



11c12 Leven Estuary

(Technical report by Jacobs)

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Policy area: 11c12 Leven Estuary

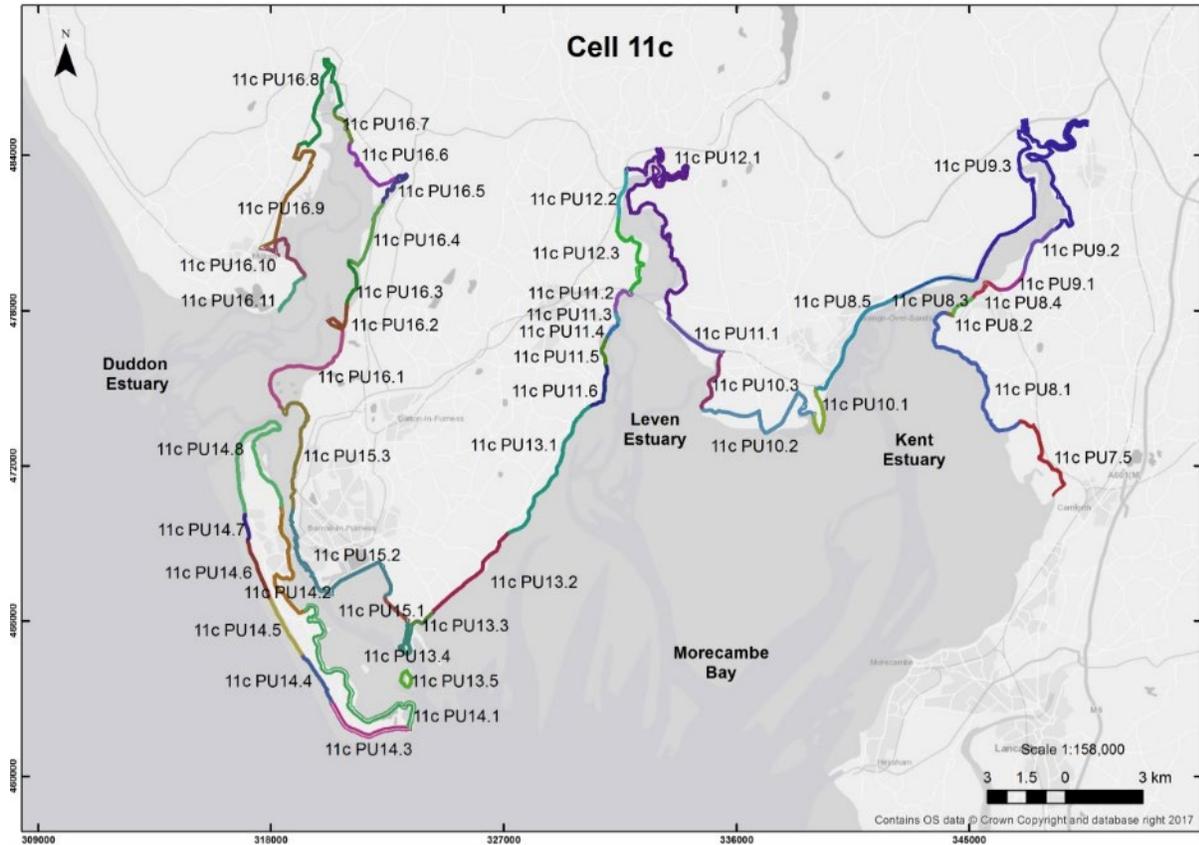


Figure 1 Sub Cell 11c Arnside to Hodbarrow Point Location Plan of policy units. Baseline mapping © Crown copyright and database rights, 2019. Ordnance Survey licence number: 1000019596.

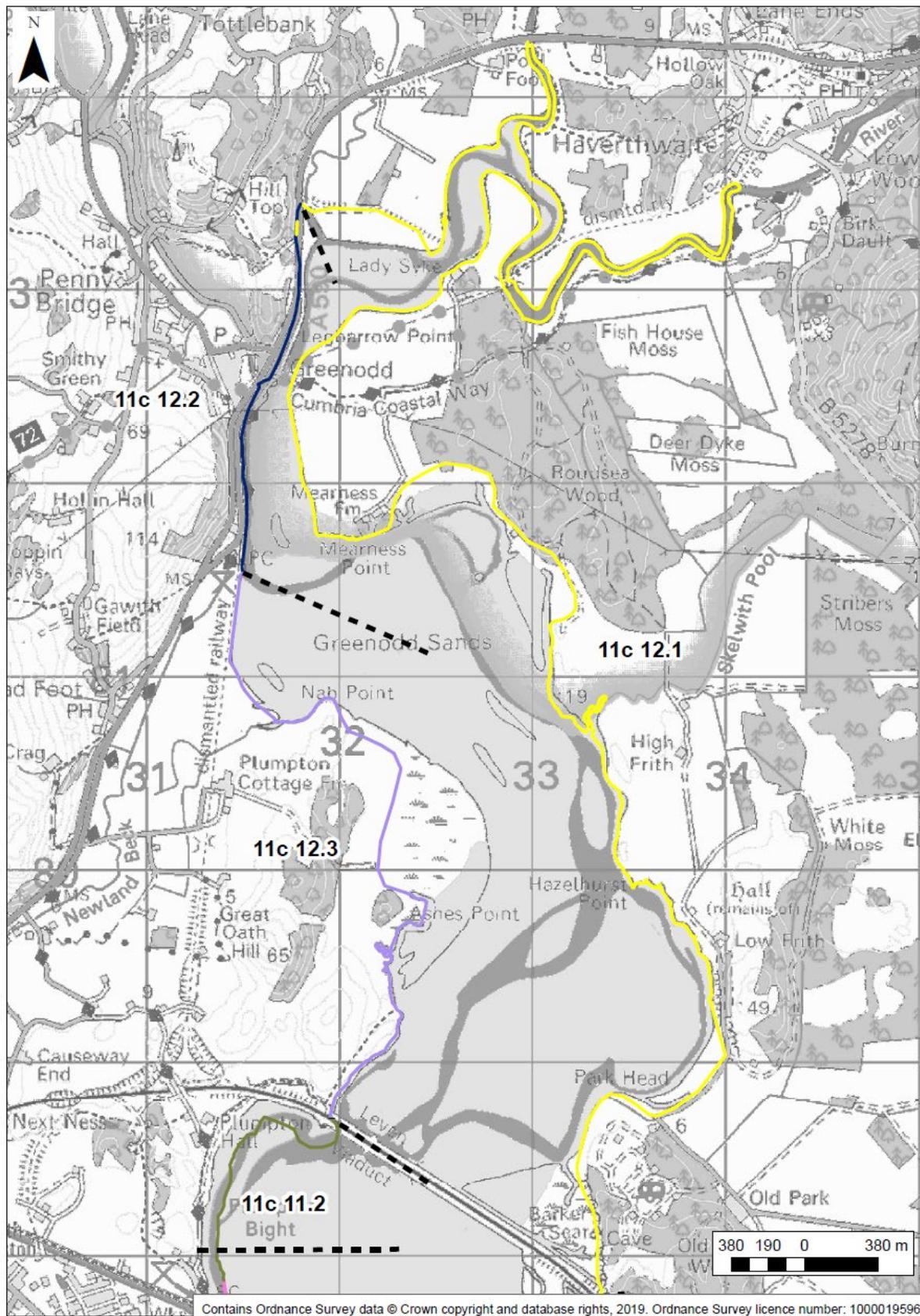


Figure 2 Location of Policy Area 11c12: Leven Estuary. Baseline mapping © Crown copyright and database rights, 2019. Ordnance Survey licence number: 1000019596.

1 Introduction

1.1 Location and site description

Policy units:	<p>11c12.1 Leven Viaduct to Haverthwaite (left bank) and Haverthwaite to Greenodd (right bank)</p> <p>11c12.2 Greenodd to Barrow End Rocks (A590)</p> <p>11c12.3 Barrow End Rocks (A590) to Leven Viaduct (priority unit)</p>
Responsibility:	<p>South Lakeland District Council</p> <p>Highways England</p> <p>Environment Agency</p> <p>Private landowners</p>
Location:	<p>The policy area falls within Sub cell 11c: (part) Arnside to Hodbarrow Point. The inner estuary extends inland from the Leven Viaduct, northwards to the normal tidal limit at Haverthwaite. Policy unit 11c12.3 extends from the Leven viaduct north to Barrow End, inclusive of the Old Railway Embankment.</p>
Site overview:	<p>The Leven Estuary is a small macro tidal estuary located on the north side of Morecambe Bay. The estuary receives freshwater flow from the River Leven and the River Crake, which are fed by Lake Windermere and Coniston Water, respectively. The catchment comprises the largely rural area south of Helvellyn. The entire estuary is designated as a SAC, SPA, Ramsar site and SSSI, forming part of the larger Morecambe Bay site.</p> <p>The estuary mouth is defined by hard rock outcrops and the morphology of the mid and inner estuary is also strongly influenced by 'hard points' composed of bedrock and/ or glacial till. Scars, present along the western shoreline in the outer estuary, fix the shoreline position, provide local stability and protection to the frontage and control the proximity of the Leven channel to the shore. The margins of the estuary are flanked by raised terraces which consist mainly of former tidal flat and marsh deposits which became emergent as a result of a slight fall in sea level following a high stand in the mid Holocene.</p> <p>The estuary is macro tidal with mean spring and neap tidal ranges of approximately 8.4 m and 5.2 m, respectively. The estuary is flood dominant, with the flood tide being both shorter in duration and having higher velocities than the ebb tide. The freshwater input to the estuary is small compared to the tidal prism. Extreme high water levels are predominantly caused by tidal surges although flooding can also occur due to runoff becoming trapped behind sea defences during high tides. The northerly orientation of the estuary, combined with the obstructive effect of the railway viaduct and breakwater, reduces any wave penetration into the estuary.</p> <p>Historically, the low water channels of the Leven have varied in their position, especially upstream of the viaduct, and this has had a major effect on patterns of saltmarsh accretion and erosion. There have been significant human interventions in the estuary, notably construction of the Leven railway viaduct and associated infrastructure in the mid 19th century and construction of a breakwater in 1860, south of the viaduct, to stabilise the main channel. The breakwater has acted to redirect the Leven channel westwards through the viaduct and consequently has encouraged saltmarsh development along the</p>

	<p>western side of the Cartmel Peninsula. At present, the viaduct acts to deflect the channel south east downstream of the structure, before dividing into two channels.</p> <p>The estuary falls within Morecambe Bay Ramsar, Site of Special Scientific Interest, Special Area of Conservation and Special Protection Area designations. The area forms one of the two largest areas of intertidal estuarine flats in Britain; internationally significant for wintering wading birds and nationally important for wintering wildfowl.</p> <p>This area has significant landscape value and parts of the estuary lie within the Lake District National Park and World Heritage Site.</p>
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1.2 Current SMP policy

The policy details for the whole policy area are shown here taken directly from the SMP2 (Halcrow, 2011), but non priority units have been greyed out.

Table 1 Current SMP Policy for policy area 11c12

Overview: <i>The long term vision is to continue to manage flood and erosion risks to property and infrastructure where economically justifiable. However, there are significant areas where shoreline defence is considered not viable leading to several opportunities to realign flood defences to higher ground. This will result in reduction in quality or loss of areas of agricultural land but will allow for expansion of the saltmarsh and tidal flats with future sea level rise in the long term.</i>				
Location		Policy and Approach (from 2010)		
		0-20 years	20-50 years	50-100 years
11c12.1	Leven Viaduct to Haverthwaite (left bank) and Haverthwaite to Greenodd (right bank)	Hold the line – For local areas where defences are present. Undertake studies to investigate opportunities and viability of realigning defences or retreating to high land where appropriate, includes assessing impacts on wider bay and railway viaduct. If viable implement in this period where practicable.	Managed realignment – Should be carried out to create more sustainable defence alignments by retreating to higher land, depending on investigations into approach.	No active intervention – By allowing natural processes to continue. However, management of private defences may be permitted subject to consent.
11c12.2	Greenodd to Barrow End Rocks (A590)	Hold the line – Manage flood and erosion risk by maintaining existing defences to an adequate standard.	Hold the line – Manage flood and erosion risk by maintaining existing defences to an adequate standard.	Hold the line – Manage flood and erosion risk by maintaining existing defences to an adequate standard.
11c12.3	Barrow End Rocks (A590) to Leven Viaduct	Hold the line – For local areas where defences are present. Undertake studies to investigate opportunities and viability of realigning defences or retreating to high land where appropriate, includes assessing impacts on wider bay and railway viaduct. If viable implement in this period where practicable.	Managed realignment – Should be carried out to create more sustainable defence alignments by retreating to higher land, or constructing set back defence, depending on investigations into approach.	No active intervention – By allowing natural processes to continue. However, management of private defences may be permitted subject to consent.

1.3 Estuary managed realignment

The inner Leven Estuary is constrained at the mouth by the railway viaduct. The estuary meanders through hills interspersed with smaller areas of low lying land which extend back to higher land. The long term vision identified in the SMP Policy (Table 1) is to continue to Hold the line to protect property and infrastructure at Greenodd, where the A590 forms the estuary margin but elsewhere to return areas of the estuary to a more natural system as sea level rises in future. As such, the SMP policy is to realign flood defences back to higher ground (CH2M, 2013). However, any realignment needs to be considered in combination with impacts on flows in and out of the estuary on the railway viaduct and A590 and possible consequences elsewhere, both within this policy area and policy area 11c11, including economic losses resulting from loss of productive agricultural land.

In the context of the other estuaries in Cell 11, the Leven is a small estuary with limited numbers of properties at risk. It has therefore been studied less than most of the others in Cell 11 and there is currently very little ongoing monitoring. There are no topographic monitoring profiles upstream of the railway viaduct and no sediment sampling has been undertaken to characterise the bed and bank sediments in this area. Due to the strong linkages in processes and continuity of habitats between the Leven Estuary and the wider Morecambe Bay, plans for studies and monitoring in the Leven should be developed in conjunction with the Kent estuary and wider Morecambe Bay area (CH2M, 2013).

There are a number of potential sites where managed realignment could be delivered within the estuary; either by removing, breaching or allowing defences to deteriorate over time or Regulated Tidal Exchange (RTE), such as where low lying areas are separated from the estuary by roads or railways.

The key issues and opportunities identified for a number of potential sites within the Leven Estuary include:

- Dependent on the size of site and its tidal prism increased tidal flows due to the additional volume flooded each tide may pose erosion risks to viaduct and defences in adjacent parts of the estuary and could modify geomorphology of estuary, impacting on the intertidal habitats in the designated sites.
- New embankments may be required to constrain the setback in some locations to manage risk of flooding to properties, roads and terrestrial or freshwater designated environmental sites.
- Potential opportunities for habitat creation schemes to compensate for impacts on the estuary Natura 2000 sites due to direct losses related to flood defence or infrastructure schemes that encroach on the estuary elsewhere.
- Some of the potential sites inland of Greenodd are unlikely to flood regularly due to location near tidal limits, flows constrained by the small estuary channel and the flood risk area located high in the tidal frame.
- Over time downstream reaches of channel may expand to accommodate tidal waters flooding site leading to pressure on defences.
- Potential impacts to geomorphology of river or tidal channel and fringing habitats including erosion and flood risk implications to hinterland.
- Potential impacts on Natura 2000 sites, Habitat Regulations requirement and potential need for compensatory habitat if adverse impacts on Natura sites identified and realignment is undertaken as a managed scheme rather than through natural processes.

- Some locations may have potential for regulated tidal exchange (RTE) schemes for habitat creation, but careful design would be required to avoid impacts on adjacent frontages.
- None of the sites are completely free of constraints, although boundary refinement could help avoid some of the constraints in some areas.
- Many of the potential sites are situated high in the tidal frame and based on current land elevations and water levels would create predominately transitional habitats. There is limited opportunity throughout the estuary to create mud or sandflat, based on current land elevations.

Further studies are required prior to the shortlisting of sites or implementation of specific schemes:

- Clarification of the objectives for undertaking managed realignment.
- More detailed desk top assessment of sites (e.g. lengths of footpaths with site, potential for contaminated land issues).
- Incorporation of local knowledge to better characterise sites.
- Preliminary designs - quantifying the length of new defences, number and positions of breaches, requirements for creek systems etc.
- Hydrodynamic modelling to determine effects on flood risk and geomorphology of estuary as well as the likely inundation of the sites, including impact on critical infrastructure such as sections of the A590.
- Costs and economics- Quantifying the costs for the works and future maintenance versus existing management activities.
- Approaching landowners and tenants to discuss implications of MR sites and gauge the level of support.
- Consideration of requirements for consenting, such as Marine Management Organisation (MMO) marine licence and Local Planning Authority planning application, Environmental Impact Assessment (EIA), HRA, Water Framework Directive (WFD).

2 Appraisal of priority units

One policy unit within this area has been defined as a priority unit:

- 11c12.3 Barrow End Rocks (A590) to Leven Viaduct

2.1 Existing approach to flood and coastal risk management

2.1.1 Justification of current SMP policy

Section 1.2 sets out the SMP policies for the priority unit. The primary justification for the policies at SMP level were:

- **Social:** Policy to Hold the line in short term is justified as it allows for managing potential impacts on isolated properties, access tracks and paths, whilst approaches to policy are confirmed.
- **Environmental:** Realigning to higher ground will result in a more naturally functioning sustainable coastline, and provide additional natural habitat. However, investigations needed to assess impacts on rest of estuary and adjacent bay.
- **Economic:** Current extensive defences are unlikely to be economically justifiable in the long term due to a lack of assets within the flood cell. Realigning or withdrawing from sections of defence will provide the most cost effective solution.

2.1.2 Current defences

The Environment Agency provided shapefiles for the frontage with a brief description of the defence type and overall condition (see Figure 3). Man-made structures and natural frontages have been divided in two tables for clarity: Table 2 and Table 3 respectively.

Descriptions of each of the man-made defences in 11c12.3 are shown in Table 2. There is no reporting of conditions for the Oak Haugh defences. Oblique aerial photographs of the man-made and natural defences are shown in Figure 4.

Table 2 Existing man-made defence details for 11c12.3, based upon information provided by the Environment Agency.

Location/ ID	Structure Type	Overall Condition	Length (m)	Crest Level (mOD) *	Residual Life (years) **
104542	Old railway embankment: stone or mortar wall at top of bank. Raised by approx. 0.5 m, is tied into next defence at upstream end, but downstream wall veers away from channel.	Poor (4)	1,050	+6.62	10
Oak Haugh, near Plumpton Cottage Farm (011KC90210 201R09)	Embankment	Poor (4)2	978	+5.95	10

* Information extracted from DTM LiDAR 2017

** Residual life estimated based on condition from asset deterioration guidance document (Environment Agency, 2013)

The remaining frontages within this policy unit are mapped as natural high ground. Descriptions of each were available in the shapefiles and are shown in Table 3.

Table 3 Natural defence details for 11c12.3, based upon information provided by the Environment Agency.

Location/ ID	Description	Overall Condition	Length (m)
88598	Natural high ground. It appears to be natural earth and sand banks vegetated with grass above.	-	870
67228	Natural high ground. Natural channel – natural estuary channel	-	1,460

The AIMS data does not provide residual life estimates for the defences and so for the strategy a broad scale estimate has been made based on Environment Agency asset condition and deterioration guidance. Typically, estuary embankments with condition grades of 2 would be expected to deteriorate to condition 5 (failure) within 30 to 40 years, whilst condition grade 3 may deteriorate to grade 5 in 20 to 30 years. Those with condition grade 4 may have residual life up to 10 to 15 years, depending on maintenance regime and exposure conditions.

The performance of the estuarine defences and their future deterioration and maintenance requirements is highly dependent on the protection provided by fronting marshes and how this natural protection may vary in the future due to natural meandering of the low water channels, changes due to ongoing general sediment accretion and the impacts of future climate change and associated sea level rise.

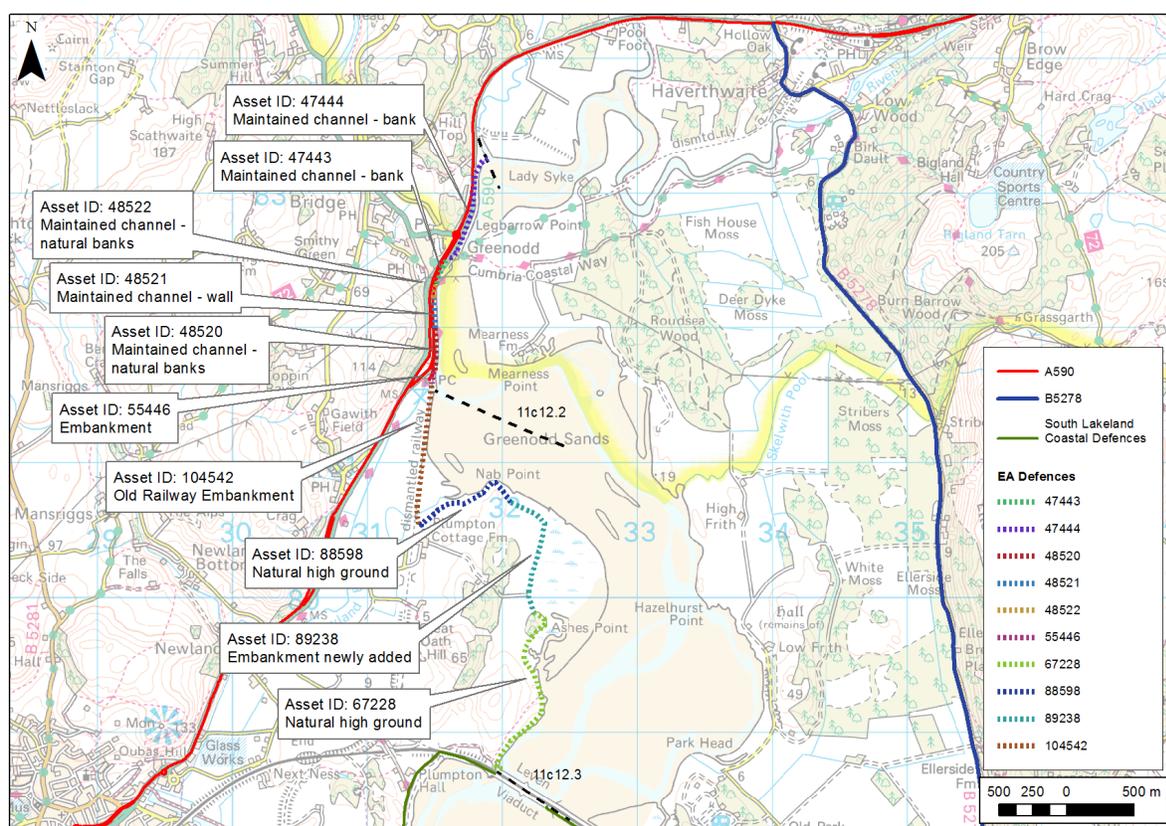


Figure 3 Policy Unit location plan and defence overview. Baseline mapping © Crown copyright and database rights, 2019. Ordnance Survey licence number: 1000019596.



Saltmarshes between Nab and Ashes Point. Oak Haugh embankment (011KC90210201R09)



Natural high ground in Ashes Point. Asset 67228

Figure 4 Oblique aerial photographs (2015) for Policy Unit 11c12.3. 2015 aerial photographs © North West Regional Monitoring Programme.

2.1.3 Shoreline change

The Leven Estuary is macrotidal, with levels of mean high water springs (MHWS) and highest astronomical tide (HAT) of 4.60 and 5.80 mOD, respectively (Halcrow, 2013). The railway viaduct has been used to define a boundary between the inner and outer estuary.

The northerly orientation of the estuary mouth combined with the construction of the railway viaduct reduces any wave penetration into the estuary (Halcrow, 2011) and upstream of the viaduct, locally generated waves are attenuated by the bank and channel alignments. The inner estuary therefore experiences a low energy regime where little or no movement of sediment is likely except under storm conditions (Halcrow, 2011). The estuary therefore acts as a sediment sink within the larger Morecambe Bay system.

There is one large saltmarsh and two areas of fringing saltmarsh within this estuary which are individual sediment sinks. Erosion of low glacial till cliffs in the outer estuary provides some sand and shingle to the littoral system, and there is some fluvial supply during floods, but the main source of sediment to the estuary is provided from Morecambe Bay (Halcrow, 2013c). The estuary is sand dominated although there are areas of sandy mud accumulation in the high intertidal zone around the fringes of the inner estuary.

The estuary presently appears to be in a state of relative equilibrium (Halcrow, 2011) in terms of the extent of mudflat and saltmarsh area. However, historically the low water channels of the Leven have varied in their position and continue to do so, especially upstream of the viaduct, and this has had a major effect on patterns of saltmarsh accretion and erosion. One example of where there is currently an issue is along a section of the A590 road at Greenodd, at the confluence of the River Leven with the River Crake (EM, 2015). Here the road is becoming undermined due to the channel scouring out material from beneath the wall. Three processes are believed to be responsible for erosion in the area: the current forces scour the banks, undermining them; wave action against the bank erodes material; and this material is then removed during the tidal cycle (EM, 2015).

Over the next 100 years there is likely to be some relatively minor supply of sediment to the estuary provided by erosion of short lengths of soft cliffs and older sedimentary formations (raised marine terraces) in northern Morecambe Bay, but the main source of sediment is likely to continue to be Morecambe Bay and the wider Irish Sea. There is no evidence to suggest that the general landward movement of sea bed sediment in Morecambe Bay will change, or that concentrations of suspended sediment will diminish. The future evolution of the estuary is therefore unlikely to be sediment supply limited. The low water channel is expected to continue to meander where not restricted by

defences or surrounding topography, which has the potential to cause the erosion of saltmarshes and undermining of defence structures, however, these marshes would be expected to re-establish over time due to redistribution of any eroded sediment within the estuary (Halcrow, 2010).

2.1.4 A590 Greenodd embankment erosion

At Greenodd (policy unit 11c12.2), the A590 road runs along the estuarine frontage for around 2 km. A previous report (EM, 2015) identified two areas of concern (see Figure 5) associated with the undermining of an area of the embankment and the failure of a retaining wall.

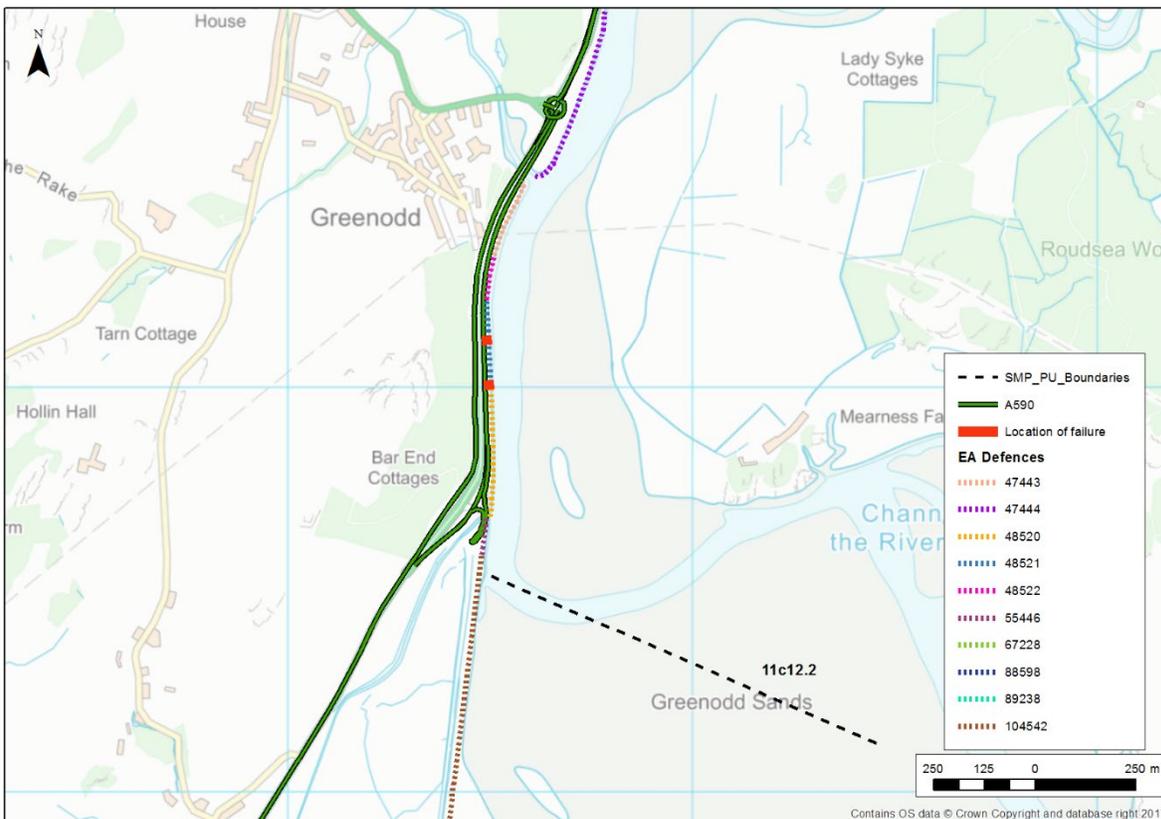


Figure 5 Location of undermining and failure of retaining wall in Greenodd (EM, 2015). Baseline mapping © Crown copyright and database rights, 2019. Ordnance Survey licence number: 1000019596.

The areas where failure was observed have been previously assessed and options for defence improvement to protect the A590 were developed by EM (2015). The scheme proposed the following (see Figure 6):

- In the area where foreshore erosion and embankment undermining have been observed, a rock armour revetment is proposed, extending along the existing shoreline of the River Leven up to a constant crest level of 6.3 mOD, with a constant slope of 1:3 over a distance of 1 km. The existing slope with concrete aprons, rock debris and rubble will be regraded to 1:3 uniform slope before construction of the new revetment begins. Figure 6 shows a typical cross section of the proposed rock revetment;
- In the area where the retaining wall or platform structure has failed repairs will be carried out and new sections of retaining wall have been designed to tie in existing ground levels and with the top of the new revetment. It was proposed to construct two sections of retaining wall at either end of an existing retaining structure at the site. These sections of



Figure 7 Aerial image showing low water channel adjacent to the old railway embankment. Photograph courtesy of North West Monitoring Programme, 2015.

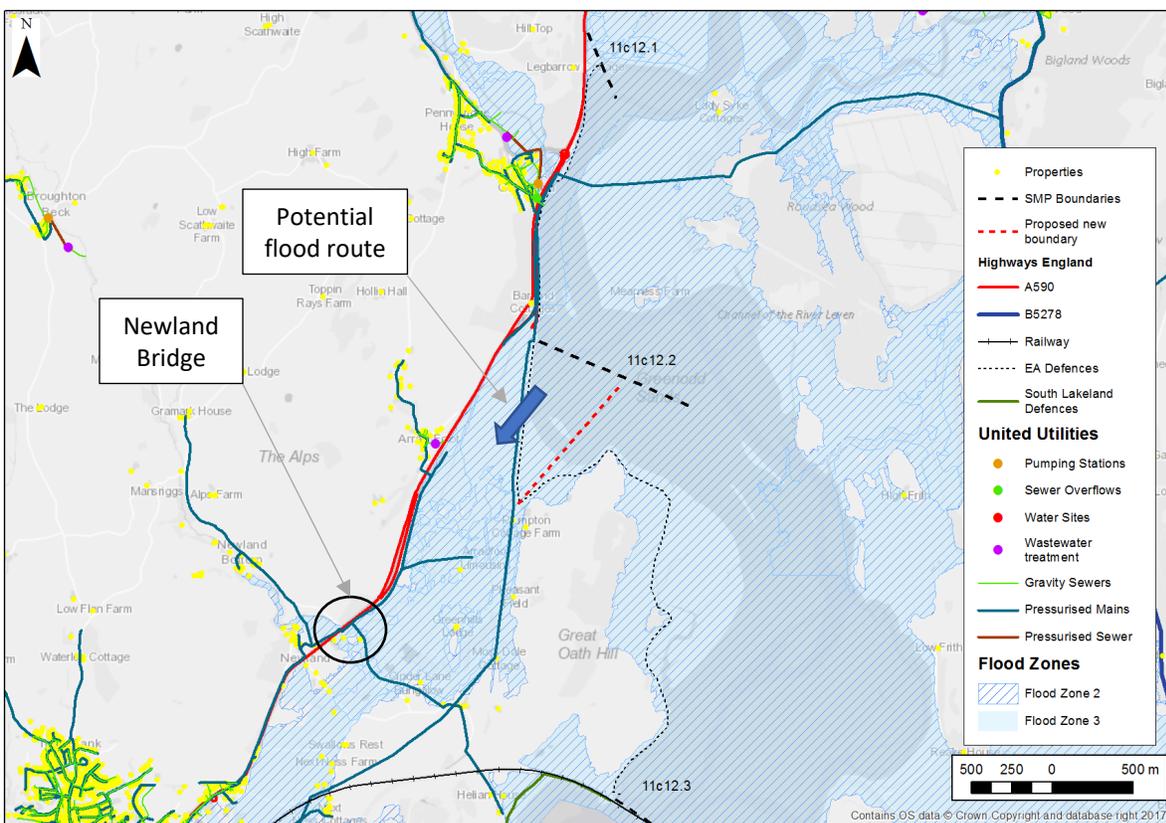


Figure 8: Flood maps and main assets at risk. Baseline mapping © Crown copyright and database rights, 2019. Ordnance Survey licence number: 1000019596.

2.2.2 Issues, constraints and opportunities

The A590 is the primary route between the M6 and Barrow-in-Furness and significant lengths of the route are at flood risk where it runs across the reclaimed coastal plain inland of the Kent and Leven

estuaries. There is a strategic road link long term plan (WSP, 2016), which identifies measures in place regarding the main coastal road at Greenodd, which would involve realignment of the route. Highways England are also looking to undertake works at Newland to improve the resilience of the A590; possible options include raising the road level of a section of the A590.

There is a proposed extension to the national cycle route, which could potentially use the disused railway line that forms a defence in 11c12.3. The cycle route would run from the existing Greenodd picnic site to Plumpton. A desktop study was undertaken for a scheme to construct a cycle path along the shoreline, named 'Greenways Phase One' Preliminary Sources Study Report 2007 (PSSR).

There are issues with fluvial outfalls where beach material builds up in the discharge channels across the foreshore and reduces the gravity outflow, thereby affecting inland drainage.

The intertidal areas are highly designated and are included within: Morecambe Bay Ramsar, Morecambe Bay SAC, Morecambe Bay and Duddon Estuary SPA and Morecambe Bay SSSI. Adjacent designations include: Roudsea Wood & Mosses SAC and SSSI, Barker Scar SSSI, Skelwith Hill SSSI. There are potential environmental enhancement opportunities within the estuary, through managed realignment, where viable.

The Inner Leven Estuary is also valued for its aesthetic landscape beauty and stretches are designated under the Lake District National Park and World Heritage Site.

2.2.3 Strategy considerations and general approach

Key considerations

Since the SMP was produced, further monitoring data and plans for developments have been collated. The strategy has considered this more recent data to appraise the impacts:

- Possible implications of the proposed long term plans for A590 (WSP, 2016).
- Possible implications of the proposed extension to the national cycle route.
- Recent designation of the Morecambe Bay and Duddon Estuary SPA (to combine and extend the two existing sites as a single SPA).
- Recent shoreline change and the A590 Greenodd Embankment Erosion proposed defence improvements to protect the road (EM, 2015). The scheme involves the proposed remediation of a section of the A590 adjacent to the Leven Estuary in policy unit 11c12.2 (further details provided in Section 2.1.4).
- The long term policy for 11c12.3 and boundary between 12.2/12.3 given possible future infrastructure works.

The flood route identified from the old railway embankment along the southern extent of policy unit 11c11.3 (see section 2.2.2), could be managed by introducing a sub unit within the existing 11c12.3, as shown in Figure 8.

The proposed new sub unit, 11c12.3.1 Old Railway Embankment is considered separately to 11c12.3 and the SMP2 management policy is assumed to be consistent with the existing policy unit 11c12.2 to the north, which is Hold the line for the strategy period. This will allow the flood risk to the south of the A590 and Newland Bridge to be managed, as well as the potential flood route inland.

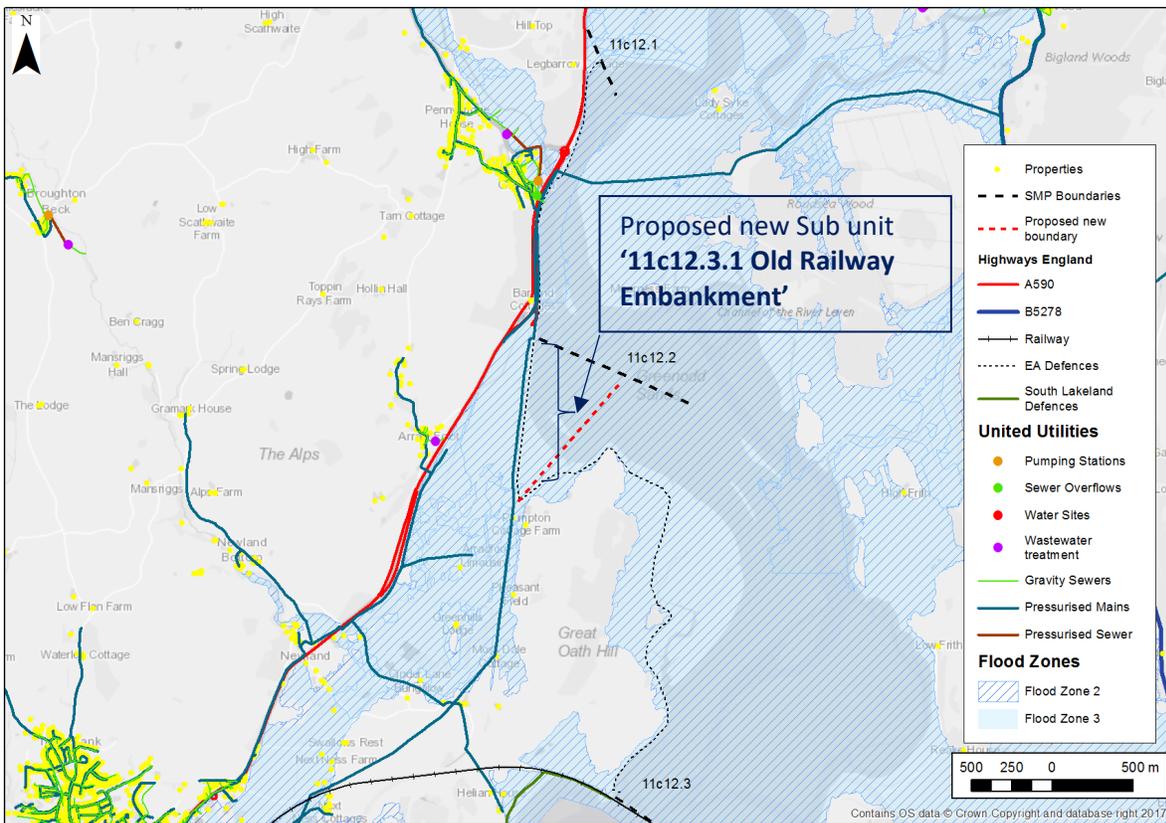


Figure 9: Proposed new sub unit 11c12.3.1 Old Railway Embankment. Baseline mapping © Crown copyright and database rights, 2019. Ordnance Survey licence number: 1000019596.

Strategy approach

Possible change to SMP2 policy – issues have been raised regarding the current policy. The strategy will consider possible measures taking account of a possible change to policy. Future works to manage flood and erosion risk may be eligible for a proportion of FDGiA funding and the economic appraisal will consider costs and benefits, following FCERM-AG guidance.

2.3 11c12.3 - Options development and appraisal

The main Options Development report defined the long list options, each of these has been screened at a high level against technical, economic and environmental criteria to develop a list for final detailed appraisal.

Table 5 summarises the long list options for each policy unit covered in this section, in addition to the baseline options of:

- Do nothing
- Do minimum.

Table 4 Long list options considered for priority units in 11c12.3.1 and 11c12.3

Priority Unit	Hold the line							Managed realignment				
	Maintain: proactive maintenance	Maintain: reinforce existing defences	Sustain: reinforce existing defences	Improve: improve existing defences	Improve: construct new shore control structures	Improve: construct new revetments or seawalls	Improve: beach recharge	Improve: cliff or slope stabilisation measure	Construct erosion slowing defences	Construct defences once set back	Construct secondary embankments	Remove existing defences
11c12.3.1: Old Railway Embankment	✓	✓	✓	✓		✓					✓	✓
11c12.3: Leven Viaduct	✓	✓	✓	✓		✓					✓	✓

As part of these options, it is also recognised that there is potential for:

- habitat creation sites
- adaptive management of assets

The entire estuary is designated as a SAC, SPA, Ramsar site and SSSI, forming part of the larger Morecambe Bay site. Options involving substantial construction across the intertidal have also been dismissed due to the international importance of this area. This does not however, exclude some extension of current defences to address outflanking issues if adjacent marsh areas erode. This will be considered as part of the Hold the line options.

The sections below outline the identification of long listed options and the assessment of shortlisted options and approaches (measures) that could be adopted to achieve these.

Do nothing has been appraised as a baseline in all frontages. This option assumes that no further works would be undertaken and the existing defences would deteriorate over time, resulting in failure.

Additional information on environmental impacts is provided in a **Strategic Environmental Assessment: Environmental Report** which systematically appraises the potential environmental consequences of the proposed strategy and recommend any actions needed to mitigate and monitor identified adverse effects.

The economic feasibility of implementing an option has been appraised through considering the packages of measures required for its implementation have been costed and the benefits of the

strategic options were identified and evaluated. The Do nothing option provides the baseline for the economic appraisal. This is reported in the **Economic assessment** report.

Each frontage has been considered in turn, in the following sections.

2.4 11c12.3.1: Old Railway Embankment

Policy unit 11c12.3.1 (Old Railway Embankment) is a proposed new sub unit. It extends from policy unit 11c12.2 Greenodd to Barrow End Rocks (A590) along the old railway embankment (Asset ID 104542). Due to flood risk through to Ulverston this frontage has a shared flood risk benefit area with other units 11c11.2, 11c11.3, 11c11.4 and 11c11.5 (note that these are all in policy area 11c11).

The Old Railway Embankment frontage has a 1,050 m stone and mortar wall at the top the of bank, which is in a poor condition. It has an approximate crest level of +6.62 mOD (Table 2) and is partly fronted by a wide foreshore.

The SMP2 policy for 11c12.3.1 Old Railway Embankment could be either:

- (i) the same as 11c12.2 Greenodd to Barrow End Rocks (A590), i.e. Hold the line – Manage flood and erosion risk by maintaining existing defences to an adequate standard for the strategy period; OR
- (ii) Hold the line in short term whilst seeking to realign and then Hold the line in long term on setback alignment. This would differ from the rest of 11c12.3 because realignment to high ground is not feasible due to the flood route through to south Ulverston and flood risk to the A590.

The option appraisal therefore has considered both Hold the line and managed realignment options.

2.4.1 11c12.3.1 - Initial screening of options

Table 5 Screening of long list options for 11c12.3.1 Old Railway Embankment

Long list options	Description	Short-listed?	Rationale
Do nothing	No further works undertaken, defences left to deteriorate and fail.	Baseline only	This option would not manage flooding to A590, agricultural land and properties. It has been assessed for comparative purposes only.
Do minimum	Reactive patch and repair of defences only.	Baseline only	This option would not manage long term flooding risk to A590, agricultural land, and properties. However, this may become the default option if funding is no longer available.
Hold the line: maintain through proactive maintenance	Measures to maintain the existing defences.	No	Patch repairs are not a viable option in this frontage as the approach would not increase level of protection against flood risk to the A590. This is effectively captured under Do minimum.
Hold the line: maintain through reinforcing existing defences	Low cost measures such as ad hoc rock toe works, gabions to improve longevity of existing defences.	No	Given the current poor condition of the stone or mortar wall and that it currently does not provide the required flood protection this is not considered to be a viable option. This option would not manage flooding to A590, agricultural land and properties.
Hold the line: sustain through reinforcing and raising existing defences	Measures to retain the current standard of flood protection through the	No	Given the current poor condition of the stone mortar wall this is not considered to be a viable option. This option would not manage flooding to A590, agricultural land and properties.

Long list options	Description	Short-listed?	Rationale
	reinforcement of existing defences		
Hold the line: improve existing defences	Measures to improve defence resilience, such as rock toe works, raising crest levels.	Yes	Given the current poor condition of the stone mortar wall it would be challenging to raise the crest level to provide the required flood risk protection and it is likely reinforcements to the existing structure would be required. It would allow a consistent approach to the A590 Greenodd Embankment Erosion scheme covering the adjacent policy unit 11c12.2. The scheme proposes a rock revetment structure with reinforcements to improve the existing seawalls, the extensive rock revetment may not be required along the whole frontage due to the wider foreshore but measures to counter any potential toe scour should be included.
Hold the line: improve through constructing new revetments or seawalls	Removal of the existing defences and construction of new revetments or seawalls.	Yes	Although options such as proprietary systems or concrete slopes would be inappropriate along most parts of this frontage, rock armour, concrete armour units, or riprap, would be potentially suited to conditions and requirements here. Construction of a new seawall may also be appropriate, although this option requires a large capital investment. This option has been taken forward for further consideration as it will offer the most resilient protection to the assets.
Managed realignment: construct secondary embankments	Removal of the existing defences and construction of a setback defence.	Yes	There are opportunities for habitat creation in this policy unit in some areas where saltmarshes are already well developed. The construction of setback defences would provide the required flood risk protection away from the estuary. It is a viable option to be considered.
Managed realignment: remove existing defences	Removal of the existing defences and allowing natural processes to resume.	No	Removal of the existing defences would further increase the flood risk.

2.4.2 11c12.3.1 - Development and appraisal of short listed options

Do nothing (Option 1)

This is considered as a baseline against which other options can be appraised. Under this option all maintenance and management of the defences would cease and defences would be allowed to fail.	
Technical	<p>The future lifespan of the existing defences would depend upon changes in exposure conditions due to migration of the low water channel. Should the channel start to infill or move away from the coast, there is potential for accretion of the fronting flats and recolonization of marsh. This would add protection to defences and effectively prolong their life. Conversely, should the channel continue to migrate onshore, the risk of undermining will remain and potentially increase.</p> <p>The existing defences are in a poor condition, residual life 10 years. Once the defences have failed the low lying land will be more susceptible to tidal inundation and regular flooding. The embankment failure would pose an outflanking risk to the adjacent policy unit 11c12.2 and could compromise the proposed erosion works planned in this policy unit to protect the A590.</p>
Environmental	<p>Failure of the embankments would result in tidal inundation of the low lying area, up to the naturally rising land. This would impact on the viability of agricultural land and could impact on the local economy.</p> <p>This option would not reduce risk of flooding or erosion to the frontage. As a result, this may impact on the flood risk to the agricultural properties along the frontage and the community of Arrad Foot, set back</p>

	<p>from the coast. This option will increase the flood risk to the A590, a key road link, which also would isolate communities, for example, the community at Arrad Foot. Additionally, the reduced operation of this road could impact on the emergency response times to isolated communities, thereby putting the health and safety of residents at risk. The increased tidal flood risk to the A590 would also impact traffic flows between the M6 and Ulverston, Dalton and Barrow-in-Furness with potentially serious consequences for the local, regional and national economy.</p> <p>The Leven Estuary is protected by several designations: Morecambe Bay Ramsar, SAC and SSSI; and Morecambe Bay and Duddon Estuary SPA. By doing nothing, more natural coastal processes may be reinstated along this frontage. This could lead to a more natural pattern of expansion or accretion of the intertidal zone and allow for the enhancement of the designated intertidal habitats. The impacts on these sites should be considered under the Habitats and Species Conservation Regulations (2017) and the Countryside and Rights of Way Act (2000). There are areas of saltmarsh, floodplain grazing marsh and mudflats (BAP habitats) within the frontage that may benefit from being allowed to evolve naturally. The saltmarshes are also an important feature of the Morecambe Bay Limestones national character area and enhancing this habitat may add value to the national character area.</p> <p>Though the frontage itself is not protected by any heritage or landscape designation, the estuary forms a part of the Lake District National Park and English Lake District World Heritage Site. Do nothing may result in potential changes in hydrodynamics of the estuary and a change in habitats, which may result in changes in landscape and views around the estuary. However, a move towards a naturally functioning system and the protection and enhancement of ‘wildness’ with emphasis on sustainability are objectives of the National Park Management Plan, which a Do nothing option would help to meet.</p>
Cost	There are no costs associated with the Do nothing option.
Damages	The key damages are flooding inland of the frontage, putting agricultural land and the A590 at greater risk and potentially linking through to Ulverston. Damages have been included in the assessment for 11c11 due to shared benefits with other units 11c11.2, 11c11.3, 11c11.4 and 11c11.5.

Do minimum (Option 2)

This is also considered as a baseline against which other options can be appraised. Under this option only reactive patch and repair maintenance would be undertaken, with no works to address any increase in risk due to sea level rise.	
Technical	<p>The works under this option are low cost and reactive. Due to the poor condition of the defence it is likely the defences will require significant maintenance on a regular basis, with the line between maintenance and potential rebuild of particularly poor condition elements of the assets.</p> <p>This is likely to extend the life of the existing structures by approximately 5 years; with subsequent failure as under Option 1.</p>
Environmental	Once the defences fail the impacts will be as in Option 1.
Costs	<p>Costs would be restricted to patch and repair works only, these are likely to be extensive due to the current poor condition of the existing defences.</p> <p>There are no Present Value Capital Works. The Present Value Total Cost with Optimism Bias (PV(OB)c) is estimated to be £90 k.</p>
Damages	As with the Do nothing, the key damages are flooding inland of the frontage, putting agricultural land and the A590 at greater risk and potentially linking through to Ulverston. Damages have been included in the assessment for 11c11 due to shared benefits with other units 11c11.2, 11c11.3, 11c11.4 and 11c11.5.

Hold the line: improve existing defences (Option 3)

A suitable solution could be to refurbish the existing structure to improve the overall condition and raise the crest level to provide the required flood risk protection. A rock revetment structure to mitigate any potential toe scour should also be allowed for.	
Technical	Raising the crest level would need to be investigated further and it is likely reinforcements to the existing structure would be required to accommodate an increase in the crest level. This could be undertaken at the same time as refurbishing the defence to improve its overall condition. The refurbishment of the existing structure would need to be undertaken periodically. The tidal gates and tie in defences on Newland Beck would also need to be considered.

	Incorporation of a rock toe may also be required to mitigate against any potential scour. This option would protect the A590 and manage the flood risk inland into the long term.
Environmental	<p>This option would reduce the risk of flooding to the assets currently defended, thereby reducing risk to communities linked to the A590 and to the agricultural viability of land as well as ensuring long term viability of a proposed new cycle route along the top of the old railway embankment. Between the existing Greenodd picnic site to Plumpton.</p> <p>The existing structure footprint would need to be made larger and may encroach into the sandy or muddy foreshore, within the Morecambe Bay international and national conservation designations. This option would result in loss of intertidal habitats during periods when the low water channel moves closer to the shoreline. The impacts on the integrity of these sites will require assessment under the Habitats and Species Conservation Regulations and the Countryside and Right of Way Act (2000). Improving the existing defences may also affect the landscape value of the frontage and views of the estuary, which may contribute to the setting of the National Park and the World Heritage Site.</p> <p>The potential increase in footprint as a result of a rock toe may alter the hydromorphological processes along the frontage, and compromise the WFD objectives of the relevant waterbodies including the Leven transitional water body.</p>
Costs	<p>Costs would be for the initial refurbishment and increasing the crest height of the structure and incorporation of a rock toe. Increase in the crest height could be undertaken in stages.</p> <p>The Present Value Capital Works are estimated to be £5,380 k and the Present Value Total Cost with Optimism Bias (PV(OB)c) is estimated to be £8,840 k.</p>
Benefits	This option would provide the required standard of flood protection to the hinterland, particularly the A590 and further inland. Benefits have been included in the assessment for 11c11 due to shared benefits with other units 11c11.2, 11c11.3, 11c11.4 and 11c11.5.

Hold the line: improve through constructing new revetments or seawalls (Option 4)

Removal of the existing stone or mortar wall at the top of the bank and construction of new revetments and seawalls. To be consistent with approach adopted for the A590 Greenodd Embankment Erosion scheme covering the adjacent policy unit 11c12.2, a rock revetment could be constructed.	
Technical	<p>The demolition of the existing defences and replacement with a consistent defence along the frontage would reduce the erosion and flooding risk by introducing a consistent and resilient solution for the length of the frontage. A suitable structure at this location would be a rock revetment with the inclusion of a seawall along the existing alignment.</p> <p>The removal of the existing poor condition stone or mortar wall and construction of a rock revetment to the required flood protection level would tie into the adjacent policy unit (11c12.2). This option would protect the A590 and manage the flood risk inland into the long term.</p>
Environmental	Impacts would be as in Option 3. There are potential opportunities to improve landscape character and integrate new or raised footpath cycleway.
Costs	<p>Large capital costs to remove the existing structure and replace with a rock revetment.</p> <p>The Present Value Capital Works are estimated to be £5,120 k and the Present Value Total Cost with Optimism Bias (PV(OB)c) is estimated to be £8,590 k.</p>
Benefits	This option could provide a suitable standard of flood protection to the hinterland, particularly the A590 and further inland. Benefits have been included in the assessment for 11c11 due to shared benefits with other units 11c11.2, 11c11.3, 11c11.4 and 11c11.5.

Managed realignment: construct secondary embankments (Option 5)

Removal of the existing defences and construction of a setback defence, likely form is a rock revetment further inland of the estuary edge.	
Technical	The removal of the existing poor condition stone or mortar wall and identifying a setback location for the construction of a setback embankment to the required flood protection level would tie into the adjacent policy unit (11c12.2). There could also be opportunities to incorporate the proposed new cycleway on the crest of the new raised defences, rather than on the old railway embankment as currently proposed.

	This option would protect the A590 and manage the flood risk inland, although investigations to assess potential impacts on the rest of estuary and adjacent bay need to be undertaken, as well as potential manage realignment implications, opportunities and constraints (Refer to Section 1.3).
Environmental	<p>Creating set back defences further inland through a phased approach would allow for a more naturally functioning system to re-establish. This may lead to gains of intertidal habitats and associated species within or adjacent to the Morecambe Bay international and national conservation designations of the estuary. The impacts of managed realignment would require assessment under the Habitats and Species Regulations (2017) and the Countryside and Rights of Way Act (2000).</p> <p>Additionally, the removal of the existing defences would remove some of the hydromorphological constraints on the estuary, and the increased area of water would likely increase spawning or nursery areas for fish, which would be beneficial for the Leven transitional waterbody.</p> <p>A more natural landscape through the move to a more natural setting may also enhance the setting of the Lake District National Park and World Heritage site. There is also potential to improve the recreational and visual amenity of the frontage.</p> <p>However, repeated inundation of land previously defended may reduce its viability for agricultural use. Construction of the new set back defences could require construction on currently undeveloped ground, which may have negative impacts on landscape, visual amenity and biodiversity of the area, which would require further consideration.</p>
Costs	<p>Large capital costs to remove the existing structure and replace with a new set back embankment. The cost estimate is indicative only as the alignment of the new embankment and extent of works required will require scheme level appraisal studies.</p> <p>The Present Value Capital Works based on a 720 m embankment and 150 m of rock armour protection are estimated to be £11,990 k and the Present Value Total Cost with Optimism Bias (PV(OB)c) is estimated to be £19,330 k.</p>
Benefits	This option would provide the required standard of flood protection to the A590 and further inland. However, loss of agricultural and other assets within the proposed zone of potential managed realignment. Benefits have been included in the assessment for 11c11 due to shared benefits with other units 11c11.2, 11c11.3, 11c11.4 and 11c11.5.

2.4.3 11c12.3.1 - Discussion

This considers a new sub unit within 11c12.3, 11c12.3.1 Old Railway Embankment, to specifically address a flood route risk to the A590 and further inland.

There is potential for managed realignment to a more sustainable position on this frontage, with this new defence line being held in the long term to reduce flood risk to Ulverston with future sea level rise. However, this will require further studies, therefore in the shorter term minimising flood risk through retaining existing defences will be required.

Due to the poor condition of the existing defences along the old railway embankment, Do minimum (option 2) would not provide a suitable flood risk management approach in the medium to long term. Option 3, improving the existing defences could be implemented, but due to the condition of the existing defences, significant refurbishment would be required to prolong the life of the structures. The cost estimates for the options considered are presented in Table 6. Note that benefits are shared with other policy units 11c11.2, 11c11.3, 11c11.4 and 11c11.5 and a combined economic assessment is included in the options assessment report for 11c11.

In the longer term, there are several alternative approaches to Hold the line, although the most suitable technical approach is to provide a formal rock revetment with a seawall (Option 4); other methods could be considered with further investigation. The defence may need to be higher than the current low bank level to manage risks from overtopping and flooding in the future. This would allow a consistent management approach along the Leven Estuary frontage; the option would align with the A590 Greenodd Embankment Erosion scheme covering the adjacent policy unit 11c12.2. Improve options that would extend the footprint of the defence into the estuary have the potential

to cause significant impacts on the Morecambe Bay SAC, SPA and SSSI and would need careful consideration and planning.

Construction of a new set back defence line (Option 5) is the environmentally preferred option but requires investigations to assess potential impacts on rest of estuary and adjacent bay, including the potential for increased erosion risk at the railway viaduct and the A590 Greenodd embankment in 11c12.2. The impacts will vary depending on the scale of realignment and the approach to removal of the existing defences. With the set back option there would also be opportunities to allow the existing front line defence to largely remain whilst creating a managed breach for habitat creation to mitigate or compensate for losses of intertidal habitats elsewhere in the estuary.

Table 6 Economic assessment – cost estimates for options for 11c12.3.1

Policy Unit	Option		Design Life	Capital Works year applied	Whole Life Cost (cash 2018)	Present Value (PV)			
						Capital Works	Maintenance and Operation Works	Total cost (PVC)	Total cost with Optimism Bias (PV(OB)c)
						£m	£m	£m	£m
11c12.3.1	Option 1	Do Nothing	10	-	0.00	0.00	0.00	0.00	0.00
11c12.3.1	Option 2	Do Minimum	15	-	0.08	0.00	0.06	0.06	0.09
11c12.3.1	Option 3	Hold the line: Improve existing defences	100	0	5.88	5.38	0.15	5.53	8.84
11c12.3.1	Option 4	Hold the line: Improve through constructing new rock revetment	100	10	8.30	5.12	0.25	5.37	8.59
11c12.3.1	Option 5	Managed Realignment: Construct secondary embankments	100	10	17.31	11.99	0.09	12.08	19.33

2.4.4 11c12.3.1 - Strategic way forward

The preferred strategic approach is to Hold the Line in the short term by maintaining and repairing the defences, effectively as present management, whilst undertaking further studies to develop the best longer term approach.

To provide long term protection, significant improvements to the existing defences or new defence construction will be required. This could either be along existing alignments (Options 3 or 4), most likely through construction of a rock revetment, or involve construction of a new set back embankment (Option 5), although this would require further study to assess potential impacts on rest of estuary. Once constructed, this new set back defence would then be maintained to continue to minimise flood risk.

Whether the existing defence line or a new line is held, this would represent a change in policy from the existing SMP policy for unit 11c12.3, which is Hold the line, followed by Managed realignment, then No Active Intervention in the long term. Introduction of this new policy unit would also require a formal SMP Change Process to be followed, which will include community and stakeholder consultation prior to being submitted for approval by local authority cabinet, submission to the Regional Flood and Coastal Committee (RFCC) and final approval by the Environment Agency.

Given the shore benefits between this and other policy units, a whole catchment approach is required to manage the flood risk.

The following activities are recommended in the future:

- Consideration of frontage within ongoing EA scheme study 'South Ulverston Integrated Flood Risk Management Scheme' considering tidal flood risk reduction measures (short term potential fluvial / surface water schemes and tidal defences scheme needed in 20 or 30 years) and also the planned erosion management works in 11c12.2 (HE).

- Scheme appraisal for old railway embankment frontage to include considering potential for realignment for habitat creation to mitigate works in adjacent frontage.
- Maintenance and repair of existing defences.
- Assessment of potential impacts of a new set back embankment on the estuary including considering impacts of managed realignment on tidal prism and erosion risks to Leven viaduct early consultation with Natural England.

Further details on actions and responsibilities are provided in the **Action Plan**.

2.5 11c12.3: Barrow End Rocks (A590) to Leven Viaduct

A revision to Policy unit 11c12.3 Barrow End Rocks (A590) to Leven Viaduct is proposed to create a new policy unit: 11c12.3.1 Old Railway Embankment (see section 2.4 above). This section therefore appraises options specifically for the remainder of 11c12.3, from the old railway embankment to the Leven Viaduct.

This policy unit consists of an embankment (Asset ID 89238) situated between two frontages of natural high ground (Asset ID: 88598 and 67228) (see Figure 3). The embankment is 978 m in length with an approximate crest level +5.95 mOD and is in poor condition (Table 2).

The current SMP2 policy for this frontage is to Hold the line in the short term and then Managed realignment to high ground to allow natural processes to continue into the medium to long term. With the separation of the Old Railway Embankment sub unit, this revised policy unit only includes a 978 m section of embankment, which lies between two areas of high land and only provides protection to an area of agricultural land.

2.5.1 11c12.3 - Initial screening of options

Table 7 Screening of long list options for 11c12.3

Long list options	Description	Short listed?	Rationale
Do nothing	No further works undertaken, defences left to deteriorate and fail.	Yes	Allowing a naturally functioning sustainable coastline to form and provide additional natural habitat requires investigation to assess impacts on wider estuary and adjacent bay. This is the long term SMP policy.
Do minimum	Reactive patch and repair of defences only.	Baseline only	This may become the default option if funding is no longer available and there is a need to maintain the existing flood risk protection to the agricultural assets.
Hold the line: maintain through proactive maintenance	Measures to maintain the existing standard of protection.	No	The existing defences are in a poor condition and would require refurbishment to improve their condition. These measures are unlikely to provide sufficient flood protection to the agricultural area at risk. Maintaining the current standard of protection would mean the agricultural assets remain at risk of flooding.
Hold the line: maintain through reinforcing existing defences	Low cost measures such as ad hoc rock toe works, gabions to improve longevity of existing defences.	No	The existing defences are in a poor condition and would require refurbishment to improve their condition. These measures are unlikely to provide sufficient flood protection to the agricultural area at risk. Maintaining the current standard of protection would mean the agricultural assets remain at risk of flooding.

Long list options	Description	Short listed?	Rationale
Hold the line: sustain through reinforcing and raising existing defences	Measures to retain the current standard of flood protection through the reinforcement of existing defences	No	Modifying the existing embankment from its poor condition to increase the height to provide ongoing protection to the hinterland could be undertaken but works to improve its current condition. Given the cost and limited assets at risk it is not considered to be a viable option.
Hold the line: improve existing defences	Measures to improve defence resilience, such as raising crest levels.	No	Options to modify or adapt existing defences would require the refurbishment of the existing. Given the capital cost and limited assets at risk it is not considered to be a viable option.
Hold the line: improve through constructing new revetments or seawalls	Construction of a new revetment tying into the higher ground on either side.	No	This option would provide a resilient solution to protect the frontage at its current alignment. Given the capital cost and limited assets at risk it is not considered to be a viable option.
Managed realignment: construct secondary embankments	Identify set back location and allow nature process to be established.	No	There are opportunities for habitat creation in this policy unit in some areas where saltmarshes are already well developed. Given the capital cost and limited assets at risk it is not considered to be a viable option.
Managed realignment: remove existing defences	Removal of the existing defences and allowing nature processes to resume.	Yes	There is potential along this frontage to realign to higher ground and allow natural processes to resume.

2.5.2 11c12.3 - Development and appraisal of short listed options

Do nothing (Option 1)

This is considered as a baseline against which other options can be appraised. Under this option all maintenance and management of the defences would cease and defences would be allowed to fail.	
Technical	The existing embankment is in a poor condition and there is a high risk of a breach forming or failure due to undercutting. The potential flood route is constrained by higher ground either side of the embankment and inland. There could, however be wider potential impacts on the rest of the estuary.
Environmental	<p>Failure of the embankments would result in tidal inundation of the low lying area, up to the naturally rising land. This would impact on the viability of a small area of agricultural land (around 25 ha) and could impact on the local economy.</p> <p>The Leven Estuary is protected by several designations: Morecambe Bay Ramsar, SAC and SSSI; and Morecambe Bay and Duddon Estuary SPA. By doing nothing, more natural coastal processes may be reinstated along this frontage. The impacts on these sites should be considered under the Habitats and Species Conservation Regulations (2017) and the Countryside and Rights of Way Act (2000). There are areas of saltmarsh, floodplain grazing marsh and mudflats (BAP habitats) within the frontage that may benefit from being allowed to evolve naturally. The saltmarshes are also an important feature of the Morecambe Bay Limestones national character area (NCA): enhancing this habitat may add value to the NCA.</p> <p>Though the frontage itself is not protected by any heritage or landscape designation, the estuary forms part of the Lake District National Park and English Lake District World Heritage Site. Do nothing may result in potential changes in hydrodynamics of the estuary and a change in habitats, which may result in changes in landscape and views around the estuary. However, a move towards a naturally functioning system and the protection and enhancement of ‘wildness’ with emphasis on sustainability are objectives of the National Park Management Plan, which a Do nothing option would help to meet.</p>
Cost	There are no costs associated with the Do nothing option.

Damages	The key damages are localised flooding inland of the frontage, putting a small area (<25 ha) of agricultural land at greater risk of flooding. Write off of agricultural land in year 10 would have potential damages of the order of £315 k, but this would need to be balanced against potential economic gains from habitat creation. Due to the limited extent at risk and uncertainties of the habitat creation calculations have not been undertaken for the strategy.
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Do minimum (Option 2)

This is also considered as a baseline against which other options can be appraised. Under this option only reactive patch and repair maintenance would be undertaken, with no works to address any increase in risk due to sea level rise.	
Technical	The works under this option are low cost and reactive. Due to the poor condition of the defences it is likely the defences will require significant maintenance on a regular basis, with partial rebuild of particularly poor condition elements of the assets.
Environmental	Once the defences fail, the impacts will be as in option 1.
Costs	Costs would be restricted to patch and repair works only, these are likely to be extensive due to the current poor condition of the existing defences. There are no Present Value Capital Works, since works are restricted to patch and repair works only. The Present Value Total Cost with Optimism Bias (PV(OB)c) is estimated to be £210 k.
Damages	As with the Do nothing, the key damages are flooding inland of the frontage, putting agricultural land at greater risk. Assuming write-off in year 20, calculated damages are of the order of £237 k. The benefits would relate to delaying the loss of the agricultural land, estimated at £78 k.

Managed realignment: remove existing defences (Option 3)

Removal of the existing defences and allowing natural processes to resume.	
Technical	The removal of the existing poor condition embankment and allowing natural processes to continue. This option would be different to the Do nothing scenario because it assumes that the existing embankments would be removed in year 5 in order to allow a more rapid return to natural processes than allowing the defences to deteriorate under do-nothing.
Environmental	Impacts would be as for Option 1, although the timing of change may differ. The process of removing defences could have a potential impact on intertidal habitat, and would require further consideration at scheme stage.
Costs	Costs to remove and dispose of the existing embankment. The Present Value Capital Works are estimated to be £250 k and the Present Value Total Cost with Optimism Bias (PV(OB)c) is estimated to be £400 k.
Benefits	As with the Do nothing, the key damages are flooding inland of the frontage, putting agricultural land at greater risk. Note, however, that the costs of defence removal may be greater than the value of habitat created.

2.5.3 11c12.3 - Discussion

Table 8 provides a summary of costs for the various options considered above. Benefits are shared with other policy units and have been included in the cost-benefit calculations for Policy area 11c11.

It is proposed that policy unit 11c12.3 Barrow End Rocks to Leven Viaduct is sub divided such that it does not include the Old Railway Embankment (11c12.3.1).

The current SMP2 policy for this frontage is to Hold the line in the short term and then managed realignment to allow natural processes to continue into the medium to long term. With the separation of the Old Railway Embankment sub unit this approach should be more likely and easier to implement given the policy unit now only has a 980 m section of embankment between two areas of high land and the embankment only provides protection to an area of agricultural land. Without

flood protection, the productivity of the agricultural land would be reduced, but this is considered very unlikely to justify public expenditure in maintaining these defences.

As there are limited assets at risk a Do nothing option could be a more suitable option for this frontage. This would allow the embankment to fail naturally in the future as sea levels rise. The realignment site is relatively small compared to others in the Inner Leven and high in the tidal frame so would not flood frequently. Due to the location and size, impacts on the tidal prism and potential for significant changes to flows at the Leven viaduct or impacts elsewhere in the estuary are lower risk than at other larger sites in policy unit 11c12.1 but should be investigated alongside recommended actions for 11c12.1, see Section 3.1.3. The potential implications of other initiatives, such as the extension of the cycle route would also need to be considered.

The environmental assessment of the options indicated that Option 3, defence removal would be environmentally preferred, however the costs of removing the defences are unlikely to be justifiable unless this was part of a habitat creation scheme justified by a requirement to create compensatory habitat due to direct losses of habitat due to schemes elsewhere and a cheaper or better quality site than others in the area.

Table 8 Economic assessment – costing of options for 11c12.3

Policy Unit	Option		Design Life	Capital Works year applied	Whole Life Cost (cash 2018)	Present Value (PV)			
						Capital Works	Maintenance and Operation Works	Total cost (PVC)	Total cost with Optimism Bias (PV(OB)c)
						Year	Year	£m	£m
11c12.3	Option 1	Do Nothing	10	-	0.00	0.00	0.00	0.00	0.00
11c12.3	Option 2	Do Minimum	20	-	0.18	0.00	0.13	0.13	0.21
11c12.3	Option 3	Managed Realignment: Remove existing defences	0	5	0.30	0.25	0.00	0.25	0.40

2.5.4 11c12.3 - Strategic way forward

Due to the change in SMP policy unit extend, there are limited assets at risk. As a result, a Do nothing approach is the preferred strategic approach for this frontage than the current policy of hold the line in the short term. This would effectively bring the long term SMP policy forward. Continuing minimum interventions to defences (Do minimum), if funded by the landowner, would not be detrimental to the longer term aim and would therefore remain acceptable in the short term.

Due to the location and size, impacts on the tidal prism and potential for significant impacts elsewhere in the estuary are of a lower risk than other locations, but should be investigated alongside recommended actions for 11c12.1.

The following activities are recommended in the future:

- As part of estuary-wide study looking at future gains and losses in marsh and flats for 11c12.1 consider impacts of managed realignment in 11C12.3 on tidal prism and erosion risks to Leven viaduct.
- Liaison with stakeholders on future management of private defences.

Further details on actions and responsibilities are provided in the **Action Plan**.

3 Appraisal of non priority units

There are two additional policy units within this area, which have been defined as non priority units:

- 11c12.1 Leven Viaduct to Haverthwaite (left bank) and Haverthwaite to Greenodd (right bank)
- 11c12.2 Greenodd to Barrow End Rocks (A590)

A light touch review has been undertaken of current SMP recommendations, taking into account conclusions from option appraisals for the adjacent frontages, where appropriate.

3.1 11c12.1 Leven Viaduct to Haverthwaite (left bank) and Haverthwaite to Greenodd (right bank)

3.1.1 11c12.1 - Existing approach to flood and coastal erosion risk management

The existing SMP2 policy along this frontage is Hold the line in the short term for local areas where defences are present to allow time for further studies to investigate opportunities and viability of realigning defences or retreating to high land where appropriate, including assessing the potential impacts on wider bay and railway viaduct. In the medium term the policy is Managed realignment, to be carried out to create more sustainable defence alignments by retreating to higher land, depending on investigations into approach. Then adopting a No active intervention SMP2 policy in the long term, allowing natural processes to continue, whilst still allowing the management of private defences subject to consent.

The SMP2 considered that the existing defences, summarised in Table 9 are not expected to be economically justifiable for national funding in the long term due to the limited assets within the flood cell. Limited data has been obtained for the defences, therefore where necessary, residual life has been estimated from available photographs.

Table 9 Existing defence details

Location	Structure Type	Residual Life (years)	Source and Assumptions
Leven Viaduct to Barker Scar	Natural Shore	-	Interpreted from oblique aerial photos only.
Park Head	Vertical Walls, fronted by sand and mudflats, saltmarsh.	>5	Interpreted from oblique aerial photos only.
Park Head to Reake Cottages	Embankment, fronted by sand and mudflats, saltmarsh.	5-10	Interpreted from oblique aerial photos only.
Reake Cottages to Frith Hall	Natural Shore	-	Interpreted from oblique aerial photos only.
Frith Hall to Hazelhurst Point	Embankment, fronted by sand and mudflats, saltmarsh.	Unknown	Interpreted from oblique

Location	Structure Type	Residual Life (years)	Source and Assumptions
			aerial photos only.
Upstream and downstream Greenodd Bridge	Earth embankment, front face reinforced with large stones. Defends Pasture. Fronted by sand and mudflats.	>20	NFCDD 2007.
North edge of Greenodd Sands	Vegetated earth embankment, fronted by sand and mudflats.	5-10	NFCDD 2007.

3.1.2 11c12.1 - Strategy considerations

The northerly orientation of the estuary, combined with the obstructive effect of the railway viaduct and breakwater, reduces any wave penetration into the estuary, therefore erosion risk is predominately driven by migration of channels, which has had a major effect on patterns of saltmarsh accretion and erosion.

The entire Leven estuary is designated as a SAC, SPA, Ramsar site and SSSI, forming part of the larger Morecambe Bay site. The whole estuarine complex of Morecambe Bay is of international significance for wintering wading birds and of national significance for wintering wildfowl. The saltmarshes are particularly important for their vegetation which is diverse, supporting a number of rare and uncommon plants, as well as a variety of nationally scarce invertebrate species. Depending upon the scale of management realignment, there is potential to impact on Roudsea Wood and Mosses and Barker Scar (SSSI, SAC, NNR) and Limestone Pavement Orders at Old Park and Waitham Wood.

The current embankments protect predominately farmland and farmsteads.

Natural England is working on proposals to improve public access along this coast but as yet the route is undefined (proposals are due to be produced in Autumn 2019).

There is a need to reconsider the boundary between policy units 11c12.1 and 11c12.2 given possible future infrastructure works to reduce traffic accident risks on the A590 north of the Greenodd roundabout where there are a series of bends on the single carriageway section. A future improvement scheme to dual this section may need to consider widening on the estuary side.

3.1.3 11c12.1 - Discussion

The SMP2 policy for most of the shoreline inland of the viaduct is a transition from current practice of Hold the line through managed realignment in the medium term to No active intervention in the long term. The transition in policy is staged in order to allow time for adaptation measures to be put in place if necessary.

At present there is no new evidence since the SMP was developed to justify for any change in policy in this unit, which supports the environmental designations of the estuary, but similarly there have been limited investigations into the potential for managed realignment schemes. Therefore, the recommendation would be for the policy to remain, with continued management of risk to isolated properties and heritage assets, whilst longer term approaches are investigated.

In the long term, realigning to higher ground will result in a more naturally functioning sustainable coastline, potentially enhance natural habitat and maintain the exposures of geological SSSIs. However, realignment could have impacts on the estuary and wider Morecambe Bay due to increasing tidal volume and sediment demand as accretion takes place in the expanded intertidal zones. As a result, there are potential risks to infrastructure such as the railway viaduct. There is therefore a need to improve understanding of these potential impacts, but this would require

modelling of flows and sediment transport which is beyond the scope of the current strategic study. More detailed economic studies will also be needed to address uncertainties associated with agricultural and infrastructure value.

Early discussion with Natural England is recommended, as environmental objectives are also a key consideration. Engagement during this strategy development in 2018 identified that there is an opportunity for coastal wetland habitat creation at Roudsea Woods and Mosses National Nature Reserve (NNR) on the eastern bank of the Leven estuary. Such habitat would potentially be saltmarsh, reed bed and upper marsh transitional habitat (to coastal woodland). The current, small embankment located in the upper shore of the NNR is protecting a very small area of degraded farm land which is of limited agricultural value. Removing this embankment and creating a small new embankment to the south has potential to create more than 5 hectares of high quality coastal habitat. It is also understood that there are other larger scale realignment opportunities in preliminary discussion. The potential managed realignment implications, opportunities and constraints are discussed in Section 1.3 on an estuary-wide scale.

If Highways England progress potential future A590 widening or improvement schemes between Greenodd and Haverthwaite there would be opportunities to consider managed realignment in the adjacent part of policy Unit 11c12.1 between Greenodd and Russland Pool to provide compensatory habitat for any encroachment into the estuary designated sites whilst also providing suitable set back flood risk management for the A590. This may require moving the boundary between policy units 11c12.1 and 11c12.2 north east to the east side of Russland Pool, so that new set-back defences for the A590 have a long-term Hold the line policy.

3.1.4 11c12.1 - Strategic way forward

The long term strategic approach is to move towards a more naturally functioning estuary shoreline. In the short term, recognising the need for short term management to allow time for adaptation and further investigations.

The short term SMP policy could be achieved through a Do minimum, risk-based approach, involving reactive patch and repair of defences only, focussing on frontages with greater risk to assets. The works under this option would be low cost although due to the poor condition of the defence it is likely the defences will require maintenance on a regular basis.

Through ongoing discussions with Natural England, opportunities should also be sought to realign or remove defences to enable small to medium scale habitats creation through managed realignment and reducing the need to continue investment in flood defence maintenance.

Future recommended activities include:

- Monitoring of the frontage. Currently there is no beach profile or saltmarsh edge monitoring within the Leven Estuary upstream of the Leven Viaduct undertaken as part of the North West Regional Monitoring Programme. Baseline information will be required to inform any modelling of possible managed realignment schemes.
- Collection of asset inspection data – very little up to date information appears to be available on the existing defences, which makes it difficult to appraise levels of risk.
- Undertake studies and consultation to investigate managed realignment viability and associated effects on the Leven Estuary and adjacent bay and infrastructure such as the Leven Viaduct and A590, to inform policy delivery and develop a long term strategy, including a Habitat Regulations Assessment. Confirm preferred technical approach, extents of managed realignments and potential for habitat gains and losses.

- A590 Greenodd to Russland Pool – As part of possible future widening and improvement of the alignment of the A590 consider opportunities for managed realignment to manage flood risk to the A590 and as part of this consider moving the boundary between policy units 11c12.1 and 11c12.2 boundary to Russland Pool such that new, set-back defences to the A590 are included in 11c12.2.

Further details on actions and responsibilities are provided in the **Action Plan**.

3.2 11c12.2 Greenodd to Barrow End Rocks (A590)

3.2.1 11c12.2 - Existing approach to flood and coastal erosion risk management

The existing policy along this frontage is Hold the line by managing flood and erosion risk by maintaining existing defences to an adequate standard. The policy manages the risk to the A590 road, a key transport link for the region, but recognises potential for impacts on internationally designated intertidal habitat in long term. The policy was considered economically viable as diverting the A590 road would be significantly more expensive.

The Environment Agency provided shapefiles for the frontage with a brief description of the defence type and overall condition. Man-made structures and natural frontages have been divided in two tables for clarity: see Table 10 and Table 11, respectively. Oblique aerial photographs for the man-made and natural defences are shown in Figure 10.

Table 10 Existing defence details for 11c12.2, based on information provided by the Environment Agency

ID	Structure Type	Overall Condition	Length (m)	Crest Level (mOD) *	Residual Life (years)**
47444	Maintained Channel (bank): Natural earth or sand banks with rocks embedded in sand at water level. There is a grassy bank with a berm above with rock armour type protection. There is then another earth bank with road beyond this.	Fair (3)	830		25
47443	Maintained Channel (bank): Natural earth or sand banks with rocks embedded in sand at water level. There is a grassy bank with a berm above with rock armour type protection. Path is at top of bank behind timber fencing. Road is beyond this.	Fair (3)	200		25
48521	Maintained Channel (Wall): Natural sand intertidal banks. Lower section of bank has many stoned embedded into sand. Above this is a small berm with a footpath running along it. There is then a stone or mortar wall with stone capping. Timber fence at top.	Poor (4)	220		10
48520	Maintained Channel: Natural sand intertidal banks. Lower section of bank has many stoned embedded into sand. Above this is a small berm with a footpath running along it. There is then a sloping bank constructed of large rocks and lumps of concrete. Timber fence at top.	Poor (4)	315		10
55446	Regraded earth embankment, with masonry wall on eastern side of crest	Good (2)	93	+6.08	45

* Information extracted from DTM LiDAR 2017

** Residual life estimated based on condition from asset deterioration guidance document (Environment Agency, 2013)

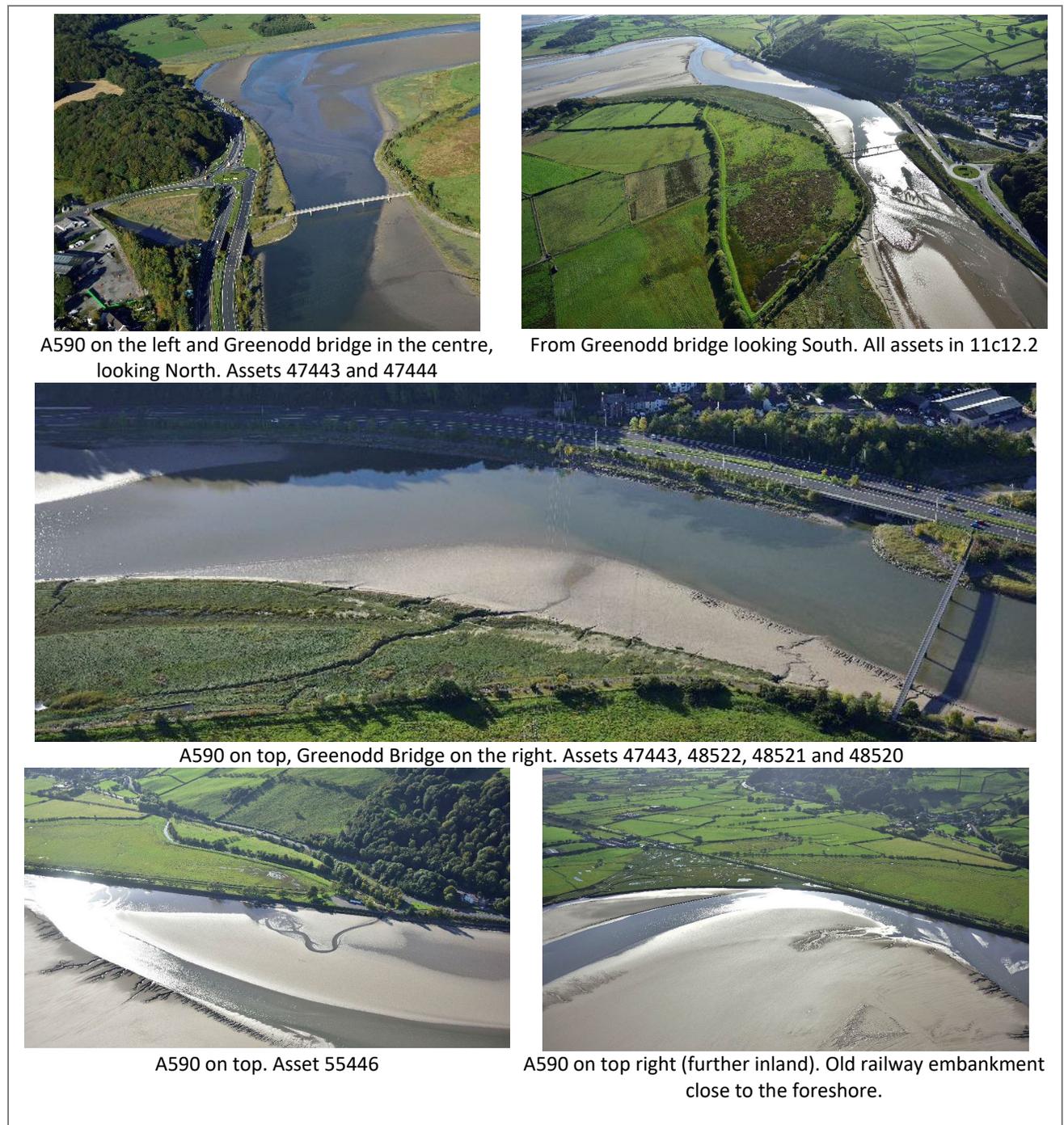


Figure 10: Oblique aerial photographs (2015) for Policy Unit 11c12.2. 2015 aerial photographs © North West Regional Monitoring Programme.

The remaining frontages within this policy unit are mapped as natural high ground. Descriptions of each of these are available in the shapefiles and are shown in Table 3.

Table 11 Existing natural defence details, based on information provided by the Environment Agency.

ID	Description	Overall Condition	Length (m)
48522	Maintained Channel: Natural earth or sand banks with rocks embedded in sand at water level. Top of bank is vegetated with trees and grass. Path is at top of bank behind timber fencing. Road is beyond this.	Poor (4)	110
88598	Natural high ground. It appears to be natural earth and sand banks vegetated with grass above.	-	870

3.2.2 11c12.2 - Strategy considerations

The orientation of the estuary, combined with the obstructive effect of the railway viaduct and breakwater, reduces any wave penetration into the estuary, therefore erosion risk is predominately driven by migration of channels, which has had a major effect on patterns of saltmarsh accretion and erosion.

The entire Leven estuary is designated as a SAC, SPA, Ramsar site and SSSI, forming part of the larger Morecambe Bay site. The whole estuarine complex of Morecambe Bay is of international significance for wintering wading birds and of national significance for wintering wildfowl. The saltmarshes are particularly important for their vegetation which is diverse, supporting a number of rare and uncommon plants, as well as a variety of nationally scarce invertebrate species.

Natural England is working on proposals to improve public access along this coast but as yet the route is undefined (proposals are due to be published in Autumn 2019).

The A590 is the key asset at risk from erosion, whilst both the road and parts of the village of Greenodd are at potential risk from flooding. Since the SMP2 was produced, there have been erosion issues along a section of the A590 and the A590 Greenodd Embankment Erosion proposed defence improvements to protect the road (EM, 2015). There is a proposed future remedial scheme, subject to future funding approvals and ongoing risk monitoring, which involves the proposed remediation of a section of the A590 adjacent to the Leven Estuary (further details provided in Section 2.1.4).

There is a need to reconsider the boundary between policy units 11c12.1 and 11c12.2 given possible future infrastructure works to reduce traffic accident risks on the A590 north of the Greenodd roundabout where there are a series of bends on the single carriageway section. A future improvement scheme to dual this section may need to consider widening on the estuary side.

There is also a need to reconsider the boundary between policy units 11c12.2 and 11c12.3 given possible future infrastructure works. The flood route identified from the old railway embankment along the southern extent of policy unit 11c11.3 (see section 2.2.2) can be managed by introducing a sub unit within the existing 11c12.3 (Figure 8). The proposed new sub unit, 11c12.3.1 Old Railway Embankment is considered separately to 11c12.3 and the SMP2 management policy is assumed to be consistent with the existing policy unit 11c12.2 to the south, which is Hold the line for the strategy period. This will allow the flood risk to the south of the A590 and Newland Bridge to be managed, as well as the potential inland flood route through to Ulverston.

3.2.3 11c12.2 - Discussion

There is no justification for any change in policy from Hold the line therefore, the recommendation would be for the policy to remain. Development of options to improve the existing protection of the A590 were undertaken by EM (2015). The scheme proposes a rock armour revetment and existing retaining wall or platform structure repairs. The scheme is still pending planning permission and seeking funding from Highway England's future programme.

There are several approaches to Hold the line in the long term, although the most suitable technical approach is to provide a formal rock revetment with a seawall; other methods could be considered with further investigation. The defence may need to be higher than the current low bank level to prevent overtopping and flooding in the future. This would allow a consistent management approach along the Leven Estuary frontage; and would align with the A590 Greenodd Embankment Erosion scheme currently being considered.

If Highways England progress potential future A590 widening or improvement schemes between Greenodd and Haverthwaite there would be opportunities to consider managed realignment in the adjacent part of policy Unit 11c12.1 between Greenodd and Russland Pool to provide compensatory habitat for any encroachment into the estuary designated sites whilst also providing suitable set back flood risk management for the A590. This may require moving the boundary between policy units 11c12.1 to 11c12.2 north east to the east side of Russland Pool, so that new set-back defences for the A590 have a long-term Hold the line policy.

3.2.4 11c12.2 - Strategic way forward

The recommended strategic approach is to implement the SMP Hold the line policy through maintaining and upgrading the defences as necessary. In the short term the risk of erosion to A590 embankment should be monitored, implementing the already developed scheme to improve the defences when necessary. This should consider opportunities for habitat creation through managed realignment in the adjacent units 11c12.1 or 11c12.3.1 to provide replacement habitat and suitable set back flood risk management for the A590.

Future recommended activities include:

- Monitoring of the frontage. Currently there is no beach profile or saltmarsh edge monitoring within the Leven Estuary upstream of the Leven Viaduct undertaken as part of the North West Regional Monitoring Programme. Given the ongoing issues of erosion along this bank, additional monitoring is recommended along this frontage.
- Collection of asset inspection data – very little up to date information appears to be available on the existing defences, which makes it difficult to appraise levels of risk.
- A590 Greenodd Embankment Erosion scheme – seek necessary planning consents and undertaken Habitats Regulations Assessment to consider direct losses to the Natura 2000 designated intertidal sites.
- A590 Greenodd to Russland Pool – As part of possible future widening and improvement of the alignment of the A590 consider opportunities for managed realignment to manage flood risk to the A590 and as part of this consider moving the boundary between policy units 11c12.1 and 11c12.2 boundary to Russland Pool such that new, set-back defences to the A590 are included in 11c12.2.
- Consider the potential to extend the proposed embankment erosion scheme in 11c12.2 to include works in the proposed new policy unit 11c12.3.1 Old Railway Embankment to mitigate flood route risk to the A590 and Ulverston, as discussed in Section 2.4. Realignment here could allow for environmental mitigation and creation of replacement habitat for the footprint of the proposed works in the Natura 2000 sites. If these works could be undertaken with the proposed Highways England Greenodd embankment scheme there could be potential efficiencies and cost savings by undertaking the work as a package.
- Consider the need for a formal SMP policy change, which would need to follow a formal process.

Further details on actions and responsibilities are provided in the **Action Plan**.

4 Summary of proposed strategy: 11c12

Preferred strategic approach: The long term vision is to move towards a more naturally functioning estuary. In the short term this would involve reactive maintenance of defences, whilst taking opportunities to realign or remove defences to enable small to medium scale habitats creation through managed realignment while managing risks to properties and infrastructure and the designated sites.

		Next 10 years	Beyond 10 years
11c12.1	Leven viaduct to Haverthwaite (left bank) and	Take opportunities to realign or remove defences to enable small to medium scale estuarine habitat creation through managed realignment with further investigations regarding need for adaptation to manage wider risks.	Subject to short term investigations allow area to function as naturally possible.
11c12.1	Haverthwaite to Greenodd (right bank)	Allow area to function as naturally as possible, whilst recognising the need for short term management to allow time for adaptation/ further investigations.	Possible SMP boundary position change depending on improvement scheme for A590, Greenodd to Russland Pool.
11c12.2	Greenodd to Barrow End Rocks (A590)	Monitor risk of erosion to A590, implementing scheme to improve defences when necessary, considering opportunities for habitat creation through managed realignment in the adjacent units 12.1 or 12.3.1 to provide replacement habitat and suitable set back flood risk management for the A590.	Hold the line through proactive maintenance of defences.
11c12.3.1	Old Railway Embankment	Consider SMP policy change to introduce new unit. Maintain defences while considering options for managed realignment and habitat creation or improving defences.	Hold the line to manage flood risk to A590 and Ulverston through proactive maintenance of defences either on current alignment or set back with habitat creation.
11c12.3	Barrow End Rocks (A590) to Leven viaduct	Allow area to function as naturally as possible and look for environmental opportunities to enhance site with further investigations regarding need for adaptation to manage wider risks.	Subject to short term investigations allow area to function as naturally possible.

Key actions and activities (next 10 years):



- Monitor condition of defences
- Monitor marsh and intertidal change
- Monitoring to inform modelling of estuarine processes



- Patch and repair degradation/damage of defence assets if required.

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- Subject to consents implement short term improvement scheme to defences at Greenodd when necessary.
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- Consider undertaking SMP change process to establish new policy unit 11c12.3.1 and redefining policy unit boundaries (11c12.1 and 11c12.2)
 - Additional studies to explore the potential for habitat creation and impact of realigning or abandoning sections of defences in 11c12.1 and 11c12.3 on tidal prism and erosion risks to Leven viaduct, the A590 and the wider geomorphology.
 - Estuary-wide scale geomorphological study looking at current and potential future gains and losses in marsh and flats.
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- Continue to develop scheme proposed to protect A590 from channel erosion risk.
 - Scheme appraisal for old railway embankment in new unit 11c12.3.1
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- Liaison between stakeholders regarding potential changes to defence management related to future plans for the A590.
 - Engagement with local land owners and the community on future management of private defences.
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Further details on actions and responsibilities are provided in the **Action Plan**.

5 References

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