence	N/A	Marshland with muddy foreshore.	NFCDD. Defences interpreted from EA oblique coastal area photos Cell 11.
Brighouse to Walls Bridge National Grid: (308800E 494820N) to (308750E 495700N)	Originally constructed in 1890 and refurbished post-1994.	Masonry wall supporting earth embankment with localised armour protection at north end.	10-20	Foreshore of sand and gravel and cobbles	Copeland coastal defence inspection March 08. Residual life assumed from condition inspection.

Location	**Defence History**	**Present Defences**	**Residual Life – (Do Nothing Scenario) Years**	**Natural Features**	**Source and Assumptions**
Roman Fort to Ravenglass National Grid: (308750E 495700N) to (308490E 496210N)	Constructed in 1980	Vertical masonry wall with counterforts in front. The wall is damaged in numerous places and breaches have occurred.	Effectively life expired in places	Foreshore of sand and gravel and cobbles	Copeland coastal defence inspection March 08. Residual life assumed from condition inspection.
Ravenglass National Grid: (308490E 496210N) to (308400E 496400N)	Property Walls constructed in 1980	Vertical concrete, brick and masonry walls to property boundaries.	>5	Shingle beach with grassy areas and sand lower beach.	Copeland coastal defence inspection March 08. Residual life assumed from condition inspection.
Ravenglass Bank National Grid: (308400E 496400N) to (308450E 496590N)	Original defence unknown. Armour block facing added in 1992	Earth embankment with armour block facing.	>10	Shingle beach with grassy areas and sand lower beach.	NFCDD 2007.
Ravenglass Viaduct (South) National Grid: (308450E 496590N) to (308380E 496700N)	Originally constructed in 1890 and refurbished 1950.	Lower sloping masonry embankment facing with upper facing of interlocking concrete blocks and vertical crest wall.	>5	Estuarine mudflats	NFCDD. Copeland coastal defence inspection March 08. Residual life assumed from condition inspection.
Ravenglass Viaduct to downstream Raven Villa National Grid: (308367E 496680N) to (308527E 496686N)	N/A	Natural defence	N/A	Estuarine mudflats	Defences interpreted from Google Earth (accessed 08/08/2008).

Location	**Defence History**	**Present Defences**	**Residual Life – (Do Nothing Scenario) Years**	**Natural Features**	**Source and Assumptions**
Downstream Raven Villa to NTL boundary River Mite National Grid: (308527E 496686N) to (309333E 497596N)	Unknown	Rail embankment	Unknown	Estuarine mudflats	Defences interpreted from Google Earth (accessed 08/08/2008).
River Mite NTL boundary to Ravenglass Viaduct National Grid: (309321E 497618N) to (308350E 496720N)	N/A	Natural defence	N/A	Estuarine mudflats	Defences interpreted from Google Earth (accessed 08/08/2008).
Ravenglass Viaduct (North) National Grid: (308350E 496720N) to (308300E 496800N)	Originally constructed in 1890.	Lower sloping masonry embankment facing with unfaced upper section and concrete access path along berm.			NFCDD. Defences interpreted from EA oblique coastal area photos Cell 11. RL based on CEUK work for Network Rail.
Ravenglass Viaduct to Irt Viaduct National Grid: (308300E 496800N) to (306791E 498505N)	Unknown	Generally natural defences with embankment in places and rock revetment protecting Saltcoats caravan park.	Unknown	Estuarine mudflats	NFCDD. Defence types interpreted from Google Earth
Irt Viaduct to River Irt NTL National Grid: (306791E 498505N) to (307168E 498850N)	N/A	Natural defence	N/A	Estuarine mudflats	Defences interpreted from Google Earth (accessed 08/08/2008).

Location	Defence History	Present Defences	Residual Life – (Do Nothing Scenario) Years	Natural Features	Source and Assumptions
River Irt NTL to Irt Viaduct National Grid: (307168E 498870N) to (306774E 498527N)	N/A	Natural defence	N/A	Estuarine mudflats	Defences interpreted from Google Earth (accessed 08/08/2008).
Irt Viaduct to midway along marsh National Grid: (306774E 498527N) to (306533E 497517N)	N/A	Natural defence	N/A	Estuarine mudflats	NFCDD
Midway along marsh to Drigg Point National Grid: (306533E 497517N) to (307090E 494995N)	N/A	Natural defence	N/A	Estuarine mudflats	NFCDD

Appendix B
Recommendations for further studies

Appendix B Recommended further studies for the Ravenglass 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, Copeland 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 £5 to £10k, if packaged with other similar work on other defences. Priority – medium - needed to feed into MR viability studies and strategy and national activities such as NaFRA etc.
2. Coastal evolution study at Ravenglass Fort	Study assumed to be led by EA, Copeland or Sefton or English Heritage Establish profile and cliff monitoring locations within CERMS programme and commence annual data collection. Obtain and analyse historical mapping at the site, e.g. using series of maps used in FutureCoast study. Review and analyse aerial photography available through CERMS. Predict future shoreline positions using NCERM methodology and assess timing of loss of site features. Provide short report to inform consultation during SMP2 review.	Estimated cost - £10k Priority – Low, study can wait until SMP2 review, but data needs to be collected in advance.
3. LiDAR and bathymetric survey for the Ravenglass Estuary complex	Study to be led by Sefton or EA. Assess data from most recent (2013?) LiDAR survey including checking coverage to low water. Possibly undertake new High level LiDAR survey of whole estuary complex on spring tide low water. Low water swath bathymetry survey of LW channel to overlap with LiDAR data.	Estimated cost: £50 to £75k. Priority – Low in comparison to other NW Estuaries.
4. Data collation and exchange	To be led by Sefton or EA or LLWR Ltd Consult with LLWR and develop approach to data sharing.	Estimated cost: N/A Priority – medium