Humber Estuary Coastal Authorities Group

Flamborough Head to Gibraltar Point Shoreline Management Plan

Appendix C – Assessment of Coastal Behaviour and Baseline Scenarios

Final

December 2010

Prepared for

Humber Estuary Coastal Authorities Group

Revision Schedule

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Appendix C – Assessment of Coastal Behaviour and Baseline Scenarios

December 2010

Rev	Date	Details	Prepared by	Reviewed by	Approved by
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C1 Assessment of Coastal Behaviour and Dynamics

Introduction

C1.1 This section provides a review of coastal behaviour and dynamics, which will be used to develop baseline scenarios, identify risks and assess the shoreline response and implications of different management policy scenarios. In accordance with the Shoreline Management Plan (SMP) Guidance (Defra 2006b), a "coastal behavioural systems" approach has been adopted. This involves the identification of the different elements that make up the coastal structure and developing an understanding of how these elements interact on a range of both temporal and spatial scales.

C1.2 The objectives of this Section are to:

- Identify and characterise large scale shoreline behaviour units within the SMP area;
- Develop a conceptual model to describe the inter-linkages between these shoreline behaviour units within the context of a larger-scale coastal behaviour system;
- Develop a series of conceptual models to describe the functioning of the individual shoreline behaviour units, including identification of the key controls on coastal behaviour;
- Describe each of the shoreline behaviour units in terms of the coastal processes and coastal changes at different scales, including local scale Management Units; and
- Predict future coastal changes, taking into account climate change and sea-level rise for each coastal behaviour system.

C1.3 The understanding of coastal processes and baseline scenarios has been developed using available reports, information and data. Notably this section builds on information held within Futurecoast (Halcrow 2002) and the Southern North Sea Sediment Transport Study (SNSSTS) (HR Wallingford 2002). These two documents provide a high-level understanding of coastal dynamics and behaviour within the SMP area and beyond. Reference has also been made to the various research studies undertaken as part of the Land-Ocean Interaction Study (LOIS; Shennan and Andrews, 2000) which focussed on Holocene changes on the east coast of England.

C1.4 There is considerable uncertainty about the scale of future climate change and sea level rise, however, Defra present guidance on future sea level rise which takes account of the scientific research undertaken by the Intergovernmental Panel on Climate Change. The sea level rise figures provided by Defra have been used by all SMPs in assessing future shoreline response. The figures relevant for this stretch of coast are given in Table 1-1 and suggest a total level of sea level rise of just under 1 metre by 2105.

C1.5 The sea level rise projections (Table 1-1) have been assumed when predicting future shoreline behaviour and evolution during the evaluation of baseline scenarios (C3 and C4).

Table 1-1: Defra sea level rise guidance (East of England and East Midlands – south of Flamborough Head)

Time period	Net sea level rise (mm per year)	Total sea level rise in each epoch (mm)	Cumulative sea level rise (mm)
Epoch 1 (2009 – 2025)	4.0	64	64
Epoch 2 (2026 – 2055)	8.5	255	319
Epoch 3a (2056 – 2085)	12.0	360	679
Epoch 3b (2086 – 2105)	15.0	300	979

C1.6 Throughout this section, reference is made to local features such as sand banks or seabed features. A map showing the location of the features referred to in subsequent chapters is provided in Figure 1.1.

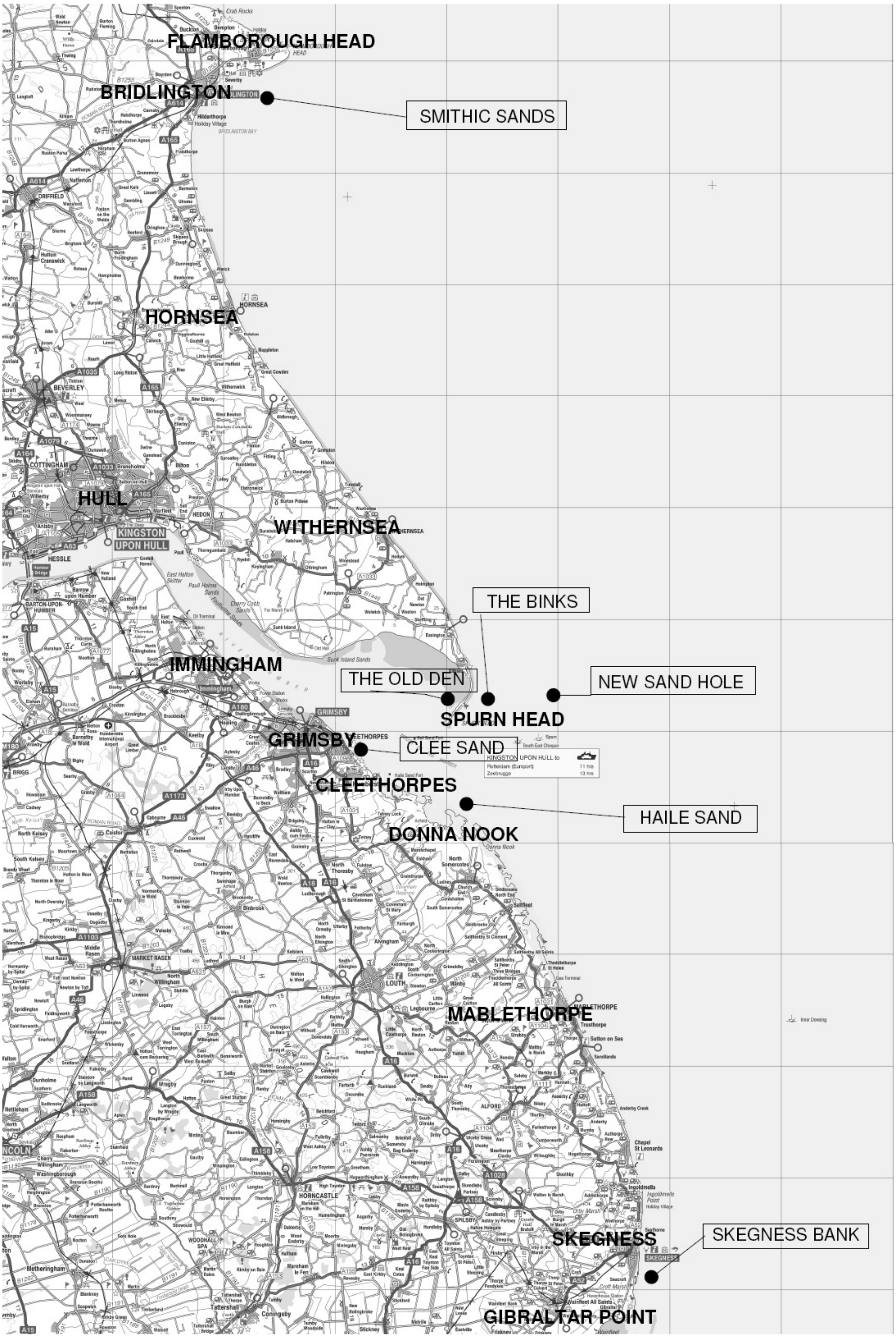

Figure 1.1.Map showing the location of local features and the major towns along the frontage.

Coastal Behaviour System: Flamborough Head to Gibraltar Point

C1.7 The Flamborough Head to Gibraltar Point coastline can be considered to be a single coastal behaviour system, in the sense that it is a coastline with high level interactions and critical dependencies. These interactions are related to the supply of sediment from shoreline erosion, sediment transport and deposition elsewhere within the system. A key factor in this unit is that there is a cascading series of compartments each with areas of erosion, transport and deposition.

C1.8 This shoreline is subject to energy inputs from four main "forcing" processes: wind waves, tides, wind, and river mouth flows. It is the relative balance of interacting forcing factors which controls the movement of sediment. The forcing processes interact with the inherited morphology (i.e. topography and bathymetry) to generate energy gradients along and across the nearshore and shoreline. Consequently sediment is transported from higher energy settings, including high energy zones of convergence (e.g. at headlands), to lower energy settings such as low energy zones of divergence (e.g. within bays).

C1.9 Background information on the forcing is presented in FutureCoast (Halcrow 2002). The dominant wave direction is from the north-northeast and north-east, has a large swell component and is not fetch-limited. The annual 10% exceedence significant wave height is 1.0 to 1.5 m. The wave heights vary along this coastline due to:

- Sheltering by Flamborough Head, of the coastline to the south;
- Exposure of the coastline between Flamborough Head and Spurn Head, such that the wave height reaches a maximum around Easington;
- Additional shoaling and refraction effects, caused by the shallow depths offshore of Spurn Head and a slight change in coastal orientation;
- Sheltering by Spurn Head of the coastline to the south, against waves originating in the North Sea; and
- Exposure of the coastline between Donna Nook and Gibraltar Point to the North Sea waves.

C1.10 The 1 in 100 year wave height for this area has been calculated to be between 4 and 8 m, decreasing in size from Flamborough Head to Gibraltar Point (Anglian Water, 1988).

C1.11 The net residual tidal currents are directed towards the south, with some onshore-directed currents from the offshore banks, to the northeast of Skegness. The mean spring tidal range ranges from 5 to > 6 m within this region. The greatest range occurs within the Humber and between Donna Nook and Gibraltar Point (Anglian Water, 1988). Extreme water levels within this stretch increase from north to south and up the Humber Estuary.

C1.12 Sediment transport is typically wave-driven in a southerly direction throughout this entire longshore stretch. Exceptions to this general trend are located at two divergence zones: within Bridlington Bay and near to Donna Nook (Figure 1.2). Depending on the availability of mobile sediment, characteristic landforms develop in specific settings within these energy gradients. Fine grained sediments tend to accumulate in sheltered, low energy environments (e.g. the Humber estuary with its inter-tidal mudflats and saltmarshes) whereas coarse sediments can be found on the open coast where the energy inputs are higher (e.g. the sand and shingle beaches of Holderness, Spurn Head and Lincolnshire) or in seabed sinks or stores (e.g. the Humber mouth). The highest energy environments are characterised by rock cliffs (i.e. the reflective rock barrier of Flamborough Head).

C1.13 The combination of variable energy inputs and mobile sediment lead to on-going morphological adjustments of the shoreline, ranging from beach profile changes over the course of a single storm to long-term changes (e.g. hundreds to thousands of years) in response to factors such as relative sea-level rise or changes in sediment availability. If the energy niche changes then the landform will either be left as a relict form, replaced by a form that is more suited to the new setting (e.g. a change in sediment size or profile shape) or lost through erosion. The geomorphological response of a coastal system to natural changes in energy and materials is capable of significant modification by coastal management. For example, the provision of coastal defence structures can alter the morphological response of a coastline over a considerable distance.

C1.14 A schematic conceptual model of the coastal behaviour system is presented in Figure 1.2. This schematic highlights that there is a series of inter-linked components that exhibit coherent behaviour patterns (shoreline behaviour units). These are:

- The Chalk Cliffs (Flamborough Head to Sewerby)
- The Holderness Cliffs (Sewerby to Kilnsea)
- Spurn Head
- The Outer Humber Bed and Banks
- The Lincolnshire Coast (Donna Nook to Gibraltar Point)

C1.15 Each of these units is described in the following sections, focusing on the system components, system controls and behaviour, system inter-linkages and future behaviour. The units are also described in terms of the key issues operating in specific local scale sub-units.

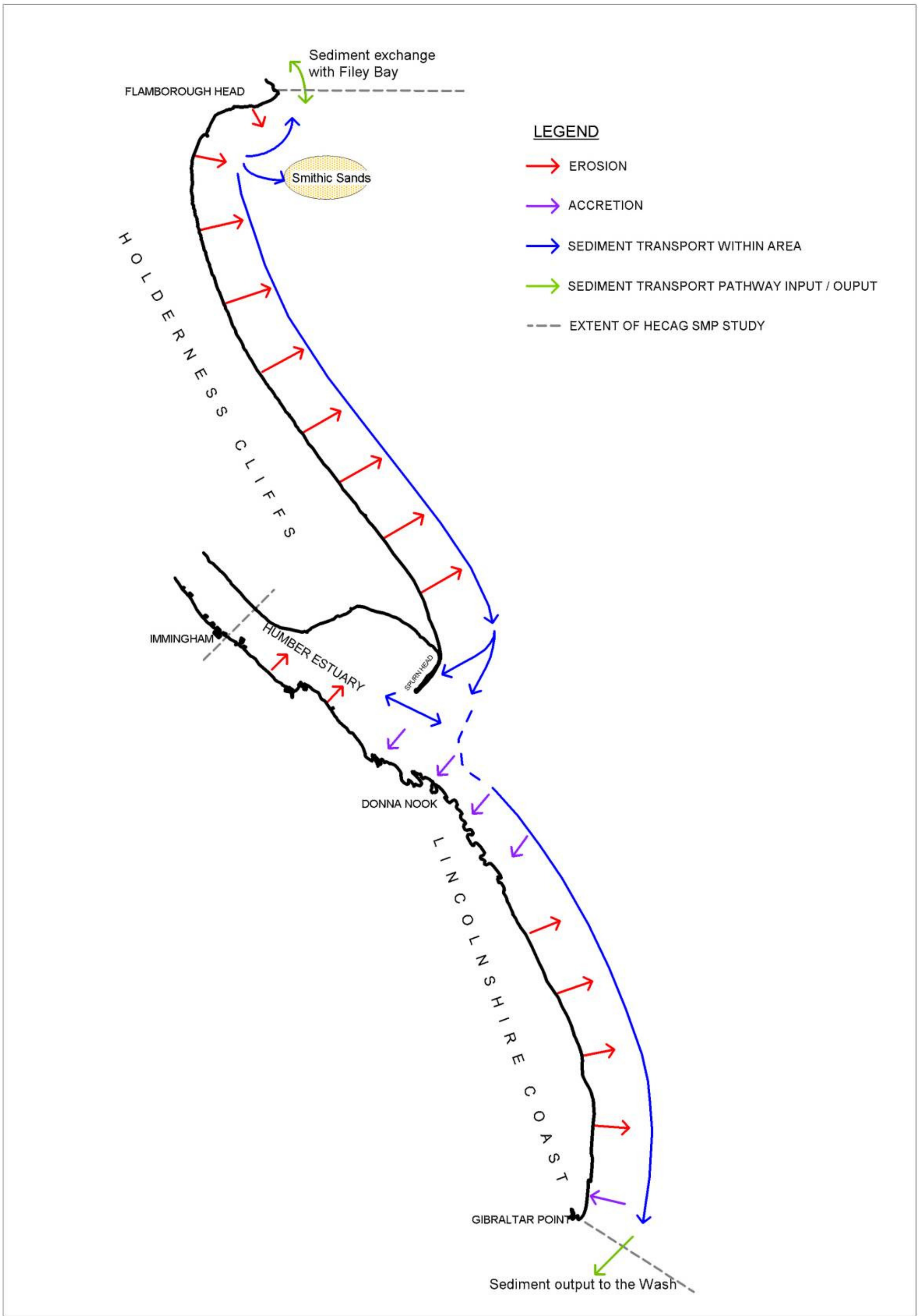

Figure 1.2. Schematic coastal behaviour model describing the processes along the frontage.

Shoreline Behaviour Unit: The Chalk Cliffs (Flamborough Head to Sewerby)

System Components

C1.16 The 7km long shoreline between Flamborough Head and Sewerby comprises:

- Cliffline: a series of 30-50m high near-vertical cliffs, arches, caves and sea stacks cut into the flint-bearing Burnham Chalk Formation, overlain by the flintless Flamborough Chalk Formation (Rawson and Wright 2000). The cliffs are mantled by a thick blanket of Devensian till, which comprise almost 50% of the cliff height in places. The cliffline runs east-west and may follow the alignment of an interglacial cliff line, which is exposed at Sewerby.
- Rocky shore platform: developed in chalk bedrock with boulder and cobble deposits. Small pocket beaches occur at South Landing and Danes Dyke and are designated as bathing beaches. The chalk platform, with ledges and gullies, extends to over 1 km from the shore in places.

C1.17 The offshore zone is dominated by Smithic Sand, a headland-attached sandbank that lies to the south of Flamborough Head at the centre of a tidal gyre. Circulation of sand around the 10km long bank is clockwise as shown by the asymmetry of megaripples on its flanks. A wide area of sands and gravels is present immediately seawards of the shore platform, some 500m from the shoreline. This sand sheet is believed to define a sediment transport pathway between Filey Bay to the north and Bridlington Bay, to the south.

System Controls and Behaviour

C1.18 Cliff recession rates are low, in the range 0.03m/year (IECS 1994a) to 0.4m/year (Matthews, 1934; Posford Duvivier 1998). Rockfalls and small landslides occasionally remove a section of the coastal footpath or damage beach access paths and steps. The key controls are wave energy arriving at the cliff foot and internal cliff factors (e.g. weathering, the presence of discontinuities). Smithic Sand is important in regulating wave energy inputs to the shoreline.

C1.19 Cliff recession yields minor quantities of flint gravels from the Chalk and coarse sediment from the till mantle; the coarse sediment yield is probably in the order of 1,000m^3/year. Little of this material is retained on the foreshore, and is probably moved towards the offshore sand sheets and the Smithic Sand.

System Linkages

C1.20 The Smithic sandbank is suspected to provide connectivity with the coastal behaviour systems north of Flamborough Head. The sandbank may receive sediment inputs from Filey Bay, as a result of north-easterly wave activity during extreme storm events (IECS, 1994). It is estimated that 40,000 m^3 of sand is transported south around Flamborough Head during the 1 in 50 year storm and swept offshore by tidal currents and deposited on Smithic Sand. Seabed morphology indicates some southerly drift close offshore to the Head and continuing south both in the offshore and along the outer face of Smithic Sands (SNSSTS; HR Wallingford 2002).

C1.21 During spring tides a weak clockwise, flood gyre net residual is believed to drive sediment north from the Smithic Sand into Filey Bay, around Flamborough Head (IECS 1994a). Mouchel (1997) reported that there is a residual tidal current from the south during spring tides of 0.11 ms^{-1}, and a residual current from the north during neap tides of 0.09 ms^{-1}. In this way, minor quantities of sediment (10m^3/tide) are able to move around the headland from Smithic Sand into Filey Bay. Sediment is likely to be driven from the Smithic Sand on to the Holderness coast, between Bridlington and Hornsea (SNSSTS; HR Wallingford 2002).

Future Behaviour

C1.22 Relative sea level rise is expected to result in accelerated cliff recession rates, although they will probably remain in the range 0.05 to 0.9m/year. However, future cliff recession rates will be critically dependent on the wave energy inputs arriving at the shoreline and, hence, the behaviour of the Smithic Sand.

Local Scale: Flamborough

C1.23 System State: hard-rock chalk cliffline, capped by glacial till and fronted by a broad rock shore platform.

C1.24 System Inputs: no significant sediment inputs to the shoreline expected.

C1.25 System Outputs: small volumes of sediment released from cliff failures (around 1,000m^3/year), probably transported to Smithic Sand or retained in pocket beaches at South Landing and Danes Dyke.

C1.26 Critical Dependencies: the unit is not dependent on longshore sediment inputs from adjacent shoreline.

C1.27 Hazards: slow cliff recession, 0.03-0.4m/year.

C1.28 Future Trends: continued slow cliff recession.

Shoreline Behaviour Unit: Holderness Cliffs (Sewerby to Kilnsea Coast)

System Components

C1.29 The Holderness cliffs extend for around 60km from Sewerby, in the north, to south of Easington. They range in height from less than 3m to around 40m. The main elements of the cliff are:

- Cliffline, developed in glacial tills, with an average height of 15m, reaching around 40m at Dimlington. The cliffs are actively eroding through repeated landslide activity. Cliff failure mechanisms typically include spalling, slumps, mudslides with some rotational and wedge failures, (Pickwell 1878; Hutchinson 1986; Richards 1987).
- The cliffline south of Hornsea is fronted by a highly mobile, thin (1-2m thick) veneer beach of sand and shingle that provides a spatially and temporally discontinuous cover to the shore platform. The upper beach, adjacent to the cliff foot, is usually convex in profile, whereas the lower beach is characterised by a gentle, even slope (Pringle 1981). The break of slope separating the two beach sections is known locally as the "grope".
- In the north, in Bridlington Bay, the beach is over 300m wide at mean low water, with a gentle overall gradient of 1.5° (i.e. 1:38 slope). It is characterised by a well developed ridge and runnel system. This beach is the shoreward margin of the Smithic Sand.
- A gently sloping (less than 1°) shore platform developed in planed-off in-situ till, with lag boulders from the eroded tills. The platform extends offshore for several kilometres; a marked break in slope occurs at about 9 to 12m below Lowest Astronomical Tide (LAT) at a distance of 1-1.4 km seawards of the cliff (IECS 1988). The average platform slope varies between 1:50 and 1:200 along most of the coast (Wingfield and Evans, 1998). Discontinuous sand sheets with low sandy bedforms (1-4m high and generally less than 50m in extent) and spreads of lag gravels occur on the submerged platform, (IECS 1988). A linear arrangement of high spots (mud huts) coincides with the remnants of a push moraine structure which, at one time, may have been continuous with the Binks off Spurn Head. A submerged clay cliff face several metres high marks the boundary between the platform and the seabed offshore.

C1.30 The cliffs are formed in a sequence of glacial tills, predominantly silty clays with chalk debris and lenses of sand and gravel. The till sequence comprises, from the bottom upwards:

- Basement Till: a lodgement till (probably of Wolstonian age, around 130,000 to 300,000 years ago) with a grey clay matrix containing erratics mainly derived from north east England;
- Skipsea Till: a late Devensian till, probably laid down between 18,000 and 13,000 years ago, with a brown clay matrix containing mainly Carboniferous aged erratics from the Pennines and much chalk; and
- Withernsea Till: also a late Devensian till, containing a dark brown clay matrix with a variety of erratics from northern England.

C1.31 The Basement Till has not been dated, but the prevailing view is that it is of Wolstonian age (i.e. the last-but-one glaciation, around 130,000 to 300,000 years Before Present (BP); Catt & Penny 1966, Madgett & Catt 1978). The till overlies a Chalk bedrock surface, recorded in boreholes at around -30 to -35 m in the

Dimlington area (Catt & Digby 1988). The surface of the Basement Till was planed-off by marine action during the Ipswichian interglacial (80,000 to 130,000 years BP) and contains many depressions which have been infilled by laminated silts containing strands of moss, known as the Dimlington Silts. In places the silts are overlain by what appear to be wind-blown sands. The mosses have yielded Carbon-14 dates of around 18,000 to 18,500 years BP, providing an indication of the timing of the deposition of the overlying Skipsea and Withernsea Tills.

C1.32 Towards the end of the last glaciation (the Devensian, around 13,000 – 18,000 BP), ice from the northern Pennines was overridden by ice from County Durham, creating a 'compound' glacier, involving two separate and distinctive layers. The material at the base of the lower layer was deposited (plastered across the underlying landscape) as the Skipsea Till, whilst the material at the base of the upper layer become the Withernsea Till.

C1.33 Table 1-2 provides an indication of the basic geotechnical properties of the till; of note, the till is over-consolidated (excess overburden pressures of about 2,000 kNm^{-2}) and of 'intermediate plasticity' (Bell & Forster 1991).

Table 1-2: Summary of the geotechnical properties of the glacial tills at Dimlington (mean values; after Bell & Forster 1991)

Till	Natural moisture content %	Plastic limit %	Liquid limit %	Plasticity index %	Unconfined compressive strength (kNm^{-2})	Triaxial shear strength, c′	Effective angle of friction, ϕ'
Basement	17	18	34	17	160	23	25
Skipsea	15.5	16	30	14	186	28	30
Withernsea	16.9	20	36	19	186	34	29

System Controls and Behaviour

C1.34 The Holderness coast has retreated by around 2km over the last 1,000 years causing the loss of 26 villages listed in the Domesday survey of 1086; 75 Million m^3 of land has been eroded in the last 100 years (Valentin, 1954; Pethick 1996). This shoreline retreat involves the retreat of the whole cliff-platform profile (Figure 1.3) generating significant hazards associated with both the cliff collapse (e.g. loss of cliff top property) and the lowering of the shore platform (e.g. undermining of defences, exposure of buried pipelines and cables).

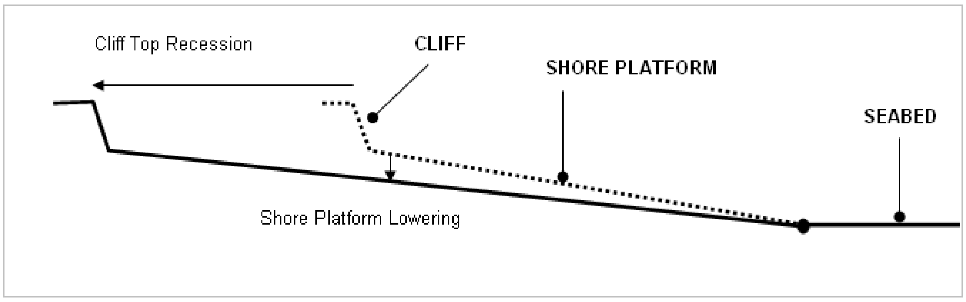

Figure 1.3 Schematic model of the cliff recession process

C1.35 Cliff recession reflects a balance between the strength of the cliff materials and the stresses imposed on the cliff by gravity and the kinetic energy of waves at the cliff foot. Wave attack and geological materials are generally the dominant factors in the recession process on the open coast. However, on the Holderness coast, foreshore processes (foreshore lowering, undercutting and the removal of debris) are the dominant control on the recession rate. Indeed, despite the lateral and vertical variations in the cliff materials, the long-term cliff recession rate along much of the coastline appears remarkably constant at an average rate of 1.8 m per year (Pethick 1996). Analysis undertaken by East Riding of Yorkshire Council on erosion post data for this area since 1951 also demonstrates this fairly constant average annual recession rate over time, with a trend of slightly increased recession rates identified in more recent years. This suggests that the variations in the geotechnical properties of the materials (Table 1-2) are of less significance than the wave energy inputs in controlling the recession rate.

C1.36 The key controls on the wave force arriving at the cliff foot are beach levels and shore platform lowering. Beaches dissipate wave energy and regulate the frequency that the cliff foot is subject to wave attack. Cliff foot erosion can occur when the combination of tidal elevation and wave run-up exceeds the elevation of the cliff-beach junction. Of particular significance is the occurrence of extreme tides and wave run-up during severe storms.

C1.37 Evidence of seasonal variation of beach profiles on the Holderness coast can be found in a number of sources, including:

- Richards and Lorriman (1987) recorded 2-2.5m of elevation change between profiles measured in the summer and winter of 1983;
- Butcher (1991) reported beach level variations of up to 3m at Cowden, between 1982 and 1986; and
- IECS (1994b) recorded 1-2m of profile variation during a programme of beach monitoring between April 1992 and August 1993.
- Since the late 1990s East Riding of Yorkshire Council has undertaken monitoring of beach profiles along the Holderness shoreline. These profiles show how the beach shape changes over time.

C1.38 Less regular, but more extreme profile variations can occur on the Holderness coast, reflecting the shoreline response to extreme wave conditions. Prominent low-tide sand bars (ords), aligned parallel to the dominant wave approach angle develop during large storm events and dissipate during periods of southerly waves. The key features of an ord system are shown in Figure 1.4 (Pringle 1981, 1985). Of particular significance is that the shore platform is exposed in the centre of the ord, with a distinct channel (runnel) draining this area at low tide. Ords tend not to occur north of Barmston, possibly due to the sheltering effect of Flamborough Head (SNSSTS, HR Wallingford 2002).

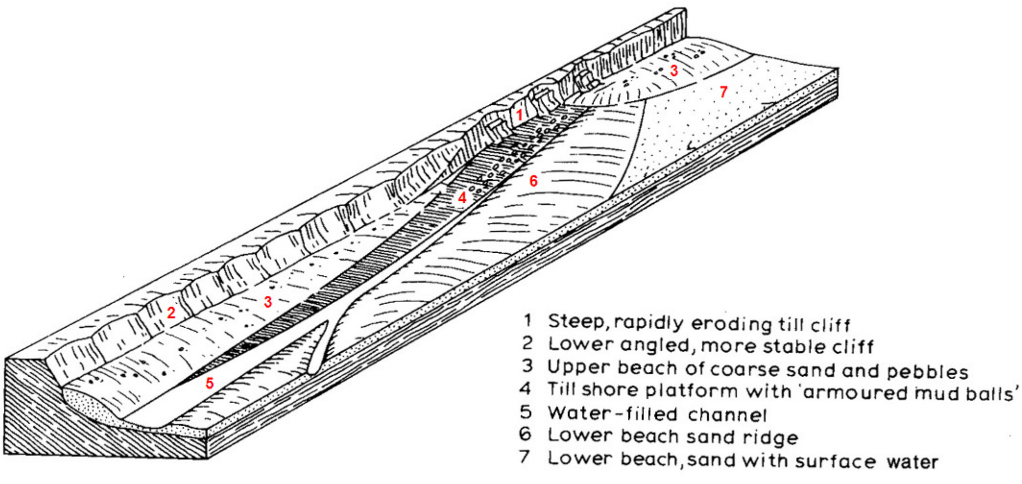

Figure 1.4. A schematic description of an ord system (from Pringle, 1985).

C1.39 The development and dissipation of ord systems can result in considerable changes in foreshore elevation. Pringle (1985) demonstrated that cliff foot elevations can vary considerably over time within an ord complex (Table 1-3). Changes of up to 3.3m in 4 months were recorded; much of the height variation occurs in the upper beach. Where an ord is present the lowering of beach levels allows most high water tides to reach the cliff foot, whereas only high water spring tides reach the cliff foot when an ord is absent. Pethick (1996) noted that inshore of these bars the erosion of the thin upper beach sand cover often results in exposure of the underlying till platform.

Table 1-3. Variations in cliff foot elevation across an ord complex south of Withernsea (1977-1983; from Pringle 1985).

Section	Beach Elevation Range (m)	Range (m)	Beach Elevation Mean (m)
Northern end	2.61-5.37m	2.76m	3.91m
Central	0.97-5.25m	4.28m	3.37m
Southern end	0.9-4.18m	3.28m	2.56m

C1.40 The shore platform exerts a significant control on the rate of cliff recession; if the platform widens in response to cliff recession, so wave dissipation increases. However if the entire shore platform is lowered at a comparable rate, then the profile remains approximately constant but gradually moves landward. The relationship between platform lowering and recession rate is often expressed as:

$$\text{Rate of cliff recession} = \frac{\text{Rate of Vertical Platform Lowering}}{\text{Shore Platform Gradient}} \quad (1)$$

C1.41 Rates of lowering can be dramatic; maximum recorded lowering rates are up to 3m/year (for 1992/93; Table 1-4; IECS 1994b). Shore platform erosion may continue irrespective of the cliff recession process. This can become an important consideration in the long term performance of coastal defence structures; the water depths in front of the structure can increase significantly over its design life, affecting the overtopping performance and standard of protection as well as increasing the risk of undermining. However, these rates are undoubtedly extreme events; a more realistic longer-term lowering rate can be estimated from:

$$\text{Lowering Rate} = \text{Cliff Recession rate} \times \tan \alpha \quad (2)$$

C1.42 If it is assumed that the recession rate is 2m/year and the foreshore gradient (tan α) 1 in 100, then the lowering rate would be 0.02m/year.

Table 1-4: Holderness shore platform lowering rates, Hornsea – Cowden (1992-1993; from IECS 1994b)

Location (South of Mappleton, m)	Maximum Foreshore Lowering Rate (m/year)
613	0.22
907	0.5
1032	0.5
1224	1.2
1326	3.0

C1.43 Long term recession rates have been estimated by Valentin (1954) using a comparison of distances from fixed points on 1:10,560 scale Ordnance Survey maps published between 1852 and 1951. Valentin made 307 measurements covering the entire cliffline and found considerable variation in the long-term (i.e. over a 100-year period) average recession rate, from 0.36 – 2.75m/year. Valentin reported that the average long-term recession rate for the cliffline was 1.2m/year and that the rate increases southwards: Sewerby (Bridlington) to Earl's Dyke 0.29m/year; Earl's Dyke to Hornsea 1.10m/year; Hornsea to Withernsea 1.12m/year; Withernsea to Kilnsea Warren 1.75m/yr. This pattern reflects the significant protection that Flamborough Head and the Smithic Sands provide to the northern section of the cliffline (Barmston to Sewerby).

C1.44 Since 1951 the local authorities have monitored cliff recession on an annual basis. A series of 120 marker posts have been installed at 500m intervals, between Sewerby and Spurn Head. These posts are replaced further inland from time to time if they become too close to the cliff top. Annual measurements have been made from each post to the cliff top (defined as the lip of the most recent cliff failure scar). An almost continuous record of annual recession is available for Post 32 (Skirlington) to Post 105 (Dimlington). Posts 1-31 appear to have been abandoned around 1970, and then re-established in 1983. In recent years as well as maintaining erosion post data East Riding of Yorkshire Council have used GPS-based survey techniques to monitor the entire cliffline as well as Lidar and Aerial surveys.

C1.45 Analysis of the erosion post data south of Barmston (Post 15) was undertaken by Pethick and Leggett (1993) who suggested that the long-term rate is around 1.8m/year. This rate is consistent with the East Riding of Yorkshire Council erosion post data, which gives rates between 1.5 and 2m/year (East Riding of Yorkshire Council, undated).

C1.46 Over this timescale (1951 - 2004) there has been marked variability in the annual recession with records varying from 0 to 14.01m/year. Pethick (1996) noted that there is a mean periodicity for recession peaks of around 6.5 years. Many peaks appear to be markedly symmetric, so that a sudden change in recession from, for example, 0m to 9m might take place between successive years, followed by a period of 3 or 4 years in which recession rates gradually decline back to zero. Pethick (1996) proposed a cliff behaviour model to explain the periodicity in peak recession. The mechanism for this cyclicity is thought to be related to the southerly movement of sand along the beach driven by north-easterly waves. The dominance of waves from the northeast tends to rapidly remove sediment from the southern extent of a failure, exposing the cliff immediately south. Cliff failure therefore tends to migrate southwards along the cliffline. However, this migration can be impacted by sediment volumes being moved southwards from failures further north. Therefore, the recession rate at a given location can vary between 0m to over 10m per year with an approximate 5-8 year cycle. This mechanism does not preclude additional cliff failures outside of the southerly migration due to local influences.

C1.47 The overall cliffline has a gently curved planform, approximating a zeta-form or log-spiral bay, developed between Flamborough Head and Spurn. However, at the local scale the frontage has been segmented by coast protection works at the communities of Bridlington, Hornsea and Withernsea. These defences were built early in the 20th century and subsequently extended and improved. Elsewhere there are small lengths of defences at Ulrome, Mappleton, and Easington, and there are short flood defence and coastal protection structures at Barmston and Tunstall drains. The undefended cliffs adjacent to these defended frontages have continued to recede rapidly causing an offset between the defended line and the natural cliff-line. The result has been the gradual development of a series of broad, shallow embayments between hard points. The resulting unprotected cliff segments are as follows, described by erosion post (EP) numbers:

- Cliff segment: Sewerby to Bridlington (EP 1 to EP 4);
- Cliff segment: Auburn Farm to Barmston (EP 5 to EP 16; 1983-2004);

- Cliff segment: Barmston to Atwick, North of Hornsea (EP 17 to EP 43);
- Cliff segment: South of Hornsea groynes to Mappleton (EP 44 to EP 51);
- Cliff segment: Mappleton to Waxholme, North of Withernsea (EP 52 to EP 85);
- Cliff segment: Golden Sands, Withernsea to Easington (EP 89 to EP 106);
- Cliff segment: Easington to Kilnsea (EP 109-111).

C1.48 East Riding of Yorkshire Council have summarised the Erosion Post data for the whole cliffline. Figure 1.5 shows the total cliff recession and the average annual recession for the EPs along the Holderness coast since 1951. These figures highlight a a general trend of increasing erosion rates from north to south along the frontage with the lowest recession rates recorded north of Bridlington (EPs 1-4) with less than 0.5m of erosion per year. Towards the southern limit of the cliff segments between Bridlington and Hornsea, and between Hornsea and Withernsea (updrfit of defended towns) there is a trend for reduced erosion rates. This pattern of erosion results in an anticlockwise shoreline re-orientation between coastal defences at Hornsea and Withernsea, with greater landwards movement at the northern ends of relative to the southern ends of the cliff segments.

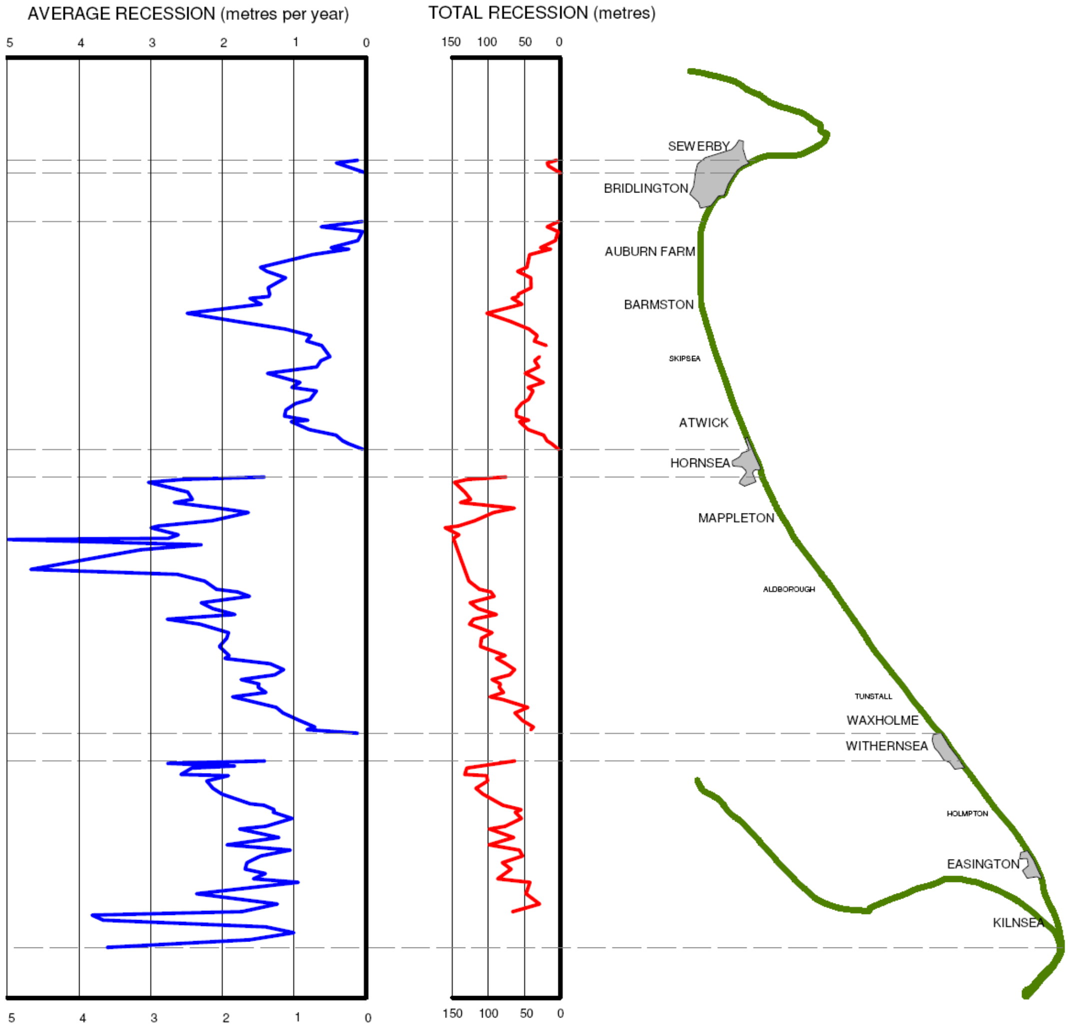

Figure 1.5. Total and Average cliff recession rates recorded at erosion posts since 1951. (For total erosion plot erosion posts installed post 1960 have been excluded).

C1.49 Table 1-5 shows the impact of the Hornsea defences on cliff recession, where differences of between 1.9 - 2.4m/year have been recorded at the cliffs a similar distance to the north and south of the defences (Posford Duvivier 1993). IECS (1991, 1994b) analysed historical records and erosion post data, and concluded that the Hornsea and Withernsea defences had led to the development of a zone of accelerated erosion which extended at least 10km south of the groyne fields. However, analysis of the data undertaken by East Riding of Yorkshire Council suggests that the impact of the Hornsea and particularly the Withensea defences is significantly more localised, being in the order of one to two kilometres. Table 1-6 shows erosion estimates derived from analysis of East Riding of Yorkshire Council erosion post data; comparison with Table 1-5 shows that the erosion rates do not have a clear trend, suggesting the influence of defences on recession does not extend significant distances.

Table 1-5. Average cliff recession rates north and south of existing protection works at Hornsea and Withernsea, Holderness (Posford Duvivier, 1993)

Length of Coast	Hornsea			Withernsea		
	North m/year	South m/year	Difference. m/year	North m/year	South m/year	Difference m/year
2km	0.38	2.81	2.43	0.26	0.97	0.71
3km	0.60	2.65	2.05	0.45	0.85	0.40
4km	0.66	2.59	1.93	0.65	1.14	0.40
5km	0.65	2.51	1.86	0.79	1.23	0.40

Table 1-6. Comparative estimates to those presented in Table 1-5 using East Riding of Yorkshire Council analysis of erosion post data (2008)

Length of Coast	Hornsea			Withernsea		
	North m/year	South m/year	Difference. m/year	North m/year	South m/year	Difference m/year
2km	1.04	2.45	1.41	0.92	2.18	1.26
3km	1.12	1.64	0.52	1.47	2.01	0.54
4km	0.74	2.62	1.88	1.45	1.35	-0.10
5km	0.92	2.75	1.83	1.74	1.03	-0.71

System Linkages

C1.50 The Holderness cliffs are a major sediment source. Erosion of these cliffs provides material which maintains the supply of sediment to Humber estuary and the Lincolnshire coast. An estimated 3-4Mm^3 of sediment per year is supplied to the coastal zone by cliff recession, shore platform lowering and seabed erosion (Balson et al 1996, 1998; Balson and Philpott, 2004). Wingfield and Evans (1998) estimated that only 23% of erosion was from the cliff, 33% from the shore platform and the remaining 44% from the seabed (e.g. Maddrell et al 1999; The East Riding of Yorkshire Council (undated) suggest that the low cliff at the seaward limit of the platform has eroded at around 1.7m/year). In addition, under extreme conditions, material is most probably fed into the Holderness shore from the Smithic bank (HR Wallingford, 2002, 2003).

C1.51 The majority of the eroded volume is composed of fine sediments, silts and clays, which do not form part of the beach or inshore sand sheets. The percentage content of sand large enough to remain on the beach (larger than 0.25 mm, medium sand) varies according to the till being eroded. Bell and Forster (1991) give figures of 25% sand for the Withernsea and Skipsea tills and 12.5% for the Basement Till (which is only exposed at the southern end of the coastline). Much of the sediment supply is believed to be derived from the Basement Till which forms the foot of the cliff section at Easington and most of the platform and seabed. Table 1-7 shows a breakdown of the sediment inputs, with the estimated volumes based on an assumed yield of $3Mm^3$/year.

Table 1-7. Sediment yield by grain size (assuming an average annual yield of 3Mm3; adapted from Balson and Philpott, 2004).

	Percentage	Volume (thousand m^3)	Sediment Stores and Sinks
Gravel	3.5	105	Spurn Head, The Binks, New Sand Hole
Medium to Coarse Sand	9	270	Spurn Head, The Binks, New Sand Hole, Sandwaves
Fine Sand	21.5	645	Sandwaves and Donna Nook
Mud (Silt and Clay)	66	1980	Humber, Wash and North Sea

C1.52 The fine grained sediments from the Holderness cliffs are moved in suspension, whereas the sands and shingle are moved along the beaches in a process known as sediment transport (also known as littoral drift or longshore drift). Sediment transport is caused by waves reaching the shoreline at an angle, rather than perpendicular. The sand beaches are generally formed of a thin veneer of sand overlying a clay base layer; this is due to the limited sand volume input from the cliff recession and the constant transport of beach material. As shown by Pethick (1996) under storm conditions the orientation of the coast maximises the potential for the export of sediment from the system; due to the angle of the incoming waves relative to the shoreline orientation. Any other orientation would result in a reduction in sediment output from the system. When sediment transport volumes are in excess of the cliff recession volumes beach levels along the shoreline will drop. If the recession volume of the cliffs is greater than the sediment transport volume then beaches accumulate sand material and the veneer of sand increases in depth. It is considered likely that the rate of debris removal dictates the rate of recession, with a balance between sediment inputs from cliff failure and sediment removal by longshore currents achieved on an annual basis.

C1.53 An important sediment transport divide separates the cliffline into two coarse sediment transport zones:

- Northern Zone (Barmston to Sewerby): the net drift is northwards, possibly feeding the Smithic Sands by the tidal re-circulation to the south of the Flamborough headland (SNSSTS- HR Wallingford 2002). This transport may be dominantly tide-driven, at around $50,000m^3$/year and is limited to the shoreline north of Bridlington (Posford Duvivier 2000). Wave driven sediment transport modelling along the Bridlington frontage indicated a strong north to south drift at the town (Posford Duvivier, 2000). However, in FutureCoast (Halcrow 2002) it is suggested that this drift divide might be around Barmston, with a net northwards drift towards Bridlington.

- Southern Zone (Barmston to Spurn Head): the net drift is southwards, transporting sediment towards Spurn Head (HR Wallingford 2003 suggest the boundary is at Fraisthorpe). The potential longshore transport rate for sand is estimated to be between 200,000m^3/year and 350,000m^3/year (SNSSTS- HR Wallingford 2002; Posford Duvivier, 1992; IECS 1994a). Progressing southwards the sheltering effect (from waves) of Flamborough Head diminishes, therefore the potential longshore drift rate to the south increases. The sediment transport is driven by higher energy events, particularly surges. The highest drift rates are within about 2km of the coast (HR Wallingford 2003). The estimated drift rate into Spurn Head is around 125,000m^3/year (Valentin 1954). It is suspected, therefore, that a significant proportion of the sediment is deflected offshore. Halcrow/GeoSea (1990) suggested that up to 60% of the sand may move offshore around Easington and the Kilnsea Coast, associated with a change in shoreline orientation.

C1.54 The coarse sediment eroded is transported to Spurn Head, the Binks and the New Sand Hole which contains predominantly gravels and coarse sands. It is likely that the gravel and coarse sand cannot cross the Humber mouth, although fine sands are transported to the Lincolnshire shoreline.

C1.55 The precise movement of the fine material is unknown but it is clear that its dominant movement is south towards the Humber estuary. Prandle et al. (2001) report that material finer than 0.02mm would be rapidly transported from the region, and that most of the material available for re-suspension would be in the range 0.02mm to 0.1mm. The erosion of fines from Holderness forms a wide plume, extending several kilometres out from the coastline. The fines are transported south where the essentially shore-parallel tidal currents along the Holderness cliffs interact with the estuary plume. Fines from Holderness are therefore available for deposition in the Humber Estuary, if the correct conditions arise. Much of the fines are transported south along the Lincolnshire coast. Some is transported into the Wash, while some joins the 'English river' and is transported across the North Sea.

Future Behaviour

C1.56 Long term cliff recession rates along the Holderness cliffline will be critically dependent on:

- Wave energy inputs arriving at the shoreline;
- Changes in sediment yield and longshore transport rate;
- The maintenance of defended sections;
- Development of the bays between the coastal communities; and
- Future changes in sea levels and potential increases in storm frequency/severity linked with climate change.

C1.57 It is widely predicted that relative sea level rise will result in an increase in wave energy at the foreshore, leading to accelerated shore platform lowering and cliff recession (e.g. Clayton, 1989; Bray and Hooke, 1997). However, the effects of relative sea level rise will be conditional on the system state, especially beach levels. Accelerated erosion in one location will release sediment for beach accretion elsewhere, regulating the effects of higher sea levels. Consequently, on Holderness, if it is assumed that defences continue to be present, the variation in recession rates in the areas adjacent to the defences is likely to be accentuated over time. Areas downdrift of the defences will see more rapid recession.

Immediately updrift of the defended stretches recession rates could be similar, or even reduced compared to the present day as the beaches build up here.

C1.58 Accelerated cliff recession and shore platform lowering would generate increased volumes of coarse sediment which may result in an increase in southward drift. However it is possible that, in the long-term, if it is assumed that defended sections continue to be maintained, the development of increasingly deep bays would result as a response to recession of the unprotected cliffs between the “hard points” (IECS 1994b). One theory postulates that over very long time periods (beyond the SMP timeframe), these bays could reach a stable form. However this theoretical situation would require defended sections to be maintained for a number of centuries (180-2,500 years or longer, (East Riding of Yorkshire Council, undated)) and constant forcing conditions.

C1.59 The theory of development of stable bays is well understood, and there are many examples in the UK and internationally. However, these are typically found on sandy coasts, where the total volume of sediment is conserved. Development of stable bays on a soft-clay coast, such as the Holderness cliffs, where the volume of sediment for beach building is a fraction of the total cliff volume, is much less certain. There is a possibility that bays would continue to erode and never reach a stable situation. In such a situation the amount of sediment exiting the bay would not tend zero, as it would for a stable bay.

C1.60 There would be some reduction in sediment transport out of the bay, because of the physical interruption caused by the downdrift headland. However, it is only a possibility that this reduction would outweigh the increased release of sediment due to sea level rise and climate change, and it is equally possible that overall sediment release would still be in excess of that occurring at present.

C1.61 In FutureCoast, Halcrow (2002) considered it unlikely that the overall system will develop what could be regarded as an equilibrium planform (i.e. a zeta bay form), in part because Spurn Head is a migrating landform so the southern limit will never be fixed. However, if the protection afforded to Spurn by the Binks is removed due to erosion, an increase in sediment output is predicted as the Holderness coast increases its drift alignment.

C1.62 Assuming defences along the Holderness continue to be maintained Haskoning (2003) estimated approximately 102, 750 m^3 / year of sediment is prevented from entering the littoral system. Under the assumption that all the sediment retained by the existing defence structures along the Holderness coast would otherwise enter the Humber this estimate represents approximately 3.4% of the overall potential volume of sediment from entering the Humber Estuary. This estimate was calculated using the estimate of sediment volume entering the Humber of 3 million m^3 per year (Binnie Black and Veatch and the Environment Agency).

Local Scale: Bridlington (Sewerby to Wilsthorpe)

C1.63 System State: soft-rock cliffline, developed in glacial till and fronted by a broad sand beach. This beach is the shoreward margin of the Smithic Sand. Bridlington town is protected by harbour walls, seawalls and groynes.

C1.64 System Inputs: minor cliff recession inputs from the unprotected cliffs. The net drift is northwards and predominantly tide-driven, at around 50,000m^3/year. Sediment is likely to be driven from the Smithic Sands on to the Holderness coast, between Bridlington and Hornsea

C1.65 System Outputs: the net drift is northwards, possibly feeding the Smithic Sands by the tidal re-circulation to the south of the Flamborough headland. Offshore transport to the Smithic Sands during storms.

C1.66 Critical Dependencies: the unit is dependent on protection from wave energy provided by the Smithic Sands and Flamborough Head. Bridlington beaches are dependent on sediment supply from the Smithic Sands and the northerly drift from the Barmston area.

C1.67 Hazards: slow cliff recession, 0.1-0.4m/year (Erosion Posts 1-7). Beach lowering in front of the Bridlington seawalls.

C1.68 Future Trends: continued slow cliff recession on the unprotected cliff sections. Beach lowering in front of the Bridlington seawalls.

Local Scale: Wilsthorpe to Fraisthorpe

C1.69 System State: soft-rock cliffline, developed in glacial till and fronted by a sand beach.

C1.70 System Inputs: minor cliff recession inputs from the unprotected cliffs. The drift is northwards and predominantly tide-driven. Sediment is likely to be driven from the Smithic Sands on to the Holderness coast, between Bridlington and Hornsea.

C1.71 System Outputs: the net drift is northwards, possibly feeding the Smithic Sands by the tidal re-circulation to the south of the Flamborough headland. Offshore transport to the Smithic Sands during storms.

C1.72 Critical Dependencies: the unit is dependent on protection from wave energy provided by the Smithic Sands and Flamborough Head. The beaches are dependent on sediment supply from the Smithic Sands and the northerly drift from the Barmston area.

C1.73 Hazards: slow cliff recession, 0.1-0.7m/year (Erosion Posts 8-11).

C1.74 Future Trends: continued slow cliff recession.

Local Scale: Fraisthorpe to Barmston

C1.75 System State: soft-rock cliffline, developed in glacial till and fronted by a sand beach and a broad shore platform.

C1.76 System Inputs: minor cliff recession inputs from the unprotected cliffs. The net drift is northwards and predominantly tide-driven, at around 50,000m^3/year. Sediment is likely to be driven from the Smithic Sands on to the Holderness coast, between Bridlington and Hornsea

C1.77 System Outputs: the net drift is northwards, possibly feeding the Smithic Sands by the tidal re-circulation to the south of the Flamborough headland. Offshore transport to the Smithic Sands during storms.

C1.78 Critical Dependencies: the unit is dependent on protection from wave energy provided by the Smithic Sands and Flamborough Head. The beaches are dependent on sediment supply from the Smithic Sands and the northerly drift from the Barmston area.

C1.79 Hazards: slow cliff recession, 1.1-1.4m/year (Erosion Posts 12-16).

C1.80 Future Trends: continued slow cliff recession. Gradual long-term development of a bay between Bridlington and Barmston, if the Barmston defences are held.

Local Scale: Barmston to Atwick

C1.81 System State: soft-rock cliffline, developed in glacial till and veneer sand beach and a broad shore platform. There is also a short section of rock armour defence protecting Barmston Drain from erosion.

C1.82 System Inputs: sediment inputs from the unprotected cliffs. The net drift is southwards and wave-driven (unknown rate). Sediment is likely to be driven from the Smithic Sands on to the Holderness coast, between Bridlington and Hornsea

C1.83 System Outputs: the net drift is southwards (the north of this unit marks a drift divide), promoting beach accretion north of Hornsea (North Cliff) and within the Hornsea groyne field, and feeding the beaches on the Hornsea to Withernsea shoreline.

C1.84 Critical Dependencies: the beaches are dependent on sediment supply from the Smithic Sands and local cliff recession.

C1.85 Hazards: moderately rapid cliff recession, 0.5-2.4m/year (Erosion Posts 17-36).

C1.86 Future Trends: continued cliff recession. Gradual development of a bay between Barmston and Hornsea (if the Barmston and Hornsea defences are maintained).

Local Scale: Hornsea (Atwick to Rolston)

C1.87 System State: soft-rock cliffline, developed in glacial till and veneer sand beach and a broad shore platform. Hornsea frontage is protected by coastal defences and a groyne field.

C1.88 System Inputs: sediment inputs from the unprotected cliffs to the north. Sediment is likely to be driven from the Smithic Sands on to the Holderness coast, between Bridlington and Hornsea. The net drift is southwards and wave-driven (around 150,00m^3/year: SNSSTS - HR Wallingford 2002).

C1.89 System Outputs: the net drift is southwards, feeding the beaches on the Hornsea to Withernsea shoreline. Some offshore transport.

C1.90 Critical Dependencies: the beaches are dependent on sediment supply from the cliff recession north of Hornsea.

C1.91 Hazards: Rapid cliff recession, 0.2-2.6m/year (Erosion Posts 37-47). Beach lowering in front of the seawalls.

C1.92 Future Trends: continued cliff recession where unprotected. Beach and shore platform lowering in front of the seawalls.

Local Scale: Rolston to Mappleton

C1.93 System State: soft-rock cliffline, developed in glacial till and veneer sand beach and a broad shore platform.

C1.94 System Inputs: significant sediment inputs from the unprotected cliffs. The net drift is southwards and wave-driven (around 200,000-350,000m^3/year; SNSSTS - HR Wallingford 2002).

C1.95 System Outputs: the net drift is southwards, promoting beach accretion north of Mappleton groynes and feeding the beaches on the Mappleton to Withernsea shoreline. Some offshore transport.

C1.96 Critical Dependencies: the beaches are dependent on sediment supply from the cliff recession to the north.

C1.97 Hazards: rapid cliff recession, up to 20m in a single year, average rates of 1.6-2.6m/year (Erosion Posts 47-51).

C1.98 Future Trends: continued cliff recession of the unprotected cliffs and platform lowering. Gradual development of a bay between Hornsea and Mappleton, leading to a possible long-term (epoch 3 and beyond) decline in sediment outputs (if the defences at Hornsea and Mappleton continue to be held).

Local Scale: Mappleton

C1.99 System State: soft-rock cliffline, developed in glacial till and veneer sand beach and a broad shore platform. Two rock groynes and a rock revetment constructed in 1991 to prevent cliff recession.

C1.100 System Inputs: minor sediment inputs from the unprotected cliffs. The net drift is southwards and wave-driven (around 200,000-350,000m^3/year; SNSSTS - HR Wallingford 2002).

C1.101 System Outputs: the net drift is southwards, feeding the beaches on the Aldbrough to Withernsea shoreline. Some offshore transport.

C1.102 Critical Dependencies: the beaches are dependent on sediment supply from the cliff recession to the north.

C1.103 Hazards: rapid cliff recession, up to 2.1m/year (Erosion Posts 51-52, for the post 1991 period).

C1.104 Future Trends: beach and platform lowering in front of the coastal defences. Emergence of this section as a headland/hard point if defences continue to be maintained.

Local Scale: Mappleton to Withernsea

C1.105 System State: soft-rock cliffline, developed in glacial till and veneer sand beach and a broad shore platform.

C1.106 System Inputs: significant sediment inputs from the unprotected cliffs. The net drift is southwards and wave-driven (around 200,000-350,000m^3/year; SNSSTS - HR Wallingford 2002).

C1.107 System Outputs: the net drift is southwards, promoting beach accretion north of Withernsea groynes (Waxholme) and feeding the beaches on the Withernsea to Easington shoreline. Some offshore transport.

C1.108 Critical Dependencies: the beaches are dependent on sediment supply from the cliff recession to the north.

C1.109 Hazards: rapid cliff recession, up to 20m in a single year, average rates of 1.2-2.9m/year, declining to 0.8m/year north of the Withernsea groynes (Erosion Posts 83-86). Flooding of farmland and the coast road due to erosion of the flood defences around Tunstall drain where the cliff line is relatively low.

C1.110 Future Trends: continued cliff recession of the unprotected cliffs and platform lowering. Gradual development of a bay between Mappleton and Withernsea, leading to a long-term (epoch 3 and beyond) possible decline in sediment outputs (if defences at Mappleton and Withernsea continue to be maintained).

Local Scale: Withernsea Frontage

C1.111 System State: soft-rock cliffline, developed in glacial till and veneer sand beach and a broad shore platform. Withernsea frontage is protected by coastal defences and a groyne field.

C1.112 System Inputs: sediment inputs from the unprotected cliffs to the north. The net drift is southwards and wave-driven (around 200,000-350,000m^3/year; SNSSTS - HR Wallingford 2002).

C1.113 System Outputs: the net drift is southwards, feeding the beaches on the Withernsea to Easington shoreline. Some offshore transport.

C1.114 Critical Dependencies: the beaches are dependent on sediment supply from the cliff recession to the north.

C1.115 Hazards: Beach and platform lowering in front of the seawalls.

C1.116 Future Trends: continued beach and shore platform lowering in front of the seawalls.

Local Scale: Withernsea to Holmpton

C1.117 System State: soft-rock cliffline, developed in glacial till and veneer sand beach and a broad shore platform.

C1.118 System Inputs: significant sediment inputs from the unprotected cliffs. The net drift is southwards and wave-driven (around 200,000-350,000m3/year; SNSSTS - HR Wallingford 2002).

C1.119 System Outputs: the net drift is southwards, feeding the beaches on the Holmpton to Easington shoreline. Some offshore transport.

C1.120 Critical Dependencies: the beaches are dependent on sediment supply from the cliff recession to the north.

C1.121 Hazards: rapid cliff recession, up to 20m in a single year, average rates of 1.6-2.7m/year (Erosion Posts 87-96).

C1.122 Future Trends: continued cliff recession of the unprotected cliffs and platform lowering. If the Easington defences are kept in place, there would be a gradual development of a bay between Withernsea and Easington, leading to a possible long-term (epoch 3 and beyond) decline in sediment outputs.

Local Scale: Easington

C1.123 System State: soft-rock cliffline, developed in glacial till and veneer sand beach and a broad shore platform. Easington frontage is protected by rock revetment.

C1.124 System Inputs: sediment inputs from the unprotected cliffs to the north. The net drift is southwards and wave-driven (around 200,000-350,000m^3/year; SNSSTS - HR Wallingford 2002).

C1.125 System Outputs: the net drift is southwards,. Up to 60% of the sand may move offshore around Easington, associated with a change in shoreline orientation.

C1.126 Critical Dependencies: the beaches are dependent on sediment supply from the cliff recession to the north.

C1.127 Hazards: Beach and platform lowering in front of the revetment, exposure of pipelines and cables on the foreshore and seabed. Defences currently to be removed after 25 years of operation due to a planning application condition.

C1.128 Future Trends: continued beach and shore platform lowering in front of the revetment as long as it remains. Long-term emergence of this section as a headland/hard point.

Local Scale: Easington to Kilnsea Coast

C1.129 System State: soft-rock cliffline, developed in glacial till and veneer sand beach and a broad shore platform. A sand and shingle ridge fronts the Lagoons SSSI. The New Bank, a clay embankment to the rear of the Lagoons SSSI provides protection against flooding to an extensive area of agricultural land and isolated farmsteads and residential properties.

C1.130 System Inputs: significant sediment inputs from the unprotected cliffs. The net drift is southwards and wave-driven (around 150,00m^3/year; SNSSTS - HR Wallingford 2002).

C1.131 System Outputs: the net drift is southwards, feeding Spurn Head. Some offshore transport.

C1.132 Critical Dependencies: the beaches are dependent on sediment supply from the cliff recession north of Easington.

C1.133 Hazards: rapid cliff recession, average rates of 0.9-1.6m/year (Erosion Posts 108-111). Flooding of Kilnsea village and surrounding agricultural land.

C1.134 Future Trends: continued cliff recession of the unprotected cliffs and platform lowering. Retreat of the sand/shingle ridge, accompanied by increasing overtopping and overwashing potential. If failure of the New Bank defences occurred it would lead to flooding of agricultural land and isolated residential properties.

Shoreline Behaviour Unit: Spurn Head

System Components

C1.135 The peninsula of Spurn Head extends from Kilnsea Warren, at the southern end of the Holderness cliffs, and forms a barrier extending 5.5 km into the mouth of the Humber Estuary. The southern end of the barrier terminates abruptly in the Humber deep-water channel. Spurn comprises:

- A sand and gravel barrier;
- A nearshore platform; and
- Largely derelict defences of various types.

C1.136 The feature has been described as a spit, although the macro-tidal range (6 m) and high tidal current velocities at the Humber mouth suggests that it is not simply an extension of the Holderness longshore sediment transport pathway into the Estuary.

C1.137 Spurn is comprised of a narrow sand and gravel barrier which is partially covered in supra-tidal sand dunes up to 15m high. The barrier changes alignment from NNW-SSE off How Hill to N-S at the southern end of Kilnsea Warren and NE-SW at High Bents where the barrier is only 30m wide. The barrier maintains this alignment to its distal end at Spurn Point and its length is now thought to be constrained by the flow in and out of the estuary (ABPmer, 2008). The barrier is underlain by a glacial till layer that slopes in a southerly direction from approximately -1m ODN in the north to -18 to -20m ODN in the south. The total volume of supratidal sediment in the barrier is estimated to be 5Mm^3 (Balson and Philpott, 2004); the total volume of stored sediment could be expected to be in the range 50-100Mm^3. The glacial till base maintains Spurn in a relatively constant position, despite the rapid westwards retreat of the coastline to the north.

C1.138 The nearshore platform at Spurn has developed in eroded tills (presumably the Basement Till) and associated lag gravels. The sea bed to the east of the barrier is dominated by exposed till and gravels (Balson and Philpott, 2004; NSSTS - HR Wallingford 2003). However, thin spreads of mobile sediments (medium to fine sands) have been recorded to the southwest and southeast, comprising megaripples (height <1.5m and wavelengths <30m) and sand waves (height 1.5-7m, wavelengths >30m). Medium sands occur further offshore. The sand wave field extends north eastwards through New Sand Hole.

C1.139 At its northern end (Kilnsea Warren) the barrier consists of a narrow, thin sand and gravel ridge with areas of vegetated dunes. Here the foreshore of the eastern (coastal) side is a mixed sand and gravel beach. There are also occasional blocks of concrete and rubble present that are remains of the former seawall (ABPmer, 2008) which formed part of the mid-19th century coastal defences constructed along this section to prevent the barrier from undergoing westwards rollover. The western (estuarine) side of the barrier rests on estuarine mudflat sediments, which are exposed at low water.

C1.140 Towards the wider, spatulate, southern end of the barrier there is a substantial volume of sand and gravel forming the beach face and extending out to the Binks. This section consists of over 18m of sands and gravels which overlie the glacial till surface at about –17mODN (Pickwell, 1878; Berridge and Pattison, 1994; Balson and Philpott, 2004). Peat deposits were recorded at around –7m ODN (dated at 6500 BP; ABPmer 2007).

C1.141 Seaward of the southern end of Spurn are the Binks, an area of sand and gravel banks which extend north-eastwards. This generally shallow area serves to dissipate wave energy under certain conditions, and consequently provide sheltering effects to Spurn (ABPmer, 2008).

Long term evolution

C1.142 Spurn is believed to have been breached repeatedly in historic times, leading to episodic growth and realignment in response to the retreat of the Holderness coast (de Boer 1964, 1981). In 1849 the barrier was breached just north of the lighthouse as the result of a storm. By 1850 the breach was 450m wide and 5m deep at high water; vessels were able to use the channel to enter the estuary. In 1855 the breach was sealed through the construction of the Chalk Bank. A series of groynes were built between 1864 and 1926 and revetments added in 1884. Due to escalating maintenance costs, the decision was taken in 1961 to cease maintenance of the defences and allow the natural processes to control the shoreline. There was also a severe breach of the dunes in 1996 that was quickly filled. Sections of the access road along Spurn were washed away in this storm and the road was realigned.

C1.143 de Boer (1964) described this process of breaching and reformation as a 250-year cycle, but it is probably more random, driven by sequences of large storm events. Indeed, it is possible that the progressive lengthening and rotation of the barrier increases its vulnerability to storm events. The extent to which the breach can recover from a particular storm is conditional on the continued supply of sediment to Spurn as well as the precise timing and sequence of subsequent storm events. Areas of "damage" (i.e. crest lowering) can be the focus of future overwashing events and, ultimately, become vulnerable to breach events. de Boer (1964) envisaged that breaching was accompanied by barrier breakdown, followed by reformation of a new barrier further to the north-west.

C1.144 It is proposed that as well as an increased rate of southerly sediment transport at this time, another potential contributor to the 1849 breach was the considerable gravel extraction from intertidal areas that was occurring during the 18th and 19th centuries (ABPmer, 2008). In the mid 19th century, 40,000 – 45,000 tons of sediment was being removed annually from the narrow northern area for use in roads, buildings, ships ballast and the cement industry (ABPmer, 2008). This volume of sediment removal relates to approximately 7 times the natural erosion rate calculated by IECS (1992). This would also have had the effect of reducing wave dissipation and is another potential cause of the significant breach. Gravel extraction has since been controlled and is limited to the Binks area.

C1.145 IECS (1992) proposed that the southern end of the barrier has been anchored in place by the moraine ridges (about 15m below High Water Mark On Spring Tide (HWMOST)) which lie off the tip of Spurn and extend to the northeast (following the line of the Binks; IECS, 1994a). IECS (1994a) postulate that these ridges, in effect, form two "guide rails" that have lead to the westwards migration of the southern end of the barrier along these "rails".

C1.146 During the 17th and 18th centuries the length of Spurn increased rapidly, recorded by the requirements for new lighthouses (ABPmer, 2008). Also, over the last 100 years the peninsula has lengthened by over 200 m (FutureCoast - Halcrow 2002) at up to 7m/year (HR Wallingford 2003). East Riding of Yorkshire Council monitoring data indicate that Spurn has lengthened by 30m since 1997. However, the tip is now at the northern edge of a deep erosional hole, the palaeochannel of the Humber and it is believed not to be extending as it is constrained by the large tidal discharges into and out of the Humber (HR Wallingford 2003, Black and Veatch, 2004; ABPmer 2008).

C1.147 Another theory, put forward by Balson and Philpot (2004), is that the southern tip is associated with a paleaovalley that extended south-westwards from New Sand Hole. A second till ridge about 2.5km to the north of the Binks follows a similar alignment, running beneath the barrier (at 6m below HWMOST) and coinciding with a muddy shingle bank, the "Old Den". This bank lies 400m to the west of the barrier, separated from it by a shallow muddy channel (the Greedy Gut). In the 17th century this bank had been an island with dunes and vegetation (May, 2003).

C1.148 The reclamation of Sunk Island in the Humber, began in the mid 17th century, led to the closure of the North Channel (Patrington Channel). This would have led to the collapse of the tidal flow which transported sand along the western shore of the barrier and around the northern shore of the Bight (relict sand dunes are present between Welwick and Skeffling). The loss of sand supply to the western side of the barrier neck resulted in it becoming increasing vulnerable to breaching (IECS, 1992).

C1.149 The long-term barrier retreat rate has been around 0.5m/year since the 19th century (May, 2003). The seaward shore along the narrow northern section of the barrier (the neck) retreated over 30m in 1978 and has experienced several major recession events since that date (IECS, 1992). The recent rate of change has increased substantially since the defences have failed (ABPmer, 2008). Since 1997 shoreface erosion has been monitored by East Riding of Yorkshire Council. These monitoring results indicate that the whole beach profile is moving landward, with 2-4m/year of erosion on the seaward side and no measurable sand build up on the Estuary side. The neck reduced in width by 20m between 2003 and 2008. The recent narrowing of the beach and dune ridge at the northern end of the peninsula has lead to frequent overwashing during storm events causing damage to the road and services. It is believed that the mid-19th century coastal defences have inhibited the roll-over process, limiting the transfer of sediment onto the western shore (IECS, 1992; Rendel Geotechnics, 1994). Failure to achieve westward roll-over and barrier migration over the last 150 years has meant that the barrier is now in an unstable position. Consequently, East Riding of Yorkshire Council believes a breach event is likely in the next 5- 10 years.

C1.150 A summary of the man-made causes of contemporary change to Spurn (developed from IECS 1992) is given in Figure 1.6.

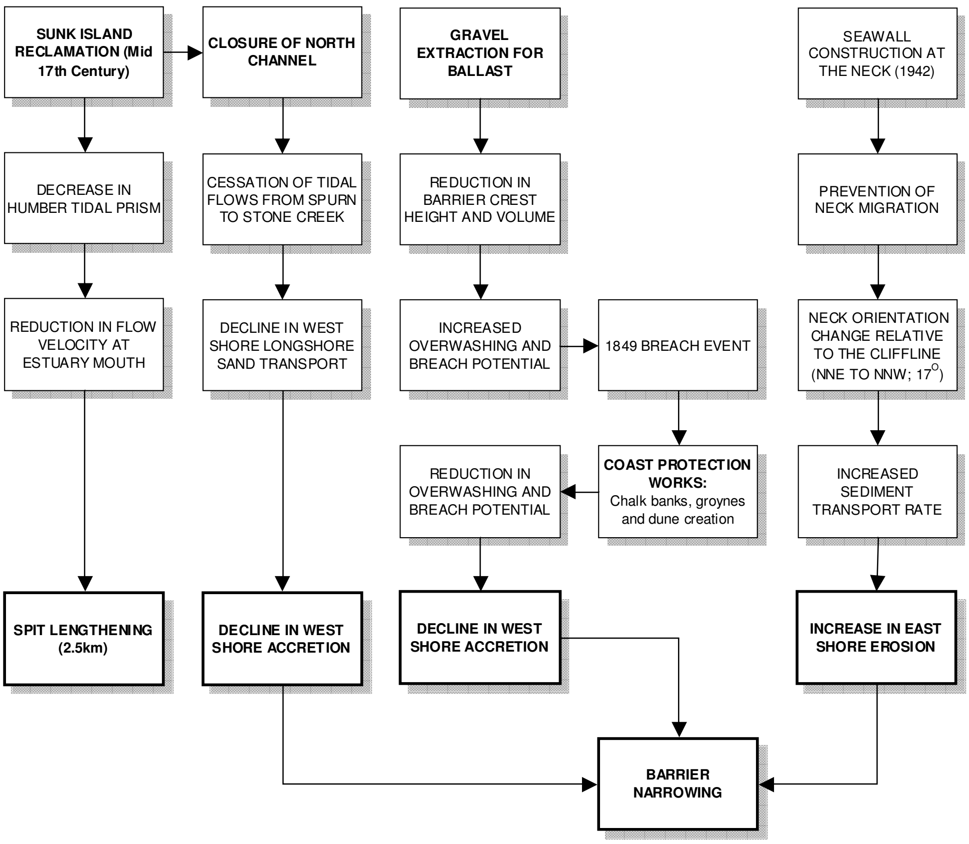

Figure 1.6. A summary of the man-made causes of contemporary change to Spurn (developed from IECS 1992).

System Controls and Behaviour

C1.151 Key controls on the dynamic behaviour of Spurn are the supply of coarse sediment generated from the retreat of the Holderness cliffs and wave energy. An estimated 125,000m^3/year is supplied to Spurn (Valentin 1954). Some of the Holderness coarse sediment is believed to be transported offshore around Withernsea (HR Wallingford 2003) or Easington (Halcrow/GeoSea, 1990). It is suspected that this sediment feeds into the Binks, which act as a temporary store for sediment (Halcrow/GeoSea, 1990). Modelling undertaken by IECS (1992) indicated that the sediment transport rate increased south of Kilnsea, because of the shoreline orientation change. This results in an increasing demand for sediment which is met by shoreface erosion. As the barrier alignment swings towards the south west, longshore wave power decreases, reducing the transport rate. As a result, deposition increases towards the head, although IECS (1992) suggested that there is no net deposition at the southern tip. Sediment is believed to be carried around the tip onto the western shore by wave and tidal current (ABPmer, 2008), where it is blown onto the barrier to form dunes. However, the Old Den acts as a barrier to the northwards transport of sediment along this shore. Consequently, sand transport does not extend as far northwards as the narrow northern section of the barrier. IECS (1992) suggest that in this area sediment accumulation has historically, and still is maintained by washover processes. However, according to East Riding of Yorkshire monitoring data there is no evidence for sediment accumulation on the northern estuarine side between 2003 and 2008. This erosion of the seaward side and lack of deposition on the estuarine side has led to considerable narrowing of the barrier to only around 10m in places.

C1.152 Spurn is a dynamic barrier, with morphological changes driven primarily by wave energy. Wave energy around the southern tip of the barrier is dissipated by the Binks. Historical behaviour includes retreat (roll-over), shoreface erosion, re-alignment and temporary breaching. Barrier retreat is controlled by the relative significance of overtopping and overwashing wave events:

- Relatively low magnitude, overtopping surge transports gravel up the beach, leading to crest height increase; and
- High magnitude overwashing surge carries gravel over the crest and down the backslope where it is deposited as a series of fans. Overwashing leads to barrier retreat (roll-over).

C1.153 The balance of these two processes controls the frequency and magnitude of roll-over events. If the crest height becomes low relative to wave run-up, then the rate of overtopping will increase and the beach crest will rise, reducing the potential for further overwashing. The presence of mudflat sediments and peat beneath the sand and gravel ridge suggests that the barrier has rolled-over into the estuary.

System Linkages

C1.154 Spurn receives coarse sediment from the Holderness cliffs, as described earlier. In turn, it probably is a source of sediment for the Binks and New Sand Hole and the mobile sand sheets within the Humber estuary.

C1.155 The barrier also provides shelter for the extensive mudflats of Spurn Bight within the Estuary that have accreted on its landward side. It also affords a limited degree of shelter from waves from the north-east to the frontages of Cleethorpes and Grimsby on the south bank of the Estuary. The morphology of the peninsular and the gravel banks of the Binks affect waves propagating around the tip of Spurn Head.

C1.156 The relationship between Spurn and the Holderness cliffline has been changing over time, because of their differential retreat rates (Spurn has retreated at 0.5m/year compared with up to 2m/year along Holderness). The barrier now stands in a relative position further seaward than it did at the time of the 1849 breach. This may contribute to the current rapid erosion on the northern sections of the barrier (IECS, 1992; May, 2003).

Future Behaviour

C1.157 Future behaviour of Spurn will be critically dependent on:

- Longshore coarse sediment supply from the Holderness cliffs;
- Wave energy inputs arriving at the shoreline;
- Breaching of the beach; and
- Condition and extent of coastal defences.

C1.158 Relative sea level rise and climate change are expected to accelerate the dynamic behaviour and trends experienced over the last few centuries. If the current defences deteriorate further, Spurn is expected to continue to be affected by shoreface erosion and could migrate westwards through roll-over, but will probably not extend further south into the estuary because of the high tidal flows (Black and Veatch, 2004; ABPmer, 2008). The tendency for overwashing at vulnerable locations along its length is likely to increase into the future which may lead to eventual breaching. East Riding of Yorkshire Council anticipates that a breach may occur within 5 to 10 years.

C1.159 Pethick (1988) suggested that as Spurn is essentially the raised edge of the Spurn Bight intertidal flats, a breach would not alter the overall shape of the Humber Estuary. Continued longshore sediment supply should ensure that breaches would eventually heal. A different view has been presented by the East Riding of Yorkshire Council (undated) who believes a breach may not be self-healing and that the Humber may use the breach channel to drain into the North Sea causing rapid erosion and possible loss of the entire peninsula. Spurn Point, would become an island under this scenario, starved of sand would rapidly erode. Its ultimate survival will be dependent upon the time taken for the peninsula to reform. Loss of the Spurn Point and Binks system could result in major changes to the Humber mouth.

Local Scale: Spurn Head

C1.160 System State: sand and gravel barrier, capped by dunes;

C1.161 System Inputs: coarse sediment input from the Holderness cliffs (>100,00m^3/year);

C1.162 System Outputs: shoreface erosion and longshore transport provides coarse sediment to the Humber mouth sediment sinks/stores (the Binks, New Sand Hole, mobile sand sheets);

C1.163 Hazards: shoreface erosion and barrier roll-over, leading to potential for breaching in severe storms. The barrier provides protection for Spurn Bight mudflats.

C1.164 Future Trends: accelerated shoreface erosion and barrier roll-over, increased susceptibility to breaching.

Shoreline Behaviour Unit: The Outer Humber (Kilnsea to Donna Nook)

System Components

C1.165 The outer Humber estuary is defined here as the estuary seaward of a line drawn between the West of Sunk Island and East Immingham (i.e. estuarine channel whose southern shore corresponds to sub-cell 2b). The seaward limit is more difficult to define since the limit of west-east tidal influence of the estuary on the essentially north-south rectilinear tides of the open coast is extremely variable.

C1.166 The components of the outer estuary system can be summarised:

- The estuary bed and banks: The seaward extent of the estuary lies between the Binks in the north, consisting of a ridge of resistant glacial tills, probably Devensian glaciation moraine, and the Haile Sands in the south: a sub-tidal area of fine sands and muds that merges with the inter-tidal area of Donna Nook. This extensive sand deposit is characterised by a series of sand waves, described as ridge and runnel by Robinson (1964). The inter-tidal sand is backed by a sand dune system.
- West of Spurn Point lies Spurn Bight, an area of inter-tidal muds and sands, backed by a narrow salt marsh extending between the Old Den and Hawkins Point.
- The Sunk and Hawk channels of the outer Humber run along the southern edge of Spurn Bight and comprise a dredged navigation channel yielding approximately 1Mm^3 dredged arising per year (Environment Agency 2000).
- A deep paleaochannel: East of the Binks and Haile Sands, the sea bed is characterised by a deep channel: the New Sand Hole, whose bed lies between -20mCD and -40mCD. This is thought to be an antecedent valley formed during fluvial phases of the Humber when glacial sea levels were low.
- A flood tide delta: The Middle Shoal lies south of the Sunk Channel. It comprises a sub-tidal sand and gravel shoal. This shoal, together with the Burcom Sand to the west and the Clee Sands to the east comprise the flood tide delta of the Humber (Stapleton 1994).

System Controls and Behaviour

C1.167 The strong tidal flows in and out of the Humber intersect the north-south sediment transport pathway along the open coast. The estuarine tidal currents act as a hydraulic groyne, partially blocking the longshore passage of sediment, and preventing all the gravels and some of the sands from passing the estuary mouth (HR Wallingford, 2003). The gravels and coarse sand components are either trapped north of the Binks or fall into the New Sand Hole which acts as a sediment sink.

C1.168 There is some uncertainty as to the pathway taken by the medium and fine sands. It may be that sands enter the estuary and accumulate in the temporary store of the flood tide delta (Middle Shoal, Burcom and Clee Sands) before moving seawards to enter the Haile Sands. HR Wallingford (2003) however, show from modelling results that sand can bypass the deep water channel of the outer estuary during severe storms. Under this model, sands are held in a temporary store at the Binks before being driven across the Humber channel in extreme storm events, to arrive at the Haile Sands promontory, north of Donna Nook. During calmer conditions sand is moved into the channel where it is ‘riffled’ in and out with the tide but with an overall southerly drift again moving onto the Haile Sands promontory (HR

Wallingford, 2003). A drift divide at Donna Nook then results in sands moving west into the Humber and south along the Lincolnshire coast (HR Wallingford, 2003).

C1.169 The functioning of the outer Humber is consistent with a classic macro-tidal delta, with well developed tidal ramparts on the southern shore (Haile Sands) and a complex but identifiable flood tide delta (the Middle Shoal area). No ebb-tide delta is identifiable: this is normal for macro-tidal estuarine systems where the high ebb discharges disperse any sediment in the open sea. The marked asymmetry of the delta system, with extensive sand ramparts to the south but only a temporary sand store behind the Binks in the north, is again typical of such systems where strong open coast unidirectional wave and tide driven currents are present (e.g. Oertel, 1984). Under this model, the pronounced ridge and runnel sequence on the inter-tidal area of the Haile/Donna Nook sands, described by Robinson (1964), may represent flood tide channels across the tidal delta and allowing peripheral flood tide flows into the estuary during the early stages of the flood while strong ebb tide flows are still moving seawards from the estuary mouth.

C1.170 The size and configuration of the tidal delta is governed both by the tidal flows in the Humber and the sediment pathways on the open coast. Changes in either of these controls will result in changes in the volume of sediment held in the various components of the delta. It has been suggested that the extensive reclamation that occurred in the Humber since medieval times has reduced the tidal prism of the estuary and thus the volume and extent of the tidal delta (IECS, 1994). This effect would have been offset slightly by the impact of sea level rise, increasing the tidal prism of the Humber and thus reducing or even reversing the loss of tidal delta sediment. There is some evidence that the sediment held in the shore and nearshore areas between Donna Nook and Saltfleetby, has increased recently. This evidence is obtained from analysis of EA shore profile monitoring (e.g., Leggett et al 1998) which extends back only over the past two decades so that it is not possible to determine whether the increase in sediment volume has been a long term process or a modern phenomenon.

C1.171 Morphological changes to the estuary between 1946 and 2000 have been established from an analysis of historical charts, along with echo sounder and lead line surveys (Black and Veatch Consulting, 2004, Appendix B). In the outer estuary (Grimsby to Spurn Head) there has been a significant gain in subtidal area on the southern side (1249 ha, 3.4ha/year), matching a comparable loss on the northern side (3897 ha, 4.6ha/year).

System Linkages

C1.172 It is suspected that almost all the non-cohesive sediment entering the Humber is derived from the erosion of the Holderness cliffs and nearshore seabed. Balson & Philpott (2004) provide some indication of the volumes of this eroded material (see Table 1-7). The gravel component of $105{,}000^3$ m^3 /year moves into the New Sand Hole sink. The total volume of gravels held here together with the thin offshore deposits represents the output from 5,000 years of Holderness erosion. Generally the deep water channel is thought to act as a barrier to the southerly movement of coarse sand and gravel into this area from Holderness, however some coarse sand deposits are found in the Donna Nook area which are thought to have been transported here from offshore.

C1.173 An estimated 800,000 m^3/year of medium to fine sand is supplied by erosion of the Holderness cliffs (Table 1-6). The volume of the sediment store held in the mouth of the Humber, including the Binks, Haile Sands and Donna Nook, is estimated to be 100 times this volume HR Wallingford (2003). This sediment store/sink potentially provides a buffer of 100 years against changes in output from Holderness before any impacts occur within the Humber or on the coast of Lincolnshire. Assuming that this sediment store is full at present then no further sediment accretion takes place here and instead sands are transported south into Lincolnshire.

C1.174 Sediment movements across the Humber mouth are estimated by HR Wallingford (2003) at between 100,000 m^3/year during relatively calm conditions and 330,000m^3/year during extreme storm events. Most of this sediment is retained in the sediment sinks of Haile Sands, Donna Nook and the coast south to Saltfleetby. Analysis of EA profiles suggest there is net accretion of around 300,000 m^3/year between Grimsby and Mablethorpe (HR Wallingford, 2003).

C1.175 The imbalance between the output of 800,000 m^3/year sand from Holderness and the maximum rate of movement across the Humber of 330,000 m^3/year is difficult to explain. It is possible that 500,000 m^3/year enters the Humber and is deposited in inter-tidal areas together with cohesive sediment, so allowing the estuary to keep pace with sea level rise.

C1.176 Relative sea level rise in the Humber was investigated by ABPmer (2003) who concluded that mean water level at Spurn showed a long term rise of 1.8mm/year rising to 2.8mm/year at Immingham. In order to keep pace with this rate of rise, HR Wallingford (2003) estimated that the inter-tidal areas of the estuary would require an accreting sediment volume of 600,000 m^3/year. The cohesive sediment supply from the Holderness cliffs is estimated to be around 2.0 x 10^6 m^3 (Table 1-6), more than enough to ensure that the Humber has been able to keep pace with sea level rise in the past. A major percentage of this cohesive material however is carried in suspension into the North Sea and it may therefore be that a significant proportion of inter-tidal accretion in the Humber consists of a fine sand fraction.

C1.177 A critical issue for prediction of future states is which of these routes taken by the sand component - into the Humber or across the estuary into Lincolnshire - is dominant since increased demand by either can only be met at the expense of the other.

Future Behaviour

C1.178 Future behaviour of the outer Humber system will depend upon:

- Availability of sediment from Holderness erosion and offshore sources;
- Geomorphology of the Spurn Point/Binks complex;
- Demand for sediment within the Humber as a result of sea level rise; and
- Maintenance dredging programme in the Sunk Dredged Channel.

C1.179 Increased sediment yield from the Holderness cliffs would not be reflected in increased rates of transport across the Humber channel unless storm event frequency showed a commensurate increase. Without such an increase in storm frequency more sand may be available for accretion within the Humber in response to sea level rise. In the longer term, if the bays were to continue to deepen along the Holderness frontage, a resulting decrease in sediment release could occur, and thus one possibility is that rates of supply to both Humber and Lincolnshire may be reduced. However, the impact may be further delayed as a result of the sand store (originating from the Holderness Cliffs) held in Humber mouth (Black and Veatch, 2004) which is thought to act as a buffer equivalent to up to 100 years' sediment transport. This may allow rates of supply to Lincolnshire to be maintained while at the same time the concept of roll-over (Townend and Pethick 2002) may maintain sand inputs into the estuary.

C1.180 The increase in demand for sediment within the Humber as a result of sea level rise is estimated to be around 300,000 m^3/year per millimetre rise in sea level (HR Wallingford, 2003). If the rate of sea level rise increases to over 1cm per year by the end of epoch 3 (Defra 2006a), this would put demand at 3,000,000 m^3/year; slightly more than the combined cohesive and non-cohesive sediment output (2 700,000 m^3/year) from Holderness at present. In addition, since it is not possible to determine the dominant sediment pathway, the increase in demand within the Humber due to relative sea level rise may not result in the diversion of sediment from its pathway across the Humber channel into Lincolnshire, so that the deficit in the estuary would be increased further.

C1.181 Changes in the geomorphology of the Spurn Point and Binks system could result in major changes to the Humber mouth:

- Increased sediment inputs from Holderness: if the protection afforded to Spurn by the Binks is removed due to erosion, an increase in sediment output is predicted as the Holderness coast increases its drift alignment.
- Reduction in sediment transfers across the Humber: morphological change in the Spurn Point/Binks area could result in a major change in the rate of transfer of these sediments across the Humber. The model proposed by HR Wallingford (2003) involves episodic movements related to storm events and relies upon a temporary store of sediment being available on the northern bank, at the Binks, during such an event. Removal of this temporary storage area would reduce sediment transfers during storms and thus the overall rate of inputs to the Lincolnshire system. Sediment would move into the channel rather than across it so increasing the Humber estuary input and decreasing the input to the Lincolnshire shore.

C1.182 Finally, the Humber mouth system is dependent at the present on the maintenance dredge programme in the Sunk Channel. Disposal of dredged deposits within the estuary reduces the impact of this programme on the geomorphology of the estuary. A change in the disposal pattern of deposits, for example to sea disposal, would be reflected in changes in the morphology of the outer estuary sand banks.

Local Scale: Kilnsea to Stone Creek

C1.183 System State: Fine sediment on the foreshore backed by earth embankment or natural high ground with a wide floodplain behind. West of Hawkins point the shoreline is largely stable and/or slightly accreting (Posford Duvivier, 1996). To the east of Hawkins point there are local areas of foreshore erosion, especially towards Kilnsea.

C1.184 System Inputs: Fed by up-estuary longshore transport of fine sediment.

C1.185 System Outputs: Local shoreface erosion coupled with longshore transport provides fine sediment to the Humber estuary sinks/stores.

C1.186 Critical dependence: Dependent upon the supply of sediment from the store at Donna Nook and Haile sand.

C1.187 Hazards: shoreface erosion leading to scour and erosion at the toe of revetments leading to destabilisation and failure of defences.

C1.188 Future Trends: Accelerated shoreface erosion as the sediment demand of the Humber estuary increases with relative sea level rise and tidal prism increases.

Local Scale: Immingham to East Grimsby

C1.189 System State: Fine sediment on the foreshore backed by earth embankment with a revetment on the estuary face topped by a reinforced concrete wave wall and splash-deck on the crest. This protects a 2 – 5 km wide floodplain behind. An erosional trend of shoreline evolution is occurring mostly in the central and western parts of the unit, with 1-2m of erosion occurring here the last 10 years. Towards the east of the unit the shoreline is largely stable and/or slightly accreting, largely as a result of the shoreline discontinuity of Grimsby docks providing some sheltering of the upper foreshore from wave and current activity (Black and Veatch, 2004).

C1.190 System Inputs: Fed by up-estuary longshore transport of fine sediment from the sand store at Haile and Donna Nook.

C1.191 System Outputs: Shoreface erosion and longshore transport provides fine sediment to the Humber estuary sinks/stores.

C1.192 Critical dependence: Dependent upon the supply of sediment from the store at Donna Nook and Haile sand.

C1.193 Hazards: shoreface erosion leading to scour and erosion at the toe of revetments leading to destabilisation and failure of defences.

C1.194 Future Trends: Accelerated shoreface erosion as the sediment demand of the Humber estuary increases with relative sea level rise and tidal prism increases.

Local Scale: East Grimsby to Cleethorpes

C1.195 System State: This urbanised frontage is defended with a variety of hard structures including wave walls, revetments, gabion baskets and dock gates. Additional man made features such as high ground and embankments also compliment the harder defences. The wide foreshore consists of fine sediment, and accretion of sediment is occurring. Littoral movement of sediment occurs in a north-westerly direction.

C1.196 System Inputs: Fine sediment provided by longshore transport of material from the sediment store at Donna Nook.

C1.197 System Outputs: Longshore transport of fines in an up-estuary direction.

C1.198 Critical dependence: Over the period, the sand deposits of Haile Sand and Donna Nook will continue to help control the evolution of the coastline.

C1.199 Hazards: Potential system change to erosion in the longer term (epoch 3 and beyond) if the sediment fed across the Humber from the Holderness cliffs is reduced due to sediment diverted into Humber estuary because of accelerated relative sea level rise.

C1.200 Future Trends: It is most probable that fine sand will continue to accrete in this area for epochs 1 and 2 at least, fed from the eroding Holderness coastline.

Local Scale: Cleethorpes to Donna Nook

C1.201 System State: wide sandy inter-tidal passing into extensive sub-tidal sand flats. Glacial till foundation with relict till cliffs at Cleethorpes. Urban frontage in the west of the unit protected by sea wall; passing to open agricultural lowland extending inland to 10km in east protected by sand dunes.

C1.202 System Inputs: Medium to fine sand inputs via transport pathways crossing the Humber channel, annual inputs between 100,000 and 330,000 m^3/year. Also some limited input of course sands and gravels from offshore. Sediment divide at Donna Nook with weak drift to west and major drift to south;

C1.203 System Outputs: Possibility of drift reversal during northerly storms and loss of sand from system;

C1.204 Critical dependence: protection from north to north easterly storms dependent of wide inter-tidal zone. Coast is accreting at present, however, future loss of sediment, due to change in Holderness erosion rates, diversion of sediment into the Humber Estuary or change in sediment pathways across the Humber would be of concern;

C1.205 Hazards: potential for shoreline erosion - sediment deficit in Humber due to accelerated relative sea level rise may divert sand from unit frontage;

C1.206 Future Trends: It is most probable that fine sand will continue to accrete in this area for epochs 1 and 2 at least, fed from the eroding Holderness coastline. In the longer term increased sediment demand in estuary; reduction in buffering store; roll-over transfer of sediment from outer to inner estuary.

Shoreline Behaviour Unit: Lincolnshire Coast (Donna Nook to Gibraltar Point)

System Components

C1.207 The Lincolnshire coast between Donna Nook and Gibraltar Point can be subdivided into four geomorphological components:

- Inter-tidal sand flats; the north east coast of Lincolnshire consists of a wide sandy inter-tidal zone merging into the sub-tidal sands of the Haile Sand. The sand beach extends between Grimsby and Mablethorpe but varies in width from 1km at Grimsby, to 3km at Donna Nook. South of Donna Nook the inter-tidal sands decrease in width towards Mablethorpe. This area has been defined (C1.170) as the ramparts of the tidal delta of the Humber. Accretion is reported in the whole of this area along with a steepening foreshore.
- Salt marshes; the back shore between Tetney Haven and Donna Nook are characterised by extensive mature salt marshes, formed of clayey-silts, in bays sheltered from waves by the extremely wide sand flats and by coastal defences. Between Donna Nook and Saltfleetby/Theddlethorpe however, salt marshes are advancing across the inter-tidal zone. Fine sediment deposition here appears to be due to shelter from waves afforded by a nearshore bar. Marshes here are formed in sandy silts due to the slightly increased wave energy experienced. There is some evidence that the salt marsh zone has extended south over the past two decades. Further south, at Gibraltar Point, salt marsh is present in a series of lows between dune ridges.
- Sand dunes; the wide sandy inter-tidal zone at Donna Nook has resulted in blown sand forming a series of sand dunes in those areas where shelter from coastal defences has not resulted in salt marsh. Further south, at Saltfleetby, sand dunes are located landward of salt marsh, pre-dating the marsh since the presence of salt marsh vegetation effectively prevents sand movement by saltation. At Gibraltar Point sand dunes have developed a classic sequence of ridges interspersed with salt marsh. These ridges are part of the tidal delta of the Witham-Welland-Boston Deep channel in the Wash that acts as an estuary within the larger embayment. Sand dune and salt marsh deposition at Gibraltar Point is due to shelter from waves afforded by nearshore banks of this delta complex, such as the Inner Knock.
- Veneer beaches; between Saltfleetby/Theddlethorpe and Gibraltar Point, the inter-tidal beaches were formerly a thin sand veneer over a glacial till foundation. Historically, during storms, the thin sand cover moved seaward and the underlying till was exposed and eroded. To counter this erosion, the Environment Agency has, since 1994, undertaken a major renourishment scheme along the entire coast between Mablethorpe and Skegness (Blott and Pye 2004).

C1.208 The Lincolnshire lowlands extend between the chalk Wolds and the sea. They represent an extension of the Holocene deposits laid down in the Fenland and consist of a sequence of peats and clays laid down on a glacial till foundation. The till is exposed in the inter-tidal zone along the coast and forms a shallow dome with maximum elevations between Ingoldmells and Chapel St Leonards forming a headland here. The overlying peats and clays represent successive regressions and transgressions of relative sea level over the past 6,000 years. The upper horizon, deposited around 2,800BP (Halcrow, 2002), consists of inter-tidal muds forming salt marsh that have now been reclaimed. These salt marshes are thought to have formed in the shelter of a nearshore barrier beach. IECS (1994) and

Halcrow (2002) considered that this barrier was a component of the Wash and Humber tidal deltas that were both formerly more extensive than today and may have coalesced along the Lincolnshire coastline. An alternative view is that the barrier was formed of relict glacial deposits now eroded away (HR Wallingford, 2003, Halcrow 2002) The following account is however based upon the work of IECS (1994).

System Controls and Behaviour

C1.209 The current system state is the product of sediment and wave energy changes that have taken place over the last millennium. The extensive reclamation of the Humber and Wash salt marshes starting in the 13th and continuing until the 19th and even 20th centuries reduced the tidal prisms of both estuaries and thus the volume and extent of their respective tidal deltas. As a result the barrier beaches gradually decreased in width so exposing the salt marsh and mudflats to greater wave energy, thus transforming the former depositional shore to one of erosion.

C1.210 The maximum extent of the retreat of the barrier to the north and south is difficult to determine since no accurate maps are available prior to the 18th century. However, it is suspected that the northern barrier, forming part of the Humber tidal delta, would have retreated at least to Saltfleetby, while the southern barrier, forming part of the Wash or more specifically the Boston Deep delta retreated to north of Gibraltar Point. Thus the coast between Mablethorpe and Skegness became increasingly exposed to wave erosion. It appears, however, that major erosion of this exposed area of the coast did not commence until the 1970s. Prior to this a veneer beach was present and the underlying tills only rarely exposed to wave erosion.

C1.211 The primary source of sand must have been, and still is, the sand released from Holderness, crossing the Humber mouth and arriving at Donna Nook. It is believed that during the phase of barrier retreat the sand input would have been augmented by sand eroded from the Humber tidal delta, (i.e. the Donna Nook sand store), so that the volume of sand moving south could have been substantially greater than that at present (IECS, 1994). In addition, sediment eroded from the underlying till of the southern Lincolnshire coast would also have contributed minor volumes of sand to the beaches.

C1.212 The Humber tidal delta stabilised as the rate of reclamation decreased, so this augmentation from the sand store ceased. Furthermore, relative sea level rise began to increase the tidal prism of the Humber so the volume of the Donna Nook sand store began to increase. As a result, recent modelling data (e.g. HR Wallingford 2003) indicated that almost the entire annual sand input from Holderness is accreted in the Haile Sands/Donna Nook/Saltfleetby inter-tidal zone. This means that very little sand is now available for transport south of Mablethorpe, although sediment eroded from the underlying till does contribute a small input, with the result that the veneer beach decreased in thickness exposing the underlying till for increasing periods and thus accelerating the erosion and steepening of the inter-tidal zone.

C1.213 Over the past 200 years accretion of the inter-tidal and sub-tidal zone has been noted between Donna Nook and Mablethorpe (Halcrow, 2003). Although there is uncertainty over exact accretion rates, some estimates have been made. As a result of beach monitoring studies and analysis of historical OS maps, Halcrow (2003) stated that despite some spatial and temporal variation, average long term (1890 – 2000) net accretion rates are around +2.3m / year between Donna Nook and Mablethorpe. More recently, other sources (HR Wallingford, 2003; Leggett et al, 1998; Pethick 2003; Environment Agency 2003; Figure 8) have also noted net accretion.

C1.214 Halcrow 2003 also identified a long term trend for foreshore steepening between Donna Nook and Saltfleet due to greater deposition of material around the high water mark relative to the low water mark. Halcrow (2003) suggested that this could be due, in part, to a possible sediment transport path from the back of the beach to the high water mark.

C1.215 Reasons for this accretion around Donna Nook are difficult to identify with any degree of confidence. A relative rise in sea level and greater tidal prism in the Humber is a possible factor which may have led to an increase in tidal delta volume and extent, although this cannot be verified from the existing data base. Whatever the cause, the accretion along this section of the coast has had an appreciable impact on the southern extremity of the sand body at Saltfleetby. The expansion of salt marshes between Saltfleetby and Theddlethorpe over the past two decades has been rapid and involves both a seaward and a southerly movement of the depositional front. This salt marsh advance is indicative of the movement of the nearshore bar at this location which has also been advancing seaward and southward (Pethick 2003) and affords increasing protection to the salt marsh depositional process (Figure 1.7).

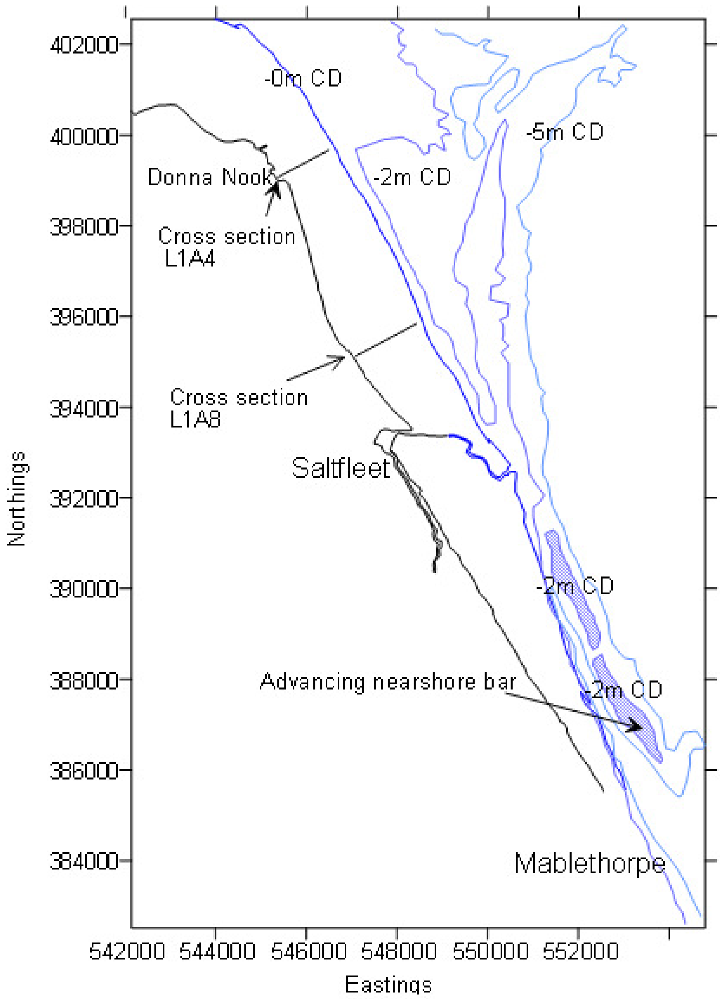

Figure 1.7. Bathymetry of nearshore between Donna Nook and Mablethorpe with location of nearshore bar shown.

C1.216 Between Mablethorpe and Ingoldmells the long term trend over recent centuries has been one of net erosion, with a net rate of -1.3m / year between 1890 – 2000, estimated from survey work and historic analysis of OS mapping (Halcrow, 2003). Halcrow (2003) suggested that this erosion pattern may be attributed to the convex shape of this area leading to exposure to the greatest wave activity. The current management response to the erosion of the coastal section between Mablethorpe and Skegness has been a programme of beach renourishment of the beaches, known as Lincshore, which started in 1994. Lincshore monitors beach profiles annually and identifies areas which fall below threshold levels. These identified areas are subsequently targeted for renourishment to restore the 'design' beach level/profile. Renourishment material for Lincshore is taken from licensed dredge sites offshore of Lincolnshire. Sea level rise is accounted for in the Lincshore scheme by annual increases in the renourishment volume. In order to monitor the effectiveness of the approach Lincshore is reviewed every 5 years. The current Linchore scheme has a recommended strategy for the next 50 years which would extend until approximately 2055 (Halcrow, 2004).

C1.217 The latest review of the Lincshore scheme (Halcrow, 2008) highlights that recent renourishment volumes during 2005-2007 have been significantly higher than those of previous years (1999-2003), indicating an increase in the amount of erosion along the Lincolnshire frontage. Although it should be noted that such short term trends may be due to above average storm frequency. Halcrow (2008) identifies 4 priority sites for renourishment, the numbers in brackets indicate the latest years in which these areas were targeted for renourishment:

- Mablethope to Sutton on Sea (2006, 2007)
- Boygrift to Huttoft (2004, 2005, 2006, 2007)
- Chapel Six Marshes (2007)
- Ingoldmells Point (2005, 2006, 2007)

C1.218 Owing to the constant requirement to target these locations for renourishment, indicated above, these locations are areas where significant erosion occurs. These areas are likely to require constant attention during future renourishment campaigns and are likely to be the first areas to show evidence of increased erosion due to sea level rise in the future.

C1.219 The Lincshore scheme has offset the erosion of beach material and the underlying tills but does not prevent the continued southerly movement of sand from the nourished beaches, resulting in the necessity for continued maintenance. The fate of the sand eroded from the nourished frontage is still unclear. Anecdotal evidence suggests that the inter-tidal zone of the Wainfleet frontage of the Wash has become sandier over recent years but this has not been substantiated.

C1.220 The majority of beaches along the Lincolnshire coastline form just part of the coastal defence at any location. Much of the beach frontage is backed by a variety of 'hard' defences (armoured revetments) and dunes which together with the beach maintain both the residual life of the defences and the standard of protection. Loss of beach material causes lower beach levels and a reduction in the beach crest width. The following points provide a simplified view of the impact of reduced beach volumes fronting the defences:

- Lower beach levels can cause the destabilisation of the hard defences landward of the beach. Defences are more susceptible to toe failure if the beach lowers, which therefore reduces the residual (effective) life of the structure. Eventually destabilisation will lead to a failure of the 'hard' defence, resulting in inundation through a breach.
- Reduced crest widths along the beach lowers the standard of protection of the combined defence, this leads to increased overtopping of hard defences at the landward edge of the beach during storms.

C1.221 The area to the south of Skegness has been accreting over recent years; a net average rate of +1.7m / year was calculated for the period 1890 to 2000 (Halcrow, 2003). Following analysis of beach and nearshore survey work, volume change on the Skegness banks has been estimated to be in the region of 17,480,000m^3 between 1995 – 2000 (Halcrow, 2003). This estimate is several times the total volume of sediment artificially placed on the updrfit beaches under the Lincshore scheme (6,200,000 m^3 by year 2000) and the total volume of sand remaining on the beach as of January 2001 (4,200,000m^3). Halcrow (2003) stated that the maximum possible contribution to the Skegness banks is 11% and that this maximum estimate is quite unlikely to be true of reality as it was stated that material would first accrete along the Lincolnshire frontage, thus resulting in a maximum of 3.5% of nourished material reaching the area south of Skegness.

C1.222 The model of the relationship between the tidal deltas of the Wash and Humber and the accretion and erosion components of the Lincolnshire coast, is based upon a general southerly drift of sand inputs crossing the Humber from Holderness. This means that, since the southern sand banks forming and fronting Gibraltar Point lie down-drift, any accretion in the Donna Nook to Mablethorpe area will reduce input to this southern system. As a result, although the Donna Nook/Mablethorpe sand body has accreted recently (see C1.213), there is some evidence to suggest that prior to the beach nourishment programme, the northerly limit of the Gibraltar Point sand bars, the Skegness Bank, had retreated south exposing more of the Skegness frontage to wave erosion (Posford 1996). If the tidal delta model developed by IECS (1994) and reiterated by Halcrow (2002) is applied to this section of the coast, then the sand bar system of which Gibraltar Point represents one component, can be viewed as the tidal delta of the Boston Deep channel in the northern Wash that flows between the Friskney Flats and the Long Sand. The Skegness Banks and Outer Dogshead Banks represent the ebb-tide delta of this estuary and the shore attached sand bars forming the Gibraltar Point complex are the tidal ramparts crossed by flood tide channels. Any increase in tidal prism, brought about for example by an increase in relative sea level, within the Wash embayment would result in a potential increase in the volume and extent of this tidal delta. The actual response of the system would depend however on the availability of sediment to allow such expansion.

System Linkages

C1.223 The Lincolnshire coastal system receives inputs of fine to medium sand from eroding updrift coastlines and from offshore sources. This area receives sediment from the eroding Holderness coastline at an annual rate of between 100,000 and 330,000 m^3/year. If this coastal system were in equilibrium, it could be expected that all of this sand would be exported from the system at the southern boundary and moved into, or possibly across the Wash. However, the system is not in equilibrium and it may be that it is still recovering from the impacts of estuarine reclamation in the Wash and Humber, combined with the subsequent rise in the relative sea level. As a result almost the entire input of sand is retained within the system, and virtually all in the northern area between Donna Nook and Mablethorpe. Annual accretion volumes here of between 290,000 and 365,000 m^3/year have been reported (HR Wallingford 2003).

C1.224 These accretion rates suggest that inputs into the Lincolnshire coast system from Holderness must be at their maximum potential value of 300,000m^3/year, yet this maximum rate of input is believed to be only achieved during extreme storm events. It may be that the sediment pathway across the Humber channel is supplemented by another pathway, possibly involving movement into the Humber from Holderness to the Middle Shoal and then a movement out of the estuary along the Clee Sands to Haile Sands sub-tidal zone.

C1.225 Modelling results indicate that movement of sediment along the exposed section of the coast, between Mablethorpe and Skegness has a potential mean annual rate of 124,000 m^3/year. If this potential rate represents the actual movement of sand then the inputs from Holderness must be increased to a maximum of 454,000 m^3/year, again reinforcing the possibility of multiple pathways across the Humber. The movement of 124,000 m^3/year along the Mablethorpe to Skegness frontage, however, does not agree with the renourishment volumes which are generally between 350,000 m^3 to 850,000m^3 per year, with a significant rise in volumes during the period 2005 to 2007.

C1.226 Sediment outputs from this system are estimated to be 350,000 m^3/year. Total inputs of sediment to the nourishment scheme however have totalled approximately 7,500,000 m^3 (1999-2007). Exports of 350,000 m^3/year over the past 13 years would mean that a total of 4,500,000 m^3 had been exported into or across the Wash over the period. It is possible that this sediment has been retained within the Gibraltar Point delta system but there is no evidence for this. However, the difficulty of tracing the movement of such a volume of sand is apparent; even if this entire volume were to have been deposited on the Friskney Flats area of the north east Wash it would represent only a few centimetres of sand accretion. Thus connectivity between the system and the adjoining southern coastal systems is still a matter of conjecture.

Future Behaviour

C1.227 There are four critical issues for the future of the Lincolnshire coast:

- The rate of sediment release from Holderness erosion;
- The pathways and rates of sediment movement across the Humber and from offshore sources;
- The accretion rate in the Donna Nook to Mablethorpe inter-tidal and sub-tidal area; and
- The nourishment programme for the area south of Mablethorpe.

C1.228 The implications of a change in the rates of sediment release from Holderness erosion and erosion of the Binks has been discussed earlier.

C1.229 Accretion in the Donna Nook to Mablethorpe area has been linked to changes in the tidal prism of the Humber. As sea levels rise, the possibility of a sediment budget deficit in the Humber would also increase the tidal prism and help maintain accretion of sands in the Donna Nook area in the short to medium term at least. In the longer term (epoch 3 and beyond) there is the potential for a rapidly accelerating rate of relative sea level rise to outpace the rate of accretion, especially if the sediment supply from the Holderness cliffs begins to reduce as a result of continuing to defend urban areas. This could cause a system change to erosion in the long term (epoch 3 and beyond). Present erosion rates along the Mablethorpe to Skegness frontage are also likely to increase as a result of accelerating relative sea level rise and a sediment budget deficit.

Local Scale: Donna Nook to Mablethorpe

C1.230 System State: Accreting and steepening wide sandy inter-tidal area with extensive sub-tidal sand flats. Backshore characterised by salt marsh and sand dunes. The inter-tidal zone decreases in width towards the south. A nearshore bar at Saltfleetby/Theddlethopre provides shelter for developing salt marsh fronting older sand dunes.

C1.231 System Inputs: Fine to medium grained sands input to Donna Nook and moved south by longshore drift. Input rates of between 100,000 and 330,000 m^3/year are estimated. Most of this is accreted within the area;

C1.232 System Outputs: Outputs to south of Mablethorpe are unknown but potential drift rates of 124,00 m^3/year are estimated;

C1.233 Critical dependence: inputs of sand from Holderness via the Humber;

C1.234 Hazards: Protection from north easterly storms is provided by the wide inter-tidal and sub-tidal zones. Reduction in sediment inputs from Holderness would reduce the level of protection.

C1.235 Future Trends: Accretion is likely to continue. Foreshore steeping will continue as sea levels rise due to greater deposition of sediment around the high water mark relative to the low water mark. Southerly movement of distal end of nearshore bar at Saltfleetby will increase shore protection at Mablethorpe. In the longer term (epoch 3 and beyond) there is the potential for accelerating relative sea level rise to begin to outpace sediment deposition, especially if the sediment supplied to this area from the Holderness cliffs begins to reduce as a result of continuing to defend urban areas.

Local Scale: Mablethorpe to Skegness

C1.236 System State: Veneer beach overlying glacial till. Erosion of underlying till was rapid with coastal retreat and foreshore steepening until programme of beach nourishment begun in 1994. Increased elevation in underlying till between Chapel Point and Ingoldmells Point has resulted in headland forming here with increasing wave focus and foreshore steepening. Skegness urban frontage is protected by hard defences fronted by veneer beach over clay tills, with recent inputs likely to come from the sand replenishment further north along the coastline.

C1.237 System Inputs: A potential input of 124,000 m^3 of sand from the north plus varying amounts from beach renourishment (typically between 350,000m^3 to 850,000m^3 per year);

C1.238 System Outputs: Unknown but renourishment maintenance programme involves volumes from 350,000 m^3 - 850,000 m^3 per year. This volume may be dispersed to sea, move into or across the Wash or be deposited in the Gibraltar Point sand bar system.

C1.239 Critical dependence: This unit depends on beach renourishment to offset erosion of the beach sand and the underlying tills. Maintenance of the beach forms an integral part of the defence line which maintains the standard of protection and extends the residual life of the combined beach and defence system;

C1.240 Hazards: Shoreline erosion and tidal flooding. Foreshore steepening continues making continuing beach nourishment increasingly difficult to sustain. Hard defences may be at threat.

C1.241 Future Trends: Without the continuation of the Lincshore renourishment scheme, erosion of the beaches would continue and hard defences may fail, or will have to be retreated, or will require upgrades in order to maintain the same standard of protection. Erosion rates are likely to increase with accelerating relative sea level rise.

Local Scale: South of Skegness to Gibraltar Point

C1.242 System State: The Gibraltar Point backshore is characterised by sand dune ridges interspersed with salt marsh. The nearshore here characterised by a complex sand bar system possibly forming the ebb-tide delta of the Boston Deep Channel in the Wash;

C1.243 System Inputs: Potential inputs from the southerly drift along the coast are estimated at 124,000 m^3/year. The majority of sediment is deposited from offshore stores. A small input of sediment to this area is derived from the artificial material placed on the updrift beaches under the Lincshore scheme.

C1.244 System Outputs: HR Wallingford (2002) suggested that there is little transport of sediment from the Lincolnshire coastline into The Wash, although they also proposed that some of the fine sediment that accumulates in the wide sandy foreshore and dune system may be washed offshore and picked up by tidal currents and transported into The Wash. However, there is uncertainty over the exact pathways and scale of sediment transported out of the system.

C1.245 Critical dependence: Supplied with material from offshore sources. The long history of accretion has been supported by onshore transport (Halcrow, 1988b). Some additional sediment supplied from updrift sediment renourishments transported to this area via longshore processes.

C1.246 Hazard: A potential reduction in sediment inputs from offshore and accelerating relative sea level rise in the longer term (epoch 3 and beyond) could lead to foreshore steepening and a system change from accretion to erosion. This would lead to the reduction in natural protection offered by the dunes and wide foreshore zone against flooding. Southerly movement of the Skegness Bank may also expose more of the shore to increased wave energy.

C1.247 Future Trends: The accretion of sediment is expected to continue for the short and medium term at least as sediment inputs to the system, mainly from offshore sources, are expected to continue. As the rate of relative sea level rise accelerates (epoch 3 and beyond) it is possible that sea level rise may begin to outpace accretion and a system change to erosion could occur if sediment inputs are not sufficient to maintain accretion.

C2 Defence Assessment

C2.1 This section details the condition of the major coastal defences that are present along the frontage. Due to the high level of this SMP, the data has primarily been sourced by filtering 'major defences' from the National Flood and Coastal Defence Database (NFCDD 2003). It should be noted that the list of defences is not exhaustive; rather it is representative of the defence types, conditions and protection offered along the different parts of the frontage. Table 2-1 has been reviewed by coastal engineers from the operating authorities who have updated or supplemented information where necessary. Data from local strategy studies has also been incorporated where available. It should be noted that up to date defence data has been compiled for the outer Humber area however this data is not yet available from the Environment Agency.

C2.2 Table 2-1 includes information regarding defence location, Character Area, SMP1 Management Unit, Authority, length of defence and design standard. The design standard is the estimated standard of protection against overtopping offered by the defences in the present day. The defences have also been characterised in terms of their estimated effective life (residual life), and their average and worst condition which is rated 1-5, with 1 being the highest and 5 being the poorest condition. The epoch in which the defences are assumed to have failed (i.e. they are no longer effective) for each management unit has been included for both baseline scenarios; No Active Intervention (NAI) and With Present Management (WPM). For detailed information on the definition of these scenarios and what the 'Failure epoch' means please refer to sections C3 and C4.

C2.3 It should be noted that many of the defences along both the Holderness and Lincolnshire coastlines are fronted by beaches and these will contribute to the estimated residual life and standard of protection of the defence structures. Significant changes reductions in beach crest level, crest width, or beach profile can significantly affect the residual life and standard of protection.

Table 2-1. Characterisation of major coastal defence assets from Flamborough Head to Gibraltar Point.

Location	Character Area	Policy Unit	Asset Name	Type of Construction	Residual Life (years)	Failure epoch (NAI)	Failure epoch (WPM)	Authority	Overall condition (1-5)	Worst condition (1-5)	Design Standard (years)
Bridlington	2	B	North Marine Promenade (north)	sea defence	>20	2	-	ERYC	2	2	1:100
Bridlington	2	B	North Marine Promenade (south)	sea defence	>20			ERYC	2	2	1:100
Bridlington	2	B	Alexandra Promenade	sea defence	>20			ERYC	1	1	1:100

Location	Character Area	Policy Unit	Asset Name	Type of Construction	Residual Life (years)	Failure epoch (NAI)	Failure epoch (WPM)	Authority	Overall condition (1-5)	Worst condition (1-5)	Design Standard (years)
Bridlington	2	B	Beaconsfield Promenade	sea defence	>20	2	-	ERYC	2	2	1:100
Bridlington	2	B	Victoria Terrace	sea defence	>20			ERYC	2	3	1:100
Bridlington	2	B	Royal Prince's Parade	sea defence	1 to 5			ERYC	2	4	1:100
Bridlington	2	B	Harbour North Pier	sea defence	11 to 20			Harbour Commissioners	3	4	1:100
Bridlington	2	B	Harbour South Pier	sea defence	11 to 20			Harbour Commissioners	3	3	1:100
Bridlington	2	B	Spa Promenade Seawall	sea defence	11 to 20			ERYC	2	3	1:100
Bridlington	2	B	Princess Mary Promenade	sea defence	>20			ERYC	2	2	1:100
Bridlington	2	B	South Cliff Promenade	sea defence	>20			ERYC	2	2	1:100
Bridlington	2	B	Belvedere Promenade	sea defence	>20			ERYC	2	2	1:100
Bridlington	2	B	Groyne Field	groynes	>20			ERYC	2	2	
Barmston (Sands Lane)	3	C	Private defences	sea defence	1 - 5	1	1	Private	4	4	Est 1:5

Location	Character Area	Policy Unit	Asset Name	Type of Construction	Residual Life (years)	Failure epoch (NAI)	Failure epoch (WPM)	Authority	Overall condition (1-5)	Worst condition (1-5)	Design Standard (years)
Barmston (EA Outfall)	3	C	Outfall Protection	sea defence	6 - 10	1	1	Private	3	4	Est 1:10
Ulrome	3	C	Campsite defences	sea defence	1 - 5			Private	3	4	Est 1:10
Hornsea	4	C	North Marine Prom (north)	sea defence	11 - 20	2	-	ERYC	2	2	1:100
Hornsea	4	D	North Marine Promenade	sea defence	>20			ERYC	3	3	1:100
Hornsea	4	D	Marine promenade (north)	sea defence	>20			ERYC	2	2	1:100
Hornsea	4	D	Marine promenade (south)	sea defence	>20			ERYC	1	1	1:100
Hornsea	4	D	South Promenade (north)	sea defence	>20			ERYC	2	2	1:100
Hornsea	4	D	South Promenade (south)	sea defence	>20			ERYC	2	2	1:100
Hornsea	4	D	Hornsea Burton Road Seawall	sea defence	>20			ERYC	2	2	1:100
Hornsea	4	D	South Promenade (south revetment)	sea defence	6 - 10			ERYC	2	3	1:100
Hornsea	4	D	Groyne Field	groynes	11 - 20			ERYC	2	3	

Location	Character Area	Policy Unit	Asset Name	Type of Construction	Residual Life (years)	Failure epoch (NAI)	Failure epoch (WPM)	Authority	Overall condition (1-5)	Worst condition (1-5)	Design Standard (years)
Mappleton	5	E	Rock revetment and groynes	sea defence	>20	2	-	ERYC	2	2	1:100
Tunstall	5	E	EA defence at Tunstall	sea defence	1 - 5	1	1	EA	4	4	1:5
Withernsea	6	F	Seathorne Promenade	sea defence	11 - 20			ERYC	2	3	1:100
Withernsea	6	F	North Gate Promenade	sea defence	>20			ERYC	2	3	1:100
Withernsea	6	F	North Promenade	sea defence	>20			ERYC	1	1	1:100
Withernsea	6	F	Central Promenade	sea defence	>20			ERYC	1	1	1:100
Withernsea	6	F	Teddy's Club	sea defence	11 - 20	2	-	Building private, Rock armour ERYC	3	3	1:50
Withernsea	6	F	Queen's Promenade (north)	sea defence	>20			ERYC	1	1	1:100
Withernsea	6	F	Queen's Promenade (south)	sea defence	>20			ERYC	2	3	1:100
Withernsea	6	F	Queen's Promenade (south terminal)	sea defence	>20			ERYC	2	2	1:100
Withernsea	6	F	Groyne Fields	groynes	6 - 10			ERYC	2	3	

Location	Character Area	Policy Unit	Asset Name	Type of Construction	Residual Life (years)	Failure epoch (NAI)	Failure epoch (WPM)	Authority	Overall condition (1-5)	Worst condition (1-5)	Design Standard (years)
Easington	8	H	Rock Revetment	sea defence	>20	2	2	ERYC	2	2	1:100
Easington and Kilnsea	9	H	Floodbank	sea defence	>20	2	2	EA / private	1	2	1:20
Skeffling	11	K	Floodbank	sea defence	11 - 20	2	2	EA	2	3	1:20 generally 1:5 locally
Sunk island – Winstead drain to Hawkins Point	11	K	Floodbank	sea defence	11 - 20			Crown Estate/ABP/EA	2	3	Generally 1:10 Locally 1:2
Sunk Island – Hawkins Point to Stone creek	11	K	Floodbank	sea defence	11 - 20	2	2	Crown Estate	2	3	Generally 1:10 Locally 1:2
Immingham to River Freshney	12	L	Revetment	sea defence	11 - 20, locally 5	2	-	EA / ABP	2	3	1:100 to 1:200
Grimsby	13a	L	Rubble bank	sea defence	1 - 5			ABP	3	4	1:200
Grimsby	13a	L	Gabion wall	sea defence	6 -10			ABP	3	3	1:200
Grimsby	13a	L	Sea wall and revetment	sea defence	11 - 20			ABP	2	3	1:200
Grimsby	13a	L	Sea wall	sea defence	6 - 10, locally 1 to 5			ABP	3	4	1:200
Grimsby	13a	L	Sea wall and gabions	sea defence	1 - 5, locally <1	2	3	ABP	3	5	1:200

Location	Character Area	Policy Unit	Asset Name	Type of Construction	Residual Life (years)	Failure epoch (NAI)	Failure epoch (WPM)	Authority	Overall condition (1-5)	Worst condition (1-5)	Design Standard (years)
Grimsby	13a	L	Seawall and revetment	sea defence	1 - 5			ABP	3	4	1:200
Grimsby	13a	L	Revetment	sea defence	6 - 10			ABP	3	3	1:200
Grimsby	13a	L	Lock	sea defence	11 - 20			ABP	2	2	1:200
Grimsby	13a	L	Dock frontage	sea defence	6 - 10			ABP	3	3	1:200
Grimsby	13a	L	Defended frontage	sea defence	11 - 20			ABP	2	3	1:200
Grimsby	13a	L	Fish docks and gates	sea defence	11-20			ABP	3	3	1:200
Grimsby	13a	L	Fish docks	sea defence	11-20	2	3	ABP	2	2	1:200
Cleethorpes	13a	L	Groynes	groynes	6 - 10			NELC	2	4	-
Cleethorpes	13a	L	Groynes	groynes	6 - 10			NELC	2	2	-
Cleethorpes north and central promenade and Kingsway	13a	L	Concrete promenade wall	sea defence	11 - 20			NELC	2		200
Cleethorpes Leisure Centre car park	13a	L	Sloping concrete sea wall	sea defence	>20			NELC	1	2	200

Location	Character Area	Policy Unit	Asset Name	Type of Construction	Residual Life (years)	Failure epoch (NAI)	Failure epoch (WPM)	Authority	Overall condition (1-5)	Worst condition (1-5)	Design Standard (years)
Humberston Fitties Car Park	13b	M	Concrete revetment/apron/ seawall	sea defence (natural)	11 - 20			Environment Agency	2	2	200
Humberston Fitties	13b	M	Groynes	groynes	6 - 10			NELC	2	-	-
Humberston Fitties	13b	M	Groynes	groynes	11 - 20	-	-	NELC	2	-	-
Humberston Fitties	13b	M	Groynes	groynes	6 - 10			NELC	3	3	-
Humberston Fitties	13b	M	Flood bank fronted by rock filled gabion	sea defence	11 - 20			NELC	2	3	5
Tetney Haven Yacht club to Louth Canal	14	N	Flood bank	sea defence	11 - 20			Environment Agency	2	3	200
East of Tetney Haven channel to secondary defence at edge of former RAF north coates	14	N	Floodbank	sea defence	11 - 20			Environment Agency	2	2	200
RAF North Coates Airfield Frontage	14	N	Floodbank	sea defence	11 - 20	-	-	Environment Agency	3	4	200
North of Horseshoe Point at Disused Airfield where beach meets Dune	14	N	Sand dune	sea defence (natural)	6 - 10			Environment Agency	2	2	200
Grainthorpe Haven	14	N	Floodbank	sea defence	11 - 20			Environment Agency	2	2	200

Location	Character Area	Policy Unit	Asset Name	Type of Construction	Residual Life (years)	Failure epoch (NAI)	Failure epoch (WPM)	Authority	Overall condition (1-5)	Worst condition (1-5)	Design Standard (years)
Grainthorpe Haven Tidal Outfall	14	N	Concrete Floodwall	sea defence	>20			Environment Agency	2	3	200
Donna Nook to Saltfleet	14	N	Earth embankment	sea defence	11 - 20	2	-	Environment Agency	2	3	200
Mablethorpe	16	O	Stepped apron and two level promenade.	sea defence	11 - 20	2	3	Environment Agency	3	3	200
Mablethorpe	16	O	Recurve Wall with embankment in places	Sea defence	11 - 20	2	3	Environment Agency	3	3	200
Trusthorpe	16	O	Return wall and Promenade	Sea defence	11 - 20	2	3	Environment Agency			200
Sutton on Sea	16	O	Angular return wall	Sea defence	11 - 20	2	3	Environment Agency			200
Sandilands	16	O	Recurve wall and two level apron	Sea defence	11 - 20	2	3	Environment Agency			200
Sandilands to Anderby Creek	17	O	Recurve wall and two level apron	Sea defence	11 - 20	2	3	Environment Agency			200
Anderby Creek	17	O	Vegetated sand dune.	sea defence (natural)	11 - 20	2	3	Environment Agency	2	2	200
Anderby Creek	17	O	Vegetated sand dune at Anderby Creek	sea defence (natural)	11 - 20			Environment Agency	2	2	200
Wolla Bank to Chapel Point	17	O	Veg. dunes with bitumen grouted stone revet.	sea defence (natural)	11 - 20	2	3	Environment Agency	2	2	200

Location	Character Area	Policy Unit	Asset Name	Type of Construction	Residual Life (years)	Failure epoch (NAI)	Failure epoch (WPM)	Authority	Overall condition (1-5)	Worst condition (1-5)	Design Standard (years)
Chapel Point	18a	O	Recurve Wall at Chapel Point	sea defence	11 - 20	2	3	Environment Agency	2	3	200
Chapel St Leonards	18a	O	Infill section of defence	sea defence	11 - 20			Environment Agency	2	2	200
Chapel St Leonards	18a	O	Promenade with recurve wall	sea defence	11 - 20	2	3	Environment Agency	2	2	200
Ingoldmells to Skegness	18a	O	Promenade with recurve wall.	sea defence	11 - 20			Environment Agency	2	2	200
Ingoldmells to Skegness	18a	O	Promenade with sloped apron and rock armour	sea defence	11 - 20			Environment Agency	2	2	200
Ingoldmells to Skegness	18a	O	Promenade with sloped apron and rock armour	sea defence	11 - 20	2	3	Environment Agency	2	2	200
Ingoldmells to Skegness	18a	O	Recurve wall with stepped apron and promenade	sea defence	11 - 20			Environment Agency	2	3	200
Ingoldmells to Skegness	18a	O	Stepped apron with promenade and rock armour	sea defence	11 - 20			Environment Agency	2	2	200
Ingoldmells to Skegness	18a	O	Stepped apron with promenade and rock armour	sea defence	6 - 10	2	3	Environment Agency	2	4	200
Ingoldmells to Skegness	18a	O	Stepped apron with promenade	sea defence	11 - 20			Environment Agency	2	3	200
Ingoldmells to Skegness	18a	O	Stepped concrete apron with promenade.	sea defence	11 - 20			Environment Agency	2	2	200

Location	Character Area	Policy Unit	Asset Name	Type of Construction	Residual Life (years)	Failure epoch (NAI)	Failure epoch (WPM)	Authority	Overall condition (1-5)	Worst condition (1-5)	Design Standard (years)
Ingoldmells to Skegness	18a	O	Recurve wall at Vickers Point	sea defence	11 - 20			Environment Agency	2	3	200
Ingoldmells to Skegness	18a	O	Infill section	sea defence (natural)	11 - 20			Environment Agency	2	3	200
Ingoldmells to Skegness	18a	O	Stepped concrete apron with promenade.	sea defence	11 - 20			Environment Agency	2	2	200
Ingoldmells to Skegness	18a	O	Recurve wall with promenade	sea defence	11 - 20	2	3	Environment Agency	2	3	200
Ingoldmells to Skegness	18a	O	Recurve wall with promenade	sea defence	6 - 10			Environment Agency	2	4	200
Ingoldmells to Skegness	18a	O	Ingoldmells Recurve Wall with promenade	sea defence	6 - 10			Environment Agency	2	2	200
Ingoldmells to Skegness	18a	O	Recurve Wall with promenade.	sea defence	11 - 20			Environment Agency	2	3	200
Ingoldmells to Skegness	18a	O	Ingoldmells - Infill section	sea defence	11 - 20			Environment Agency	2	3	200
Ingoldmells to Skegness	18a	O	Ingoldmells Point Recurve Wall	sea defence	6 - 10			Environment Agency	2	4	200
Ingoldmells to Skegness	18a	O	Recurve Wall with promenade	sea defence	6 - 10	2	3	Environment Agency	2	3	200
Ingoldmells to Skegness	18b	O	Promenade with rock armour	sea defence	6 - 10			Environment Agency	2	4	200

Location	Character Area	Policy Unit	Asset Name	Type of Construction	Residual Life (years)	Failure epoch (NAI)	Failure epoch (WPM)	Authority	Overall condition (1-5)	Worst condition (1-5)	Design Standard (years)
Ingoldmells to Skegness	18b	O	Recurve Wall and Promenade	sea defence	1 - 5			Environment Agency	2	4	200
Ingoldmells to Skegness	18b	O	Promenade with stepped apron	sea defence	11 - 20			Environment Agency	3	4	200
Ingoldmells to Skegness	18b	O	Skegness Pier Abutment	sea defence	11 - 20	2	3	Environment Agency	2	2	200
Ingoldmells to Skegness	18b	O	Recurve wall with promenade	sea defence	11 - 20			Environment Agency	2	3	200
Ingoldmells to Skegness	18b	O	Recurve wall with promenade	sea defence	11 - 20			Environment Agency	2	2	200
Seacroft to Gibraltar Point	19	P	Dunes	sea defence (natural)	>20			Environment Agency	2	2	200
Seacroft to Gibraltar Point	19	P	Vegetated Dune	sea defence (natural)	11 - 20	2	2	Environment Agency	2	2	200
Seacroft to Gibraltar Point	19	P	Vegetated Dune Ridge	sea defence (natural)	11 - 20			Environment Agency	2	2	200
Seacroft to Gibraltar Point	19	P	Concrete floodwall	sea defence	>20	2	2	Environment Agency	1	1	200
Seacroft to Gibraltar Point	19	P	Grassed Embankment	sea defence (natural)	11 - 20			Environment Agency	2	2	200
Seacroft to Gibraltar Point	19	P	Sea Bank	sea defence	>20			Environment Agency	2	2	200

C3 Baseline Scenario – No Active Intervention

Introduction

C3.1 This section outlines the predicted shoreline response associated with the 'No Active Intervention' scenario. This scenario assumes that there is no expenditure on maintaining or improving defences and therefore defences would fail at a time dependent upon their residual life and the condition of any beaches fronting the defences.

C3.2 The analysis has been developed using the understanding of coastal behaviour from the baseline understanding report (see Section C1), existing coastal change data and information on the nature and condition of existing coastal defences.

C3.3 The analysis presents the anticipated coastal evolution within three time epochs: epoch 1 (approximately 0 – 20 years); epoch 2 (20 – 50 years); and epoch 3 (50 – 100 years). Defra's Shoreline Management Plan Guidance (2006b, Defra) recommends the output for all baseline scenarios be provided for years 2025, 2055 and 2105.

C3.4 The shoreline response associated with the No Active Intervention scenario has been presented graphically in section C7.

Coastal Response

C3.5 Climate change and relative sea-level rise are expected to enhance existing shoreline evolution trends.

C3.6 The change in sea level rise is the difference between the historical and future sea level rise at the site. The historical rate on this shoreline is 1.11mm per year (Immingham, 1960-1995; standard error of ± 0.52mm; Woodworth et al., 1999). Although there is uncertainty about the future rate of sea-level rise over the next century, Defra (2006a) present guidance which takes account of the IPCC (2001) high emissions scenario and regional tectonic/isostatic changes (Shennan and Horton, 2002; Table 3-1).

Table 3-1. Defra Predictions for the East of England: Net sea-level rise (mm/year) relative to 1990 mean level (from Defra, October 2006)

Assumed Vertical Land Movement (mm/ year)	High Emissions: Net sea-level rise (mm/year)			
	1990-2025	2026-2055	2055-2085	2085-2115
-0.8	4.0	8.5	12.0	15.0

C3.7 There is some uncertainty over the nature and scale of future climate and relative sea level change. In addition, there is no established relationship between the scale of these changes and the resulting modifications to the behaviour of cliffs, beaches and barriers. As a result, it is not possible to make precise predictions about future shoreline positions; however, estimates have been made, using best available methods in the following sections.

Chalk Cliffs (Flamborough Head to Sewerby)

C3.8 Under the 'No Active Intervention' scenario, climate change and relative sea level rise are expected to enhance existing shoreline evolution trends. There is no agreed method for estimating the impact of relative sea level rise on cliff recession. However, relative sea level rise is expected to result in increased recession rates (e.g. Clayton 1989; Bray and Hooke 1997). Two approaches have been used to estimate upper and lower bounds to a range of possible cliff recession rates:

- Lower bound estimate; extrapolation of past trends, with no account taken for the impact of relative sea level rise; and
- Upper bound estimate; use of the Bruun Rule to estimate an adjustment factor that is applied to the historical rate. In this model relative sea level rise is assumed to result in the parallel retreat of the cliff profile, albeit with a corresponding rise in elevation of the cliff foot (Bruun 1962, 1988).

C3.9 Historical recession rates have been extrapolated to produce lower bound estimates of future recession. The future cliff position is simply a function of the mean recession rate and the time period (T):

$$\text{Recession by Year A} = \text{mean historic recession rate} \times \text{T Years} \qquad (3)$$

C3.10 Historic cliff recession rates along the 30-50m high chalk cliffs between Flamborough Head and Sewerby are low, in the range 0.03m/year (IECS 1994a) to 0.4m/year (Matthews, 1934; Posford Duvivier, 1998). The predicted lower bound recession distances at the end of epochs 1, 2 and 3 (after 20, 50 and 100 years, respectively) are presented in Table 3.2 and are based on the historic recession rate of 0.1m/year used in the River Tyne to Flamborough Head SMP (Royal Haskoning, 2007).

C3.11 The predicted upper bound recession distances at the end of epochs 1, 2 and 3 (after 20, 50 and 100 years, respectively) are presented in Table 3-2 based on use of the Bruun Rule. The Bruun Rule assumes that an equilibrium profile is maintained as a landform (i.e. cliff) moves inland in response to sea-level rise. This is achieved through the transfer of eroded material from the upper profile (cliff) to the lower profile (beach and nearshore). The Bruun Rule can be used to estimate the rate of profile migration (R):

$$R = \frac{LS}{H} \qquad (4)$$

S = Rate of sea-level rise
L = Profile width i.e. offshore distance to the depth of closure – see below
H = Profile depth at the depth of closure

C3.12 For example, if sea level rise was 5mm/yr, and the depth of closure of 10m occurs 300m offshore, the annual predicted profile migration rate would be:

$$R = \frac{LS}{H} \qquad (5)$$

$$R = \frac{0.005 \times 300}{10}$$

$$R = 0.15\text{m/yr}$$

C3.13 The Bruun Rule is essentially two-dimensional (onshore-offshore) and assumes that longshore sediment inputs and outputs are equal and equivalent, a condition rarely achieved in reality. To model reliably the three-dimensional situation, a full sediment budget needs to be calculated for the shoreline. If it is assumed, however, that the historical recession rate represents the net contribution to the sediment budget, then the Bruun Rule can be modified to provide an adjustment factor that represents the recession increase due to sea level rise (R) as follows (Dean 1991):

$$R = R_1 + S_c\left(\frac{L}{P(B+H)}\right) \qquad (6)$$

R_1 = Historical recession rate (m/year)
S_c = Change in rate of sea level rise (m)
P = Sediment overfill (the proportion of sediment eroded that is sufficiently coarse to remain within the equilibrium profile)
B = Cliff height (m)
H = Closure depth (m)
L = Length of cliff profile (to the closure depth, m)

C3.14 Note that in this form, the adjustment factor is an additional increment to the historical rate, not a multiplication factor.

C3.15 The closure depth is the boundary of the profile beyond which there is little loss of sediment. The closure depth can be estimated as being twice the maximum wave height for a 50 year return period (Bruun 1988; around 6m high for this coast) i.e. a closure depth of 12m. This corresponds with the marked break in seabed slope which occurs at about 9 - 12m below LAT at a distance of 1-1.4 km seawards of the cliff (IECS 1988).

C3.16 The length of active cliff profile was measured from the hydrographic charts by using the closure depth (12m) to indicate the seaward limits, taken here as 1,000m.

C3.17 The sediment overfill function is the proportion of sediment eroded that is sufficiently coarse to remain within the equilibrium profile.

C3.18 The Bruun Rule is not without its critics (e.g. Komar et al 1991), although the overall validity of this approach appears to have been confirmed for the eroding glacial till cliff shores of the Great Lakes (Hands, 1983; Dubois 1992; Zurek et al

2003). Rising lake levels have produced a transfer of material from the cliff to the nearshore bed resulting in recession rates that were very close to those predicted by the Bruun model. Bray and Hooke (1997) used the Bruun Rule it to examine the possible impacts of changing relative sea level rise on eroding cliffs in southern England. The model indicated that relative sea level rise could increase cliff recession rates on the south coast of England by 22% to 133% by 2050.

Table 3-2. Table Chalk Cliffs: estimated recession distances (m) by particular dates (No active intervention on the unprotected cliff lines).

Recession distances (m)								
Epoch 1 (2025)			**Epoch 2 (2055)**			**Epoch 3 (2105)**		
Lower	Mid	Upper	Lower	Mid	Upper	Lower	Mid	Upper
2	4	5	5	15	25	10	40	70

C3.19 The maps plotted for epoch 1 of the ‘No Active Intervention’ scenario (NAI PU A to PU P 1) show the estimated erosion recession distance for epoch 1 from the ‘Mid’ values. The maps plotted for epoch 2 of the ‘No Active Intervention’ scenario (NAI PU A to PU P 2) show estimated erosion recession distance for epoch 2 from the ‘Mid’ values. The epoch 3 ‘No Active Intervention’ mapping (NAI PUA to PUP 3) shows estimated erosion recession distance for epoch 3 from the ‘Mid’ values.

Holderness Cliffs (Sewerby to Kilnsea Coast)

Undefended Frontage

C3.20 Under the ‘No Active Intervention’ scenario, relative sea level rise is expected to cause increased cliff recession and shore platform lowering rates. This would result in an enhanced supply of a range of sediment sizes to the shoreline and sea bed. The coarse sediment supplies Spurn Head, the Binks and the New Sand Hole which contains predominantly gravels and coarse sands. It is likely that the gravel and coarse sand cannot cross the Humber mouth, although fine sands are transported to the Lincolnshire shoreline. Failure of the defences along the cliffline would restore full sediment connectivity between the source areas and sinks such as Spurn.

C3.21 The coastal response to climate change and relative sea level rise would include:

- The on-going development of a bay between headlands at Flamborough Head and the remnant moraines in the Humber mouth (the Binks and the Old Den) which control the location of Spurn. In the long-term the overall planform of the bay may change because, in the past Spurn has failed and reformed to the west. The available accommodation space within the Humber mouth is also an important control on the long-term evolution of Spurn.
- The continued recession of cliffs between the defended frontages at Bridlington, Hornsea, Mappleton, Withernsea and Easington. The undefended cliffs adjacent to these frontages would continue to recede rapidly enhancing the offset between the defended line and the natural cliffline and reducing sediment transfers between adjacent bays. This process would continue until the defences fail, triggering a renewal of cliff recession. It may take decades after defence failure for the currently protected sections to “catch-up” with the unprotected sections.
- Accelerated cliff recession and shore platform lowering rates on the unprotected clifflines, controlled by the rate of relative sea level rise. In general, beaches would remain narrow and thin, despite the increasing

sediment inputs. However, there would be continued beach accretion on the updrift margins of the defended frontages until the groyne systems and seawalls fail.

C3.22 Simple extrapolation of historic recession rates and use of the Bruun Rule (see paragraph C3.11) have been used to generate lower and upper bound estimates for future recession.

C3.23 Historical recession data from individual erosion posts has been extrapolated to produce lower bound estimates of future recession. The future cliff position is simply a function of the mean recession rate and the time period (T):

Recession by Year A = mean historic recession rate x T Years (3)

C3.24 The mean recession rates for unprotected sections of the Holderness coast were calculated from East Riding of Yorkshire Council's cliff erosion monitoring data, up to and including the survey carried out in April 2009. The unprotected cliff segments between frontages are as follows, described by erosion post (EP) numbers:

- Cliff segment; Sewerby to Bridlington (EP 1 to EP 4);
- Cliff segment; Auburn Farm to Barmston (EP 5 to EP 16; 1983-2004);
- Cliff segment; Barmston to Atwick, North of Hornsea (EP 17 to EP 43);
- Cliff segment; South of Hornsea groynes to Mappleton (EP 44 to EP 51);
- Cliff segment; Mappleton to Waxholme, North of Withernsea (EP 52 to EP 85);
- Cliff segment; Golden Sands, Withernsea to Easington (EP 89 to EP 106);
- Cliff segment; Easington to Kilnsea (EP 109 to EP 111)

C3.25 The predicted 20, 50 and 100 year recession distances (based on extrapolation of historic recession rates) are shown in Figure 3.1, for EPs within each cliff segment.

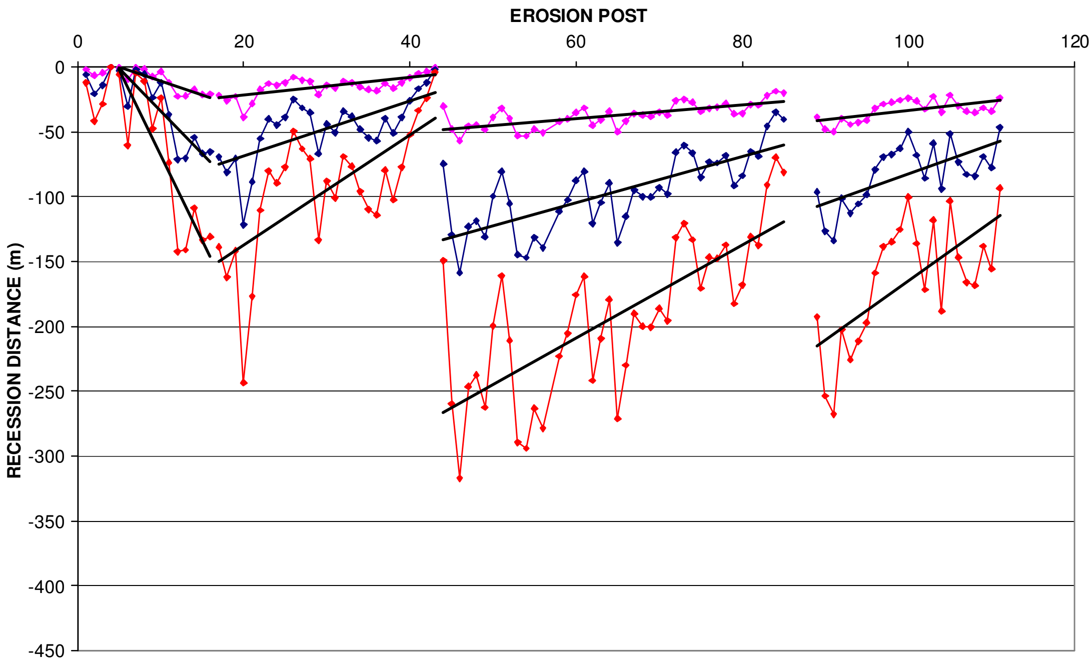

Figure 3.1. Extrapolation of past cliff recession rates: the predicted 20, 50 and 100 year recession distances for EPs within each cliff segment. (Top line (magenta) for epoch 1, middle line (blue) for epoch 2, bottom line (red) for epoch 3; with linear trend lines shown).

C3.26 The sediment overfill function is the proportion of sediment eroded that is sufficiently coarse to remain within the equilibrium profile. For the Holderness cliffs, the majority of the eroded volume is composed of fine sediments, silts and clays, which do not form part of the beach or inshore sand sheets. The percentage content of sand large enough to remain on the beach (larger than 0.25mm, medium sand) varies according to the till being eroded. Bell and Forster (1991) give figures of 25% sand for the Withernsea and Skipsea tills; 12.5% for the Basement Till (which is only exposed at the southern end of the coastline). A value of 25% has been used for the whole cliffline.

C3.27 Historical recession rates and cliff heights were taken from East Riding of Yorkshire Council's cliff erosion monitoring data, up to and including the survey carried out in April 2009.

C3.28 The predicted 20, 50 and 100 year recession distances (based on the Bruun rule calculations) for unprotected cliff segments are shown in Figure 3.2.

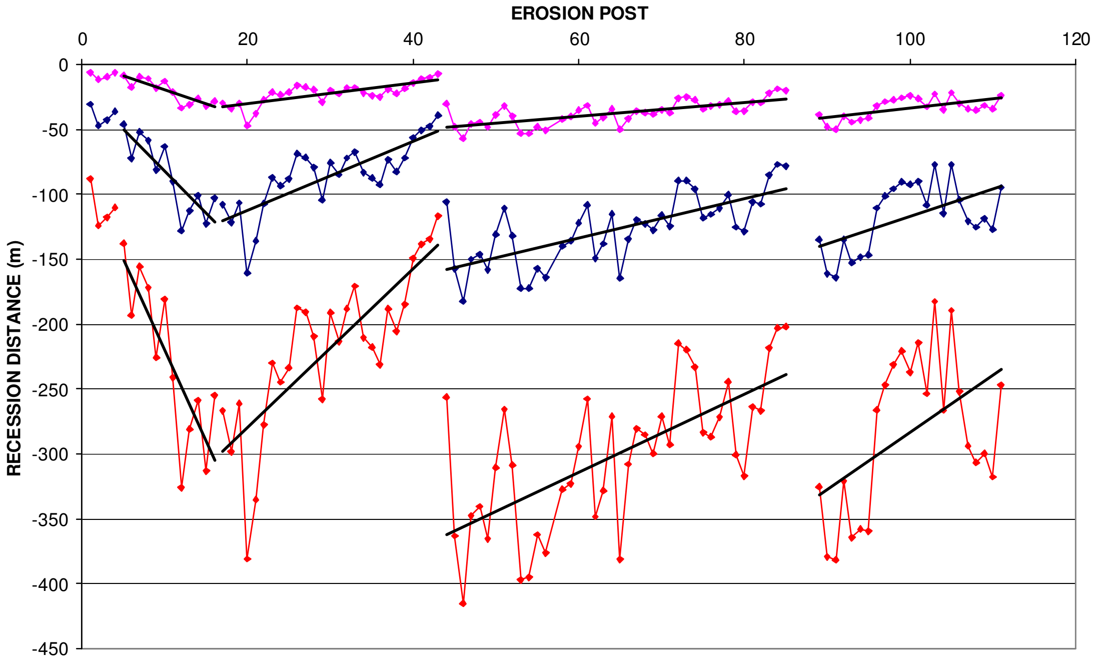

Figure 3.2. Bruun Rule-based prediction of cliff recession rates: the predicted 20, 50 and 100 year recession distances for EPs within each cliff segment. Top line (magenta) for 20 years, middle line (blue) for 50 years, bottom line (red) for 100 years; with linear trend lines shown).

C3.29 Figure 3.3 shows both the extrapolation and Bruun Rule-based estimates, with linear trend lines included through the data sets for each cliff segment.

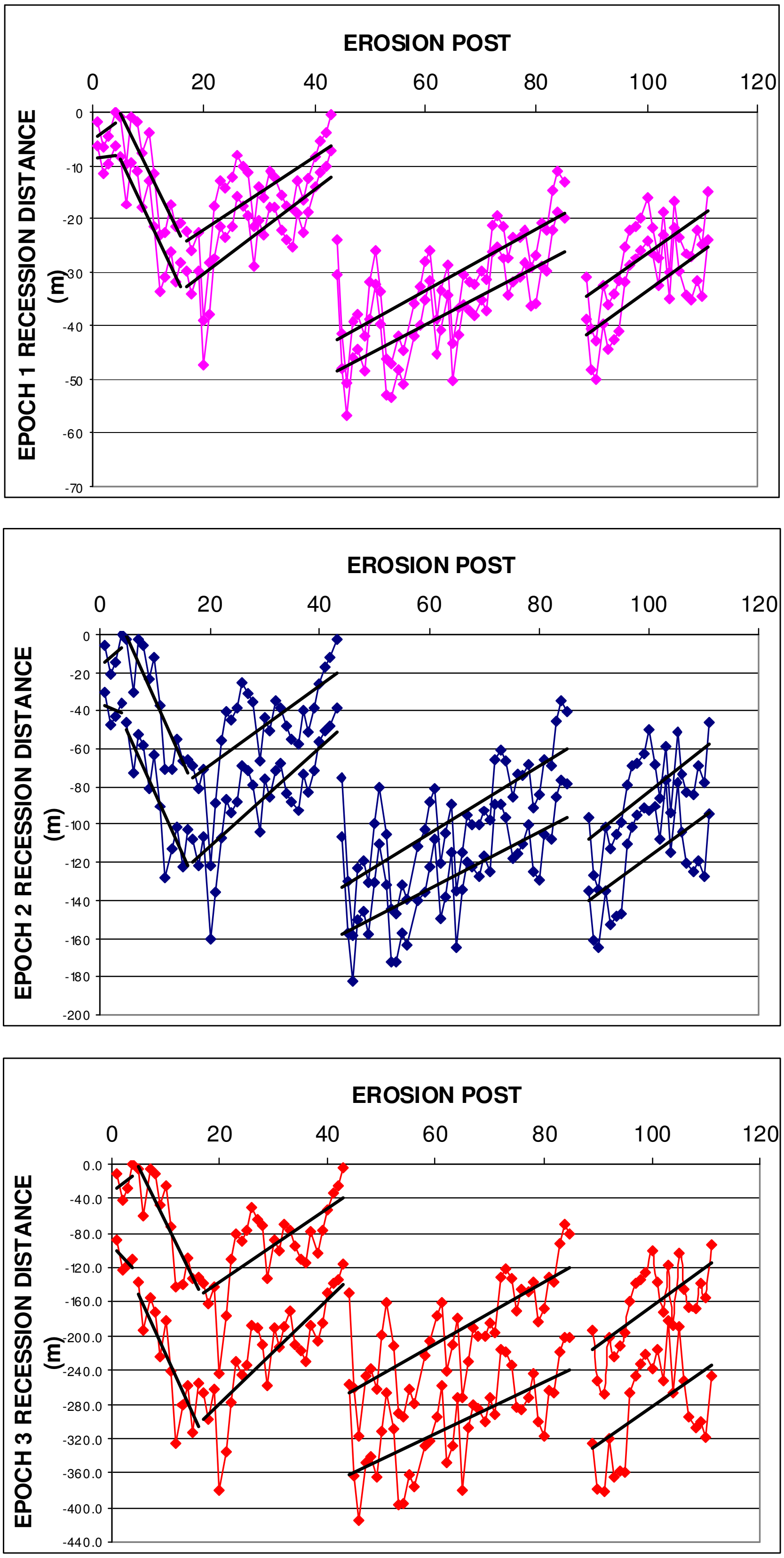

Figure 3.3. Lower and upper bound predictions of cliff recession rates: the predicted epoch 1 (top), epoch 2 (middle) and epoch 3 (bottom) recession distances for EPs within each cliff segment.
(In each chart the top line for extrapolation of past rates, bottom line for Bruun Rule-based predictions; with linear trend lines shown).

C3.30 Table 3-3 presents the upper and lower bound estimates for each unprotected cliff segment. These figures have been generated from the linear trend lines through the data series rather than using specific EP values. It is worth noting how the separation between estimates increases over time, from generally less than 10 metres in epoch 1 to 20-40 metres (epoch 2) and greater than 100 metres (epoch 3). The significant discrepancy between estimates by 2105 reflects the predicted acceleration in relative sea level rise to 12mm/year after 50 years and the impact that rapid relative sea level rise is expected to have on cliff recession.

C3.31 Points to bear in mind when considering the upper bound estimates are:

- Use of the Bruun model demonstrates the potential for a significant increase in the cliff recession rate in response to relative sea level rise. This predicted increase is because of the need within the model for the cliffs to deliver large volumes of beach-building sediment in order to maintain an equilibrium profile (an assumption of the Bruun model) i.e. the sediment budget is the dominant factor controlling recession.
- The response to changes in the rate of sea-level rise are unlikely to be immediate i.e. there could be a lag of several years, or even decades, until the predicted cliff adjustments are fully developed. A period of profile steepening should be expected before the equilibrium profile is restored. However, this is an area of considerable uncertainty.
- There is some doubt as to the validity of the Bruun model on what could be considered as a series of "quasi-protected" clifflines. This is because of the long-term planform of the cliff segments is controlled by hard points. Each segment is probably not entirely free to adjust to changes in the rate of sea-level rise in the way that the model assumes.

Table 3-3. Holderness Cliffs: estimated lower and upper bound recession distances (m) by particular dates (No active intervention on the unprotected cliff segments; N – North M – Middle, S - South).

Unprotected Cliff Segment	Epoch 1 (2025)			Epoch 2 (2055)			Epoch 3 (2105)		
	Lower	**Mid**	**Upper**	**Lower**	**Mid**	**Upper**	**Lower**	**Mid**	**Upper**
Cliff segment 1	3	6	8	10	25	40	20	70	110
Cliff segment 2 N	2	5	8	5	30	50	10	80	150
Cliff segment 2 S	23	28	33	75	100	120	150	230	310
Cliff segment 3 N	24	29	33	75	100	120	150	230	300
Cliff segment 3 M	15	19	23	50	70	85	100	160	220
Cliff segment 3 S	6	9	12	20	35	50	40	90	140
Cliff segment 4 N	42	45	48	135	145	155	270	320	360
Cliff segment 4 M	31	34	37	100	115	125	200	250	300
Cliff segment 4 S	19	23	26	60	80	95	120	180	240
Cliff segment 5 N	34	38	42	105	125	140	210	270	330
Cliff segment 5 M	26	30	34	85	105	120	160	220	280
Cliff segment 5 S	18	22	26	60	80	95	120	180	240

C3.32 The maps plotted for epoch 1 of the 'No Active Intervention' scenario show the mid-value recession distance (NAI PU A 1 to PUP P 1). The maps plotted for epoch 2 of the 'No Active Intervention' scenario show the mid-value recession distance for epoch 2 (NAI PU A 2 to PUP P 2). Similarly, the epoch 3 'No Active Intervention' mapping shows the mid-value recession distance for epoch 3 (NAI PU A 3 to PUP P 3).

Defended Frontages

C3.33 Under the 'No Active Intervention' scenario, the coastal response to relative sea level rise and climate change would include shore platform lowering and beach loss in front of the defended frontages along the Holderness Cliffs. This would increase the potential for defence failure.

C3.34 Defence failure would trigger a renewal of cliff recession on the currently protected frontages of East Riding. The rate of future recession would be controlled by extent to which the failed structures continue to provide some protection to the shoreline. Over time, these frontages would "catch-up" with the adjacent cliffline positions and re-establish a continuous bay between Flamborough Head and Spurn.

C3.35 Along the Lincolnshire frontage defence failure would lead to inundation of extensive areas of low-lying land immediately behind the current foreshore. Frequent inundation in the future would result in the low lying land being uninhabitable due to the frequency, depth and extent of flooding.

C3.36 The towns of Bridlington, Hornsea and Withernsea are protected by coastal defences which are unlikely to fail within the next 25 years. Defences were constructed in front of Mappleton village in 1991, with a design life of 50 years. The defences at Easington were constructed in 1999 and have an expected life of 25 years of operation. However in the 'No Active Intervention' scenario these defences would remain in place until they fail (probably before 2055). Short lengths of defences exist at Ulrome and coastal protection structures are present at Tunstall and Barmston Drain. Due to their short length, these sections of defence are highly susceptible to breaching and outflanking. It is not anticipated that these defences would remain in place beyond Epoch 1 under the 'No Active Intervention' scenario. Other sections of private defences are also not expected to remain in place beyond 2025 (Epoch 1).

C3.37 Defence failure may be associated with:

- A general deterioration over time, i.e. due to general wear and tear. At some point in the future the defence will cease to be effective.
- Design conditions being exceeded, e.g. destroyed by a storm, or undermined by falling beach levels (forcing conditions).

C3.38 On the protected frontages along the East Riding, the defences have simply delayed the recession process. Once the defences fail, cliff recession would re-commence. However, the post-failure retreat may differ from natural retreat, at least for some period of time. This might take two forms:

- Initial slow retreat rate, with the residual effects of the failed defences still offering some limited protection and not allowing full cliff instability and erosion to take place.
- Rapid (probably non-linear) catch-up process, i.e. the cliff reassuming its position had defences not existed by initially eroding at a rate much faster than the natural rate.

C3.39 A method for estimating the effect of defence failure and subsequent cliff recession has been developed as part of Defra's R&D project "Risk Assessment of Coastal Erosion" (RACE; Halcrow, 2006). Spreadsheets are provided as part of the RACE outputs to model the recession distance over time for three scenarios (Figure 3.4):

- **Scenario 1**: the onset of potential erosion is simply delayed until the point in time at which the defence fails.
- **Scenario 2**: the potential erosion line stays in the originally defined position (i.e. starting in year 0) but the onset of actual erosion is delayed until the defence fails followed by a 'catch up', which would be a straight line up from the zero erosion to meet the (original potential) erosion profile after a set period of time.
- **Scenario 3**: considers the effect on the erosion timeline if the defence had been in place (delaying erosion) for certain period of time. Thus the potential erosion line is shifted back in time to a starting time representative of the age of the defence, and once the defence fails there is again a catch up period.

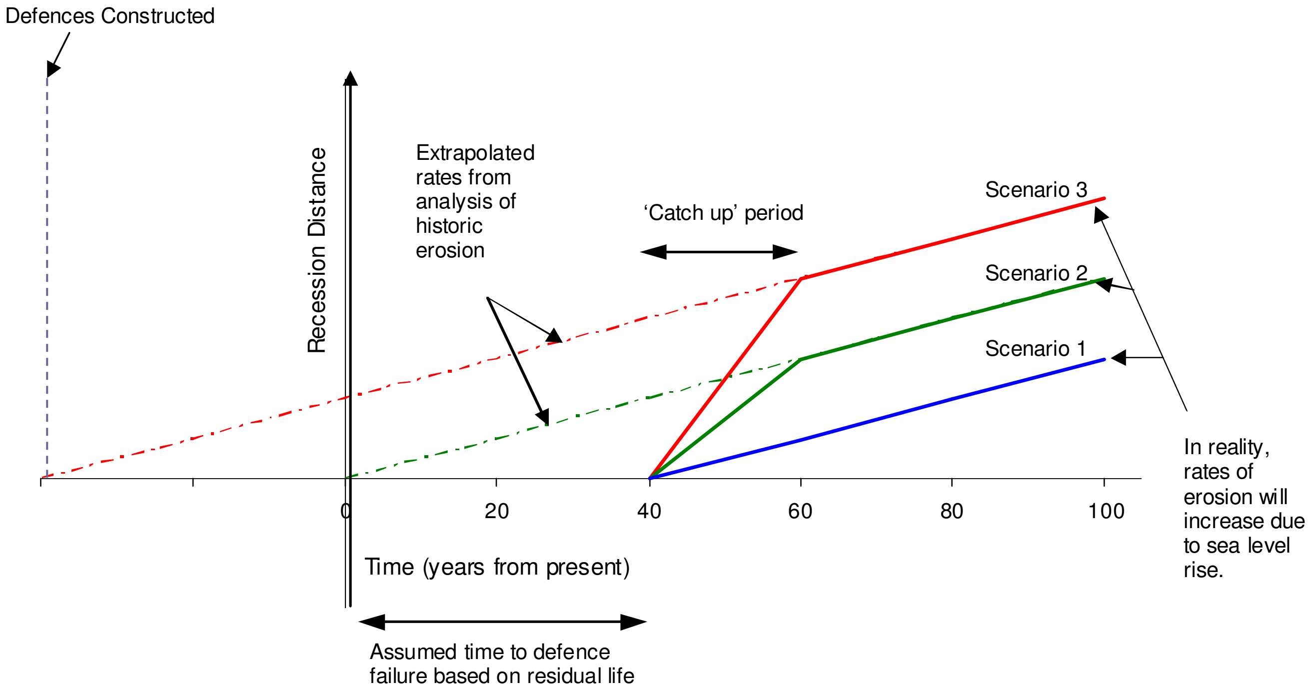

Figure 3.4. Estimated erosion distances with scenario 1 (blue line), scenario 2 (green line) and scenario 3 (red line).

C3.40 These three scenarios have been modelled for the protected frontages at Bridlington, Hornsea, Mappleton, Withernsea and Easington. The input data for the models is shown in Table 3-4, and includes:

- Predicted recession profiles for the worst case (Bruun model), best case (simple extrapolation of past rates) and intermediate case (the average of the best and worst cases). The recession rate used as the starting point for the predictions is the average of the erosion posts immediately to the north and south of the defended frontage.
- Timing of defence failure is based on the assessment of residual life (see Section C2) and is used in the calculation of recession under all 3 scenarios.
- The catch up time is the period over which the failed structure continues to provide some protection to the clifflines. After the catch up time, recession proceeds as if no defences were present. This is used in the calculation of scenarios 2 and 3.

- The structure age is the period in which the defence has been in place, preventing or reducing the recession rate. This is used in the calculation of scenario 3 recession rates.

C3.41 The results are presented in Table 3-5 as predicted recession distances after 20, 50 and 100 years, for each of the three scenarios.

C3.42 It is considered that the three methods used by the RACE project for predicting the effect of defence failure produce conservative (higher) values of recession distance than would occur in reality, since they are based on extrapolating the historic recession rate of the soft cliffs on either side of the defended frontage. The rate at which a natural clay material erodes is clearly greater than the rate at which an urban area erodes since urban areas are reinforced by structural foundations which present a greater resistance to erosion than natural clay material. As a result, mapping for the 'No Active Intervention' scenario presents the figures generated by Scenario 1 from Table 3-5 since these figures are considered to be conservative.

Table 3-4. Input data; modelling the effect of defence failure at Bridlington, Hornsea, Mappleton, Withernsea and Easington (for use in the RACE models; Halcrow, 2006).

Frontage	Input Erosion Rates	Estimated Timing (Years)		
		Defence Failure	Catch Up Time	Structure in Place (Age)
Bridlington	Average of EP 3 and 9 (0.4m/year)	40	50	100
Hornsea	Average of EP 36 and 44 (1.3m/year)	40	50	100
Mappleton	Average of EP 50 and 51 (1.8m/year)	40	50	18
Withernsea	Average of EP 85 and 90 (1.6m/year)	40	50	100
Easington	Average of EP 106 and 107 (1.6m/year)	40	50	10

Table 3-5. Modelling the effect of defence failure at Bridlington, Hornsea, Mappleton, Withernsea and Easington: predicted recession distance at particular times (intermediate case; based on use of the RACE models; Halcrow, 2006)

Location	Years	Recession Distance (m)		
		Scenario 1	**Scenario 2**	**Scenario 3**
Bridlington	2025	0	0	0
	2055	4	11	26
	2105	50	101	230
Hornsea	2025	0	0	0
	2055	9	20	46
	2105	99	183	393
Mappleton	2025	0	0	0
	2055	12	26	31
	2105	125	228	275
Withernsea	2025	0	0	0

Location	Years	Recession Distance (m)		
		Scenario 1	Scenario 2	Scenario 3
	2055	11	25	55
	2105	121	223	477
Easington	2025	0	0	0
	2055	11	23	26
	2105	114	209	233

Spurn Head

C3.43 Relative sea level rise is expected to accelerate the dynamic behaviour and trends experienced over the last few centuries, such as shoreline erosion, overwashing, and barrier realignments with increased potential for breaching of the barrier.

C3.44 As the current derelict defences deteriorate further, Spurn is expected to continue to be affected by shoreface erosion. A theory is that the barrier may also migrate westwards through roll-over, although this is highly conjectural, and historical records show the barrier position has remained largely stable over the past century (ERYC, undated). However, the barrier will probably not extend further south into the estuary because of the high tidal flows (Black and Veatch, 2004; ABPmer, 2008)). The tendency for overwashing at vulnerable locations along its length is likely to increase into the future which may lead to eventual breaching. East Riding of Yorkshire Council anticipates that a breach may occur within 5 to 10 years time.

C3.45 There are differing theories as to the outcome of future breaches. One possibility is that continued longshore sediment supply would ensure that breaches eventually self-heal. A different view is that a significant breach would not be self-healing and that the Humber will use the breach channel to drain into the North Sea causing rapid erosion and possible loss of the entire peninsula. Spurn Point, which would become an island, starved of sand would rapidly erode. Its ultimate survival will be dependent upon the time taken for the peninsula to reform. Loss of the Spurn Point and Binks system could result in major changes to the Humber mouth.

C3.46 If roll-over of the barrier does occur, in order to maintain its relative position relative to the Holderness cliffline, the barrier could be expected to retreat by around 120 to 240m over the next 100 years (i.e. the recession rates predicted for cliff segment 5b S; Table 3-3). However, the relationship between Spurn and the cliffline has been changing over time, because of the differential retreat rates (Spurn has retreated at 0.5m/year compared with up to 2m/year along Holderness i.e. 25%).

C3.47 Table 3-6 presents upper and lower bound estimates for the retreat of Spurn. The upper estimate assumes that the barrier retreats at the same rate as the upper bound rate for the cliffs; the lower rate assumes that the retreat rate is 25% of the lower bound cliff recession rate.

C3.48 The East Riding of Yorkshire Council (undated) suggest that as Spurn has been artificially held in position over 150 years, future readjustment may cause major reshaping of the whole peninsula and a shift westward by as much as 500m or more.

Table 3-6. Spurn Head: estimated lower and upper bound retreat distances (m) by particular dates (No active intervention).

Epoch 1 (2025)		Epoch 2 (2055)		Epoch 3 (2105)	
Lower	Upper	Lower	Upper	Lower	Upper
6	30	15	100	30	250

Outer Humber Estuary (Kilnsea to Donna Nook)

C3.49 Where the foreshore is erosional and the shoreline has retreated, damage to earth embankment defences has resulted. This pattern of erosion is predicted to continue and accelerate with relative sea level rise and with no intervention, the defences and embankments would be undermined through erosion and would fail.

C3.50 Where failure occurs, regular breaching would result, and as relative sea level rise accelerates, the extensive tidal floodplain would be inundated with increasing frequency.

C3.51 The trend for foreshore lowering and erosion would continue between Immingham and Pyewipe. This would cause toe erosion and failure of the defences, and the shoreline would then retreat at a natural rate.

C3.52 The most significant erosion and defence degradation is likely to occur around Stallingborough and least deterioration is expected towards Grimsby. It is likely that the defences in the central and western parts of the southern estuarine shore would fail rapidly due to damage from erosion. This would lead to regular and widespread flooding of the low-lying floodplain behind the current defence line.

C3.53 Accretion is expected to continue between Grimsby and Donna Nook, as the sediment eroded from the Holderness cliffs would continue to feed across the Humber mouth. The foreshore is likely to steepen over time with relative sea level rise, however dune building and saltmarsh progradation is predicted to match, or more likely outpace, the rising sea levels over the SMP timeframe. This would occur as the supply of sediment from the updrift eroding Holderness cliffs would increase as current defences deteriorate and erosion accelerates due to relative sea level rise. Deposition on the foreshore between Donna Nook and Grimsby would consequently increase under this scenario.

Lincolnshire coast (Donna Nook to Gibraltar Point)

C3.54 Donna Nook is currently accreting and this would continue, fed by sediments originating from the Holderness coastline, north of the Humber estuary. Foreshore steepening would continue or increase as sea levels rise due to greater deposition of sediment around the high water mark relative to the low water mark. Under this scenario this supply of sediment would increase and consequently lead to further dune building and progradation of the high water mark. Greatest accretion would occur nearest to Donna Nook, with a more stable beach profile near to Mablethorpe. If the present trend for a southwards progression of the deposition zone continues, areas of accretion would extend further towards Mablethorpe.

C3.55 In the longer term (epoch 3 and beyond), if relative sea level rise begins to outpace the foreshore deposition and dune building, or the feed of fine material is diverted into the Humber as the tidal prism increases, the natural protection offered by the dune ridges would begin to fall as the water levels rise relative to the dune crests. This would increase the threat of overtopping and breaches, especially during severe storm events.

C3.56 If increased storminess results from climatic alterations, this may facilitate a greater sediment feed from the Binks to this region, and consequently accretion rates would increase, especially in the northern area around Donna Nook.

C3.57 The area between Mablethorpe and Ingoldmells has historically shown erosion. Here the coastline consists of a combination of man-made ‘hard’ defence structures of varying type and stabilised dunes. A short distance behind the coastal defences, the majority of the terrain is at a lower level than the crest level of the coastal defences. In some areas, this low lying land extends several kilometres inland, putting large areas at risk of flooding should the coastal defences be severely overtopped or breached. The ‘hard’ defences along this frontage generally have residual lives of 11-20 years or greater than 20 years meaning that the majority of defences would be structurally stable until approximately the end of the first epoch (2025). From the NFCDD database there are a small percentage of defences along the coastline that have residual lives shorter than the first epoch. These defences have a high likelihood of failure before the end of the first epoch.

C3.58 The hard defences are fronted by veneer beaches which are susceptible to erosion. Since 1994 the veneer beaches have been maintained artificially through a sediment renourishing scheme known as Lincshore. Greatest erosion occurs during storms when the top layer of sand of the veneer beaches is washed away exposing the underlying clay tills. Once the clay tills are eroded they can never return as the material is carried offshore in suspension. The sand veneer returns during calm periods as longshore transport brings materials from further north and offshore deposits; however the volume is generally insufficient to maintain the pre-storm crest levels. These veneer beaches offer protection to the 'hard' defences and dunes at the rear of the beaches. Preserving the beach frontage helps extend the residual life of those defences at the rear by reducing the wave exposure and providing structural support to the toe of the structures. The advantage of renourishment in this location is that material is transported alongshore and passes the frontages to the south.

C3.59 The shoreline between Skegness and Ingoldmells is considered relatively stable however it has shown some erosion prior to the Lincshore scheme. Today it relies on a constant supply of material from the beaches immediately to the north. The Lincshore scheme presently re-nourishes the Mablethorpe to Skegness coastline with approximately 350,000 m^3 of material annually, the aim being to maintain both the crest level and the crest width of the beaches in front of the defences. (Environment Agency 2003). The baseline scenario for the Mablethorpe to Skegness frontage with 'No Active Intervention' considers the effect of coastal morphology assuming the Lincshore renourishment scheme is abandoned.

C3.60 Virtually all the defences along the Lincshore frontage currently offer protection to the 1 in 200 standard of protection. It should be noted that defences which are classified as offering a 1 in 200 standard of protection do allow for some overtopping during extreme events. Overtopping of a defence does not mean that the defence has failed. However, if the frequency and rate of overtopping significantly increases, then the defence becomes ineffective, although it may be structurally sound. For the purpose of developing the scenarios the standard of protection offered by the beaches and the hard defences at the rear of the beaches are considered to be independent. In reality it is the combination of these two defence elements that provides the current standard of protection and residual life of the hard defences.

C3.61 The shoreline north of Mablethorpe towards Donna Nook and South of Skegness to Gibraltar Point is considered to be accreting. The 'No Active Intervention' scenario assumes that north of Mablethorpe (the Donna Nook area) remains accretive and that no significant development occurs which may alter the current coastal processes and morphology that is observed along the coastline at present.

C3.62 Under a No Active Intervention scenario, erosion would lead to a loss of beach volumes along the shoreline. Over time this trend would continue, and an acceleration of erosion rates and shore platform lowering rates would occur as a result of relative sea level rise; this would consequently increase the potential for defence failure between Mablethorpe and Skegness. Defence failure along this frontage would lead to inundation of extensive areas of low-lying land behind the current defence line. Frequent inundation in the future would result in the land currently within the tidal floodplain being uninhabitable due to the frequency, depth and extent of flooding. Under this scenario the veneer beaches would be eroded as material is rapidly transported out of the system, and consequently, the hard defences would be subjected to direct wave attack and would degrade rapidly.

C3.63 Gibraltar Point is currently accreting (C1.221); and this trend would continue in the short to medium term due to a continued feed of sediment from offshore. In the short term this input of material will also be supplemented by sediment transported by longshore processes as the beaches to the north lose sediment due to erosion. In the longer term the beaches in this area could begin to erode unless the input of sediment transported from offshore is sufficient to offset accelerating sea level rise.

Summary by Epoch (No Active Intervention)

C3.64 The following text provides a summary of the analysis of the shoreline response under this scenario with details specific to each location and epoch contained within the Scenario Assessment Table (Table 3-7).

Epoch 0-20 Years (2025)

C3.65 During this period there would be increased pressure on the coastline, with accelerated recession of the unprotected cliffs. The more substantial defences of the Holderness coastline, such as seawalls and revetments would remain along the urban frontages, but there would be failure of groynes during this period. The long-term trend of erosion on the undefended sections between defences would continue with decreasing erosion rates towards the southern limit of the bays (cliff segments 4 and 5). Where defences remain, beaches would narrow as exposure increases due to continued transgression of the coastal system and deeper nearshore areas.

C3.66 It is assumed that the privately owned defences along the Holderness coast and around Kilnsea would have largely deteriorated and failed. At these locations, there would be an initial acceleration in retreat rates as cliff recession re-commences and "catches-up" with the adjacent coast. Frequent tidal inundation may occur in low-lying areas, such as Tunstall, Kilnsea and Hornsea.

C3.67 There would be increased input of sediment into the system. It is expected that this would mainly result in maintaining rather than building beaches. However, along the Holderness coast beach accretion would continue to occur immediately updrift of the defended frontages.

C3.68 There are two main views about the future evolution of Spurn. The first is that Spurn will migrate westwards through washover processes and roll-over and that the continued and increasing sediment feed from the erosion of the Holderness cliffs would allow any breaches to self-heal. An alternative view is that Spurn will become increasingly susceptible to breaches, which may be significant and may not be self-healing. The East Riding of Yorkshire Council anticipates Spurn may breach significantly within 5 to 10 years.

C3.69 In the outer Humber Estuary the current pattern of erosion which operates locally between Spurn and Hawkins Point, on the north bank; and more extensively between Immingham and Pyewipe, on the south bank, is predicted to continue with relative sea levels rise, despite some additional input of fine sediment into the system from the increased erosion of the Holderness cliffs.

C3.70 The earth embankment between Kilnsea and Stone Creek, and the revetment between Immingham and Pyewipe would begin to fail. The most significant erosion and defence degradation is likely to occur around Stallingborough and least deterioration is expected towards Grimsby. Failure of defences would occur through undermining as the shoreline retreats. This would cause the increased probability of breaching and coastal flooding for the low lying floodplains currently protected by the defences. Due to the relatively low residual life of some of the hard defences at Grimsby, failure is expected by the end of the epoch and flood risk to the Port of Grimsby and low-lying areas of the town would increase with No Active Intervention to maintain the defences.

C3.71 Between Cleethorpes and Saltfleet the present trend for shoreline accretion is likely to be maintained as sediment continues to move into the system across the mouth of the Humber from the erosion of the Holderness cliffs. Foreshore steepening would continue as greater deposition of sediment would occur around the high water mark compared to the low water mark. The sand dunes that currently provide protection against flooding here would remain and would still provide a natural barrier to coastal waters by the end of the epoch.

C3.72 Along the Lincolnshire coast the man-made defences and dunes are likely to be fronted by little or no beach at locations where significant historic erosion has been seen. The Lincshore Strategy Review (Environment Agency, 2003) report stated that 3% of the defences along the Lincshore frontage would fail in a 1 in 50 year storm which would lead to the inundation of 1,200 hectares of mixed use land. Mott MacDonald (2007) undertook a study to determine the areas at risk from flooding during the 1 in 200 year storm, the conclusions identified that some of the current defence crest levels are at or below the 1 in 200 year water level. Lincshore (2004) estimates the residual life for the beach frontages ranging from 4.5 to 36 years, with 16.9 years the average residual life of the beach frontage. Therefore along the area of the Lincshore scheme (Mablethorpe to Skegness) much of the beach material from renourishments would have been completely eroded by the end of the epoch, or at best, would have significantly reduced, resulting in major reductions in both beach crest height and crest width. The loss of the veneer beaches would allow rapid erosion of the underlying clays causing further drawdown of the foreshore; this would have a knock on effect in the protection offered by the current defences.

C3.73 Presently, some areas of Mablethorpe and Skegness are at risk from flooding during a 1 in 200 year event. Lincshore (2004) estimated that by 2015 the percentage of defences at risk of failure under a 'No Active Intervention' scenario would increase above 24% with the severity of the flooding increased to over 5,000 hectares. By 2025 the area at risk of flooding due to breach and overtopping would be in the region of 100 km^2, which would include extensive areas of agricultural land and some residential areas.

C3.74 The majority of defences along the Mablethorpe to Skegness frontage are estimated to have a residual life of 11-20 years in the NFCDD database and therefore with 'No Active Intervention' the man-made defences would remain but would be at the end of their effective life and the majority would be in a poor state of repair. Potential breach locations of the defences are scattered along the frontage, however due to the low-lying nature of the land behind the defences the flood extent is less sensitive to the breach location and wherever a significant breach occurs the flood extent would cover significant inland areas. Lincshore (2004) estimates that the value of assets affected if a breach were to occur by 2025 would be in the region of £1 Billion under a 'Do Nothing' scenario.

Epoch 20-50 Years (2055)

C3.75 There would be increased pressure on the coastal system due to accelerating sea level rise. During this period many of the remaining coastal defences would fail due to the combination of low beach levels, progressive platform lowering in front of the structures and increased exposure (with no maintenance, Withernsea and Hornsea groyne fields are expected to have failed by around Year 20). This would result in very rapid erosion at these locations, especially where the shoreline position has been held for over 100 years (i.e. Bridlington, Hornsea and Withernsea and Stallingborough).

C3.76 At a limited number of locations the seawall may remain. Beaches are likely reduce or disappear, which would result in deeper water and greater wave exposure at the seawalls. These conditions would not be conducive to beach retention and any sediment arriving on these frontages is likely to be rapidly transported offshore again.

C3.77 Along undefended sections, cliff recession would continue at rates significantly higher than those currently experienced, due to relative sea level rise at around 8mm/year. This would release more material into the system, which may help maintain the Spurn barrier and the beaches further south in Lincolnshire. Spurn is likely to be affected by overwashing events which could increase in frequency. One possibility is that the barrier could migrate westwards through roll-over, maintained by washover processes. Breaching events would be expected and it is a matter of conjecture as to whether or not these breaches would be able to self heal due to the continued sediment supply from the eroding clifflines. If the barrier breaches do not self-heal, they could widen and deepen, with Spurn Point effectively forming an island from the mainland.

C3.78 With the exception of areas where accretion would continue (i.e. between Grimsby and Saltfleet) a 'No Active Intervention' scenario would lead to the total failure of all current defences in the Outer Humber area through erosion and defence degradation as sea level rise accelerates. This would allow the natural processes to control shoreline behaviour and dynamics, and the shoreline would retreat at a natural rate. An extensive area of tidal floodplain would be inundated with increasing frequency.

C3.79 Due to the increased influence of coastal, rather than estuarine processes, accretion would continue between Grimsby and Donna Nook, as the fine sediment eroded from the Holderness cliffs continues to feed across the Humber mouth. The foreshore is likely to have steepened further by the end of the epoch with the rise in relative sea level. The natural dunes and embankment would still provide protection against coastal flooding between Humberston and Saltfleet, as dune building continues.

C3.80 Along the rest of the Lincolnshire coast the standard of protection offered by defences in 2055 would be virtually nil under a 'No Active Intervention' scenario. There would be no beach frontage and the underlying clays would be severely eroded from direct wave attack. The drawdown of the beaches in front of the structures would increase the probability of defence failure at the toe of the structures (Lincshore, 2004). The likelihood of a breach of the defences and thus flooding inland would be increased and the frequency of overtopping events would also increase significantly due to sea level rise. All defences along the frontage would be significantly degraded and protection along the frontage would be patchy; coastal defences would have high rates of overtopping and are likely to have been breached in many parts, due to lack of maintenance/repair. Flood events would continue to occur through established breaches and would increase in frequency and severity as sea levels rise.

C3.81 By the end of the epoch the entire Lincolnshire frontage would have no significant standard of protection. Flood waters would flow through breaches and behind coastal defences, possibly cutting off coastal communities along the current coastline.

Epoch 50-100 Years (2105)

C3.82 It should be noted that there is a significant degree of uncertainty over the timescales, magnitudes and interactions of the different processes in the longer term. This means that confidence in the predictions of coastal response in the longer term is unavoidably lower than for earlier epochs. The following summary should be regarded as a discussion of likely possibilities of coastal responses to the various processes anticipated, based on expert predictions and currently available data.

C3.83 By 2105, all the coastal defences would have failed or deteriorated by the end of this period. Cliff recession rates along the Holderness coast would continue to increase because of accelerating relative sea level rise at around 12-15mm/year. Over time, the current arrangement of defended points and undefended sections would have been removed, leaving a more connected coastline with a fully functioning sediment transport system. There would be a continuous unprotected cliffline between Flamborough and Spurn. Beaches would continue to be narrow and thin.

C3.84 Enhanced input of coarse sediment and longshore transport could help ensure the integrity of the Spurn barrier, and possibly westwards roll-over. The probability of breaching would increase due to rising sea levels and increased storminess and significant breach events are likely. Due to the increased sediment supply it is feasible that breaches on Spurn may be able to entirely self-heal. If the alternative view is taken, and self healing does not occur, a breach would continue to widen and deepen allowing significant exchange of estuarine and coastal waters. Low-lying areas would be affected by frequent tidal inundation under this case.

C3.85 The shoreline of the Outer Humber would continue to retreat except in areas still experiencing accretion (i.e. Grimsby to Saltfleet). In many areas the effective shoreline is likely to be situated considerably further inland than the current shoreline position; if not due to erosion of the material then the area would be frequently inundated the low-lying areas such that the area would be uninhabitable as sea levels would have risen by over 1m.

C3.86 Greater transport of sediment across the Humber mouth would occur as relative sea level rise would increase the erosion of material from the Holderness cliffs, especially as the frontage re-aligns under the 'No Active Intervention' scenario. Over this time period, the foreshore around Donna Nook is expected to steepen further, and by the end of the epoch, the sediment demands of the Humber Estuary would also have increased because of the rising sea levels increasing the estuarine tidal prism. Despite the increased sediment input from the eroding Holderness cliffs the larger estuarine sediment demands, coupled with the rapidly rising water levels may lead to deposition rate of sediment between Grimsby and Saltfleet beginning to get matched by the rising water levels by the end of the epoch. A similar trend is expected for the area around Gibraltar Point, where a current trend of net accretion of the foreshore and dunes may change to one of net erosion as sea level rise accelerates.

C3.87 By 2105, the existing Lincolnshire coastline is likely to have changed substantially. Sea level rise along this frontage would cause an increase in mean sea level of approximately 1.02m. Virtually all of the current beach frontage would have disappeared and the foreshore significantly drawn-down where the soft underlying clays are present. No operational defences would remain along the frontage. Overtopping and breaches of the foreshore would occur frequently through new and previously established breaches. Significantly increased sea levels would exacerbate flooding depths, flood extents, and flood frequency. A large area of the low-lying land behind the current defences would be inundated frequently and would exhibit conditions similar to an inter-tidal saltmarsh or mud flat area, this area of land would be considered uninhabitable. Flood waters would cut off many of today's coastal towns which are located on slightly raised land along the current coastline and access to these areas would be significantly impeded. Erosion of these higher land areas would also occur during the epoch.

Table 3-7 NAI Scenario Assessment Table

Location	Predicted Change for 'No Active Intervention'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Flamborough Head to Bridlington	There are no defences along this frontage	No defences	No defences
PU A **CA 1**	Cliff erosion would continue at enhanced rates to those experienced historically, with a net retreat of the cliff line of between 2 and 5m by year 2025. Small volumes of sediment supplied from cliff failures (around 1,000m3/year), probably transported to Smithic Sand or retained on in pocket beaches at South Landing and Danes Dyke.	Cliff erosion would continue at an increased rate, due to sea level rise, with a net change in cliff line position of between 5 and 25m by 2055. No significant change to the contribution to regional sediment budget.	Cliff erosion would continue at an increased rate, due to sea level rise, with a net change in cliff line position of between 10 and 72m by 2105. No significant change to the contribution to regional sediment budget.

Location	Predicted Change for 'No Active Intervention'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Bridlington (Sewerby to Wilsthorpe) **PU B** **CA 2**	The concrete and masonry seawalls would remain in place for this period (Royal Princes Parade may have failed). The groyne system would deteriorate and begin to fail.	The seawall would remain in place for most of this period, although it would deteriorate and may suffer collapses towards the end of the period. The groynes may survive through this period if beach levels remain high.	No defences
	The shoreline position would be held, although beach levels would decline and the groynes would become exposed as the shore platform continues to lower.	Defence failure would lead to a renewal of shoreline retreat. Approximately 6m of retreat could occur, depending on the timing of failure and the post failure recession scenario. Smithic Sands would continue to provide a degree of protection to the shoreline. Beach levels may decline following groyne failure. Renewed cliff recession would result in an increase to the local sediment budget, with coarse sediment transported north towards the Smithic Sands.	Continued shoreline retreat (approximately 56m by the end of the period, depending on the recession scenario). Smithic Sands would continue to provide a degree of protection to the shoreline. Low beach levels in front of the retreating cliffline. Increasing sediment yield and contribution to the local sediment budget.

Location	Predicted Change for 'No Active Intervention'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Wilsthorpe to Barmston **PU C** **CA 3**	There are no defences along most of this frontage. The private defences at Barmston drain would fail during this period.	No defences	No defences
	Accelerated cliff recession and shore platform lowering. By the end of this period the predicted cliff retreat is: 2-8m (North) and 23-33m (South). There would be rapid "catch-up" along the defended section at Barmston drain. Thin, narrow beaches fronting the cliffs. Increased sediment inputs from cliff recession and platform lowering, with transport northwards towards Bridlington and the Smithic Sands.	Accelerated cliff recession and shore platform lowering. By the end of this period the predicted cliff retreat is: 5-50m (North) and 75-120m (South). The local impact of the Barmston defences on shoreline orientation would have ceased, leading to a continuous shoreline through this unit. Thin, narrow beaches fronting the cliffs. Increased sediment inputs from cliff recession and platform lowering, with transport northwards towards Bridlington and the Smithic Sands.	Accelerated cliff recession and shore platform lowering. By the end of this period the predicted cliff retreat is: 10-150m (North) and 150-310m (South). Thin, narrow beaches fronting the cliffs. Increased sediment inputs from cliff recession and platform lowering, with transport southwards and a minor component northwards towards Bridlington and the Smithic Sands.

Location	Predicted Change for 'No Active Intervention'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Barmston to Atwick **PU C** **CA 3**	There are no defences along most of this frontage. The defences at Barmston Drain are likely to fail within this epoch. The private defences at Ulrome would fail during this period.	No defences	No defences
	Accelerated cliff recession and shore platform lowering. By the end of this period the predicted cliff retreat is: 24-33m (North) and 6-12m (South). There would be rapid "catch-up" along the defended section at Ulrome. Thin, narrow beaches fronting the cliffs. Beach accretion would occur immediately north of the Hornsea defences. Increased sediment inputs from cliff recession and platform lowering, with transport southwards towards Hornsea.	Accelerated cliff recession and shore platform lowering. By the end of this period the predicted cliff retreat is: 75-120m (North) and 20-50m (South). The local impact of the Ulrome defences on shoreline orientation would have ceased, leading to a continuous shoreline through this unit. Thin, narrow beaches fronting the cliffs. Increased sediment inputs from cliff recession and platform lowering, with transport southwards towards Hornsea.	Accelerated cliff recession and shore platform lowering. By the end of this period the predicted cliff retreat is: 150-300m (North) and 40-140m (South). Thin, narrow beaches fronting the cliffs. Increased sediment inputs from cliff recession and platform lowering, with transport southwards towards Hornsea.

Location	Predicted Change for 'No Active Intervention'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Hornsea **PU D** **CA 4**	The concrete seawalls and rock armouring would remain in place for this period (North Marine promenade may have failed by the end of this period). The groyne system would deteriorate and begin to fail.	The seawall and rock armour would remain in place for most of this period, although they would deteriorate and may suffer collapses towards the end of the period.	No defences
	The shoreline position would be held, although beach levels would decline as the groyne system deteriorates and the shore platform continues to lower.	Defence failure would lead to a renewal of shoreline retreat. Approximately 15m of retreat could occur, depending on the timing of failure and the post failure recession scenario. Beach levels would decline following groyne failure. Renewed cliff recession would result in an increase to the local sediment budget, with coarse sediment transported southwards.	Continued shoreline retreat (approximately 105m by the end of the period, depending on the recession scenario). Low beach levels in front of the retreating cliffline. Increasing sediment yield and contribution to the local sediment budget.

Location	Predicted Change for 'No Active Intervention'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Hornsea to Mappleton **PU E** **CA 5**	There are no defences along this frontage.	No defences	No defences
	Accelerated cliff recession and shore platform lowering. By the end of this period the predicted cliff retreat is: 42-48m. Thin, narrow beaches fronting the cliffs. Beach accretion would occur immediately north of the Mappleton defences. Increased sediment inputs from cliff recession and platform lowering, with transport southwards towards Mappleton and Withernsea.	Accelerated cliff recession and shore platform lowering. By the end of this period the predicted cliff retreat is: 135-155m. Thin, narrow beaches fronting the cliffs. Increased sediment inputs from cliff recession and platform lowering, with transport southwards towards Mappleton and Withernsea.	Accelerated cliff recession and shore platform lowering. By the end of this period the predicted cliff retreat is: 270-360m. Thin, narrow beaches fronting the cliffs. Increased sediment inputs from cliff recession and platform lowering, with transport southwards towards Mappleton and Withernsea.

Location	Predicted Change for 'No Active Intervention'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Mappleton **PU E** **CA 5**	The rock revetment and groynes would remain in place for this period.	The rock revetment and groynes would remain in place for most of this period, although they would deteriorate and may suffer collapses towards the end of the period.	No defences
	The shoreline position would be held, although beach levels would decline as the shore platform continues to lower.	Defence failure would lead to a renewal of shoreline retreat. Approximately 21m of retreat could occur, depending on the timing of failure and the post failure recession scenario. Beach levels would decline following groyne failure. Renewed cliff recession would result in an increase to the local sediment budget, with coarse sediment transported southwards.	Continued shoreline retreat (approximately 138m by the end of the period, depending on the recession scenario). Low beach levels in front of the retreating cliffline. Increasing sediment yield and contribution to the local sediment budget.

Location	Predicted Change for 'No Active Intervention'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Mappleton to Withernsea **PU E** **CA 5**	There are no defences along most of this frontage. The private coastal protection structures at Tunstall would fail during this period.	No defences	No defences
	Accelerated cliff recession and shore platform lowering. By the end of this period the predicted cliff retreat is: 31-37m (North), 19-26m (South). There would be rapid "catch-up" along the defended section at Tunstall. Erosion would also result in flooding around Tunstall. Thin, narrow beaches fronting the cliffs. Beach accretion would occur immediately north of the Withernsea defences. Increased sediment inputs from cliff recession and platform lowering, with transport southwards towards Withernsea.	Accelerated cliff recession and shore platform lowering. By the end of this period the predicted cliff retreat is: 100-125m (North), 60-95m (South). The local impact of the Tunstall defences on shoreline orientation would have ceased, leading to a continuous shoreline through this unit. Inundation at Tunstall would increase as sea levels rise. Thin, narrow beaches fronting the cliffs. Increased sediment inputs from cliff recession and platform lowering, with transport southwards towards Withernsea.	Accelerated cliff recession and shore platform lowering. By the end of this period the predicted cliff retreat is: 200-300m (North), 120-240m (South). Thin, narrow beaches fronting the cliffs. Increased sediment inputs from cliff recession and platform lowering, with transport southwards towards Withernsea.

Location	Predicted Change for 'No Active Intervention'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Withernsea **PU F** **CA 6**	The concrete seawalls and rock armouring would remain in place for this period (Seathorne promenade may have failed by the end of this period). The groyne system would deteriorate and begin to fail.	The seawall and rock armour would remain in place for most of this period, although they would deteriorate and may suffer collapses towards the end of the period.	No defences
	The shoreline position would be held, although beach levels would decline as the groyne system deteriorates and the shore platform continues to lower.	Defence failure would lead to a renewal of shoreline retreat. Approximately 19m of retreat could occur, depending on the timing of failure and the post failure recession scenario. Beach levels would decline following groyne failure. Renewed cliff recession would result in an increase to the local sediment budget, with coarse sediment transported southwards.	Continued shoreline retreat (approximately 129m by the end of the period, depending on the recession scenario). Low beach levels in front of the retreating cliffline. Increasing sediment yield and contribution to the local sediment budget.

Location	Predicted Change for 'No Active Intervention'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Withernsea to Easington **PU G** **CA 7**	There are no defences along this frontage.	No defences	No defences
	Accelerated cliff recession and shore platform lowering. By the end of this period the predicted cliff retreat is: 34-42m (North), 26-34m (South). Thin, narrow beaches fronting the cliffs. Beach accretion would occur immediately north of the Easington defences. Increased sediment inputs from cliff recession and platform lowering, with transport southwards towards Easington and Spurn.	Accelerated cliff recession and shore platform lowering. By the end of this period the predicted cliff retreat is: 105-140m (North), 85-120m (South). Thin, narrow beaches fronting the cliffs. Increased sediment inputs from cliff recession and platform lowering, with transport southwards towards Easington and Spurn.	Accelerated cliff recession and shore platform lowering. By the end of this period the predicted cliff retreat is: 210-330m (North), 160-280 (South). Thin, narrow beaches fronting the cliffs. Increased sediment inputs from cliff recession and platform lowering, with transport southwards towards Easington and Spurn.

Location	Predicted Change for 'No Active Intervention'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Easington Gas Terminals **PU H** **CA 8**	The rock revetment would remain in place for this period.	The rock armour would remain in place for most of this period, although it would deteriorate and may suffer collapses towards the end of the period.	No defences
	The shoreline position would be held, although beach levels would decline as the shore platform continues to lower.	Defence failure would lead to a renewal of shoreline retreat. Approximately 18m of retreat could occur, depending on the timing of failure and the post failure recession scenario. Renewed cliff recession would result in an increase to the local sediment budget, with coarse sediment transported southwards.	Continued shoreline retreat (approximately 123m by the end of the period, depending on the recession scenario). Low beach levels in front of the retreating cliffline. Increasing sediment yield and contribution to the local sediment budget.

Location	Predicted Change for 'No Active Intervention'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Easington to Kilnsea **PU I** **CA 9**	There are no shoreline defences along this frontage. The New Bank, a clay embankment to the rear of the Lagoons SSSI is expected to have failed.	No defences	No defences
	Current average erosion rate of 2.8m/yr (Black and Veatch, 2005a) continues or accelerates over the period destabilising and undermining New Bank earth embankment, especially in areas where defences are in close proximity to the present shoreline. Accelerated cliff recession and shore platform lowering. By the end of this period the predicted cliff retreat is: 24-28m. Flooding of agricultural land and residential properties. Thin, narrow beaches fronting the cliffs. Increased sediment inputs from cliff recession and platform lowering, with transport southwards towards Spurn.	Accelerated cliff recession and shore platform lowering. By the end of this period the predicted cliff retreat is: 60-98m. Flooding of agricultural land and residential properties. Thin, narrow beaches fronting the cliffs. Increased sediment inputs from cliff recession and platform lowering, with transport southwards towards Spurn.	Accelerated cliff recession and shore platform lowering. By the end of this period the predicted cliff retreat is: 120-240m. Flooding of agricultural land and residential properties. Thin, narrow beaches fronting the cliffs. Increased sediment inputs from cliff recession and platform lowering, with transport southwards towards Spurn.

Location	Predicted Change for 'No Active Intervention'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Spurn **PU J** **CA 10**	The existing concrete seawalls, timber groynes and rock armouring are largely derelict and would have failed during this period.	No defences	No defences
	Accelerated shoreface erosion and barrier retreat. Increased potential for breaches, especially around the neck. One possibility is that breaches may not self-heal and the breach may become wider and deeper. Alternative theory that sediment inputs from the Holderness cliff erosion would help self healing and the barrier would undergo westwards migration through rollover. There is the potential for 6-30m retreat by the end of this period. Cell also at risk of flooding from adjacent cells.	Shoreface erosion. Increased potential for breaches, especially around the neck. One possibility is that breaches may not self-heal and the breach may become wider and deeper and permit exchange of estuarine and coastal waters. Alternative theory that sediment inputs from the Holderness cliff erosion would help self healing and the barrier may undergo westwards migration through rollover. There is the potential for 15-100m retreat by the end of this period. Cell also at risk of flooding from adjacent cells.	Shoreface erosion. Increased potential for breaches, especially around the neck. One possibility is that breaches may not self-heal and the breach may become wider and deeper and permit significant exchange of estuarine and coastal waters. Alternative theory that sediment inputs from the Holderness cliff erosion would help self healing and the barrier may undergo westwards migration through rollover. There is the potential for 30-250m retreat by the end of this period). Cell also at risk of flooding from adjacent cells.

Location	Predicted Change for 'No Active Intervention'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Kilnsea to Hawkins Point **PU K** **CA 11**	Frontage remains defended by earth embankments and natural higher ground although failure and local collapses forming low points develop. Also ad-hoc informal defences in the form of rubble/rock banks remain although degrade over the period.	Total deterioration and loss of embankments and defences by the end of the period.	No defences present.
	Increased breaching and overtopping risk as relative sea levels rise, especially south of East Bank Farm, Welwick bank and Humber Lane pumping station where low spots are present. By 2025, the protection standard would be much less than 1 in 1 year and their protection effects would be very low. Impact of severe storm events becomes more significant. Cell also at risk of flooding from adjacent cells.	Regular extensive flooding of the low-lying floodplain. Total loss of embankment due to erosion and collapse. Frontage would be undergoing natural coastal morphological changes. Erosion of the shoreline would occur as relative sea level rise accelerates. Cell also at risk of flooding from adjacent cells. Failure of the defences and shoreline retreat could have a major impact on the estuarine sediment demand.	Frequent extensive flooding of low lying land behind the current defence line the due to a relative sea level rise of 1.02m This would lead to the loss property and farmsteads within the tidal floodplain. Cell also at risk of flooding from adjacent cells. Shoreline erosion would continue. Failure of the defences and shoreline retreat could have a major impact on the estuarine sediment demand

Location	Predicted Change for 'No Active Intervention'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Hawkins Point to Stone Creek **PU L** **CA 11**	Frontage remains defended by earth embankments although and local failure and collapses forming low points develop due to erosion.	Total deterioration and loss of embankments and defences by the end of the period.	No defences present.
	Some degradation and toe destabilisation of defences where they are in close proximity to the present shoreline. Increased breaching and overtopping risk as relative sea levels rise. Impacts of severe storm events become more significant. Cell also at risk of flooding from adjacent cells.	Total loss of embankment due to increased wave attack and natural degradation. Frequent extensive flooding of the low-lying floodplain. Cell also at risk of flooding from adjacent cells. Frontage would be undergoing natural coastal morphological changes. Regression of the shoreline would occur as relative sea level rise accelerates. Failure of the defences and shoreline retreat could have a major impact on the estuarine sediment demand.	Frequent flooding of the tidal floodplain due to a relative sea level rise of 1.02m This would lead to the loss of all property and farmsteads within the floodplain. Cell also at risk of flooding from adjacent cells. Shoreline erosion would continue.

Location	Predicted Change for 'No Active Intervention'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
East Immingham to Grimsby Docks **PU M** **CA 12**	Earth embankment, revetment and reinforced concrete wave wall would deteriorate and begin to fail through toe erosion, undermining and collapse.	Current sea defences failed. No protection.	No defences
	Increased risk of overtopping and breaches. The foreshore would continue to erode and lower. Greatest erosion and retreat would occur around Stallingborough and defences failure highly likely to occur here first. Local erosion rates of up to 1-2m / ten years (Black and Veatch, 2005b) predicted here, with general shoreline retreat of up to 2m expected quite widely from Pyewipe to Immingham. Stable or slight accretion predicted on foreshore near Grimsby Docks due to sheltering effects of the shoreline discontinuity. Westward movement of sediment alongshore would continue. Cell also at risk of flooding from adjacent cells.	Rapid retreat of shoreline and increasingly frequent inundation of the tidal floodplain. Cell also at risk of flooding from adjacent cells. Significant erosion predicted in the central and western areas of the unit. This would accelerate with sea level rise. More stable foreshore towards the eastern end of the frontage. Land behind current defence line would become subject to direct wave attack as defences no longer present.	Frequent extensive flooding of the low lying land behind the current defence line causing significant loss of property and assets. Shoreline would have retreated appreciably landwards of its current position especially in the western and central sections of the unit. Draw down of material would occur as erosion continues to accelerate with sea level rise. More stable foreshore present towards Grimsby. Cell also at risk of flooding from adjacent cells.

Location	Predicted Change for 'No Active Intervention'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Grimsby Docks to East Cleethorpes **PU M** **CA 13a**	Variety of hard defences along frontage including Seawalls, Revetments, Quay walls, Dock gates, locks, and gabion baskets would begin to fail or would have failed completely. Also groyne fields present at Cleethorpes would deteriorate significantly.	Total deterioration and failure of all defences so that no there is no protection against overtopping and flooding by the end of the epoch.	No defences.
	Defences would still offer some form of protection against overtopping and flooding, however breach points in the defences would develop widely, especially where current defences are in poor condition. Defences that are likely to fail first include the recurved wall around North Beck outfall and the concrete sea wall north of Cleethorpes. Low points are also identified as the Dock Gates and the dock quay wall south east of Grimsby. Cell also at risk of flooding from adjacent cells.	Frequent and extensive flooding of the dock areas as well as residential Grimsby and Cleethorpes. Abandonment of homes highly likely as regularity of flooding would render low lying property inhabitable. The current influence of the port and dock developments in enhancing flood protection standard to residential areas behind them would reduce as their current capacity to store flood water would have diminished due to relative sea level rise. Impacts of severe storm events increasingly far-reaching. Cell also at risk of flooding from adjacent cells.	Extensive, frequent flooding of the tidal floodplain causing significant loss of property and assets. Most of Grimsby and Cleethorpes tidally inundated on a frequent basis due to a relative sea level rise of approximately 1m by the end of the cepoch, coupled with a lack of effective defences. Cell also at risk of flooding from adjacent cells.

Location	Predicted Change for 'No Active Intervention'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
East Cleethorpes to Donna Nook **PU M/N** **CA 13b/14**	Naturally defended by sand dunes, saltmarshes which would continue to accrete and advance their seaward extent. Groyne fields at Humberston Fitties would deteriorate, although foreshore accretion would slow this process.	Natural protection against flooding remains from sand dunes and saltmarshes. Saltmarshes likely to continue accreting, and would continue to expand, although the rate may slow as relative sea level rise increase.	Natural protection against flooding of saltmarsh and dunes maintained by sediment from increasing erosion of the Holderness cliffs. Accretion may slow despite increasing sediment inputs as rate of sea level rise accelerates and, the Humber tidal prism and sediment demand increases.
	Dunes and Saltmarshes continue to accrete and undergo progradation. This would enhance the natural defence line against overtopping and breaching. The foreshore accretion would also help limit the effects of wave attack on deteriorating the groyne fields and their presence would further stabilise the beach. The current trend of inter tidal steepening is predicted to continue. Groyne fields likely to become buried by 2025.	Despite continued accretion, as relative sea level rise accelerates, the rate of dune building and saltmarsh growth is likely to slow. A potential increased sediment feed from material transported from the Holderness coastline across the Humber may reduce the effects of rising water levels outpacing accretion. Natural protection of the floodplain would be maintained, although as increased storminess through climate change occurs, and accretion rate possibly slows, the risk of breaching increases and the impacts of storm events may become more significant. Cell also at risk of flooding from adjacent cells.	Accretion likely to continue along the frontage, however, due to rapid acceleration of relative sea level rise over this period, the pace at which the dunes and the saltmarshes undergo building would slow. Steepening of the foreshore and some deterioration of the seaward saltmarsh edge would occur. Cell at risk of flooding from adjacent cells.

Location	Predicted Change for 'No Active Intervention'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Donna Nook to Saltfleet **PU N** **CA 14**	Defended by an earth floodbank which would remain in position for the period. Continued accretion of the sand dunes which also form the natural defence line against flooding.	Natural protection against flooding remains from sand dunes as they continue to accrete. Reduction in effect of floodbank by 2055 due to natural degradation and collapse.	Natural protection where sand dunes present. No man-made defences remain.
	Dunes and continue to accrete. Foreshore steepening would continue as greater deposition of sediment is likely to occur around the high water mark relative to the low water mark. This would enhance the natural defence line against overtopping and breaching. The foreshore accretion would also help limit the effects of wave attack on deteriorating the earth embankment.	Deterioration of the earth embankment which could lead to breaching and flooding in areas where this is the primary form of flood defence. Despite continued accretion, as relative sea level rise accelerates, the rate of dune building and saltmarsh growth is likely to slow. A potential increased sediment feed from material transported from the Holderness coastline across the Humber may reduce the effects of rising water levels outpacing accretion. Foreshore steepening would continue as greater deposition of sediment is likely to occur around the high water mark relative to the low water mark. Natural protection of the floodplain would be maintained, although as increased storminess through climate change occurs, and accretion rate possibly slows, the risk of breaching increases and the impacts of storm events may become more significant. Cell also at risk of flooding from adjacent cells.	Accretion likely to continue along the frontage, however, due to rapid acceleration of relative sea level rise over this period, and the potential reduction in sediment fed to the area, the pace at which the dunes and the saltmarshes undergo building would slow. Steepening of the foreshore and some deterioration of the seaward saltmarsh edge would occur. The probability of dune breaching, especially during storm events would increase and if damage occurs, low points would remain and may allow more regular breaching and consequently flooding of the floodplain behind. Cell also at risk of flooding from adjacent cells.

Location	Predicted Change for 'No Active Intervention'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Saltfleet to Mablethorpe **PU N** **CA 15**	Sand dunes form the natural defence line against flooding.	Natural protection against flooding remains from sand dunes.	Natural flood protection from sand dunes especially towards Saltfleet, however natural reduction in protection standard offered nearer Mablethorpe.
	Continued accretion of sand dunes as sediment feed from material eroded along Holderness frontage maintained. Progradation of the shoreline. Greatest accretion occurs towards Saltfleet, least near Mablethorpe where beach is effectively stable.	Accretion of sand dunes highly dependent on sediment feed from material eroded along Holderness frontage. Predicted that erosion of Holderness cliffs would increase with relative sea level rise so further dune building anticipated. However as relative sea level rise accelerates, progradation of the shoreline may slow. Greatest accretion occurs towards Saltfleet, least near Mablethorpe where beach is effectively stable or may even start eroding unless sediment supplied to system increases sufficiently to cause depositional front to move south. Natural protection standard likely to be similar or slightly in excess of today, however the probability of overtopping or breaching from severe events increases due to climate change. Cell also at risk of flooding from adjacent cells.	Sand dunes continue to provide natural protection against flooding, especially towards Saltfleet. Sea level rise accelerates to 15.8mm / year and is likely to begin to match or outpace accretion of foreshore, unless the sediment supplied to the system across the Humber mouth increases substantially. This may lead to decline in the rate of accretion and dune building causing the protection standard offered by the dunes to reduce, especially towards Mablethorpe where a less accretive, more stable beach theme is present today. Erosion and draw down of dune material is predicted in the south of this section and the probability of breaching and overtopping would increase, especially as an increased frequency of severe events is predicted due to climate change. Cell also at risk of flooding from adjacent cells.

Location	Predicted Change for 'No Active Intervention'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Mablethorpe **PU O** **CA 16**	Naturally vegetated / stabilised dunes and Concrete stepped apron with splash wall fronted by veneer beaches. Defence structures would remain in place for this period but would deteriorate in standard of protection and structural stability.	Defences behind veneer beaches would become increasingly unstable as structure toes are exposed with loss of beaches. Standard of protection would be significantly reduced due to sea level rise. Dunes would be eroded and drawn down as direct wave exposure increases. Total failure of defences would occur within the epoch.	No defences.
	Veneer beaches fronting defences would erode away within approximately ten years. Exposed clay tills underlying beach veneer would quickly erode. Defences would become subject to direct wave attack and the standard of protection would fall in the absence of beaches infront of the hard defences. This would lead to more frequent flooding.	Veneer beaches fronting defences would have completely disappeared and underlying clay tills would be significantly eroded. Probability of defence breach and frequency of overtopping would increase significantly with time. Defences would breach, and would not be repaired. Once a breach occurs the flood cell would be inundated frequently. Cell also at risk of flooding from adjacent cells.	A significant area of low-lying land behind the current foreshore line would be frequently inundated and there would be significant loss of property and assets. Significant foreshore retreat would have occurred during this epoch. Cell also at risk of flooding from adjacent cells.

Location	Predicted Change for 'No Active Intervention'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Sandilands to Anderby Creek **PU O** **CA 17**	Two level concrete apron with recurve wall, to the south a Seabee revetment topped with wave wall with dunes behind. Both sets of defences would remain during this period but would deteriorate in standard of protection and structural stability.	Defences behind veneer beaches would become increasingly unstable as structure toes are exposed with loss of beaches. Standard of protection would be significantly reduced due to sea level rise. Dunes would be eroded and drawn down as direct wave exposure increases. Total failure of defences would occur within the epoch.	No defences.
	Veneer beaches fronting defences would erode away within approximately ten years. Exposed clay tills underlying beach veneer would quickly erode. Defences would become subject to direct wave attack and the standard of protection would fall in the absence of beaches infront of the hard defences. This would lead to more frequent flooding.	Veneer beaches fronting defences would have completely disappeared and underlying clay tills would be significantly eroded. Probability of defences breaching and frequency of overtopping would increase significantly over the epoch. When defences breach, they would not be repaired. Once a breach occurs the flood cell would be frequently inundated. Cell also at risk of flooding from adjacent cells.	A significant area of low-lying land behind the current defence line would be frequently inundated and there would be significant loss of property and assets. Cell also at risk of flooding from adjacent cells. Significant foreshore retreat would have occurred during this epoch;

Location	Predicted Change for 'No Active Intervention'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Anderby Creek **PU O** **CA 17**	Vegetated sand dunes would remain for the majority of this epoch, but would become increasingly susceptible to erosion as the veneer beaches in front the dunes erode.	With the veneer beaches eroded, the dunes would become increasingly exposed to wave action. Erosion of the face of the dunes would cause them to reduce in width and drawdown the crest. Total failure of defences would occur within the epoch.	No defences.
	Veneer beaches fronting defences would erode away within approximately ten years. Exposed clay tills underlying beach veneer would quickly erode. Defences would become subject to direct wave attack and the standard of protection would fall in the absence of beaches infront of the hard defences. This would lead to more frequent flooding.	Veneer beaches fronting defences would have completely disappeared and underlying clay tills would be significantly eroded. Probability of dunes and defences breaching and frequency of overtopping would increase significantly over the epoch. When defences breach, they would not be repaired. Once a breach occurs the flood cell would be inundated frequently. Cell also at risk of flooding from adjacent cells.	A significant area of low–lying land behind the current defence line would be frequently inundated and there would be loss of property and assets. Cell also at risk of flooding from adjacent cells. Significant foreshore retreat would have occurred during this epoch;

Location	Predicted Change for 'No Active Intervention'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Anderby Creek to Chapel St Leonards **PU O** **CA 17**	Timber groynes support the beach frontage backed by dunes. The groynes would deteriorate with time and would be at the end of their operational life towards the end of the epoch. Vegetated Dunes stabilised with grouted stone revetment to front face would remain during this period. Approximately 200m behind the dunes an earth embankment provides additional flood protection limiting the extent of overtopping water during storms.	The timber groynes would have deteriorated significantly and offer little or no support to beach material. The toe of the stone revetment structures stabilising the dune front would become susceptible to undermining and would fail during the epoch due to increased wave exposure, elevated sea levels, and structural degradation. The vegetated dunes would become increasingly exposed to wave action and would erode as a result of frequent wave exposure and elevated sea levels.	No defences.
	The timber groynes on the beach would deteriorate resulting in the reduction of veneer beach level although due to the presence of the groynes this would occur over a longer period than areas north and south where groynes do not exist. Defences would become subject to direct wave attack and the standard of protection would fall in the absence of beaches infront of the hard defences. This would lead to more frequent flooding.	Beaches would reduce in level as groynes deteriorate and fail. Once exposed the clay tills underlying the beach veneer would erode quickly. Overtopping and the likelihood of a breach would increase with time; initially during less severe storm events flooding should be limited to the area directly behind the dunes due to the presence of an earth embankment 200m behind the dunes. Towards the end of the epoch little protection would be offered by the dunes or the flood embankment. Defence breaches would not be repaired. Cell also at risk of flooding from adjacent cells.	A significant area of low-lying land behind the current defence line would be frequently inundated and there would be loss of property and assets on the current 1 in 200 year floodplain. Cell also at risk of flooding from adjacent cells. Significant foreshore retreat would have occurred during this epoch.

Location	Predicted Change for 'No Active Intervention'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Chapel St Leonards **PU O** **CA 18a**	At Chapel Point a stepped concrete apron topped with wave return wall provides protection. At this point the beach fronting the defence is very narrow and the rock armour at the toe of the defence is exposed. During this epoch the defence would remain but would deteriorate in standard of protection and structural integrity. At Chapel St Leonard a concrete tunnel outfall exists through the dune, this has been extended due to sand blockage associated with the renourishment scheme. South of Chapel St Leonard promenade exists between the beach and the dunes behind.	With the beach frontage eroded defences would be exposed and structural elements would deteriorate leading to failure of the defences within the epoch. Failure of the promenade to the south would lead to rapid erosion of the dunes behind from direct wave exposure during storms. Locally the concrete outfall structure at Chapel St Leonard's would offer some stability to the dunes but erosion of the dunes either side of the outfall would occur, flood waters would flank the structure.	No defences.

Location	Predicted Change for 'No Active Intervention'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Chapel St Leonards **PU O** **CA 18a**	Veneer beaches fronting defences would erode away within approximately ten years, exposing the clay tills underlying beach veneer these would quickly erode. Defences would become subject to direct wave attack and the standard of protection would fall in the absence of beaches infront of the hard defences. This would lead to more frequent flooding.	Veneer beaches along the frontage would have completely disappeared and underlying clay tills would be significantly eroded. The dunes behind the promenade to the south would become exposed to wave action and would rapidly erode. Due to rising sea levels defences would breach, and would not be repaired. Once a breach occurs the flood cell would be inundated frequently. Frequent overtopping and breaches of existing defences and dunes would occur over the epoch. Cell also at risk of flooding from adjacent cells.	A significant area of low-lying land behind the current defence line would be frequently inundated and there would be significant loss of property and assets. The relatively higher land at Chapel St Leonards would be less susceptible to flooding than much of the surrounding area but would be cut off during large flood events as the low lying land behind is inundated. Cell also at risk of flooding from adjacent cells. Significant foreshore retreat would have occurred during this epoch.

Location	Predicted Change for 'No Active Intervention'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Chapel St Leonards to Ingoldmells **PU O** **CA 18a**	The defences along this section consist of a raised promenade with combination of smooth concrete sloped revetment or stepped concrete apron down to beach. Behind the promenade the land level is significantly lower than the defence structure. The toe of defences is likely to become increasingly exposed during the epoch but the defences would remain during this period, with reduced standard of protection.	Erosion of the beach would lead to further exposure of the toe of the structure and sea level rise would cause increased overtopping. Defence failure would occur within the epoch.	No defences
	The shoreline position would be held, although beach levels would decline through erosion. During storms the clay tills would become exposed and be subject to erosion. Defences would become subject to direct wave attack and the standard of protection would fall in the absence of beaches infront of the hard defences. This would lead to more frequent flooding.	Veneer beaches fronting defences would have completely disappeared and underlying clay tills would be significantly eroded. Due to rising sea levels defences would breach, and would not be repaired. Once a breach occurs the flood cell would be inundated frequently. Frequent overtopping and breaches of existing defences and dunes would occur over the epoch. Cell also at risk of flooding from adjacent cells.	A significant area of low-lying land behind the current defence line would be frequently inundated and there would be a significant loss of property and assets. Cell also at risk of flooding from adjacent cells. Significant foreshore retreat would have occurred during this epoch;

Location	Predicted Change for 'No Active Intervention'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Ingoldmells to Skegness **PU O** **CA 18b**	This unit consists of a number of types of defence structures mainly Seabee revetments or stepped concrete aprons. Behind the concrete revetments in the majority of the length there is a promenade with or without further wave walls. Between Ingoldmells and Skegness some of the shoreline is backed by dunes, in particular at the golf course which is fronted by rock revetment not concrete defences. Some groynes exist along the beach frontage of this unit; however the majority of the groynes are already in a poor state of repair and would offer little support to the beach during the epoch. South of Skegness the Lagoon Walk development is a concrete promenade protected by rock armour; it heads seaward and then turns south parallel to the shoreline. Behind this is an area of dunes which provides the defence to the land behind. The defences along this unit would remain in this epoch but would deteriorate in structural stability, condition, and standard of protection.	Erosion of the beach would lead to exposure of the toe of the defence structure. Defence failure would occur within the epoch.	No defences

Location	Predicted Change for 'No Active Intervention'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Ingoldmells to Skegness **PU P** **CA 18b**	The shoreline position would be held, although beach levels would decline, exposing the underlying clay tills. Dunes would remain stable due to defences and stabilisation but would begin to become increasingly exposed as defences deteriorate. Defences would become subject to direct wave attack and the standard of protection would fall in the absence of beaches infront of the hard defences. This would lead to more frequent flooding.	Veneer beaches fronting defences would have completely disappeared and underlying clay tills would be significantly eroded. Due to rising sea levels defences would breach, and would not be repaired. Once a breach occurs the flood cell would be inundated frequently. Frequent overtopping and breaches of existing defences and dunes would occur over the epoch. Cell also at risk of flooding from adjacent cells.	A significant area of low-lying land behind the current foreshore line would be frequently inundated and there would be significant loss of property and assets. Cell also at risk of flooding from adjacent cells. Significant foreshore retreat would have occurred during this epoch;

Location	Predicted Change for 'No Active Intervention'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
South of Skegness **PU 16** **CA 19**	Vegetated sand dunes would remain for this epoch.	With the veneer beaches eroded, the dunes would become increasingly exposed to wave action. Erosion of the face of the dunes would cause them to reduce in width and drawdown the crest. Total failure of hard defences would occur within the epoch.	Dunes degraded. No hard defences present.
	The area south of Skegness consists of a wide swath of vegetated dunes and wetlands, as sea levels increase these areas would become increasingly overtopped/inundated during storms. Breaching of these areas is unlikely to occur during this epoch. The beach material transport from along the Lincolnshire coast to the north would pass this area and some accretion may occur causing a widening of the foreshore, making the area less susceptible to breaching. Cell also at risk of flooding from adjacent cells.	The dune ridge would remain but accretion may slow as sea level rise accelerates. Longshore sediment transport to this area would reduce without continued renourishments. Rising sea levels would increase the risk of overtopping along this frontage and may cause erosion, destabilisation and drawdown of the dune ridge. Cell also at risk of flooding from adjacent cells.	Overtopping of the degrading dunes and breaching in the absence of hard defences would increase. This would lead to increased inundation of the low-lying land behind the dunes. This would put property and assets on the floodplain at risk of damage and loss. Cell also at risk of flooding from adjacent cells.

Location	Predicted Change for 'No Active Intervention'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Gibraltar Point **PU 16** **CA 19**	Grassed earth embankment fronted by dunes provides protection from flood waters towards the south of Gibraltar Point. Along the tidal stretch of the River Steeping flood banks and flood walls provide protection from erosion and tidal flooding, although the standard of protection would fall significantly due to no maintenance and rising sea levels.	Continued accretion and wide foreshore would prevent direct wave action on the earth embankment on the seaward coast. However the embankment around river Steeping would deteriorate and fail and increasingly frequent flooding would occur behind the embankment.	Continued accretion and wide foreshore would prevent direct wave action on the earth embankment on the seaward coast. However the embankment around river Steeping would deteriorate and fail and increasingly frequent flooding would occur behind the embankment.
	Large swath of dunes and wetland/salt marsh are fronted by beaches along the east and intertidal mud flats to the south. The River Steeping cuts a path through the intertidal mud flats to the south and discharges into the Wash. Inundation of this area would occur with increasing frequency as sea levels rise and earth embankments deteriorate. Accretion of the beach and inter-tidal area would continue to occur as sediments wash down from the Lincolnshire coast. Cell also at risk of flooding from adjacent cells.	The flood banks and walls would deteriorate and fail around the river Steeping leading to widespread and significant frequent flooding. The dunes and foreshore on the coast would continue, fed by sediments transported from offshore and erosion of updrfit frontages. However, areas behind the dunes would be flooded via the River Steeping. Cell also at risk of flooding from adjacent cells.	The river Steeping would regularly inundate the low-lying areas with the absence of any defences and rapidly rising sea levels, leading to widespread and significant frequent flooding. The dunes and foreshore on the coast would continue to be present, fed by sediments transported from offshore and erosion of updrfit frontages however areas behind the dunes would be flooded via the River Steeping. Cell also at risk of flooding from adjacent cells.

C4 Baseline Case – With Present Management

Introduction

C4.1 This section outlines the predicted shoreline response associated with the 'With Present Management' scenario. This scenario is used to illustrate the evolution of the shoreline and the effects on the SMP area if current management practices continue to be applied over the next 100 years.

C4.2 Due to the variation in current practices and management approaches operating along the SMP frontage, the 'With Present Management' scenario produces different actions for different stretches of the coastline. The assumed situation for different areas of the coast for the 'With Present Management' scenario is summarised below. It should be noted that this scenario is for comparative purposes only and is not a proposed policy.

Flamborough Head to Kilnsea Coast

- Currently undefended coastline would be allowed to erode naturally without any intervention.
- Where defences exist, the standard of protection would be maintained or improved for epochs 1, 2 and 3. This would take into account sea level rise and defences would be raised accordingly.
- Where short lengths and minor defences are present, a review will be undertaken to assess the epoch in which they are deemed to be ineffective due to outflanking.
- No new defences would be constructed (e.g. to prevent outflanking of current defences).

Spurn

- Currently defences are largely derelict as they have not been maintained since the 1960's. These would continue to be allowed to deteriorate and would not be maintained or repaired. However, breaches of the Spurn access road would be repaired because of access requirements for the Humber Pilots, RNLI etc.

Outer Humber Estuary

- For the purposes of this theoretical baseline, it is assumed that current management practices would continue and the flood defences and standard of protection will be maintained for all epochs. This would involve repairing, maintaining and raising the defences to take account of sea level rise.

  Given the uncertainties in future funding for defences, the effect of sea level rise on existing defences, and the requirements of current environmental legislation, it is recognised that continuing the current management practices in all areas may not be sustainable in reality. Consequently, the Humber Flood Risk Management Strategy has identified areas in the Outer Humber where defence realignments may be considered to increase sustainability and provide habitat creation. These potential defence realignments will be considered in SMP policy option assessments during policy development, rather than including them in this baseline scenario which is intended to provide a basis for comparison.

Lincolnshire Coast

- The current Lincshore strategy between Donna Nook and Gibraltar Point provides a 1 in 200 standard of protection. To continue with the current standards of protection for Lincolnshire, sea defences would need to be maintained and improved to keep pace with sea level rise over the plan period.

C4.3 The analysis has been developed using the understanding of coastal behaviour from the assessment of shoreline dynamics (see Section C1), existing coastal change data and information on the nature and condition of existing coastal defences. The shoreline response associated with the 'With Present Management' scenario has been presented graphically in section C9.

Coastal Response

C4.4 As much of the East Riding shoreline is unprotected, the 'With Present Management' scenario is very similar to the 'No Active Intervention' scenario in terms of future evolution along this frontage. The main difference of this scenario compared to the 'No Active Intervention' scenario is that the currently protected areas would continue to be defended, leading to the continued erosion of undefended areas and, over time, the development of increasingly deeper bays between the defended frontages

C4.5 Climate change and relative sea-level rise are expected to enhance existing shoreline evolution trends:

- The on-going development of a bay between headlands at Flamborough Head and the remnant moraines in the Humber mouth (the Binks and the Old Den) which control the location of Spurn.
- The defended frontages along the Holderness coast would continue to exert a significant control on shoreline evolution, with the progressive formation of a series of bays between the defended frontages at Bridlington, Hornsea, Mappleton, Withernsea and Easington. The undefended cliffs between the defended frontages would continue to recede rapidly, enhancing the offset between the defended line and the natural cliffline.
- Increased cliff recession and shore platform lowering rates along the undefended frontages. This would result in an enhanced supply of a range of sediment sizes to the shoreline and sea bed. The coarse sediment supplies Spurn Head, the Binks and the New Sand Hole which contains predominantly gravels and coarse sands. It is likely that the gravel and coarse sand cannot cross the Humber mouth, although fine sands are transported to the Lincolnshire shoreline. However, beyond the SMP timeframe, if defended 'hardpoints' were maintained, the long term consequence of continued bay development would be a net decline in the output of sediment from the whole coastal cell; this would result from reduced recession rates and the increased storage of sediment within individual cells.
- On the north bank of the Humber Estuary, it is assumed that the standard of protection provided by flood defences would continue.
- An acceleration of the current erosion and accretion patterns is likely along the south bank of the Humber Estuary and Lincolnshire coastline. Shoreline response has been considered in three main areas:
    1. Areas currently experiencing natural accretion, such as between Humberston Fitties and Theddlethorpe St Helen, would continue to gain sediments originating from the Holderness coastline, north of the Humber estuary, which would extend the current foreshore area. Current trend for foreshore steepening would continue.
    2. The majority of the Lincolnshire coast (Mablethorpe to Skegness) is currently eroding resulting in the loss of beach volumes along the shoreline. However under the 'With Present Management' scenario these beaches and defences would be maintained to a 1 in 200 standard of protection, with renourishment under the Lincshore scheme. Due to increasing sea levels and the induced acceleration of erosion rates, increasing renourishment volumes would be required to maintain the beaches and the protection standards.

3. The area south of Skegness and at Gibraltar Point is currently accreting; under the 'With Present Management' scenario this trend would continue due to a continued feed of sediment from offshore, supplemented by sediment transported from beaches to the north (Mablethorpe to Skegness) which would be maintained and enhanced due to the increased renourishment volumes.

C4.6 The following text provides a summary of the analysis of the shoreline response under the 'With Present Management' scenario for specific sections of the coast. Details specific to each location and epoch are contained within the Scenario Assessment Table (Table 4-1).

Chalk Cliffs (Flamborough Head to Sewerby) and Holderness Cliffs (Sewerby to Kilnsea Coast)

C4.7 Accelerated cliff recession and shore platform lowering rates on the unprotected clifflines (the Chalk Cliffs and Holderness Cliffs), controlled by the rate of relative sea level rise. Beaches would remain narrow and thin, despite the increasing sediment inputs.

C4.8 Increased beach lowering in front of the defended areas would lead to the need for enhanced toe protection and increase wave loadings. Defences may need to be strengthened.

C4.9 Continued development of bays between the defended frontages, with a tendency for higher recession rates immediately down drift of defences at Hornsea, Mappleton and Withernsea. If this management intent was continued into the future and beyond the SMP timescale (>100 years) a decline in recession rates may occur as the bays between the defended frontages would continue to deepen.

C4.10 Maintenance of the coastal protection and flood defences at Barmston and Tunstall Drains would extend their residual life under the 'With Present Management' scenario beyond epoch 1. However, without alterations to the current defences, including significant extension or setback, outflanking from erosion to the north and south of the defences would render the defences ineffective by epoch 2.

C4.11 Towards the end of epoch 3 it is unlikely that beaches would be present in front of the Holderness defences due to shore platform lowering and drawdown. The removal of the beaches would increase the wave energy that reaches the defence line and thus would significantly increase the potential for defence failure.

C4.12 The maps plotted for epoch 1 of the 'With Present Management' scenario (WPM PU A 1 to PUP 1) shows the mid-value recession distance between the defended frontages for epoch 1. The maps plotted for epoch 2 of the 'With Present Management' scenario (WPM PU A 2 to PUP 2) shows show the mid-value recession distance between the defended frontages for epoch 2. Similarly, the epoch 3 'With Present Management' mapping (WPM PU A 3 to PUP 3) shows the mid-value recession distance between the defended frontages for epoch 3. These 'With Present Management' maps are all included in section C9.

Spurn

C4.13 Erosion of the undefended Holderness cliffs would continue to supply sediment to Spurn under this scenario. Over time, some sediment would be retained behind defences at Hornsea, Mappleton, Withernsea and the Dimlington and Easington Gas Terminals. However due to the relatively short lengths of defences in relation to the undefended areas, the overall impacts on sediment supplied to Spurn would not be significant over the SMP timeframe, especially as this would be offset by increased erosion rates on the undefended cliffs due to accelerating sea level rise.

C4.14 For epochs 1 and 2 the supply of sediment would be maintained, or increased due to greater rates of updrfit cliff erosion. By the end of epoch 3 and beyond, the Holderness defences would form increasingly significant promontories which may begin to affect the longshore transport of sediment, and consequently may reduce the net sediment volume supplied to the Spurn barrier; however, there is a great deal of uncertainty of the timing in magnitude of the relative processes,

C4.15 The current management practices are to not undertake defence maintenance along the Spurn barrier. The 'With Present Management' scenario therefore assumes that continued deterioration of derelict defences would occur as repairs would not be carried out. Relative sea level rise is expected to accelerate the dynamic behaviour and trends experienced over the last few centuries, such as shoreline erosion, overwashing and possibly westward migration of Spurn, with increased potential for breaching of the barrier.

C4.16 Although an area of much conjecture and discussion, there appears two main theories regarding the future fate of Spurn:

- One is that in order to maintain its position relative to the Holderness cliffline, the barrier could be expected to retreat. Westward migration could occur through washover events feeding the estuarine side of the barrier with sediment, which causes the barrier to roll over as the coastal side erodes. Under this scenario it is anticipated that any breaches that occur would be self healing, because of the continued longshore feed of sediments from the erosion of the Holderness cliffs, thus maintaining the integrity of the barrier.
- An alternative view is that the barrier is fragile and susceptible to breaching and breaches are not likely to self heal should they occur. Such a view suggests a possible outcome is for a significant breach leading to the opening of a new channel allowing exchange of estuarine and coastal waters, and effectively creating an Island of Spurn detached from the mainland. This view is founded in evidence from Riding of Yorkshire Council data which shows that since the cessation of defence maintenance in the 1960's, rapid erosion has occurred to the coastal side of the barrier and minimal accumulation of sediment from washover has occurred on the estuarine side of the neck.

C4.17 Despite the possibility of breaches not self healing, the 'With Present Management' scenario assumes that any breaches would be repaired to maintain access to the Spurn Point facilities, and thus the integrity of the barrier (whether in situ or having rolled back) can be assumed over the SMP timeframe under this scenario. This may become increasingly difficult to maintain if increased barrier fragility and erosion results from sea level rise.

Outer Humber Estuary (Kilnsea to Donna Nook)

C4.18 On the north bank of the Humber the defences would be repaired and maintained to provide present protection standards. As sea levels rise foreshore lowering and direct wave attack will mean that maintaining the defences would become increasingly difficult to sustain.

C4.19 On the south bank of the estuary, between Immingham and Pyewipe, foreshore lowering would continue. The current reinforcements made to the revetment toe would need to continue and be extended in terms of frequency and extent to prevent the damage and loss of defences due to destabilisation, undercutting and collapse. The crest height of defences which currently provides 1 in 200 year overtopping protection would need to be raised to maintain this standard of protection as sea levels rise over the epochs.

C4.20 The hard defences and Port at Grimsby, and the defences at Cleethorpes, would provide a 1 in 200 standard of protection over each epoch. This standard would be maintained by repairing and upgrading the defences to account for sea level rise. The locks and dock gates are recognised as particular low points, and although the Docks and Port currently provide a flood storage facility which increases the standard of protection against tidal flooding, these would need substantial improvements as sea levels rise to maintain a 1 in 200 standard of protection to the residential area of Grimsby.

C4.21 The foreshore between Cleethorpes and Donna Nook would also continue accreting due to the continued erosion of the Holderness cliffs. The accretion rate would be dependent on the balance of relative sea level rise and the sediment volume supplied to the frontage. In addition to acceleration in erosion due to sea level rise, if storminess increases significantly due to climate change, greater volumes of material would be transported across the Humber mouth to the sediment store at Donna Nook which may increase the accretion rate along this stretch.

Lincolnshire coast (Donna Nook to Gibraltar Point)

C4.22 The Donna Nook area is currently experiencing accretion and this area would continue to gain sediments originating from the Holderness coastline to the north of the Humber Estuary. This would lead to further dune building and progradation of the high water mark. Foreshore steepening would continue as sea levels rise as greater deposition of sediment is likely to occur around the high water mark relative to the low water mark.

C4.23 Greatest accretion would occur nearest to Donna Nook, with a more stable beach profile near to Mablethorpe. If the present trend for a southwards progression of the depositional front continues, the accretion zone would extend further towards Mablethorpe. This is likely if the feed of fine sediments to the system rises due to the accelerated erosion of the Holderness cliffs.

C4.24 By epoch 3, it is possible that sea level rise may begin to match or exceed the foreshore deposition rate between Donna Nook and Mablethorpe, especially if the feed of fine material is diverted into the Humber as the tidal prism increases. In addition, by the end of the SMP timeframe, the defended promontories between increasingly segmented bays along the Holderness coast may begin to reduce the longshore sediment feed and restrict the sediment supplied across the Humber mouth to Donna Nook. Consequently, accretion rates at Donna Nook would start to slow and rising sea levels could begin to exceed the pace of accretion, the natural protection offered by the dune ridges would begin to fall as the water levels would rise relative to the dune crests. However, these processes which could reduce accretion rates may be countered by increased storminess resulting from climate change which would facilitate a greater sediment feed from the Binks Banks to this region. This could help maintain accretion rates, or even enhance them, especially in the northern area around Donna Nook.

C4.25 These possible future outcomes relate to the relative balance of processes operating. The accretion rate over time is dependent on the relative magnitude, interactions and timings of the aforementioned processes. Despite the effects of changes to current processes and climate alterations on the accretion trend at Donna Nook, the 'With Present Management' scenario assumes that the current standard of protection offered by the dunes, beaches and defences would be maintained.

C4.26 The man made defences between Donna Nook and Saltfleet would remain, and under the 'With Present Management' scenario these would need to be maintained and improved to keep pace with sea level rise over the plan period.

C4.27 Between Mablethorpe and Skegness the majority of this coastline consists of a combination of man-made 'hard' defence structures of varying type and stabilised dunes. A short distance behind the defended foreshore the majority of the terrain is below the crest level of the coastal defences. In some areas, this low lying land extends several kilometres inland, putting large areas at risk of flooding should the coastal defences be severely overtopped or breached.

C4.28 These defences are fronted by veneer beaches which offer protection to the 'hard' defences and dunes at the rear of the beaches. Since 1994 the beaches have been maintained by a renourishing scheme known as Lincshore. The area between

Mablethorpe and Ingoldmells has historically demonstrated erosion and is the main focus for the Lincshore renourishment scheme. Preserving the beach frontage helps extend the residual life of those defences at the rear by reducing the wave exposure and providing structural support to the toe of the structures. Under the 'With Present Management' scenario coastal defences would need to be maintained and improved to keep pace with sea level rise over the plan period.

C4.29 The 'With Present Management' scenario for the Mablethorpe to Skegness frontage considers the effect of coastal morphology with the continuation of the Lincshore scheme. The Lincshore scheme re-nourishement volume placed between Mablethorpe to Skegness in 2008 was approximately 400,000 m^3 (Van Ord, 2008). The 'With Present Management scenario assumes the Lincshore scheme continues nourishing the beaches to maintain the standard of protection over the epochs. This includes nourishing with additional volumes of material to account for sea level rise.

C4.30 The shoreline between Ingoldmells and Skegness is considered stable but relies on a constant supply of material from the beaches immediately to the north. This scenario assumes that the renourishments continue and increase in volume to account for sea level rise. As a result the beaches of this area are expected to remain stable and maintain the standard of protection in each epoch.

C4.31 The area south of Skegness to Gibraltar Point is currently accreting; this trend would continue due to a continued feed of sediment from offshore and by sediment transported by longshore processes from the renourished beaches to the north. In the longer term (epoch 3 and beyond) there is a possibility that the system could become stable or erosional if the input of sediment is not sufficient to offset the accelerating rate of sea level rise and associated increased wave exposure.

Summary by epoch (With Present Management)

C4.32 The following text provides a summary of the analysis of the shoreline response with details specific to each location and epoch contained within the Scenario Assessment Table (Table 4-1).

Epoch 0-20 Years (2025)

C4.33 During this period there would be increased pressure on the coastline with accelerated cliff recession The Holderness defences would remain along the urban frontages, with continued retention of sediment immediately updrift and within the groyne fields. Erosion of the undefended stretches would continue, with decreasing erosion rates towards the southern limit of the bays. Where defences remain, beaches would narrow as exposure increases due to continued platform lowering and deeper nearshore areas. Hard defences would be maintained and upgraded as necessary to provide protection against erosion. It is expected that the privately owned defences would be maintained over epoch 1; however, by the end of the epoch the small private defences are likely to start becoming outflanked, as it is assumed that no new defences or structures are built i.e. assumed to be no longer effective by the end of epoch 2.

C4.34 Although the Spurn barrier may remain in-situ, maintained by the increased input of sediment into the system and the glacial till ridge foundations, it is possible that Spurn could undergo westward migration through roll over maintained by washover processes. Breaches are expected over this period, and if breaches were not self-healing, the Spurn barrier would be repaired to ensure the road link is maintained.

C4.35 On the north bank of the outer Humber Estuary the defences would be repaired and raised to maintain the current standard of protection in epoch 1. Defences on the south bank of the Humber would also be repaired to maintain the current 1 in 200 standard of protection. Due to foreshore lowering, and localised erosion, the defences would require increasing levels of intervention to maintain them.

C4.36 Accretion would continue between Cleethorpes and Mablethorpe over this epoch Foreshore steepening would continue as greater deposition of sediment is likely to occur around the high water mark relative to the low water mark. Fine sediments eroded from the Holderness cliffs would continue to be transported across the Humber mouth to this area and the foreshore would continue to prograde. Where man-made defences are present, these would need to be maintained and improved to keep pace with sea level rise over the plan period.

C4.37 Along the area of the Lincshore scheme (Mablethorpe to Skegness), renourishment of the beaches and defence maintenance would be carried out. Currently, the Lincshore scheme proposes to account for sea level rise effects by increasing the width of the beach crest (berm).

C4.38 The Lincshore scheme presently re-nourishes the Mablethorpe to Skegness coastline with approximately 350,000 to 855,000 m^3 of material per annum. An initial period of marginally higher recharge rates was followed by recharge volumes averaging around 317,000 m^3, however significant increases in volume have been required over the last three years (2005-2007) with 855,000 m^3 placed in 2006, and 800,000 m^3 placed in 2007 to maintain the standard of protection.

C4.39 The volume of renourishment required to maintain the protection standard of the beaches in line with sea level rise for this epoch is estimated to be an additional 7,500m^3 per annum. It should be noted that these volumes may not account for increases in severity and frequency of storms over the next century. Storms have the effect of increasing erosion rates, and consequently further additions to the nourishment volume may be required to maintain the standard of protection if increased storminess occurs. Erosion of the underlying clay tills would be limited but may occur during severe storms, due to the monitoring and management under Lincshore, sand renourishment would substitute the lost clay volume.

C4.40 Along the Lincolnshire coast the preservation of a healthy beach frontage would help to maintain the effectiveness of the man-made defences, at the rear of the beaches during severe storms. The beaches would also naturally extend the residual life of the defences. The 'With Present Management' scenario assumes that the defences would need to be maintained and improved to keep pace with sea level rise over the plan period.

C4.41 The area south of Skegness to Gibraltar Point would continue to accrete due to a continued feed of sediment from offshore and by sediment transported by longshore processes from the renourished beaches to the north. Defences around the River Steeping would be maintained and upgraded to continue protecting against flooding.

Epoch 20-50 Years (2055)

C4.42 There would be increased pressure on the coastal system due to accelerating sea level rise.

C4.43 On the Holderness defended frontages, the shoreline position would be held and defences would be maintained and upgraded as required. However, the beaches are likely to decline, as there would be deeper water and greater wave exposure at the seawalls. These conditions would not be conducive to beach retention and any sediment arriving on these frontages is likely to be rapidly transported offshore again.

C4.44 Along undefended sections, cliff recession would continue at higher rates than those currently experienced, due to relative sea level rise of around 8mm/year. The trend of bay development would continue, with decreasing erosion rates towards the southern limit of the bays. This accelerating erosion rate would release more material into the system, which would help maintain the Spurn barrier and the beaches further south in Lincolnshire.

C4.45 Spurn would be affected by overwashing and breaching events. If breaching events were unable to self heal a 'With Present Management' scenario assumes they would be repaired to maintain the road link along the barrier. Therefore the integrity of the barrier would remain and westwards roll-over is a possible outcome as the barrier re-aligns with the Holderness cliffs.

C4.46 On the north bank of the outer Humber Estuary the defences would be repaired and raised to maintain the current standard of protection in epoch 2. Due to foreshore lowering, and localised erosion, the defences would require increasing levels of intervention to maintain them.

C4.47 On the south bank of the estuary, between Immingham and Cleethorpes, foreshore lowering would continue and increasing intervention and upgrades would be required to maintain the defences. To account for a 0.4m sea level rise by the end of epoch 2 the crest height of defences would need to be raised to provide overtopping protection.

C4.48 Between Cleethorpes and Mablethorpe, accretion would occur as fine sediment eroded from the Holderness cliffs continues to be fed to the area across the mouth of the Humber. The present trend for foreshore steepening would continue as sea levels rise. This accretion would naturally help maintain the standard of protection offered by the dunes and beaches. Where man made defences are present and subject to direct wave attack, defences would need to be maintained and improved to keep pace with sea level rise over the plan period..

C4.49 By 2055 sea level rise is likely to cause an increased rate of erosion in the area of the Lincshore scheme. Consequently under this scenario it is assumed that greater renourishment volumes would be placed on the beaches to account for the effects of a 0.4m sea level rise. This would increase the width and crest height of the beaches. Hard defences at the rear of the beaches would also need to be maintained and improved to keep pace with sea level rise over the plan period.

Epoch 50-100 Years (2105)

C4.50 It should be noted that there is a significant degree of uncertainty over the timescales, magnitudes and interactions of the different processes in the longer term. This means that confidence in the predictions of coastal response in the longer term is unavoidably lower than for earlier epochs. The following summary should be regarded as a discussion of likely possibilities of coastal responses to the various processes anticipated, based on expert predictions and currently available data.

C4.51 On the undefended Holderness coast, cliff recession rates would continue to increase because of the trend of accelerating sea level rise at around 12-15mm/year. At the end of this epoch, hard defences would have created a series of promontories, in many cases extending 100-200m out from the adjacent eroded shoreline. The bays between the defended frontages would become deeper by up to a 400m. The defences would be highly exposed to waves in deeper water, requiring high levels of intervention and upgrading to maintain their integrity. Outflanking at the margins of these defences would become an increasing problem. The 'With Present Management' assumption of building no new defences would mean that the current defences are likely to be largely ineffective due to outflanking by the end of the epoch. There would be virtually no beaches present along these frontages and the groynes would have become redundant.

C4.52 The defended promontories would also begin to act as a series of terminal groynes upon beach sediment transport, which may begin to reduce the sediment exchange throughout much of the Holderness shoreline. Consequently the longshore transport of coarse sediment could be interrupted and there is potential for more of this beach-building material to be transported offshore. These promontories would help to stabilise beaches on their up-drift side, but are also likely to exacerbate erosion down-drift. The deeper water at these headlands is expected to result in some of the sediment reaching these points being deflected offshore rather than moving down the coast.

C4.53 Due to the continued creation of embayments between defended frontages along the Holderness coast, there is the potential for decreased longshore transport to Spurn. However a general acceleration in sea level rise would generally increase recession rates on undefended frontages which would help offset the effect of embayments on the sediment supply. By the end of epoch 3, there is increased potential for the interruption to the sediment supply to Spurn. This could threaten the integrity of the Spurn barrier. Breaching events would become more frequent and natural healing may cease to occur. The 'With Present Management' scenario assumes all breaches would be healed; but if sediment supply from the Holderness frontage to the north reduces, increasing human intervention would be required to maintain the integrity of the barrier, which may not be sustainable over the longer term.

C4.54 On the north bank of the outer Humber Estuary the defences would be repaired and raised to maintain the current standard of protection in epoch 3. Defences on the south bank of the Humber would also be repaired to maintain the current 1 in 200 standard of protection. Due to foreshore lowering, and localised erosion, the defences would require increasing levels of intervention to maintain them.

C4.55 The current Lincshore scheme is due to run for 50 years till approximately 2050. The 'With Present Management' scenario assumes that the Lincshore scheme is extended and continues renourishments to maintain the standard of protection, including allowances for sea level rise until 2105. By the end of the century, sea level rise of approximately 1m is predicted. The volume of renourishment required to maintain the beaches in line with sea level rise is likely to increase significantly towards 2105 owing to the predicted acceleration in erosion due to sea level rise. Renourishment allowances would also need to take into account climate change which may also cause an increase in the severity and frequency of storms which would increase the exposure of the defence structures behind the beach between renourishment cycles.

C4.56 Behind the beaches significant maintenance and upgrading of hard defences would continue to ensure that the low-lying land behind the defences would be protected from overtopping and from breaches.

C4.57 Accretion could continue at Gibraltar Point due to the continued feed of sediment from offshore, supplemented by increased longshore sediment transport from the renourished beaches to the north. There is a possibility that the system could become stable or erosional if the input of sediment is not sufficient to offset the accelerating rate of sea level rise and associated increased wave exposure.

Table 4-1: WPM Scenario Assessment Table

Location	Predicted Change for 'With Present Management'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Flamborough Head to Bridlington	There are no defences along this frontage	No defences	No defences
PU A **CA 1**	Cliff erosion would continue at enhanced rates to those experienced historically, with a net retreat of the cliff line of between 2 and 5m by year 2025. Small volumes of sediment supplied from cliff failures (around 1,000m^3/year), probably transported to Smithic Sand or retained in pocket beaches at South Landing and Danes Dyke.	Cliff erosion would continue at an increased rate, due to sea level rise, with a net change in cliff line position of between 5 and 25m by 2055. No significant change to the contribution to regional sediment budget.	Cliff erosion would continue at an increased rate, due to sea level rise, with a net change in cliff line position of between 10 and 72m by 2105. No significant change to the contribution to regional sediment budget.

Location	Predicted Change for 'With Present Management '		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Bridlington (Sewerby to Wilsthorpe)	The concrete and masonry seawalls would remain in place for this period With Present Management practices assumed.		
PU B **CA 2**	The shoreline position would be held, although beach levels would decline as the shore platform continues to lower in front of the walls. There would be continued sediment transport into this area from the south.	The shoreline position would be held, although the beaches would steepen and narrow as relative sea level rises and the shore platform continues to lower in front of the walls. There would be continued sediment transport into this area from the south. Smithic Sands would continue to provide a degree of protection to the shoreline.	The shoreline would continue to be held in its current position. However, the beaches are likely to have disappeared or be very limited. Cliff recession either side of the defence line would continue, leaving Bridlington as an exposed headland. Outflanking at either end of the defence line is expected by the end of the epoch.

Location	Predicted Change for 'With Present Management'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Wilsthorpe to Barmston	There are no defences along this frontage.	No defences	No defences
PU C **CA 3**	Accelerated cliff recession and shore platform lowering. By the end of this period the predicted cliff retreat is: 2-8m (North) and 23-33m (South). Thin, narrow beaches fronting the cliffs. Increased sediment inputs from cliff recession and platform lowering, with transport northwards towards Bridlington and the Smithic Sands.	Accelerated cliff recession and shore platform lowering. By the end of this period the predicted cliff retreat is: 5-50m (North) and 75-120m (South). Thin, narrow beaches fronting the cliffs. Increased sediment inputs from accelerating cliff recession and platform lowering, with transport northwards towards Bridlington and the Smithic Sands.	Accelerated cliff recession and shore platform lowering. By the end of this period the predicted cliff retreat is: 10-150m (North) and 150-310m (South). Thin, narrow beaches fronting the cliffs. Increased sediment inputs from accelerating cliff recession and platform lowering, with transport northwards towards Bridlington and the Smithic Sands.

Location	Predicted Change for 'With Present Management'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Barmston to Atwick **PU C** **CA 3**	There are no defences along most of this frontage. The flood defence and shoreline protection structures at Barmston drain are assumed to be maintained and would remain during this period. The private defences at Ulrome are assumed to fail during this period.	There are no defences along most of this frontage. The flood defence and shoreline protection structures at Barmston drain would be maintained and would be realigned as adjacent cliffs erode.	There are no defences along most of this frontage. The flood defence and shoreline protection structures at Barmston drain would be maintained and would be realigned as adjacent cliffs erode.
	Accelerated cliff recession and shore platform lowering. By the end of this period the predicted cliff retreat is: 24-33m (North) and 6-12m (South). There would be rapid "catch-up" along the defended section at Ulrome. Generally thin, narrow beaches fronting the cliffs. Beach accretion would occur immediately north of the Hornsea defences so would widen the beach in this location. Increased sediment inputs from cliff recession and platform lowering, with transport southwards towards Hornsea.	Accelerated cliff recession and shore platform lowering. By the end of this period the predicted cliff retreat is: 75-120m (North) and 20-50m (South). The local impact of the Ulrome defences on shoreline orientation would have ceased. The previously defended section at Barmston drain would erode as drain infrastructure and flood defence structures are realigned. Generally thin, narrow beaches fronting the cliffs. Beach accretion would occur immediately north of the Hornsea defences so would widen the beach in this location. Increased sediment inputs from accelerating cliff recession and platform lowering, with transport southwards towards Hornsea.	Accelerated cliff recession and shore platform lowering. By the end of this period the predicted cliff retreat is: 150-300m (North) and 40-140m (South). The previously defended section at Barmston drain would erode as drain infrastructure and flood defence structures are realigned. Generally thin, narrow beaches fronting the cliffs. Beach accretion would occur immediately north of the Hornsea defences so would widen the beach in this location. Increased sediment inputs from accelerating cliff recession and platform lowering, with transport southwards towards Hornsea.

Location	Predicted Change for 'With Present Management '		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Hornsea	The concrete seawalls and rock armouring would remain in place for this period under the With Present Management scenario.		
PU D **CA 4**	The shoreline position would be held, although beach levels would decline as the shore platform continues to lower in front of the walls. There would be continued sediment transport into this area from the north. Some sediment would be locked in behind the defences.	The shoreline position would be held, although the beaches would steepen and narrow as relative sea level rises and the shore platform continues to lower in front of the walls. There would be continued sediment transport into this area from the north. Increasing volumes of sediment would be locked in behind the defences.	The shoreline would continue to be held in its current position. However, the beaches are likely to have disappeared or be very limited. Cliff recession either side of the defence line would continue with greatest south of the defences, leaving Hornsea as an exposed headland. Outflanking is expected especially at the southern end of the defence line as the undefended shoreline retreats. There would be some interruption to longshore sediment transfers between the bays to the north and south of the defended frontage. Increasing volumes of sediment would be locked in behind the defences.

Location	Predicted Change for 'With Present Management'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Hornsea to Mappleton	There are no defences along this frontage.	No defences	No defences
PU E **CA 5**	Accelerated cliff recession and shore platform lowering. By the end of this period the predicted cliff retreat is: 42-48m. Thin, narrow beaches fronting the cliffs. Beach accretion would occur immediately north of the Mappleton defences. Increased sediment inputs from cliff recession and platform lowering, with transport southwards towards Mappleton and Withernsea.	Accelerated cliff recession and shore platform lowering. By the end of this period the predicted cliff retreat is: 135-155m. Thin, narrow beaches fronting the cliffs. Increased sediment inputs from accelerating cliff recession and platform lowering, with transport southwards towards Mappleton and Withernsea.	Accelerated cliff recession and shore platform lowering. By the end of this period the predicted cliff retreat is: 270-360m. Thin, narrow beaches fronting the cliffs. Increased sediment inputs from accelerating cliff recession and platform lowering, with transport southwards towards Mappleton where some would be locked in behind the emerging headland.

Location	Predicted Change for 'With Present Management'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Mappleton	The rock revetment and groynes would remain in place for this period.		
PU E **CA 5**	The shoreline position would be held, although beach levels would decline as the shore platform continues to lower. There would be continued sediment transport into this area from the north. Some sediment would be locked in behind the defences.	The shoreline position would be held, although the beaches would steepen and narrow as relative sea level rises and the shore platform continues to lower in front of the walls. There would be continued sediment transport into this area from the north. Increasing volumes of sediment would be locked in behind the defences.	The shoreline would continue to be held in its current position. However, the beaches are likely to have disappeared or would be very thin. Cliff recession either side of the defence line would continue, especially south of the defences, leaving Mappleton as an exposed headland. There would be some interruption to the longshore sediment transfers between the bays to the north and south of the defended frontage. Depending on the rate of retreat the outflanking it may be difficult to sustain the maintenance of the defences by the end of the epoch. Increasing volumes of sediment would be locked in behind the defences.

Location	Predicted Change for 'With Present Management '		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Mappleton to Withernsea	There are no defences along most of this frontage. The coastal protection and flood defences at Tunstall would be maintained and would remain during this period.	There are no defences along most of this frontage. The flood defence and shoreline protection structures at Tunstall drain would be maintained and would be realigned as adjacent cliffs erode.	There are no defences along most of this frontage. The flood defence and shoreline protection structures at Tunstall drain would be maintained and would be realigned as adjacent cliffs erode.
PU E **CA 5**	Accelerated cliff recession and shore platform lowering. By the end of this period the predicted cliff retreat is: 31-37m (North), 19-26m (South). Shoreline position held at the defended section around Tunstall drain. Generally thin, narrow beaches fronting the cliffs. Beach accretion would occur immediately north of the Withernsea defences so would widen the beach in this location. Increased sediment inputs from cliff recession and platform lowering, with transport southwards towards Withernsea.	Accelerated cliff recession and shore platform lowering. By the end of this period the predicted cliff retreat is: 100-125m (North), 60-95m (South). Tunstall drain infrastructure and flood defence structures would be realigned as adjacent cliffs erode. Generally thin, narrow beaches fronting the cliffs. Beach accretion would occur immediately north of the Withernsea defences so would widen the beach in this location. Increased sediment inputs from accelerating cliff recession and platform lowering, with transport southwards towards Withernsea.	Accelerated cliff recession and shore platform lowering. By the end of this period the predicted cliff retreat is: 200-300m (North), 120-240m (South). Generally thin, narrow beaches fronting the cliffs. Beach accretion would occur immediately north of the Withernsea defences so would widen the beach in this location. Tunstall drain infrastructure and flood defence structures would be realigned as adjacent cliffs erode. Increased sediment inputs from accelerating cliff recession and platform lowering, with transport southwards towards Withernsea.

Location	Predicted Change for 'With Present Management'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Withernsea	The concrete seawalls and rock armouring would remain in place for this period.		
PU F **CA 6**	The shoreline position would be held, although beach levels would decline as the groyne system deteriorates and the shore platform continues to lower. Some sediment would be locked in behind the defences.	The shoreline position would be held, although the beaches would steepen and narrow as relative sea level rises and the shore platform continues to lower in front of the walls. There would be continued sediment transport into this area from the north. Increasing volumes of sediment would be locked in behind the defences.	The shoreline would continue to be held in its current position. However, the beaches are likely to have disappeared or would be very thin. Cliff recession either side of the defence line would continue especially south of the defences, leaving Withernsea as an exposed headland. There would be some interruption to longshore transport of sediment between the bays to the north and south of the defended frontage. Increasing volumes of sediment would be locked in behind the defences.

Location	Predicted Change for 'With Present Management'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Withernsea to Easington	There are no defences along this frontage.	No defences	No defences
PU G **CA 7**	Accelerated cliff recession and shore platform lowering. By the end of this period the predicted cliff retreat is: 34-42m (North), 26-34m (South). Generally thin, narrow beaches fronting the cliffs. Beach accretion would occur immediately north of the Easington defences so would widen the beach in this location. Increased sediment inputs from cliff recession and platform lowering, with transport southwards towards Easington and Spurn.	Accelerated cliff recession and shore platform lowering. By the end of this period the predicted cliff retreat is: 105m – 140m (north), 85-120m (South). Generally thin, narrow beaches fronting the cliffs. Beach accretion would occur immediately north of the Easington defences so would widen the beach in this location. Increased sediment inputs from accelerating cliff recession and platform lowering, with transport southwards towards Easington and Spurn.	Accelerated cliff recession and shore platform lowering. By the end of this period the predicted cliff retreat is: 210-330m (North), 160-280m (South). Generally thin, narrow beaches fronting the cliffs. Beach accretion would occur immediately north of the Easington defences so would widen the beach in this location. Increased sediment inputs from accelerating cliff recession and platform lowering, with transport southwards towards Easington and Spurn.

Location	Predicted Change for 'With Present Management'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Easington Gas Terminals	The rock revetment would remain in place for this period.	The rock revetment would remain in place for this period.	The rock revetment would remain in place for this period.
PU H **CA 8**	The shoreline position would be held, although beach levels would decline as the shore platform continues to lower. Some sediment would be locked in behind the defences.	The shoreline position would be held, although beach levels would decline as the shore platform continues to lower. Increased risk of outflanking around the edges of the revetment. Increasing volumes of sediment would be locked in behind the defences.	The shoreline position would be held, although beach levels would decline as the shore platform continues to lower. Cliff recession either side of the defence line would continue especially south of the defences, leaving Easington Gas terminals as an exposed headland. There would be some interruption to longshore sediment transfers between the bays to the north and south of the defended frontage. Depending on the rate of retreat the outflanking may cause the maintenance of defending this area to be unsustainable. Increasing volumes of sediment would be locked in behind the defences.

Location	Predicted Change for 'With Present Management'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Easington to Kilnsea	Flood bank at the rear of the Easington Lagoons will be maintained and would continue to provide present standard of protection. There would be no defences elsewhere along the frontage.	Defences would provide a similar standard of flood protection as the present day. There would be no defences elsewhere along the frontage.	Defences would continue to provide present standard of protection against flooding. There are no defences elsewhere along the frontage where erosion would continue.
PU I **CA 9**	Accelerated cliff recession and shore platform lowering. By the end of this period the predicted cliff retreat is: 18-26m. Thin, narrow beaches fronting the cliffs. Barrier beach infront of the lagoons would continue to migrate landwards and would become increasingly susceptible to breaching. Lagoons would diminish in quality and extent as sea levels rise. Increased sediment inputs from accelerating cliff recession and platform lowering, with transport southwards towards Spurn.	Accelerated cliff recession and shore platform lowering. By the end of this period the predicted cliff retreat is: 60-95m. Thin, narrow beaches fronting the cliffs. Barrier beach will retreat and lagoons would no longer exist. Defences would need to be significantly upgraded to maintain the present day standard of flood protection. This would require significant upgrades as it becomes susceptible to direct wave attack. Increased sediment inputs from accelerating cliff recession and platform lowering, with continued transport southwards towards Spurn.	Accelerated cliff recession and shore platform lowering. By the end of this period the predicted cliff retreat is: 120-240m. Thin, narrow beaches fronting the cliffs. Flood defences would need to be significant structures to maintain the standard of protection against flooding. Increased sediment inputs from accelerating cliff recession and platform lowering, with continued transport southwards towards Spurn.

Location	Predicted Change for 'With Present Management'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Spurn **PU J** **CA 10**	The existing concrete seawalls, timber groynes and rock armouring are largely derelict and would have failed during this period.	No defences	No defences
	Accelerated shoreface erosion. Increased potential for breaches, especially around the neck. If breaches are not self healing, intervention will ensure integrity of the barrier and roadway would remain. The barrier may undergo westwards migration through rollover. There is the potential for 6-30m retreat by the end of this period. Cell also at risk of flooding from adjacent cells.	Shoreface erosion. Increased potential for breaches, especially around the neck. If breaches are not self healing, intervention would ensure integrity of the barrier and roadway would remain. The barrier could undergo westwards migration through rollover. There is the potential for 15-100m retreat by the end of this period. Cell also at risk of flooding from adjacent cells.	Shoreface erosion. Increased potential for breaches, especially around the neck. Breaches may become increasingly difficult to repair, however 'With Present Management' assumes that intervention would occur to ensure the integrity of the barrier and roadway. The barrier could undergo westwards migration through rollover. There is the potential for 30-250m retreat by the end of this period). Cell also at risk of flooding from adjacent cells.

Location	Predicted Change for 'With Present Management'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Kilnsea to Hawkins Point	Earth embankments and defences would need maintenance and upgrades to maintain the standard of protection.	Defences would be raised and upgraded to maintain the standard of protection against flooding as sea levels rise.	Defences would be raised and upgraded to maintain the standard of protection against flooding as sea levels rise.
PU K **CA 11**	The defences would be maintained and upgraded. Flood embankments would become increasingly susceptible to toe erosion as the foreshore lowers and sea level rise.	The foreshore would lower as sea levels rise causing increased toe erosion and undermining of defences. Defences would need significant upgrades and crest raising to maintain the standard of protection against flooding as sea levels rise.	The foreshore would lower as sea levels rise causing increased toe erosion and undermining of defences. Defences would need significant upgrades and crest raising to maintain the standard of protection against flooding as sea levels rise.

Location	Predicted Change for 'With Present Management'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Hawkins Point to Stone Creek	Earth embankments and defences would need maintenance and upgrades to maintain the standard of protection.	Defences would be raised and upgraded to maintain the standard of protection against flooding as sea levels rise.	Defences would be raised and upgraded to maintain the standard of protection against flooding as sea levels rise.
PU K **CA 11**	The defences would be maintained and upgraded. Flood embankments would become increasingly susceptible to toe erosion as the foreshore lowers and sea level rise.	Erosion would be prevented by defences as sea levels rise. The foreshore would lower as sea levels rise causing increased toe erosion and undermining of defences. Defences would need significant upgrades and crest raising to maintain the standard of protection against flooding as sea levels rise.	Erosion would be prevented by defences as sea levels rise. The foreshore would lower as sea levels rise causing increased toe erosion and undermining of defences. Defences would need significant upgrades and crest raising to maintain the standard of protection against flooding as sea levels rise.

Location	Predicted Change for 'With Present Management'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
East Immingham to Grimsby Docks	Earth embankment, revetment and reinforced concrete wave wall would remain in place for the period and are repaired, maintained and upgraded when necessary to account for sea level rise and to maintain the standard of protection.		
PU L **CA 12**	The shoreline position would be held through maintaining and upgrading defences as sea levels rise. Transport of material would continue from east to west. The foreshore would remain fairly stable towards Grimsby but would undergo lowering towards Immingham leading to increased pressure on the toe of revetments.	Present day defence line would be maintained, however beach levels would have reduced significantly in western and central parts of the unit as sediment is eroded from the foreshore. Relative sea level rise of 44cm by 2055 would mean significant improvements to the defences would be required to maintain the standard of protection.	Increasing levels of intervention and defence improvements would be required as sea levels rise by over 1m and the foreshore continues to lower, especially in the west of this area.

Location	Predicted Change for 'With Present Management'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Grimsby Docks to East Cleethorpes	Variety of hard defences along frontage including seawalls, revetments, quay walls, dock gates, locks, and gabion baskets offering different standards of protection and variable in condition. These defences would be maintained, repaired and upgraded as required to account for sea level rise and maintain the standard of protection. Also groyne fields present at Cleethorpes would be maintained.		
PU L **CA 13a**	Defence improvements and maintenance would be required to maintain the standard of protection against flooding. Transport of material would continue from east to west. The foreshore would remain fairly stable towards Grimsby and would continue accreting towards Cleethorpes due to the continued feed of fine sediment across the Humber mouth from the eroding Holderness cliffs.	Present day defence line maintained, however beach levels could reduce slightly towards Grimsby. Continued accretion would occur near Cleethorpes due to the deposition of fine sediment fed across the Humber mouth from the eroding Holderness cliffs. Relative sea level rise of 44cm by 2055 would mean significant improvements to the defences would be required to maintain the standard of protection.	Increasing levels of intervention and defence improvements would be required as sea levels rise by over 1m. Foreshore levels may begin to lower as the rate of sea level accelerates and the relative input of sediment from the Holderness cliffs could start to reduce as defended promontories begin to interrupt longshore sediment transport.

Location	Predicted Change for 'With Present Management '		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
East Cleethorpes to Donna Nook.	Naturally defended by sand dunes, saltmarshes. Groyne fields at Humberston Fitties. Earth embankments also supplement the natural defences.	Natural protection against flooding remains from sand dunes and saltmarshes. Earth embankments also supplement the natural defences.	Natural protection against flooding of saltmarsh and dunes. Earth embankments also supplement the natural defences.
PU M/N **CA 13b/14**	Dunes and Saltmarshes continue to accrete and undergo progradation. This would enhance the natural defence line against overtopping and breaching. Groyne fields maintained by man and their presence would further stabilise the beach. The current trend of inter tidal steepening is predicted to continue. Cell also at risk of flooding from adjacent cells.	Continued accretion would occur as the rate of relative sea level rise and the rate of erosion of updrift cliffs accelerates thus increasing the supply of sediment to this area. This would allow further dune building and saltmarsh growth. Natural protection of the floodplain would be maintained, although if increased storminess occurs, the risk of breaching would increase. If flood embankments require maintenance or upgrades, human intervention would occur, if necessary, to maintain the current standard of protection to the floodplain. Cell also at risk of flooding from adjacent cells.	Due to rapid acceleration of sea level rise over this period the pace at which the dunes and the saltmarshes undergo building may slow, especially if the input of sediment across the Humber mouth reduces as a result of continuing to defend sections leading to promontories. Steepening of the foreshore and some deterioration of the seaward saltmarsh edge would occur. Due to increased storminess, the probability of dune breaching, from storm events would increase. If natural protection falls, human intervention would be undertaken, if necessary, to maintain the current standard of protection to the floodplain Cell also at risk of flooding from adjacent cells.

Location	Predicted Change for 'With Present Management'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Donna Nook to Saltfleet	Defended by an earth floodbank and sand dunes.	Earth floodbank and sand dunes form the defence line.	Earth floodbank and sand dunes form the defence line.
PU N **CA 14**	Earth embankment would continue to offer protection against flooding. The standard of protection is maintained through raising crest heights and undertaking improvements to account for the 8 cm relative sea level rise by 2025. Dunes and beaches would continue to accrete. This would maintain or enhance the natural defence line against overtopping and breaching.	Earth embankment would be maintained and improved to account for sea level rise to continue to provide the standard of protection. Continued accretion and dune building predicted as sediment feed across Humber mouth from the Holderness cliffs increases. If natural protection falls due to rising sea levels, human intervention would occur, if necessary, to maintain the current standard of protection to the floodplain.	Earth embankment would be maintained and improved to provide the current standard of protection accounting for an approximate rise in relative sea level of 1.02m by 2105. Due to rapid acceleration of relative sea level rise over this period the pace at which accretion and dune building occurs may slow or even change to erosion by 2105, especially if the supply of sediment across the Humber mouth reduces as a result of continuing to defend sections leading to promontories. Steepening of the foreshore would occur. Due to increased storminess, the probability of dune breaching, from storm events may increase. If natural protection falls, human intervention would be undertaken, if necessary, to maintain the current standard of protection to the floodplain

Location	Predicted Change for 'With Present Management'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Saltfleet to Mablethorpe **PU N** **CA 15**	Sand dunes form the natural defence line against flooding.	Natural protection against flooding remains from sand dunes.	Natural flood protection from sand dunes especially towards Saltfleet, however natural reduction in protection standard offered nearer Mablethorpe. Human intervention may be required to maintain the current standard of protection offered by the dunes.
	Continued accretion of sand dunes as sediment feed from material eroded along Holderness frontage maintained. Progradation of the shoreline. Greatest accretion occurs towards Saltfleet, least near Mablethorpe where beach is effectively stable.	Accretion of sand dunes highly dependent on sediment feed from material eroded along Holderness frontage. It is predicted that erosion of Holderness cliffs would increase with relative sea level rise so further dune building anticipated. Natural protection standard likely to be similar or slightly in excess of today. Greatest accretion occurs towards Saltfleet, least near Mablethorpe where beach is effectively stable or may even begin eroding unless sediment supplied to system increases sufficiently to cause depositional front to move south.	Sand dunes continue to provide some natural protection against flooding. Sea level rise accelerates to 15.8mm / year. Due to rapid acceleration of relative sea level rise over this period the pace at which accretion and dune building occurs may slow or even change to erosion by 2105, especially if the supply of sediment across the Humber mouth reduces as a result of continuing to defend some sections leading to promontories which would interrupt some of the longshore transport along the frontage. This, coupled with greater storminess, may increase the probability of dune breaching. If the standard of protection from natural dunes falls, human intervention would be undertaken, if necessary, to maintain the current standard of protection to the floodplain.

Location	Predicted Change for 'With Present Management'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Mablethorpe **PU O** **CA 16**	Naturally vegetated / stabilised dunes and Concrete stepped apron with splash wall fronted by veneer beaches. Defences and the veneer beaches would remain in place.	Defences and the veneer beaches would remain in place.	Defences and the veneer beaches would remain in place.
	Veneer beaches fronting defences would be maintained by renourishment under the Lincshore scheme. The beach volume would keep pace with sea level rise due to the 7,500m^3 nourishment allowance. Defences would be maintained and improved to account for sea level rise.	Veneer beaches fronting defences would be maintained by renourishment under the Lincshore scheme. Increasing volumes of sediment would need to be placed to account for the accelerating rise in sea level. The structures at the rear of the beaches would be maintained and raised to account for the rising sea levels.	Erosion of the beaches would accelerate with sea level rise and increased storminess. Increasing beach nourishment volumes would be required to maintain the veneer beaches. Increasing levels of intervention would be needed to maintain and raise the structures at the rear of the beaches to keep pace with sea level rise over the plan period.

Location	Predicted Change for 'With Present Management'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Sandilands to Anderby Creek **PU O** **CA 17**	Two level concrete apron with recurve wall, to the south a Seabee revetment topped with wave wall with dunes behind. Veneer beaches fronting the structures. Defences and the veneer beaches would remain in place.	Defences and the veneer beaches would remain in place.	Defences and the veneer beaches would remain in place.
	Veneer beaches fronting defences would be maintained by renourishment under the Lincshore scheme. The beach volume would keep pace with sea level rise due to the 7,500m^3 nourishment allowance. Defences would be maintained and improved to account for sea level rise.	Veneer beaches fronting defences would be maintained by renourishment under the Lincshore scheme. Increasing volumes of sediment would need to be placed to account for the accelerating rise in sea level. The structures at the rear of the beaches would be maintained and raised to account for the rising sea levels.	Erosion of the beaches would accelerate with sea level rise and increased storminess. Increasing beach nourishment volumes would be required to maintain the veneer beaches. Increasing levels of intervention would be needed to maintain and raise the structures at the rear of the beaches to keep pace with sea level rise over the plan period.

Location	Predicted Change for 'With Present Management'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Anderby Creek	Vegetated sand dunes providing natural protection would remain and would be protected by the continued presence of the veneer beaches.		
PU O **CA 17**	Veneer beaches fronting the dunes would be maintained by renourishment under the Lincshore scheme. The beach volume would keep pace with sea level rise due to the 7,500m^3 nourishment allowance.	Veneer beaches fronting the dunes would be maintained by renourishment under the Lincshore scheme. Increasing volumes of sediment would need to be placed to account for the accelerating rise in sea level to ensure that the current standard of protection provided by the dunes and beaches remains.	Erosion of the beaches would accelerate with sea level rise and increased storminess. Increasing beach nourishment volumes would be required to maintain the veneer beaches to ensure that the current standard of protection provided by the beaches and the dunes remains.

Location	Predicted Change for 'With Present Management'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Anderby Creek to Chapel St Leonards **PU O** **CA 17**	The timber groynes that support the beach frontage backed by dunes are to be gradually removed under the Lincshore scheme. Vegetated Dunes stabilised with grouted stone revetment to front face would remain during this period. Approximately 200m behind the dunes an earth embankment provides additional flood protection. The combination of defences provides the standard of protection.	The timber groynes would have gone under the Lincshore scheme. Vegetated Dunes stabilised with grouted stone revetment to front face would remain and undergo improvements during this period. The earth embankment approximately 200m behind the dunes would be improved to account for sea level rise. The combination of defences provides the standard of protection.	Vegetated Dunes stabilised with grouted stone revetment to front face would remain and undergo improvements during this period. The earth embankment approximately 200m behind the dunes would be improved to account for sea level rise. The combination of defences provides the standard of protection.
	Veneer beaches fronting defences would be maintained by renourishment under the Lincshore scheme. The beach volume would keep pace with sea level rise due to the 7,500m^3 nourishment allowance. Structures and embankment maintained to provide the standard of protection.	Veneer beaches fronting defences would be maintained by renourishment under the Lincshore scheme. Increasing volumes of sediment would need to be placed to account for the accelerating rise in sea level to ensure that the current standard of protection provided by the dunes remains. Structures and embankment maintained and improved to keep pace with sea level rise .	Erosion of the beaches would accelerate with sea level rise and increased storminess. Increasing beach nourishment volumes would be required to maintain the veneer beaches to ensure that the current standard of protection provided by beaches and the dunes remains. Structures and embankments maintained and improved to keep pace with sea level rise .

Location	Predicted Change for 'With Present Management'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Chapel St Leonards **PU O** **CA 18a**	At Chapel Point a stepped concrete apron topped with wave return wall provides protection. At Chapel St Leonards a concrete tunnel outfall exists. South of Chapel St Leonards promenade exists between the beach and the dunes behind. All of these structures and the veneer beaches would remain.	All defence structures and the veneer beaches would be maintained and improved to keep pace with sea level rise.	All defence structures and the veneer beaches would be maintained and improved to keep pace with sea level rise.
	Veneer beaches fronting defences would be maintained by renourishment under the Lincshore scheme. The beach volume would keep pace with sea level rise due to the 7,500m^3 nourishment allowance. Defences would be maintained and improved to account for sea level rise.	Veneer beaches fronting defences would be maintained by renourishment under the Lincshore scheme. Increasing volumes of sediment would need to be placed to account for the accelerating rise in sea level. The structures at the rear of the beaches would be maintained and raised to account for the rising sea levels.	Erosion of the beaches would accelerate with sea level rise and increased storminess. Increasing beach nourishment volumes would be required to maintain the veneer beaches. Increasing levels of intervention would be needed to maintain and raise the structures at the rear of the beaches to keep pace with sea level rise.

Location	Predicted Change for 'With Present Management'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Chapel St Leonard to Ingoldmells **PU O** **CA18a**	The defences along this section consist of a raised promenade with combination of smooth concrete sloped revetment or stepped concrete apron down to beach. All of these structures and the veneer beaches would remain.	All defence structures and the veneer beaches would be maintained and improved to keep pace with sea level rise.	All defence structures and the veneer beaches would be maintained and improved to keep pace with sea level rise.
	Veneer beaches fronting defences would be maintained by renourishment under the Lincshore scheme. The beach volume would keep pace with sea level rise due to the 7,500m^3 nourishment allowance. Defences would be maintained and improved to account for sea level rise.	Veneer beaches fronting defences would be maintained by renourishment under the Lincshore scheme. Increasing volumes of sediment would need to be placed to account for the accelerating rise in sea level. The structures at the rear of the beaches would be maintained and raised to account for the rising sea levels.	Erosion of the beaches would accelerate with sea level rise and increased storminess. Increasing beach nourishment volumes would be required to maintain the veneer beaches. Increasing levels of intervention would be needed to maintain and raise the structures at the rear of the beaches to keep pace with sea level rise.

Location	Predicted Change for 'With Present Management'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Ingoldmells to Skegness **PU O** **CA 18b**	This unit consists of a number of types of defence structures mainly Seabee revetments or stepped concrete aprons. Behind the concrete revetments in the majority of the length there is a promenade with and without additional wave wall sections. Between Ingoldmells and Skegness some of the shoreline is backed by dunes, in particular at the golf course, this area is fronted by rock revetment not concrete defences. Some groynes exist along the beach frontage of this unit; however, under the Lincshore scheme it is proposed that these groynes are removed. South of Skegness the Lagoon Walk development is a concrete promenade protected by rock armour; it heads seaward and before turning south parallel to the shoreline. Behind this is an area of dunes which provides protection to the land behind. The various defences would remain and be improved over the epoch to keep pace with sea level rise.	All defence structures and the veneer beaches would be maintained and improved to keep pace with sea level rise.	All defence structures and the veneer beaches would be maintained and improved to keep pace with sea level rise.

Location	Predicted Change for 'With Present Management'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
	Veneer beaches fronting defences would be maintained by renourishment under the Lincshore scheme. The beach volume would keep pace with sea level rise due to the 7,500m^3 nourishment allowance. Defences would be maintained and improved to account for sea level rise.	Veneer beaches fronting defences would be maintained by renourishment under the Lincshore scheme. Increasing volumes of sediment would need to be placed to account for the accelerating rise in sea level. The structures at the rear of the beaches would be maintained and raised to account for the rising sea levels.	Erosion of the beaches would accelerate with sea level rise and increased storminess. Increasing beach nourishment volumes would be required to maintain the veneer beaches. Increasing levels of intervention would be needed to maintain and raise the structures at the rear of the beaches to keep pace with sea level rise.

Location	Predicted Change for 'With Present Management'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
South Skegness **PU P** **CA 19**	The area south of Skegness consists of a wide swath of vegetated dunes and wetlands. Vegetated sand dunes would remain for this epoch and would continue to offer natural protection.	Vegetated sand dunes would remain for this epoch, fed by sediment transported southwards from the Lincshore nourishments and from offshore. The dunes would continue to offer natural protection.	Vegetated sand dunes would remain for this epoch, fed by sediment transported southwards from the Lincshore nourishments and from offshore. The dunes would continue to offer natural protection.
	The Lincshore renourishment scheme would ensure the continuation of the sediment supply along this frontage which would allow accretion to continue. Natural protection offered by the dunes would remain.	The Lincshore renourishment scheme and transport of sediment from offshore would ensure the continuation of the sediment supply along this frontage which would allow accretion to continue despite accelerating sea level rise. Natural protection offered by the dunes would remain.	Natural protection offered by the dunes would remain. The continued and enhanced nourishment of updrift beaches, along with the input of material from offshore, would help maintain the dunes. However, accretion rate would slow and the system state could change to one of erosion due to rapidly rising sea levels unless the supply of sediment to this area increased sufficiently to offset relative sea level rise.

Location	Predicted Change for 'With Present Management'		
	Epoch 1 (2025)	*Epoch 2 (2055)*	*Epoch 3 (2105)*
Gibraltar Point **PU P** **CA 19**	Grassed earth embankment fronted by dunes provides protection from flood waters towards the south of Gibraltar Point. Along the tidal stretch of the River Steeping flood banks and flood walls provide protection from tidal flooding.	Natural protection offered by the dunes would remain. Earth embankments and flood walls would be maintained and improved to keep pace with sea level rise.	Natural protection offered by the dunes would remain. Earth embankments and flood walls would be maintained and improved to keep pace with sea level rise.
	Large swath of dunes and wetland/salt marsh are fronted by beaches along the east and intertidal mud flats to the south. The River Steep cuts a path through the intertidal mud flat/salt marsh to the south and discharges into the Wash. Flood walls and earth embankments would be repaired and maintained. Continued accretion of the dunes would occur as sediment feed from nourished updrfit beaches would continue. Natural protection offered by the dunes would remain.	Flood walls and earth embankments would be maintained and improved. Beaches would steepen due to rising sea levels. Continued accretion of the dunes would occur as sediment feed from offshore and from nourished updrifit beaches would continue. Natural protection offered by the dunes would remain.	Flood walls and earth embankments would be maintained and improved. Beaches would steepen due to rising sea levels. Continued accretion of the dunes may occur due to the continued feed of sediment from offshore and from nourished updrifit beaches. However the rate of accretion would slow and the system could change to an eroding state if the rate that sediment deposited is insufficient to outpace accelerating sea level rise. Natural protection offered by the dunes would remain, however if low points / breaches occur due to rapidly rising sea levels and increased storminess, intervention would be carried out ensure that the current standard of protection is maintained.

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C6 Glossary

Term	Definition
Accretion	The addition of newly deposited sediment.
Adaptation	The need for a community or habitat to modify the way it functions in response to a changing environment.
Baseline scenarios	Concept used in developing a SMP to illustrate the role of shoreline management by assessing the effect of two contrasting management approaches – 'no active intervention' and 'with present management' – for all frontages and all epochs.
Bathymetry	Relating to sea bed levels
Beach nourishment	Artificial process of replenishing the beach with material from another source.
Beach recycling	Artificial process of replenishing a beach by taking surplus sand from one part of the coastline to recharge depleted areas.
Breaker zone	Area in the sea where incoming waves begin to break.
Climate change	Long-term change in the patterns of average weather. Its relevance to shoreline management concerns its effect on sea levels, current patterns and storminess.
Coastal squeeze	The reduction in habitat area that can arise if the natural landward migration of a habitat due to sea level rise is prevented by the fixing of the high water mark, for example by sea wall.
Condition grade	Indicator based on visual inspection of defence condition ranging from condition grade 1 (very good) to grade 5 (very poor). Undertaken by the operating authority.
Downdrift	In the direction of movement of beach materials along the shoreline.
Ebb tide	The falling tide, the part of the tidal cycle between high water and the next low water.
Ecosystem	Organisation of the biological community and the physical environment in a specific geographical area.
Epoch	A period of time. For SMPs, three epochs are defined: Epoch 1: present day to 2025 Epoch 2: 2025 to 2055 Epoch 3: 2055 to 2105
Erosion	The process of removing sediment from the cliff or beach
Feature	Something tangible that provides a service to society in one form or another or, more simply, benefits certain aspects of society by its very existence. Usually this will be in a specific place and relevant to the SMP.
Flood tide	Rising tide, part of the tidal cycle between low water and the next high water.
Foreshore	Zone between the high water and low water marks.
Gabion	A cage filled with rock used to stabilise the shoreline against erosion.

Term	Definition
Geomorphology	The branch of physical geography/geology that deals with the form of the Earth, the general configuration of its surface, the distribution of the land, water etc.
Groyne	Coast protection structure built perpendicular to the shoreline and designed to trap sediment (shingle, sand and mud).
Intent of management	A vision for the future of shoreline management along a certain frontage for all epochs. This vision is then translated to specific policies for the purpose of management.
Intertidal	The area between high and low tide.
Longshore transport/ drift	The natural transport of beach material along the coast.
Maintain	That the value of a feature is not allowed to deteriorate
Mean sea level	Average height of the sea surface over a 19-year period.
Mean high water	The average level of all high waters observed over a sufficiently long period.
Mean low water	The average level of all low waters observed over a sufficiently long period.
Mudflat	Low-lying muddy land that is covered at high tide and exposed at low tide.
Offshore zone	Extends from the low water mark seawards
Ordnance datum	Elevation used on ordnance survey maps for deriving height. IN the UK, this is mean sea level in Newlyn, Cornwall, measured between 1915 and 1921.
Outflanking	The process whereby erosion occurs immediately adjacent to a defended section of coast, eventually resulting in the land behind the defence being eroded from the side.
Policy	In this context, "policy" refers to the generic shoreline management options (no active intervention, hold the existing line of defence, managed realignment and advance the existing line of defence)
Prograding	When the shoreline is developing and building seaward through accretion.
Residual life	Period of time until a defence has deteriorated to a state in which it no longer performs its function
Revetment	A structure at the rear of the beach to provide protection to the cliff, dune or hard structure at the rear of the beach.
Sea level rise	Increase in sea levels relative to land levels
Sediment cell	A sediment cell is a length of coastline and its nearshore area within which the movement of sand and shingle is largely self-contained.
Sediment transport	The movement of shingle, sand and mud within the coastal zone through the actions of waves, currents, tides and wind.
Shoreline Management Plan	A non-statutory plan that provides a large-scale assessment of the risks associated with coastal processes and presents a policy framework to reduce these risks to people and the developed, historic and natural environment in a sustainable manner.

Term	Definition
Storm surge	A rise in the sea surface on an open coast resulting from a storm.
Sub-littoral	The area of the seas between the intertidal zone and the edge of the continental shelf.
Sustainable	Meeting the needs of the present generation without compromising the ability of future generations to meet their own needs. In terms of sustainability of coastal defences, this refers to the technical, economic and environmental viability of maintaining a defence line.
Swell	Waves that have travelled out of the area in which they were generated.
Tidal prism	The volume of water within an estuary between the level of high and low tide, typically taken for mean spring tides.
Tidal flood risk	The risk of flooding associated with the normal and extreme tidal cycles. Flood risk is measured as the probability of flooding (that is, at location X, there is a 1 in 100 or one per cent chance of flooding in any given year) multiplied by the impact or consequences that will result if flooding occurs.
Tide	Periodic rising and falling of large bodies of water resulting from the gravitational attraction of the moon and sun acting on the rotating earth.
Topography	Level or surface of the land
Transgression	The landward movement of the shoreline in response to a rise in sea level.
Water table	The upper surface of groundwater. Below this level, the soil is saturated with water.

C7 No Active Intervention Mapping

Introduction

C7.1 This section outlines the approach adopted by the HECAG SMP to mapping flood likelihood under the No Active Intervention scenario; for consistency with the adjacent area, the approach used in this SMP was largely similar on that used in the Wash SMP.

Overview of the Wash SMP Flood mapping approach

C7.2 The Wash SMP mapped the extent of an extreme water level (1:1000 years) at 4 different times (present and at the ends of epochs 1, 2 and 3) for the No Active Intervention case. The same water level was used across the entire area. The mapping showed the likelihood of flooding within land areas lower than this level as follows:

Very Low - Low - Medium - High - Very High

C7.3 Likelihood of flooding was assessed according to how many (from 1 to 3) significant flood barriers lay between the area and the sea, and according to the condition of the defences as defined by NFCDD, projected into the future based on the No Active Intervention scenario.

Condition 1 = Very low probability of failure
Condition 2 = Low probability of failure
Condition 3 = Medium probability of failure
Condition 4 = High probability of failure
Condition 5 = Very high probability of failure

C7.4 The Wash SMP estimated the residual life of structures based on their condition, following the SMP guidance. Table 7-1 shows the theoretical deterioration of structures:

Table 7-1: Estimate of deterioration for assessment of the residual life (from SMP guidance).

Defence Description		Estimate of Residual Life (years)				
		Grade 1	Grade 2	Grade 3	Grade 4	Grade 5
Seawall (concrete/masonry)	Fastest	25	15	10	5	0
	Slowest	35	25	15	7	0
Revetment (concrete/rock)	Fastest	25	15	10	5	7
	Slowest	35	25	15	7	0
Timber groynes/timber structures	Fastest	15	10	8	2	0
	Slowest	25	20	12	7	0
Gabion	Fastest	10	6	4	1	0
	Slowest	25	10	7	3	0

C7.5 As the SMP guidance does not contain residual life estimates for grass earth embankments, the Wash SMP team, along with consultation with the EA and Defra, used the information used in the Environment Agency's Strategic Asset Management Plan (SAMP 2007) to predict the residual life profile for this defence type. The deterioration profile was presented in the same format as for other defences provided in the SMP guidance. This is summarised in Table 7-2.

Table 7-2: Deterioration profile for wide earth embankment with a turf revetment (SAMP, 2007).

Defence Description		Estimate of Residual Life (years)				
		Grade 1	Grade 2	Grade 3	Grade 4	Grade 5
Sea bank	Fastest	25	15	10	3	0
	Slowest	40	25	15	5	0

C7.6 On the basis of these residual life profiles, all defences, even if grade 1 standard can be assumed to have very high probability of failure (Grade 5 or lower) by the end of epoch 2, as the maximum residual life is 40 years as the slowest deterioration of sea banks.

Methodology for mapping No Active Intervention flood likelihood used in the HECAG SMP

C7.7 Similar to the Wash SMP identification of flood risk, a single water level representative of the 1 in 200 year event was adopted for each epoch across the entire HECAG SMP2 area; It was agreed with the CSG that a water level with a return period of 200 years fits better with PPS25 instead of a 1 in 1000 year return period as used by the Wash SMP.

C7.8 The extreme water levels at the end of each epoch were projected on to a Digital Elevation Model of the study area created from LiDAR data. From this, a simplified outer envelope of the flood extent was generated showing the maximum area at risk of flooding for each epoch.

Extreme water levels used

C7.9 Based on water level data provided (See Section 0), the 1 in 200 year water level (with a base year of 2006) ranges from 4.56m OD at Spurn to 5.09m OD at Immingham and 5.03m OD at Burgh Sluice. It is considered that a median water level of 4.8m OD (with a base year of 2006) is broadly representative of the 1 in 200 year water level along the coastline at risk from flooding. Based on this figure, the 1 in 200 year water levels at the end of each epoch have been calculated including sea level rise on the basis of the sea level rise projections within Defra's FCDPAG3 climate change impacts guidance – see Table 7-3 . These water levels were used to map flood likelihood (0).

Table 7-3. Extreme water levels used for each epoch for the NAI Flood Mapping.

2006 Water Level (mOD)	2008 Water Level (mOD)	Epoch 1:2025 Water Level (mOD)	Epoch 2: 2055 Water Level (mOD)	Epoch 3: 2105 Water Level (mOD)
4.8	4.81	4.88	5.13	5.79

Extreme water levels were estimated from data present in the following sources:

- Northern Area Tidal Modelling (2007): Pilot Study Commission No AN645, May 2007, Mott MacDonald
- Humber Estuary Shoreline Management Plan Phase 2 (2005): Geomorphology Addendum, June 2005, Black & Veatch / Halcrow
- Humber Tidal Database and Joint Probability Analysis of Large Waves and High Water Levels (2007): Project Ref: R/3689/1, Report No: R.810, Annex II Addendum to Data Report, October 2007

Flood likelihood classification

C7.10 The approach of the Wash SMP was adapted for the HECAG SMP, with the effect of multiple barriers replaced by defence standards based on condition ratings ().

Table 7-4: Flood likelihood classification on the basis of standard of protection and condition ratings.

Defence standard (return period, yrs)	Condition				
	1	2	3	4	5
≤10	Very High	Very High	Very High	Very High	Very high
11 - 49	Medium	Medium	High	High	Very high
50-199	Low	Low	Medium	Medium	Very high
≥200	Very low	Very low	Low	Medium	Very high

C7.11 As used in the Wash SMP, the decay of defences was calculated using the tables provided in the Defra guidance. To maintain consistency, the residual life of earth embankments was based on the SAMP (2007) deterioration profile also used by the Wash SMP.

C7.12 Due to sea level rise, the standard of protection offered by the defences will fall and this was accounted for in the future flood risk likelihood predictions.

No Active Intervention Scenario mapping

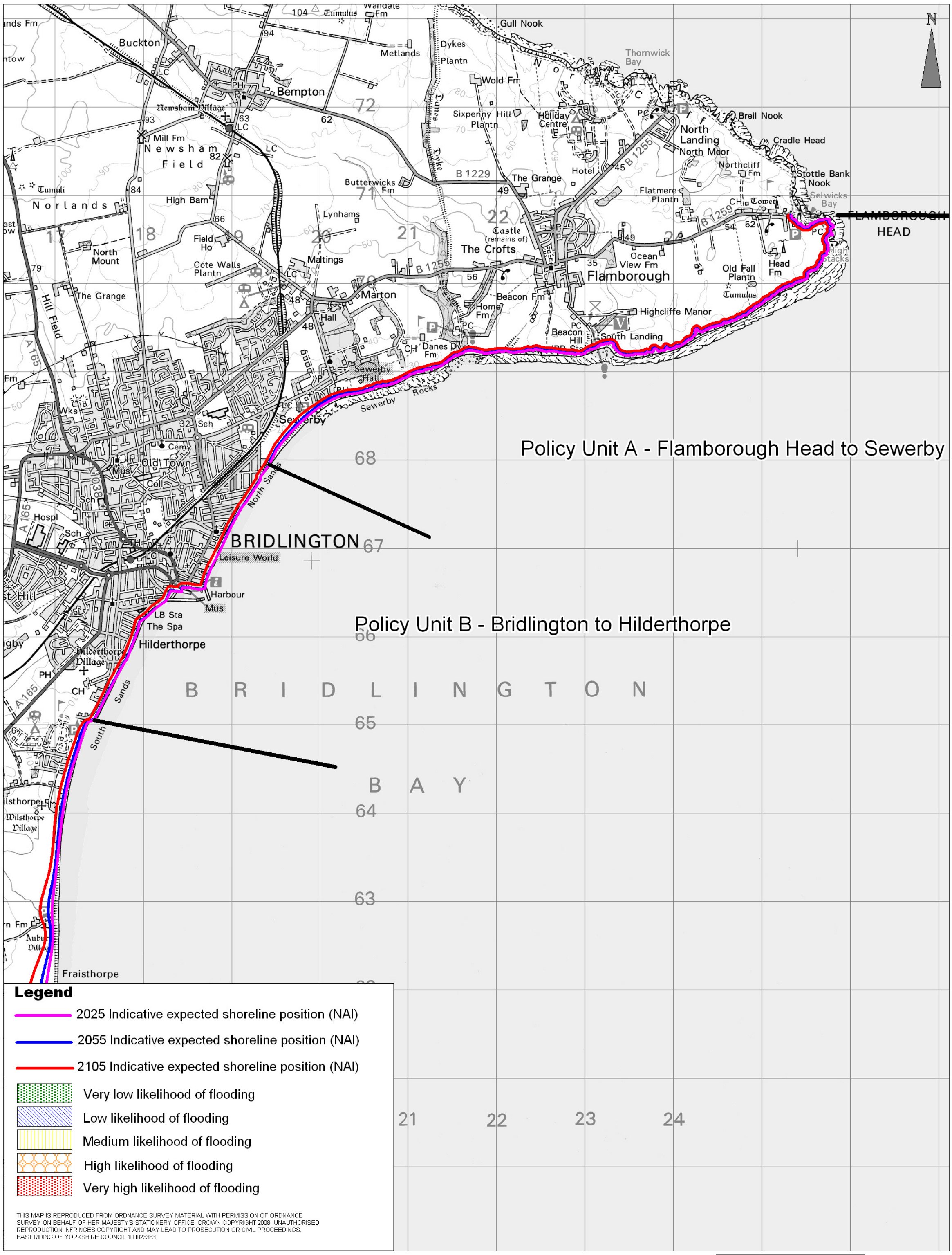
C7.13 The following mapping (NAI PU A to PU P 1, 2 and 3 – see Section C8) has been produced using the above methodology (C7.7 - C7.12) to show the likelihood of flooding at the end of each epoch for the No Active Intervention scenario described in section C3. The predicted indicative shoreline positions for the eroding coast are also shown on the maps for this scenario.

With Present Management Scenario mapping

C7.14 The following maps (WPM PU A to PU P – see section C9) show the expected shoreline behaviour under 'With Present Management' described in section C4. As protection against flooding would remain at the present day standard, the Environment Agency Flood Zone 3 Area has been used to indicate the floodplain protected by the defences. The predicted indicative shoreline positions along the undefended eroding coast have also been mapped for each epoch.

C8 No Active Intervention Mapping

Note: Following consultation, the predicted indicative erosion lines presented here were modified and smoothed for the SMP preferred policy to represent more likely ‘on the ground’ cliff positions (See Main Document and Non Technical Summary). The erosion rates at Flamborough were also revised and updated following consultation review.



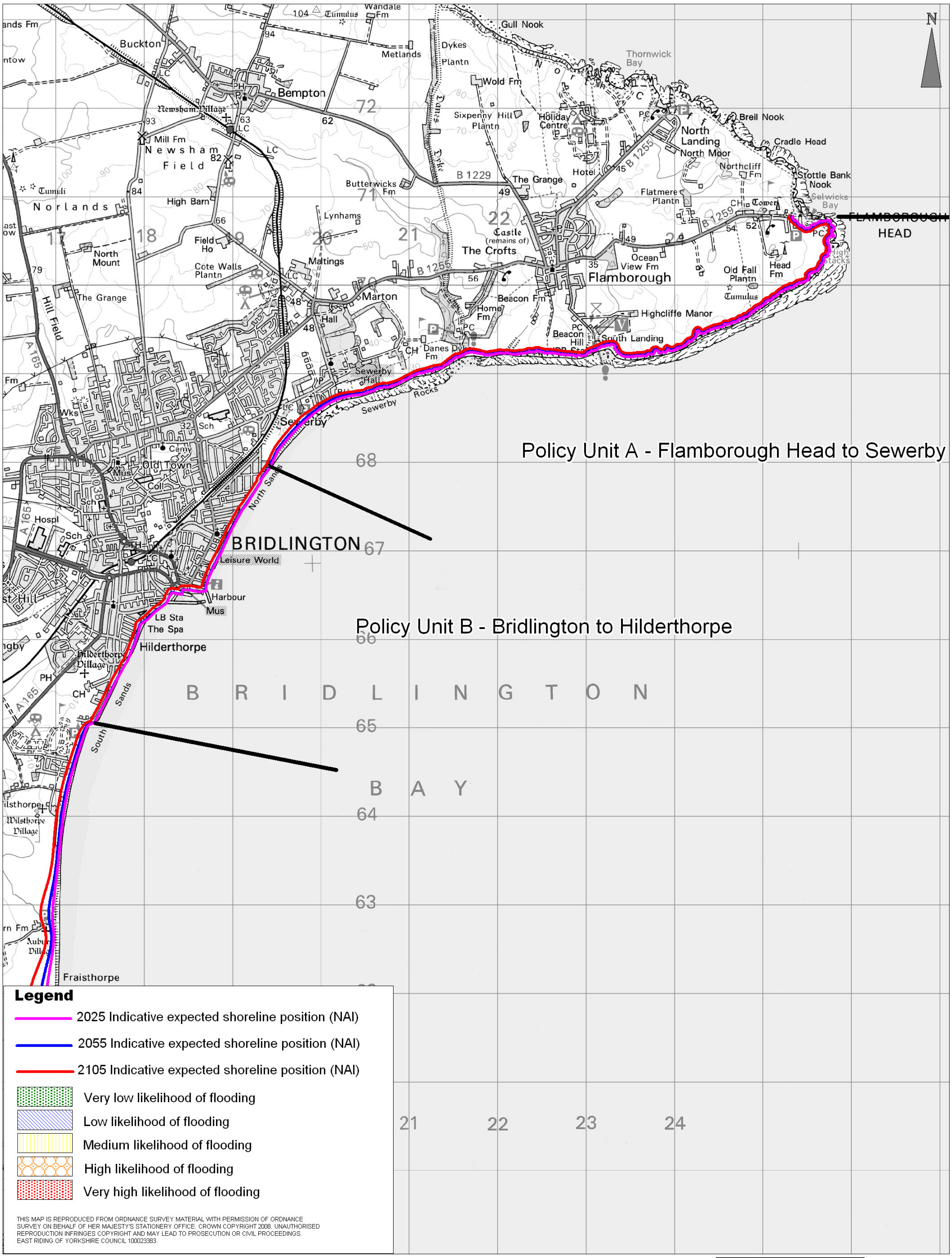
Project:
HECAG SMP

Title:
Baseline Scenario: No Active Intervention - Epoch 1

NAI PU A&B 1

Scale: 1:60,000

Drw	App	Chk
JS	LM	DD
Rev 1	Date Final	



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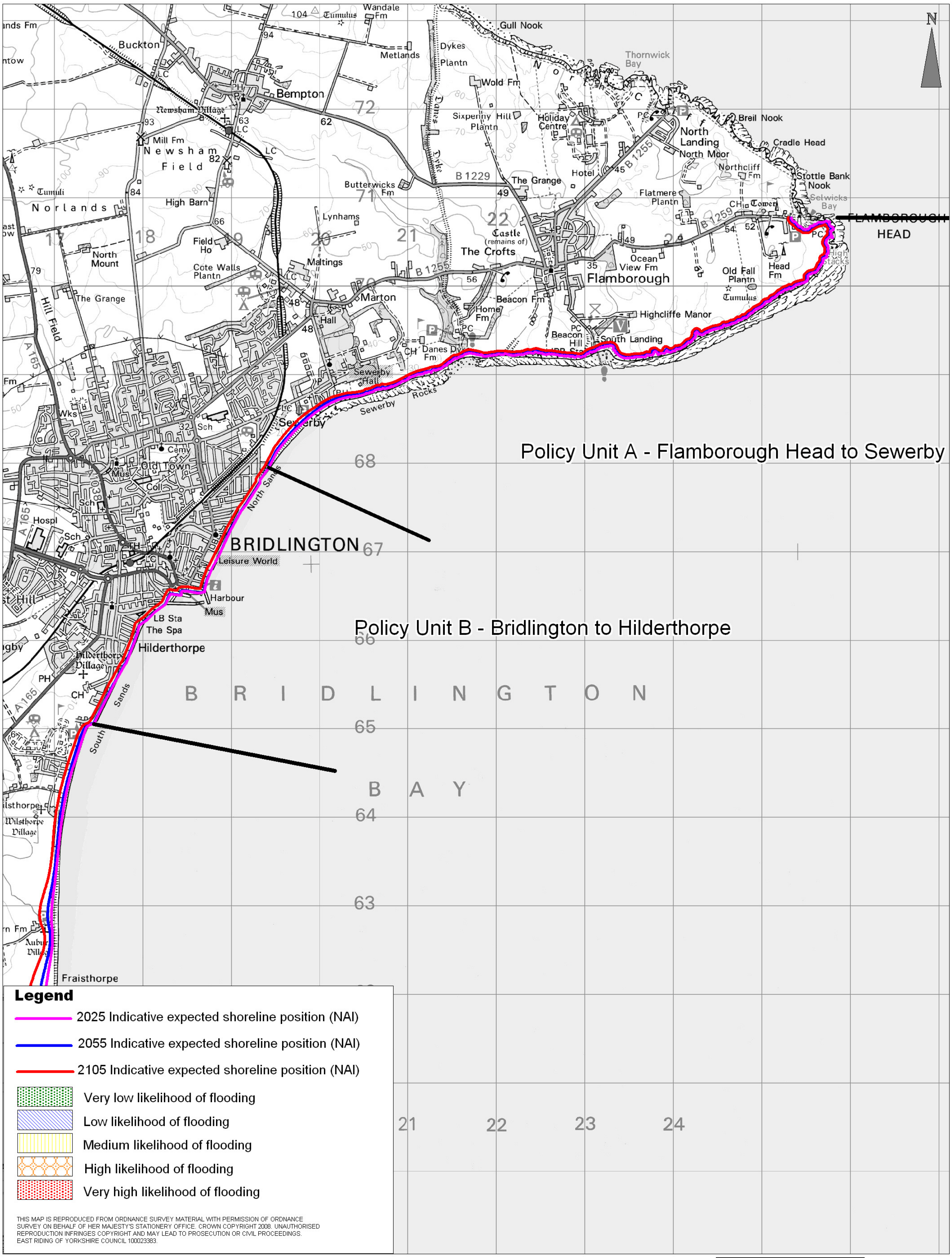
	Scale: 1:60,000		
Title: **Baseline Scenario: No Active Intervention - Epoch 2**	Drw JS	App LM	Chk DD
	Rev 1	Date Final	



Project:
HECAG SMP

Title:
Baseline Scenario: No Active Intervention - Epoch 3

NAI PU A&B 3

Scale: 1:60,000

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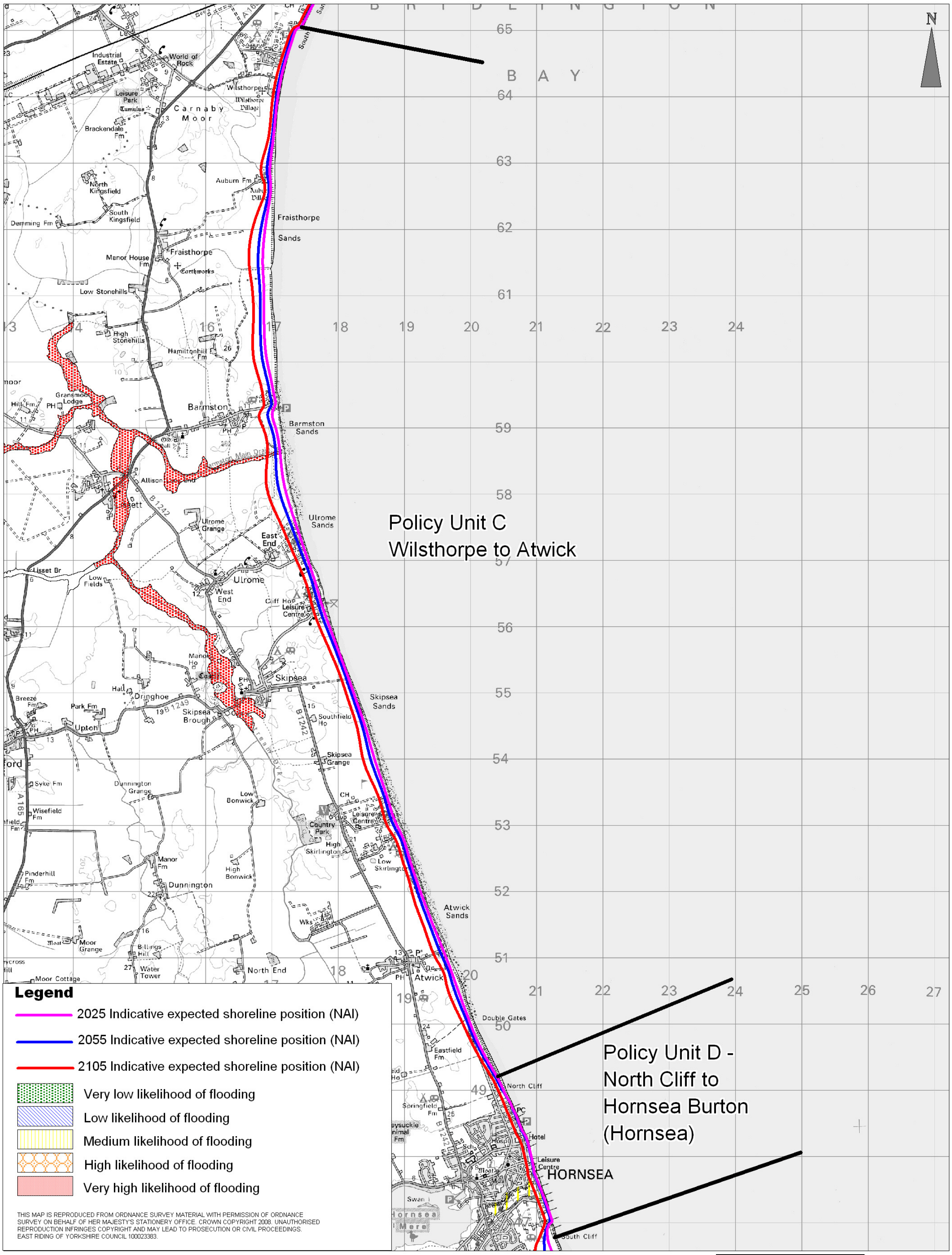
JS	LM	DD
Rev 1	Date Final	



Project:
HECAG SMP

Title:
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NAI PU C&D 1

Scale: 1:80,000

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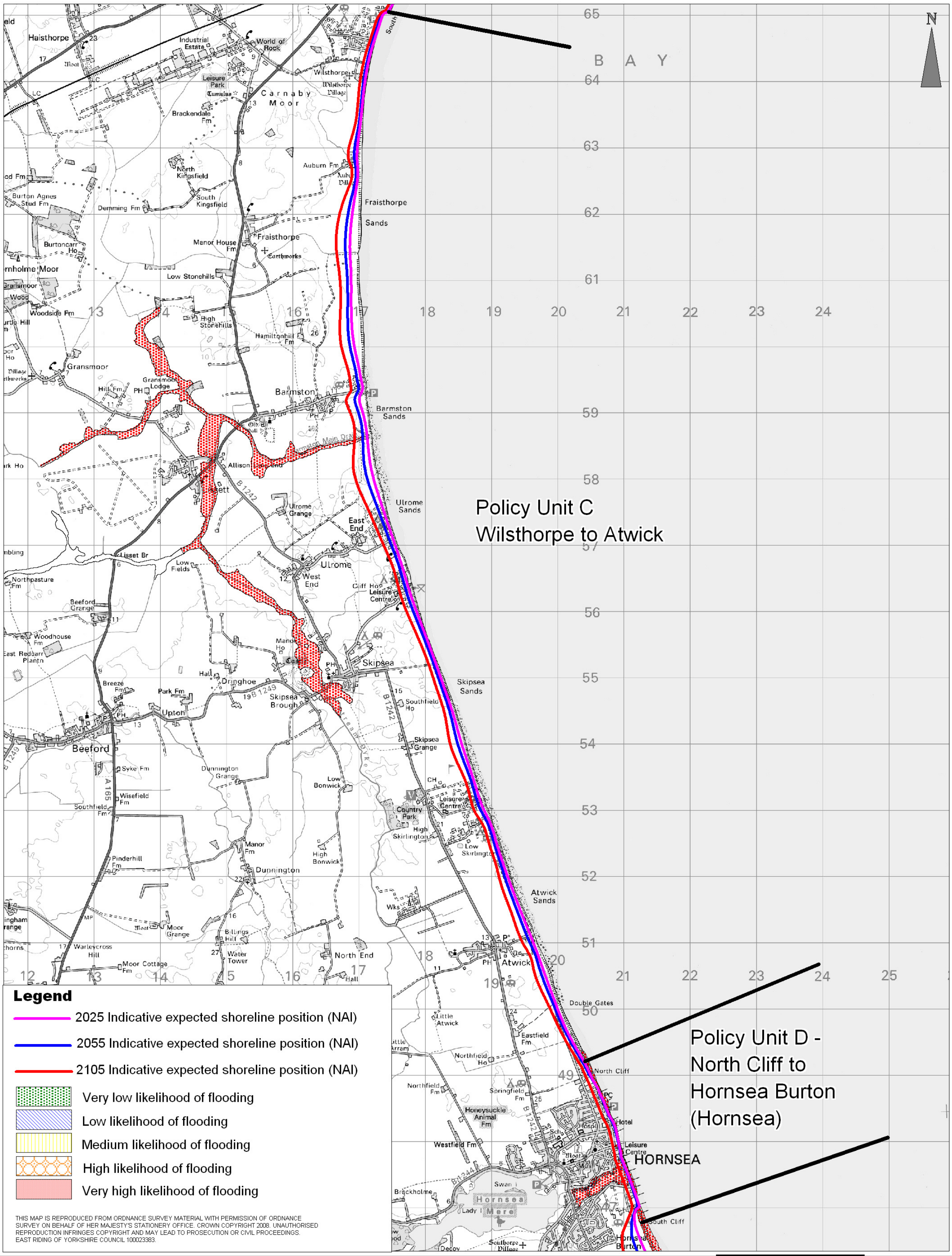
JS	LM	DD
Rev 1	Date Final	



Project:

HECAG SMP

Title:

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NAI PU C&D 2

Scale: 1:80,000

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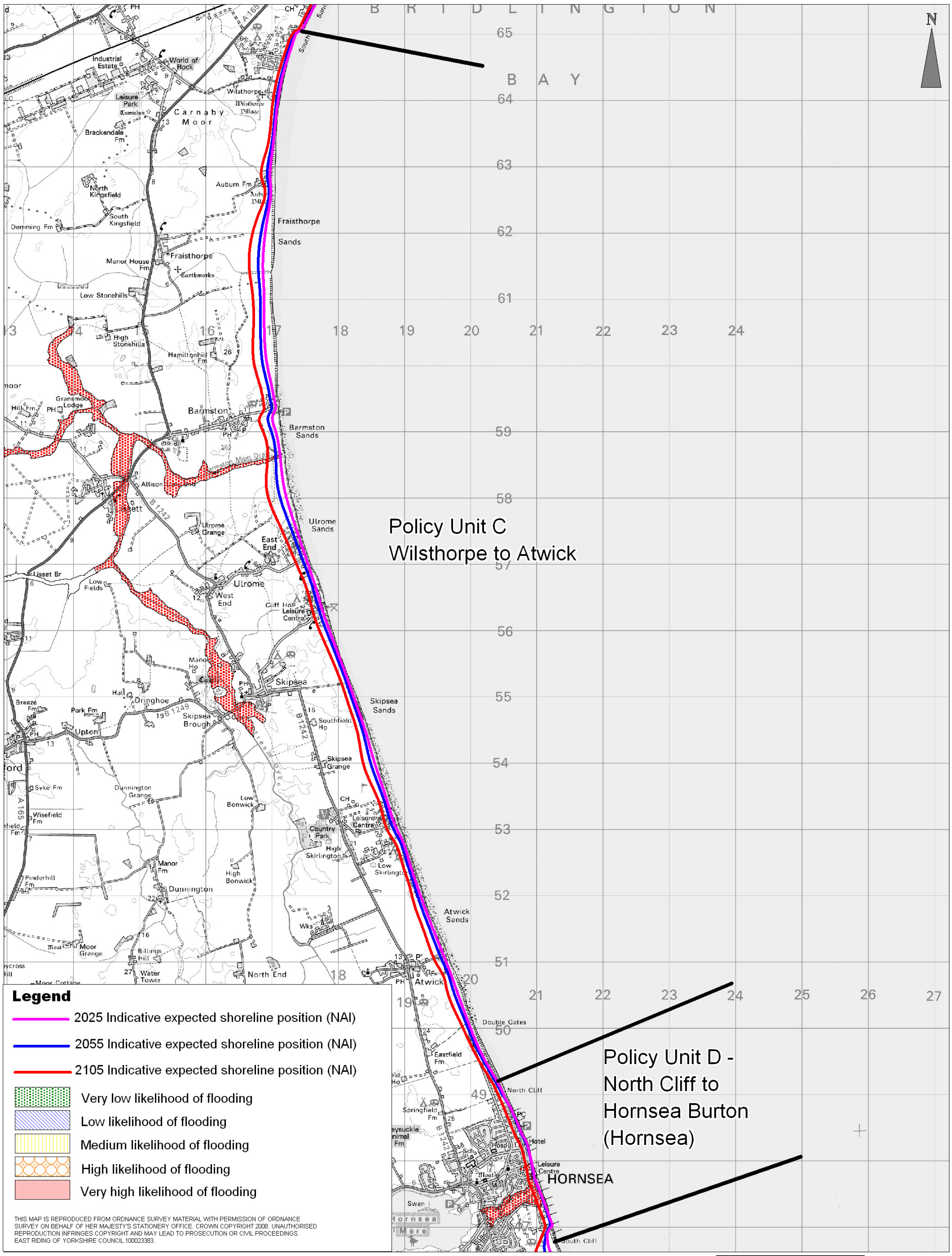
Rev 1	Date Final	



Project:
HECAG SMP

Title:
Baseline Scenario: No Active Intervention - Epoch 3

NAI PU C&D 3

Scale: 1:80,000

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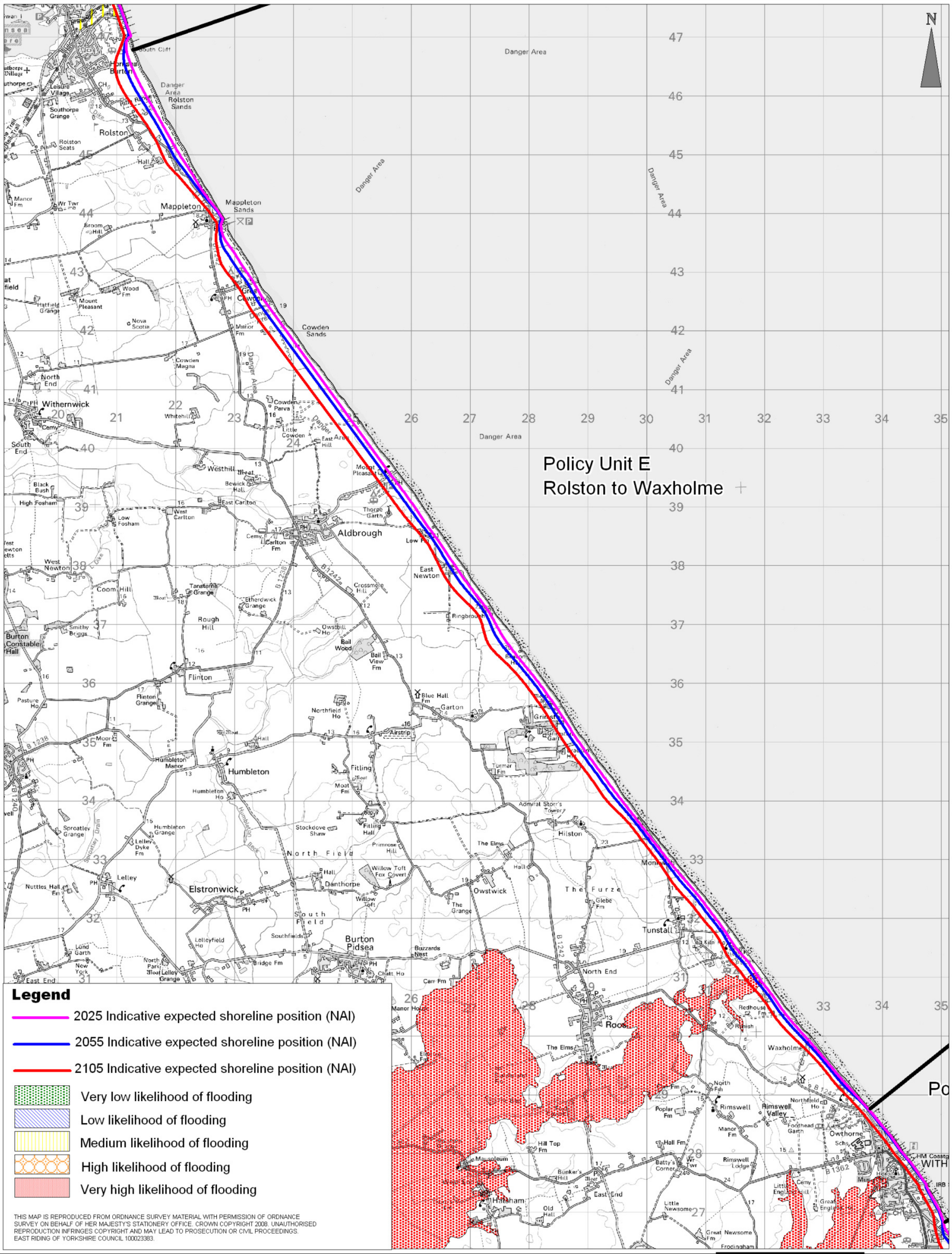
JS	LM	DD
Rev 1	Date Final	



Project:

HECAG SMP

Title:

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NAI PU E 1

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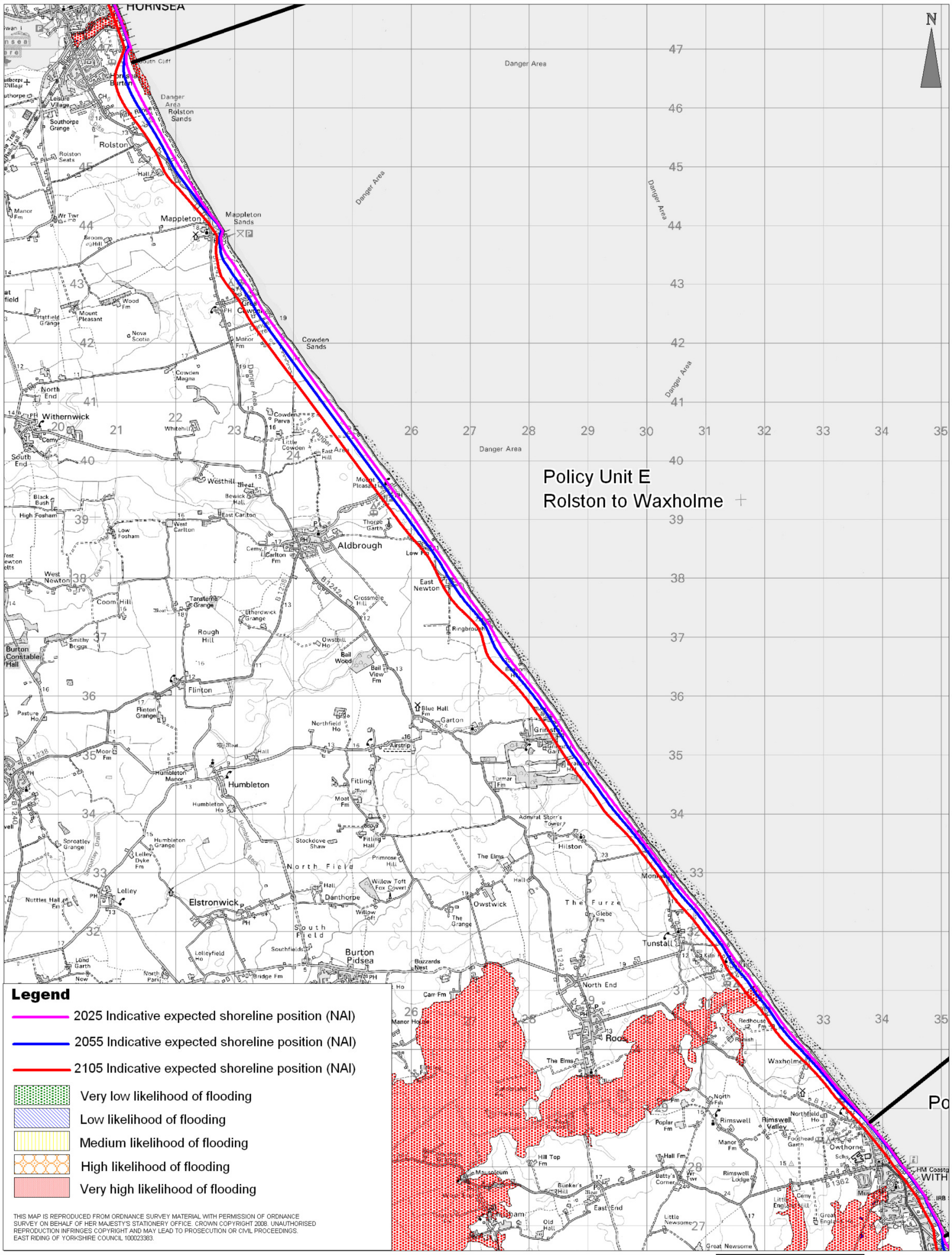
JS	LM	DD
Rev 1	Date Final	



Project:

HECAG SMP

Title:

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NAI PU E 2

Scale: 1:90,000

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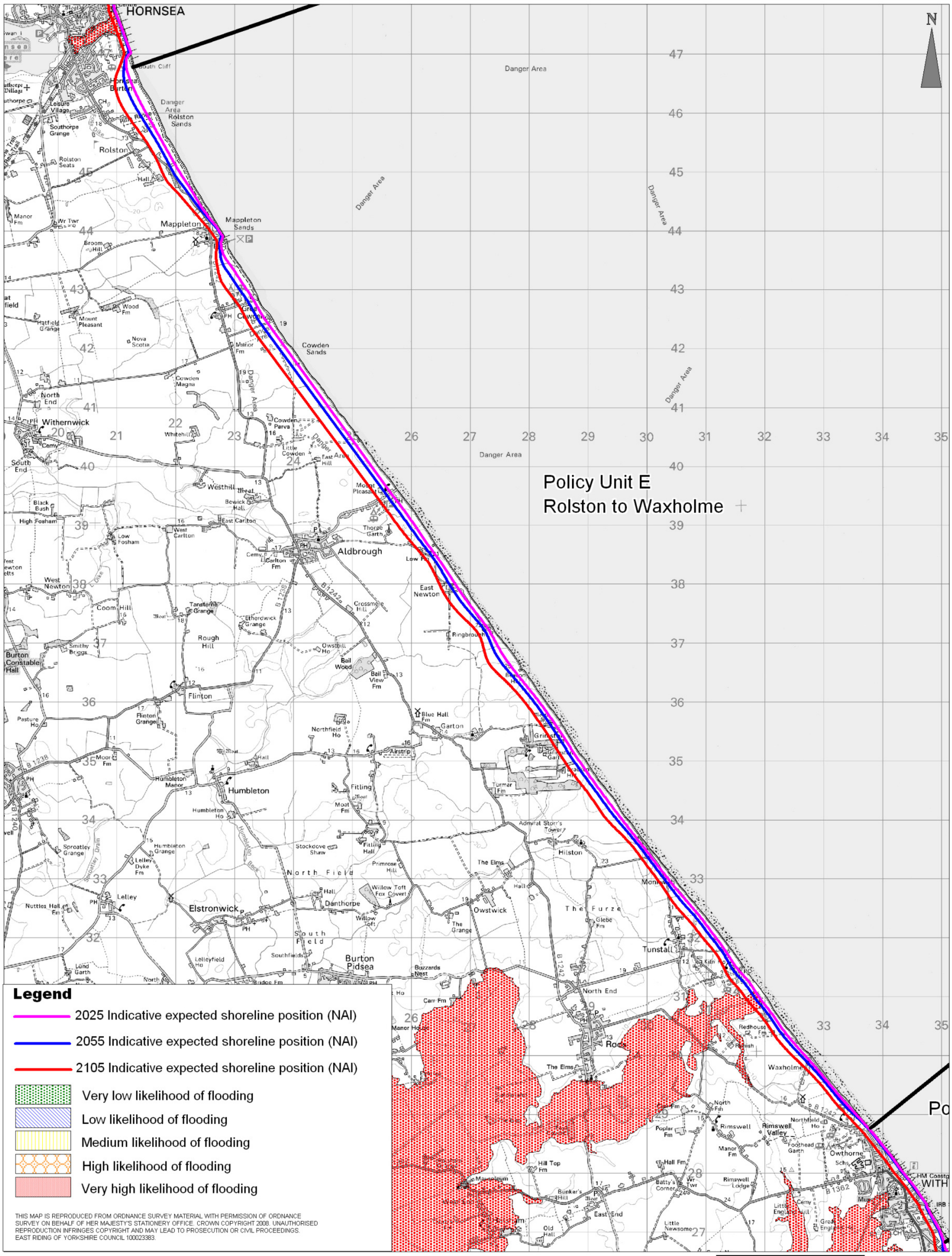
JS	LM	DD
Rev	Date	
1	Final	



Project:

HECAG SMP

Title:

Baseline Scenario: No Active Intervention - Epoch 3

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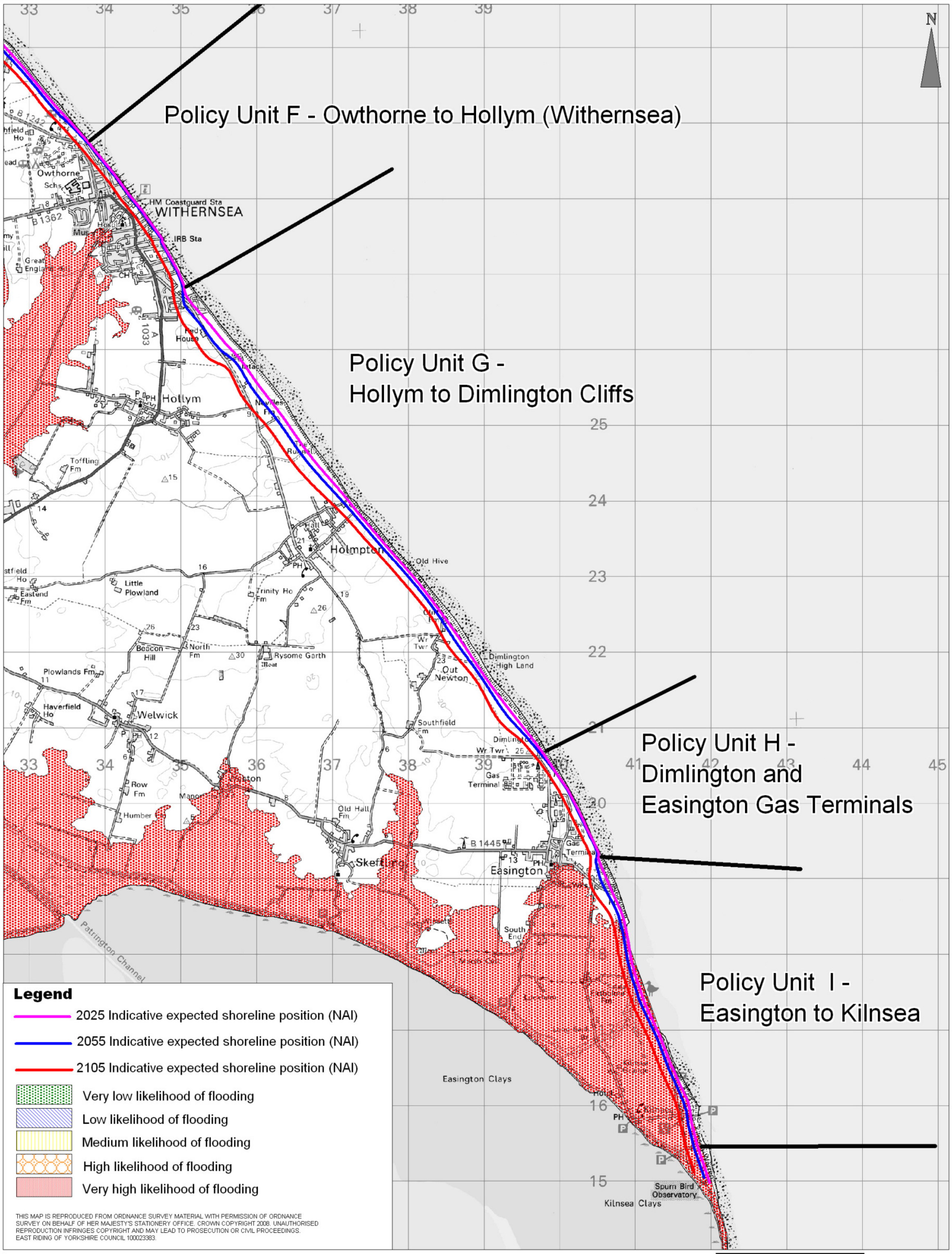
Rev **1**	Date Final	



Project:
HECAG SMP

Title:
Baseline Scenario: No Active Intervention - Epoch 1

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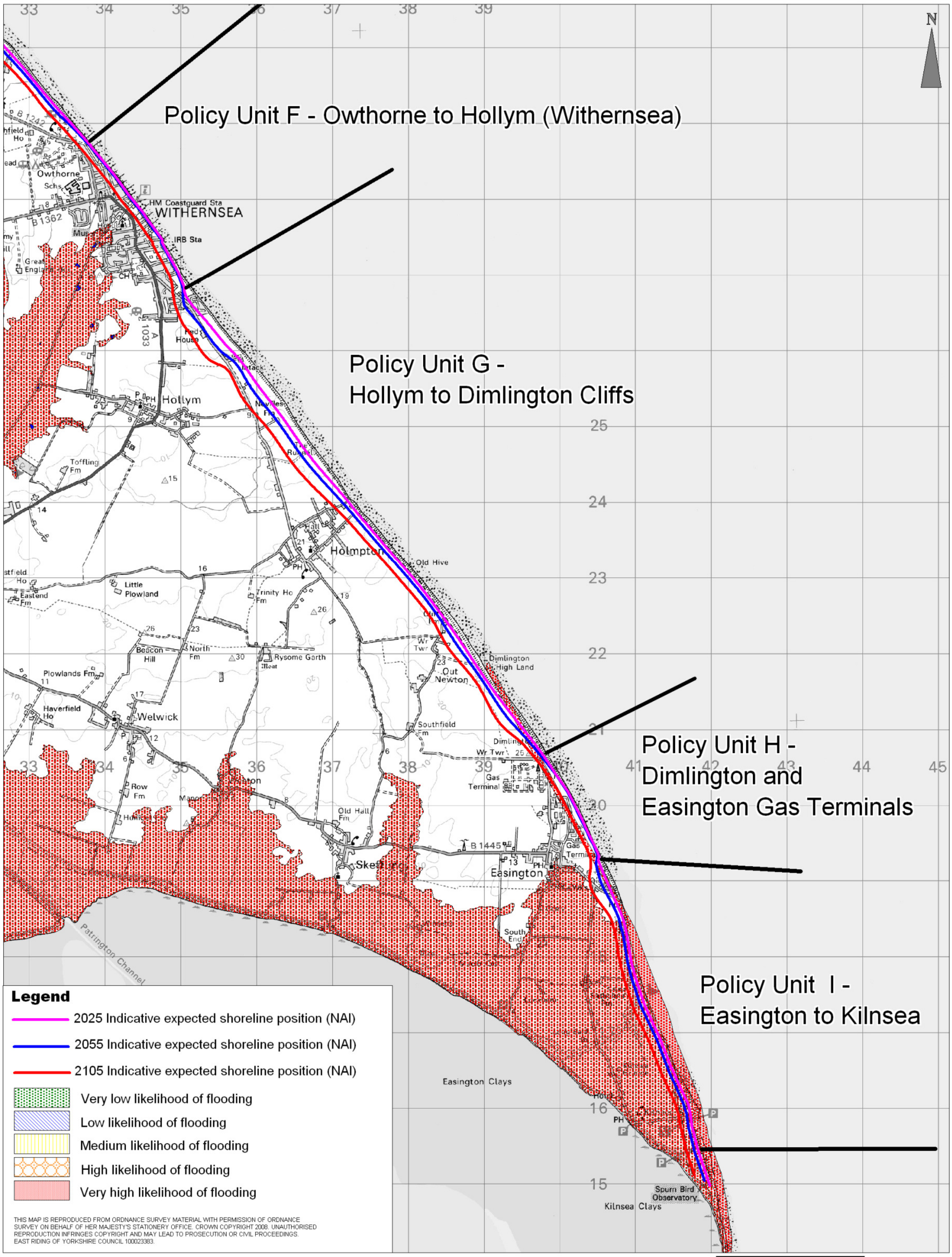
Rev 1	Date Final	



Project:
HECAG SMP

Title:
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NAI PU F-I 2

Scale: 1:70,000

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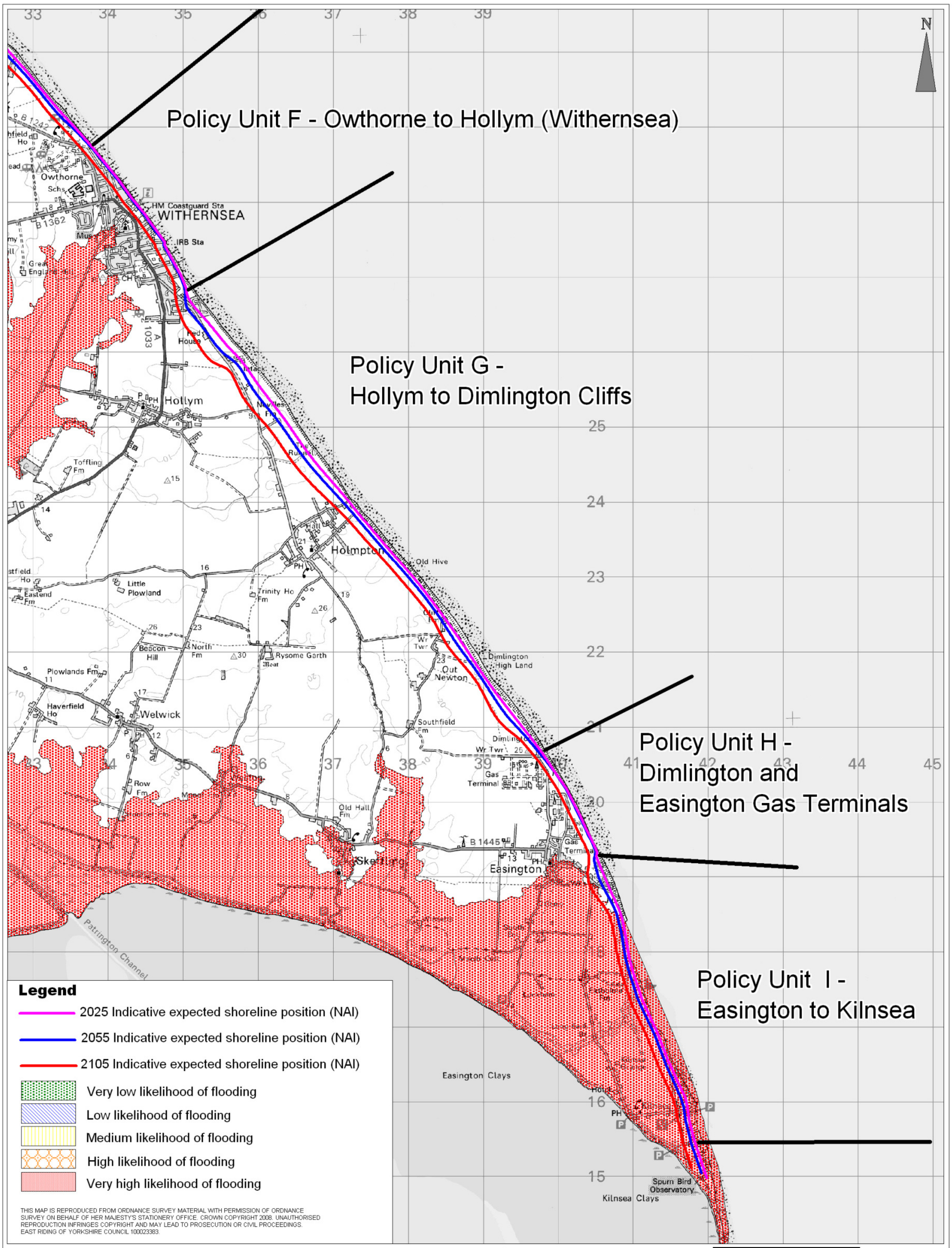
JS	LM	DD
Rev 1	Date Final	



Project:
HECAG SMP

Title:
Baseline Scenario: No Active Intervention - Epoch 3

NAI PU F-I 3

Scale: 1:70,000

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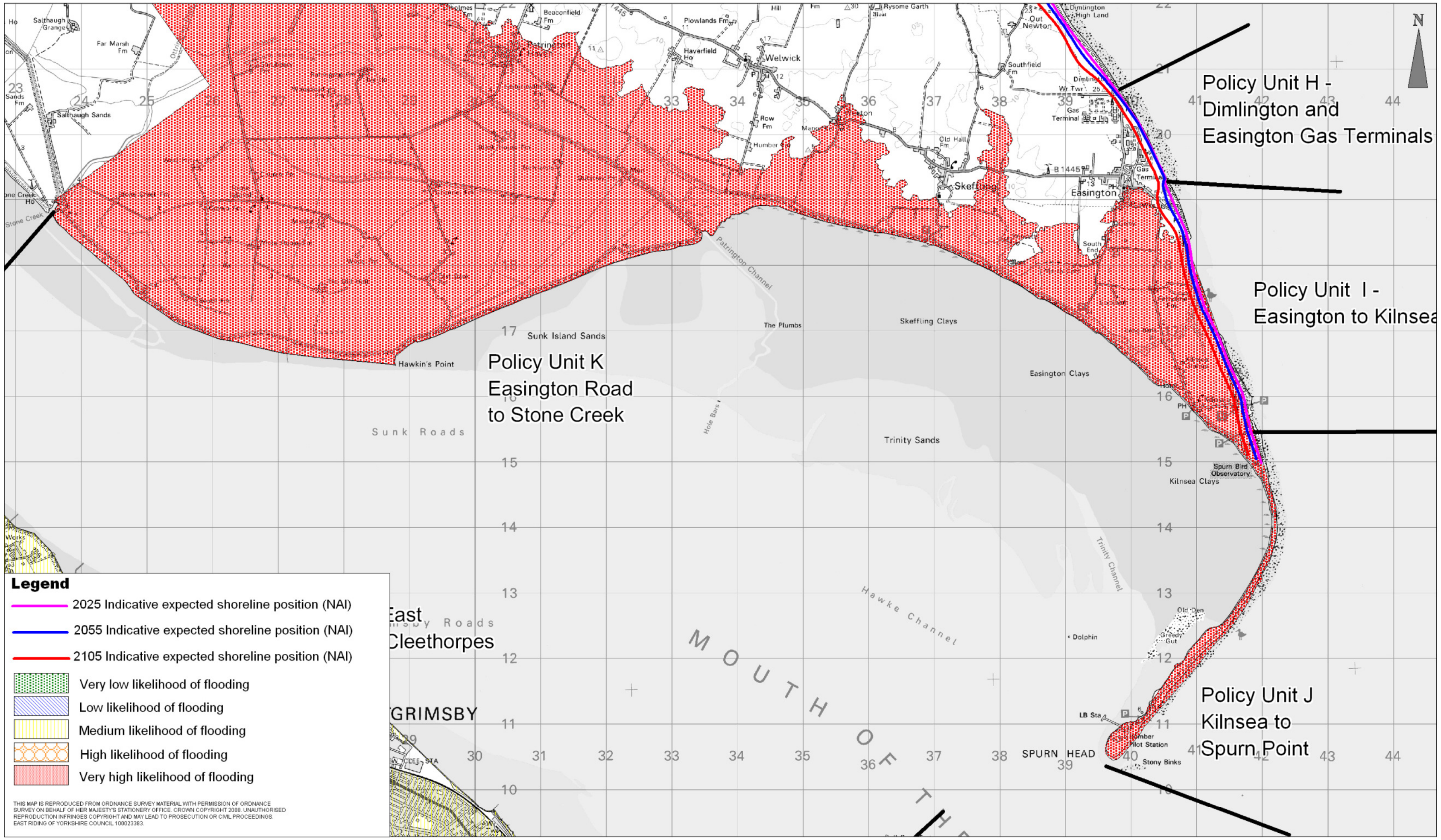
JS	LM	DD
Rev 1	Date Final	



Project:

HECAG SMP

Title:

Baseline Scenario: No Active Intervention - Epoch 1

NAI PU J&K 1

Scale: 1:80,000

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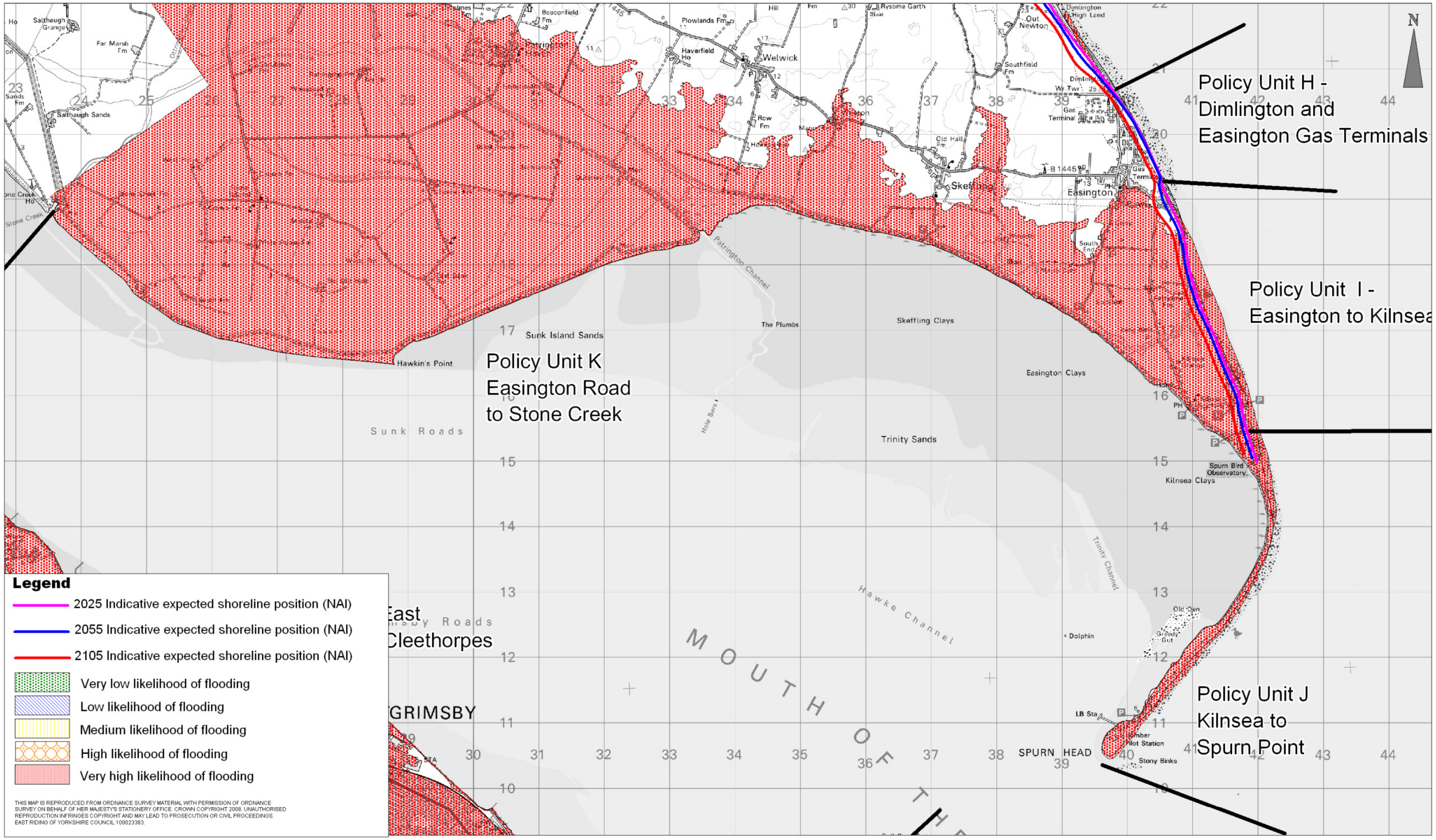
JS	LM	DD
Rev 1	Date Final	



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HECAG SMP

Title:

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NAI PU J&K 2

Scale: 1:80,000

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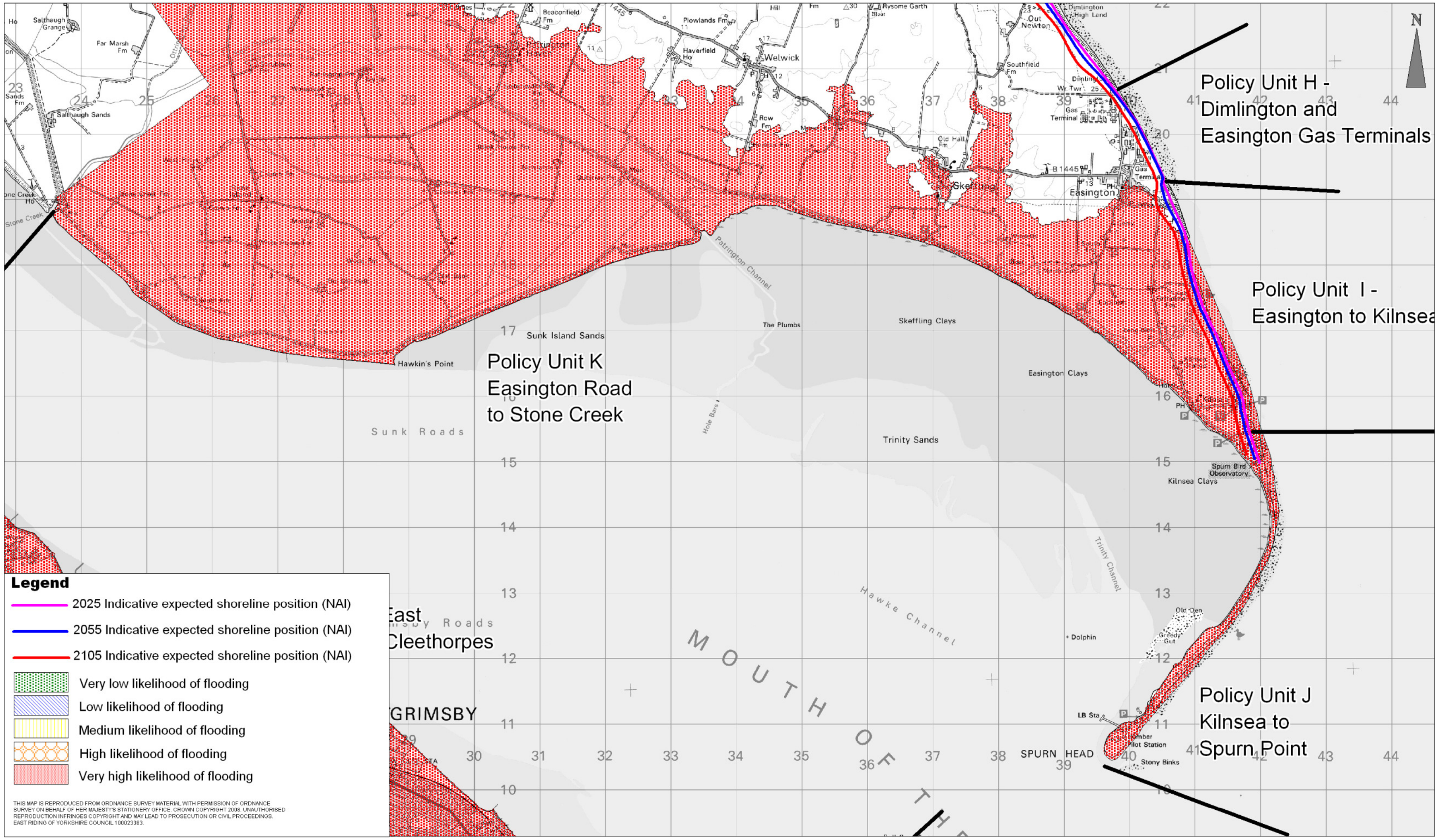
Rev 1	Date Final	



Project:

HECAG SMP

Title:

Baseline Scenario: No Active Intervention - Epoch 3

NAI PU J&K 3		
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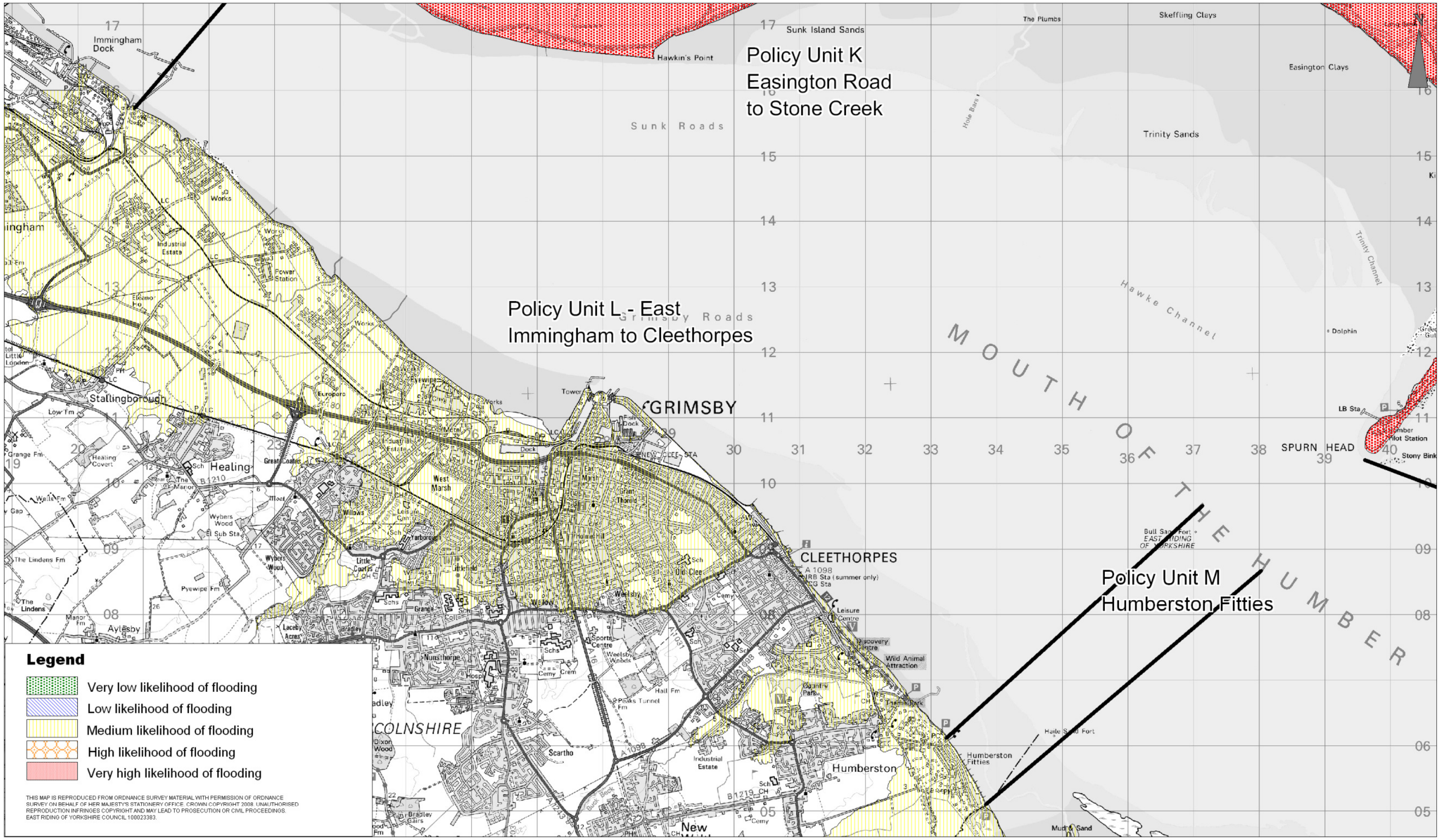
Rev 1	Date Final	



Project:

HECAG SMP

Title:

Baseline Scenario: No Active Intervention - Epoch 1

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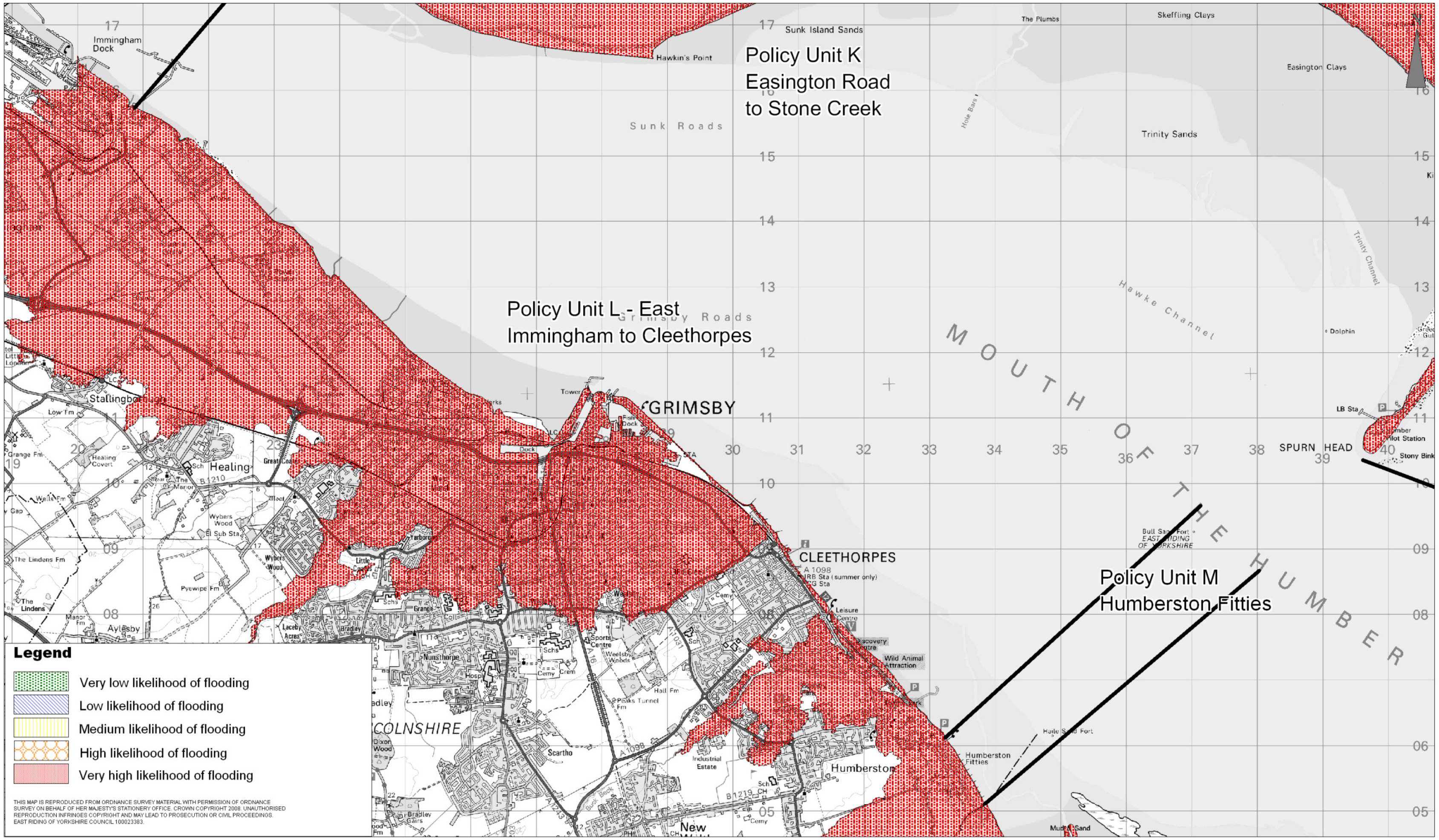
Rev 1	Date Final	



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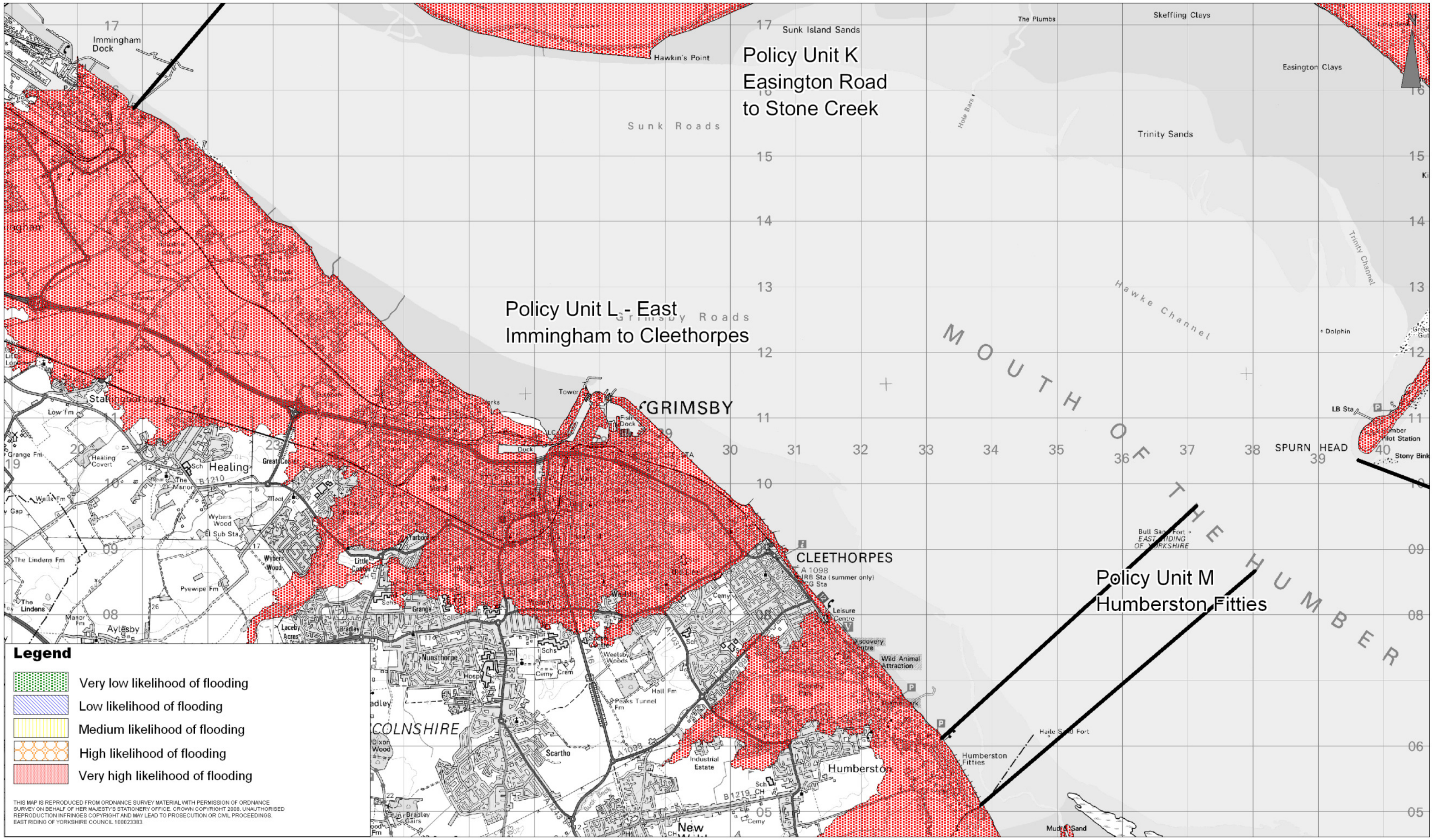

Project:

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Title:

Baseline Scenario: No Active Intervention - Epoch 3

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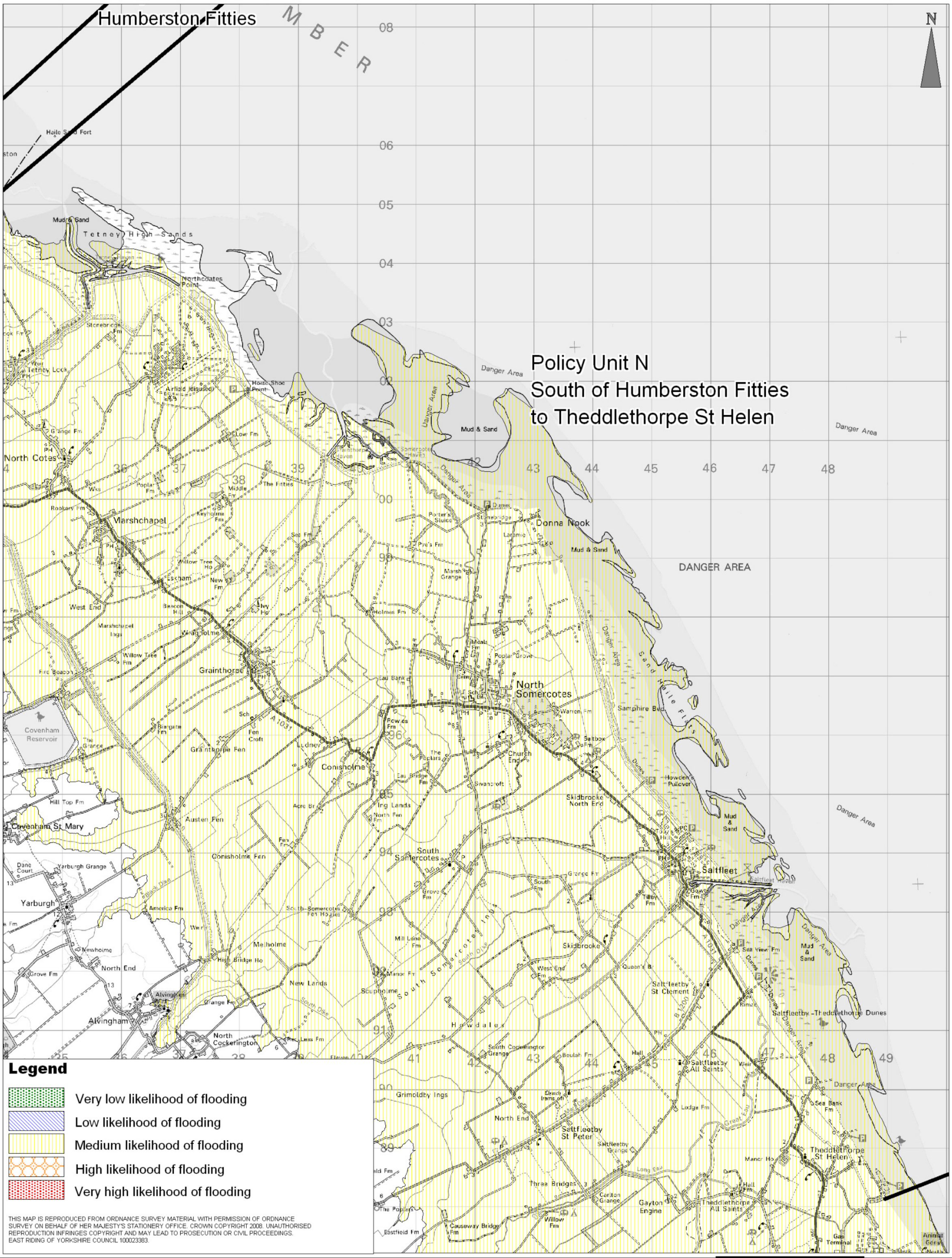
Rev 1	Date Final	



Project:

HECAG SMP

Title:

Baseline Scenario: No Active Intervention - Epoch 1

NAI PU N 1

Scale: 1:90,000

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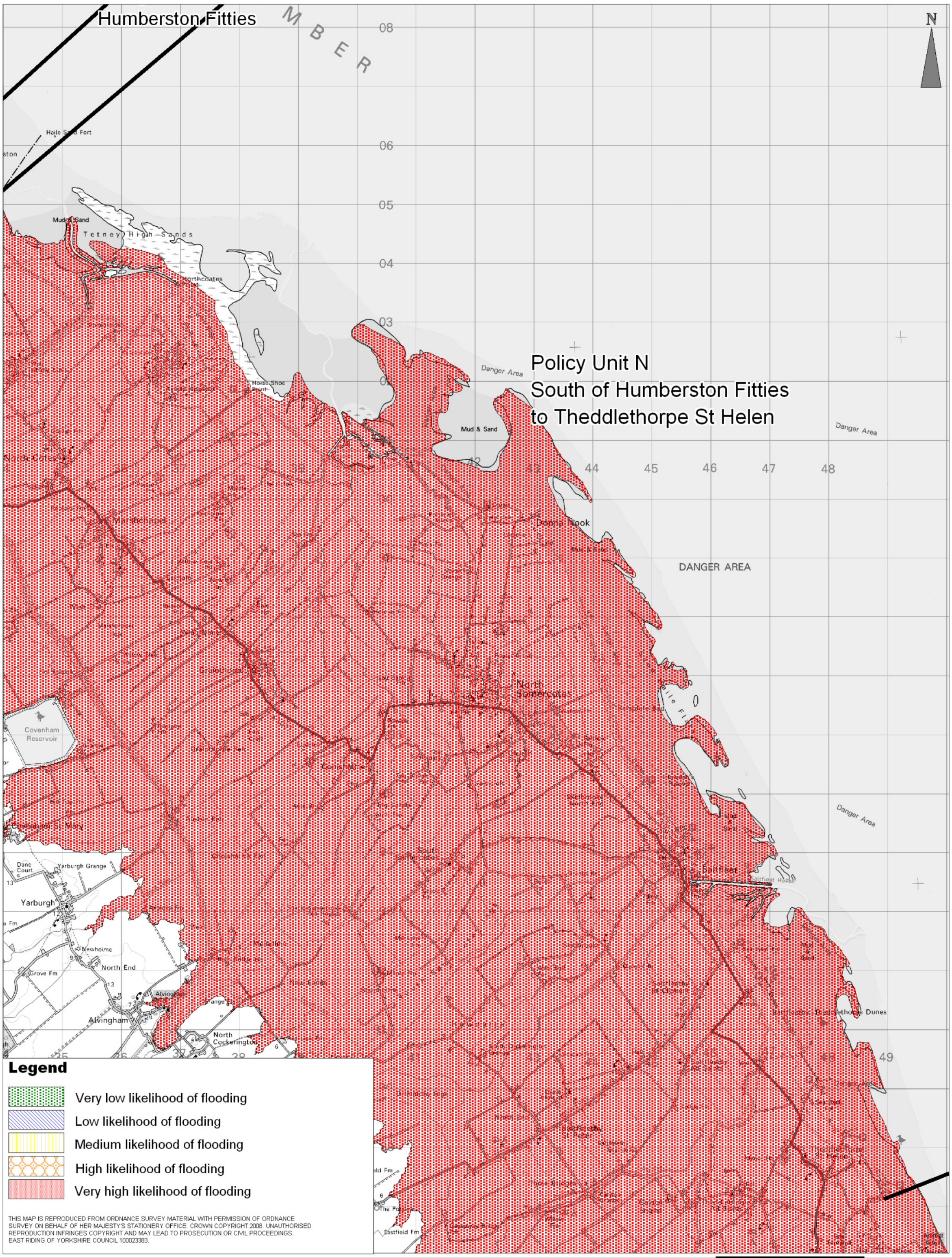
JS	LM	DD
Rev 1	Date Final	



Project:
HECAG SMP

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Scale: 1:90,000

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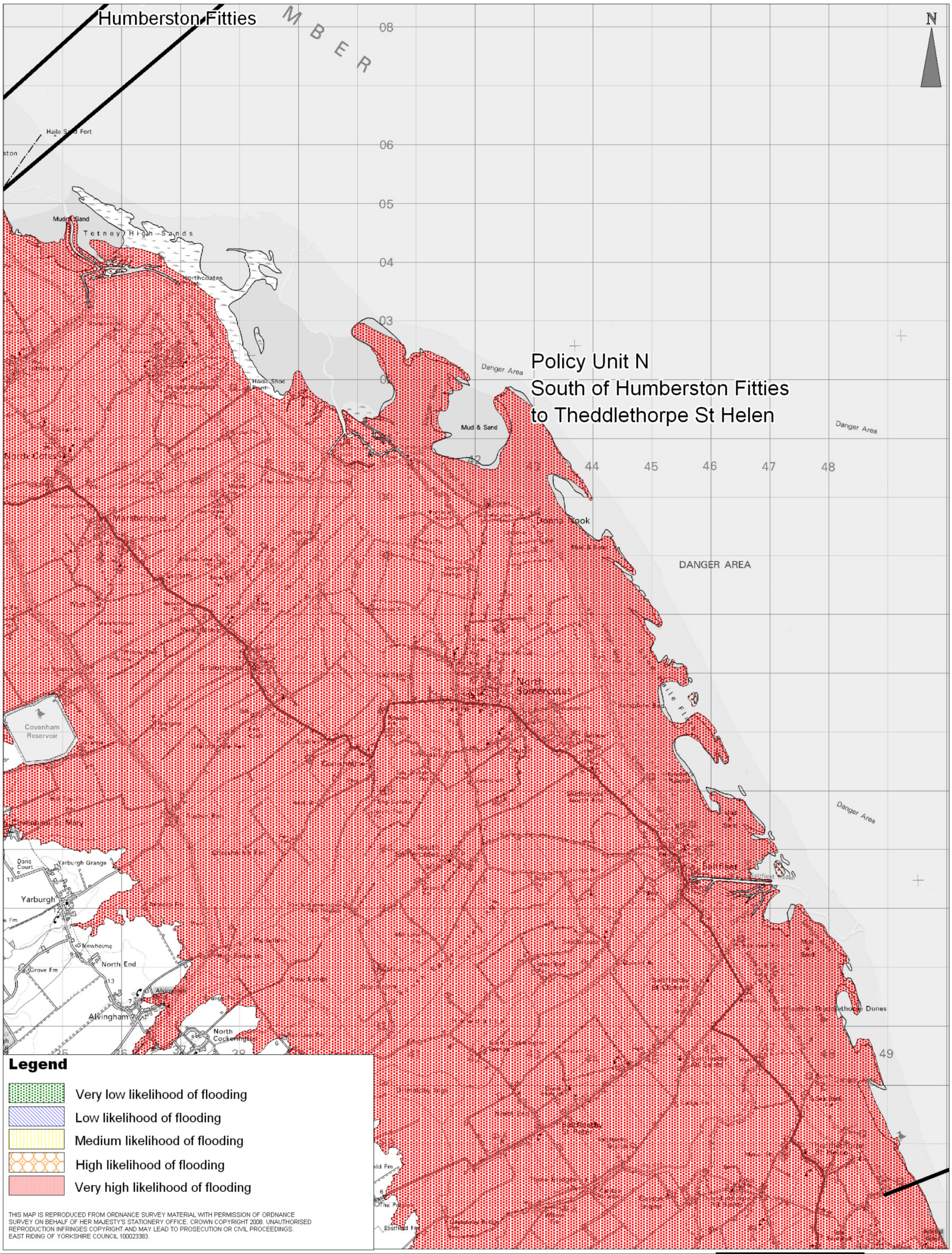
JS	LM	DD
Rev 1	Date Final	



Project:

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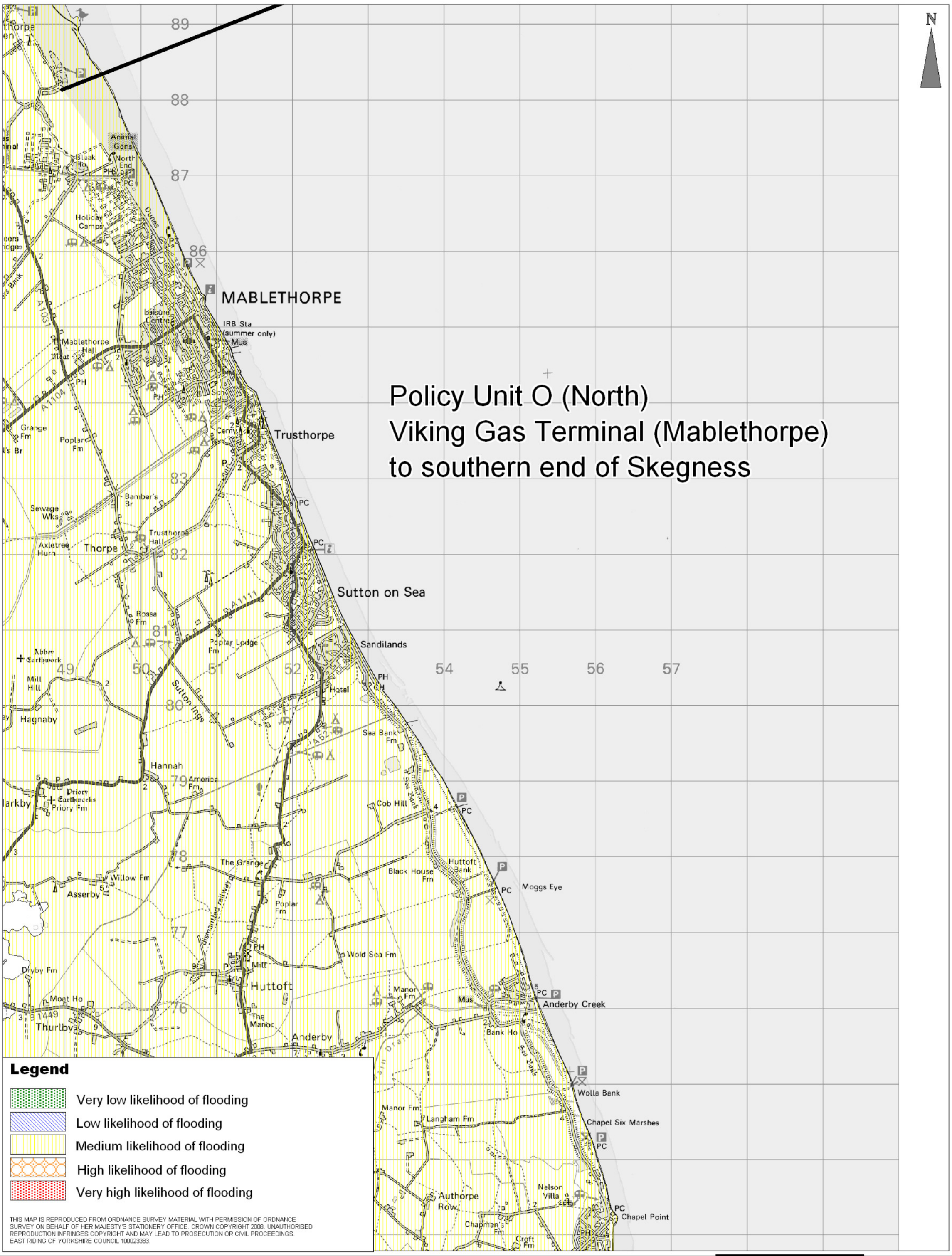
JS	LM	DD
Rev 1	Date Final	



Project:

HECAG SMP

Title:

Baseline Scenario: No Active Intervention - Epoch 1

NAI PU O N 1		
Scale: 1:70,000		
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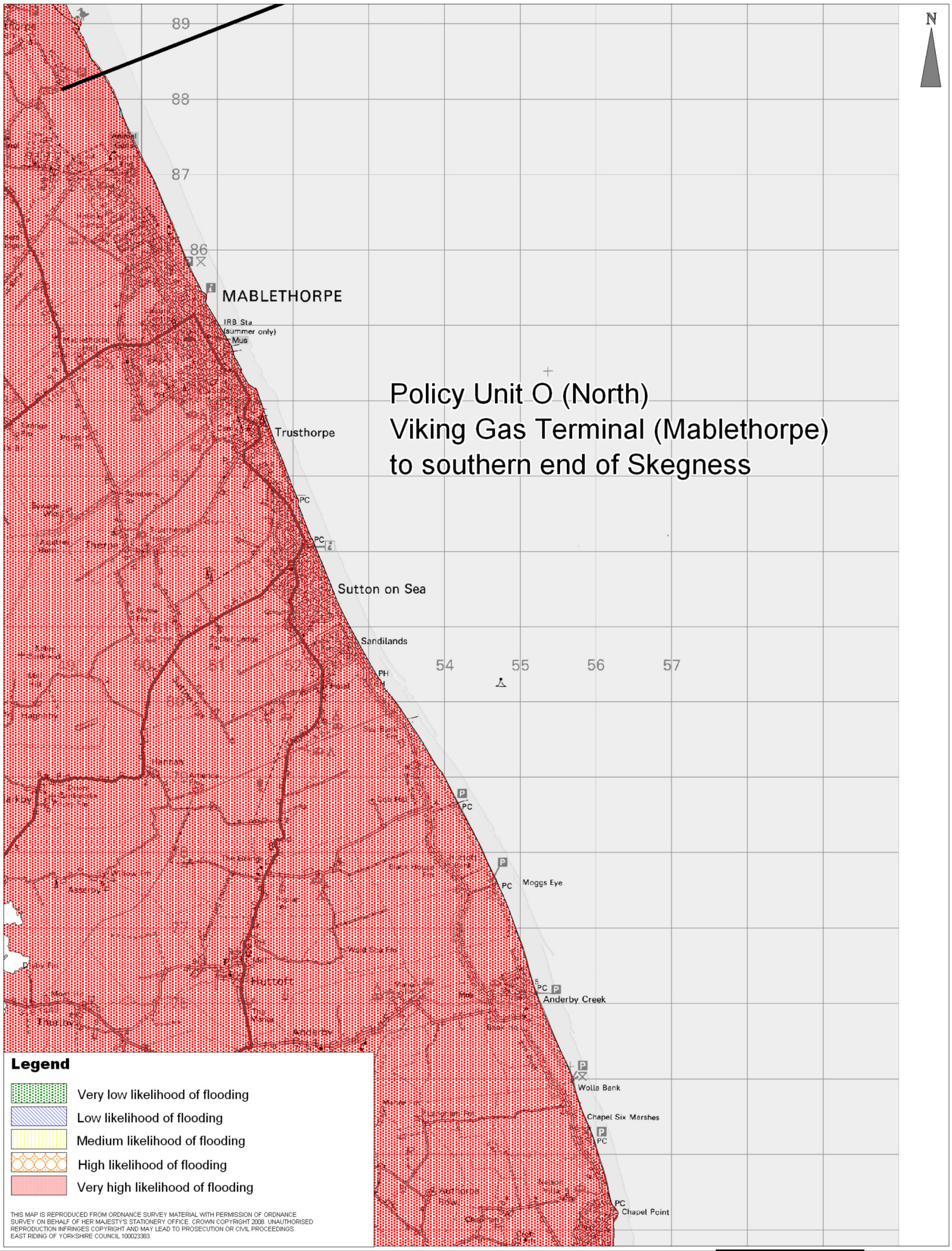
Rev 1	Date Final	



Project:

HECAG SMP

Title:

Baseline Scenario: No Active Intervention - Epoch 2

NAI PU O N 2

Scale: 1:70,000

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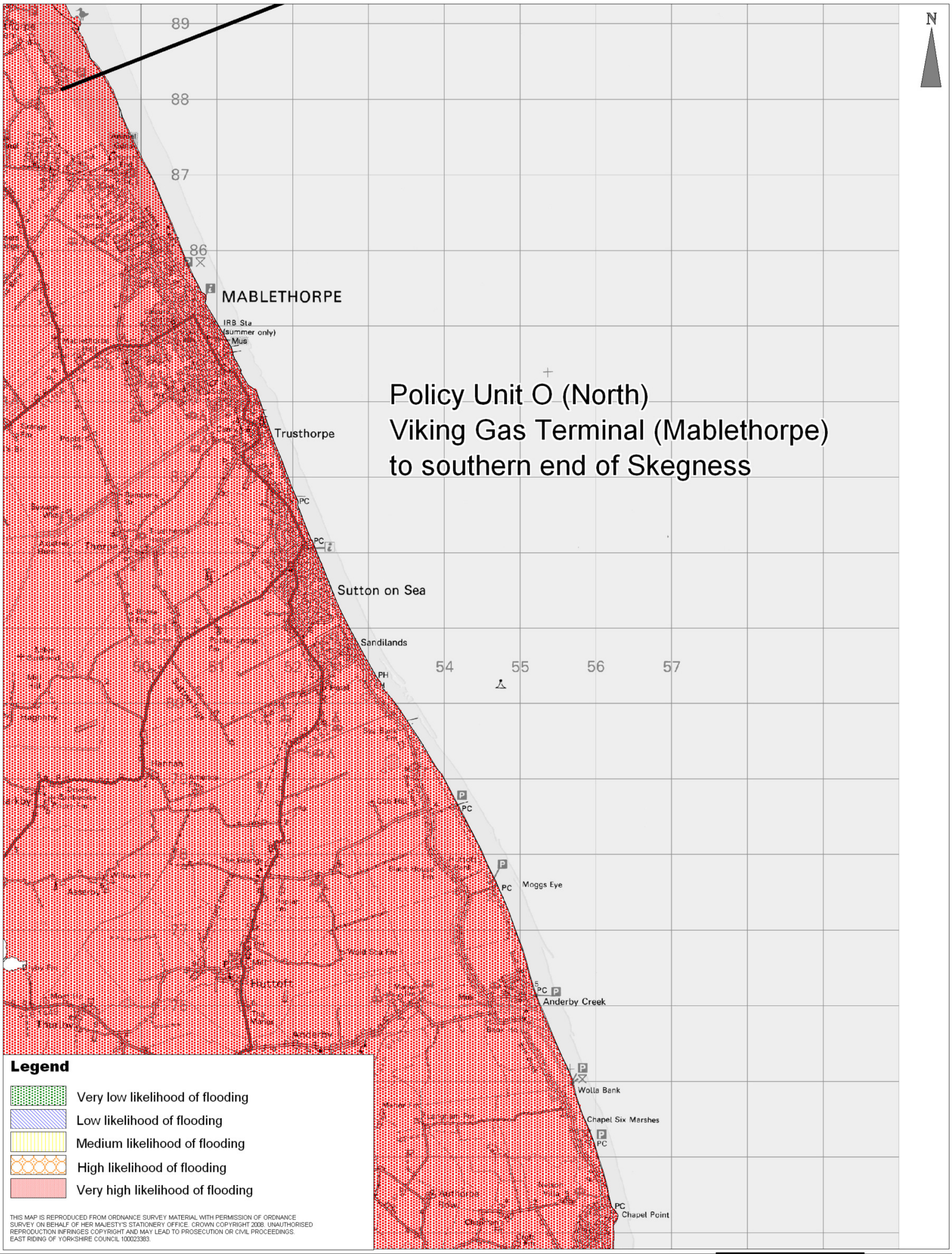
JS	LM	DD
Rev 1	Date Final	



Project:
HECAG SMP

Title:
Baseline Scenario: No Active Intervention - Epoch 3

NAI PU O N 3

Scale: 1:70,000

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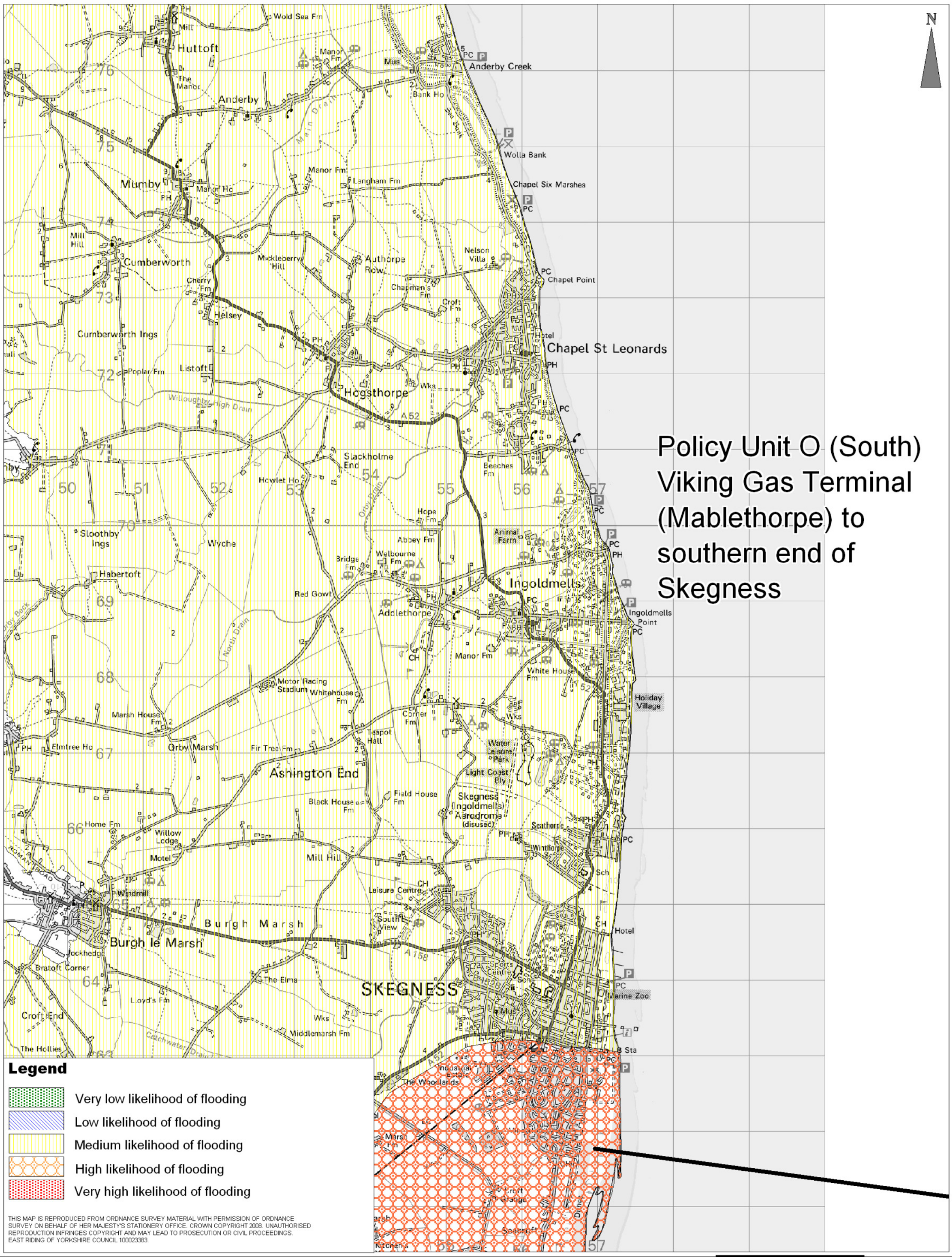
JS	LM	DD
Rev 1	Date Final	



Project:

HECAG SMP

Title:

Baseline Scenario: No Active Intervention - Epoch 1

NAI PU O S 1

Scale: 1:70,000

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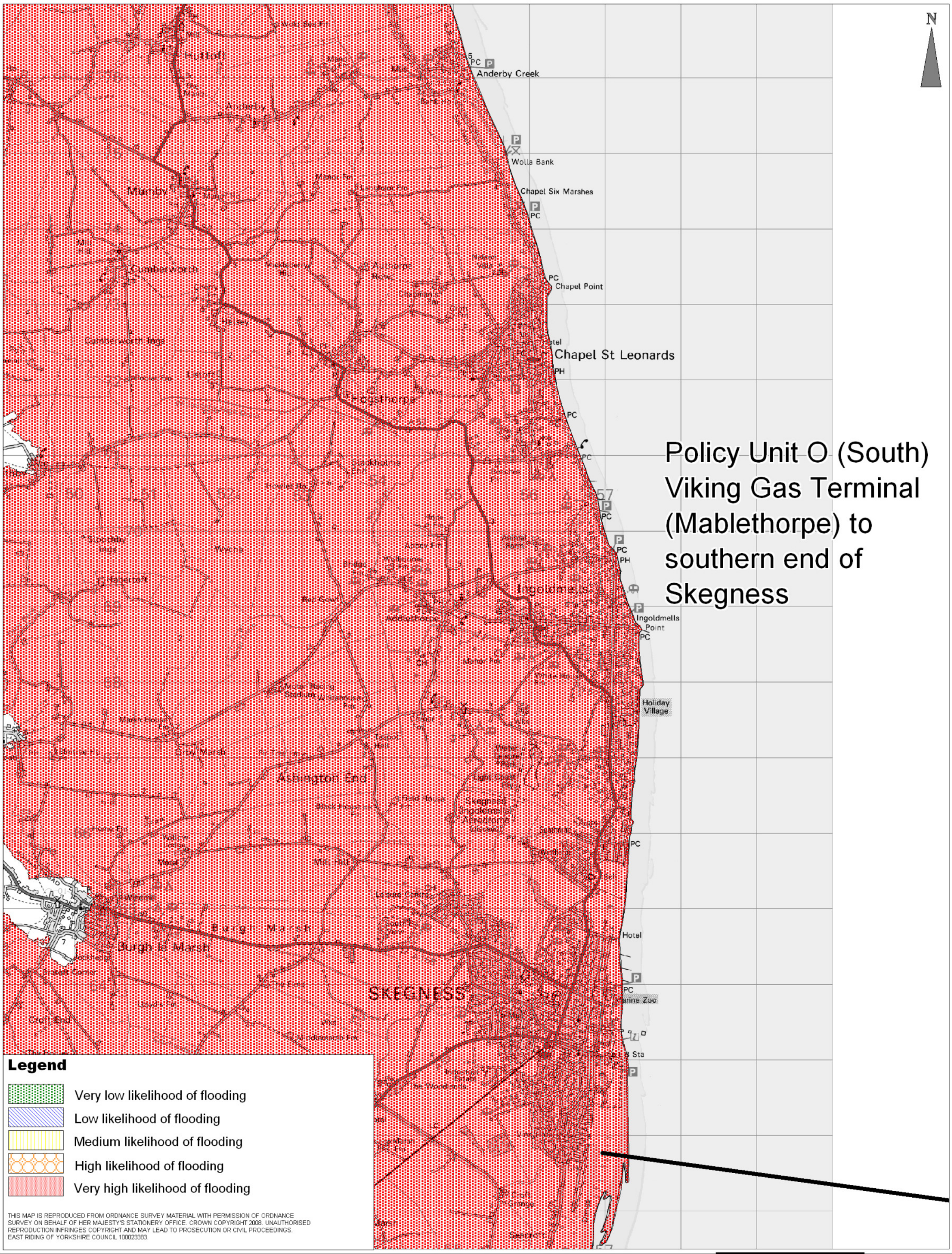
JS	LM	DD
Rev 1	Date Final	



Project:

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Title:

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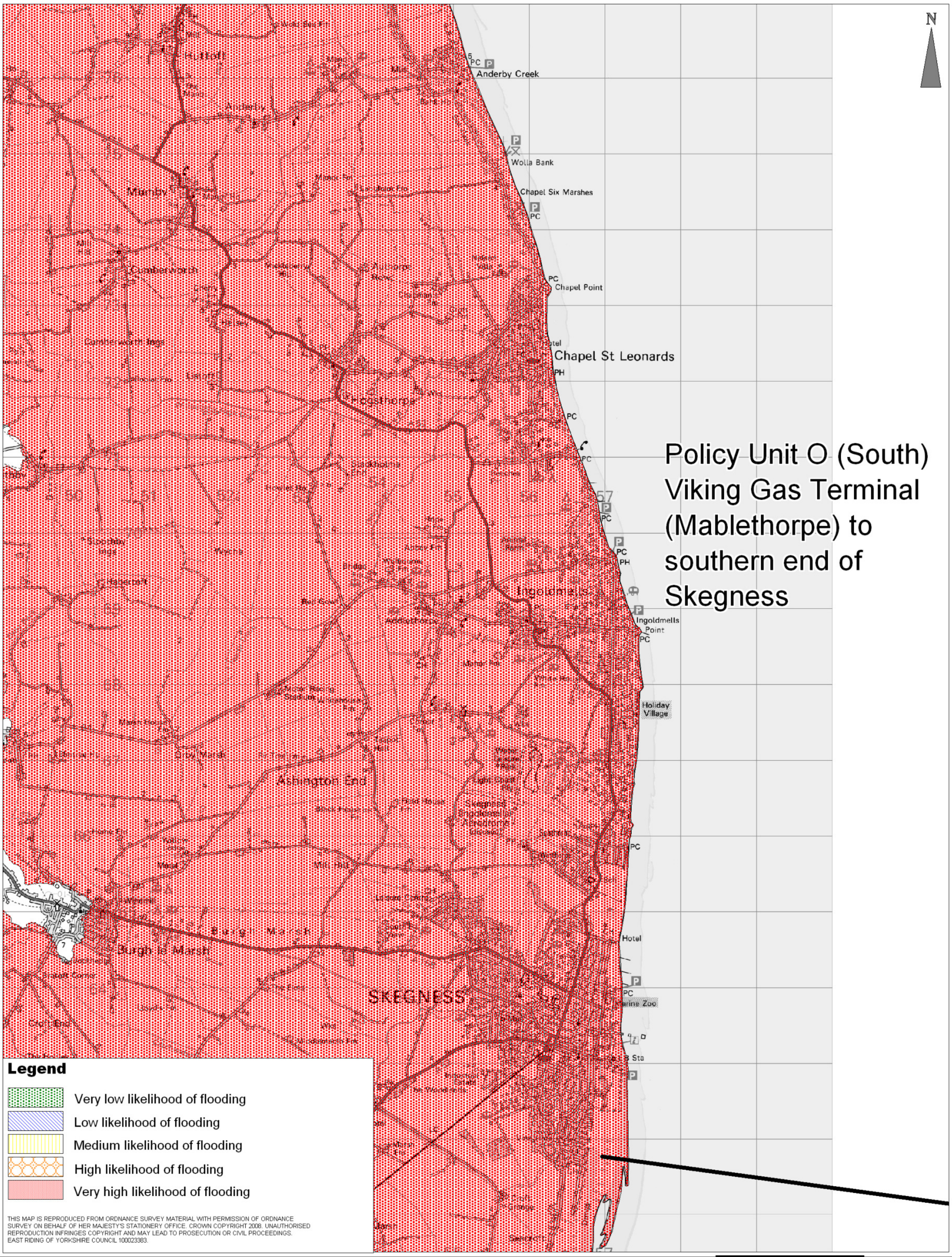
Rev 1	Date Final	



Project:
HECAG SMP

Title:
Baseline Scenario: No Active Intervention - Epoch 3

NAI PU O S 3

Scale: 1:70,000

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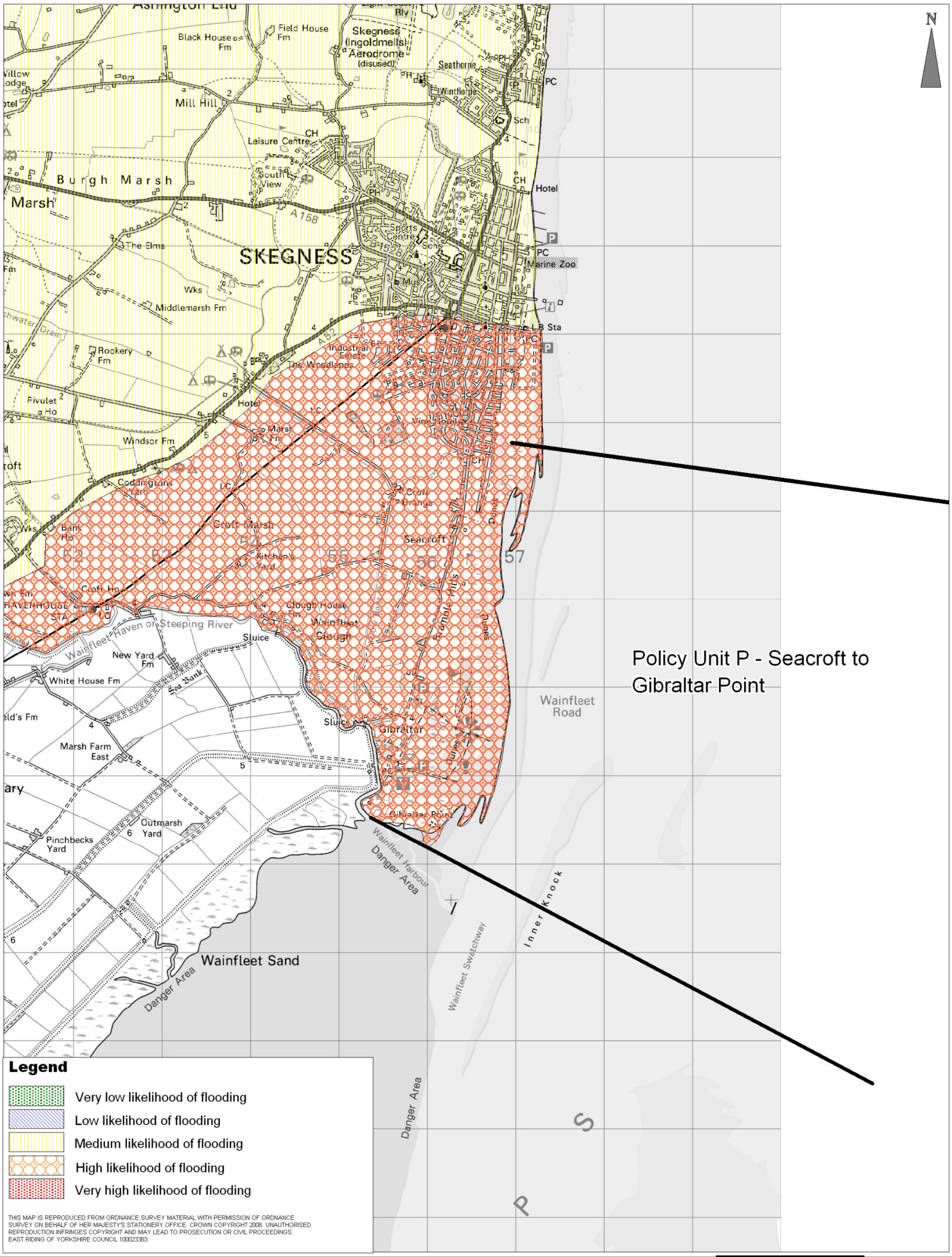
JS	LM	DD
Rev 1	Date Final	



Project:

HECAG SMP

Title:

Baseline Scenario: No Active Intervention - Epoch 1

NAI PU P 1				
Scale: 1:60,000				
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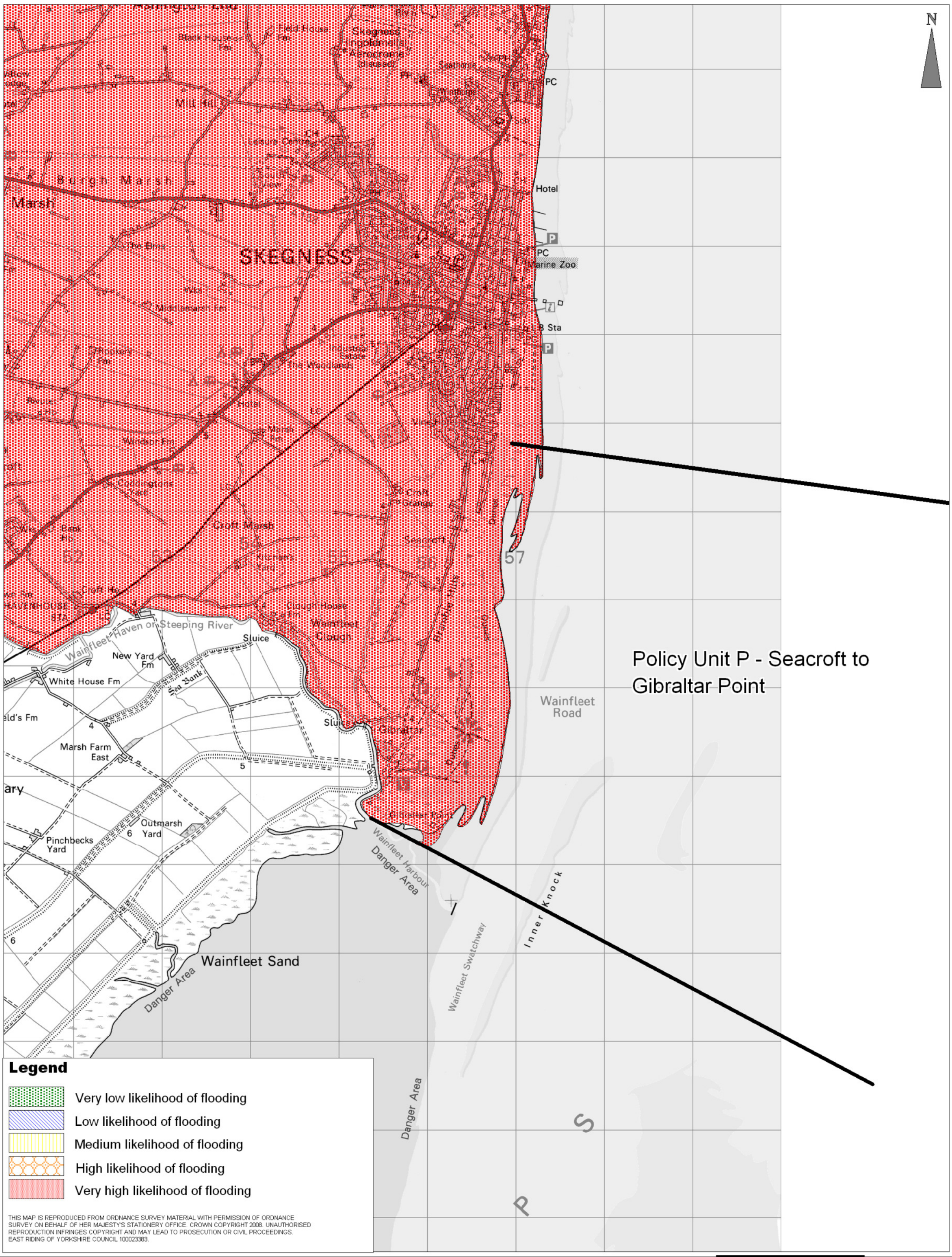
Rev	1	Date Final		



Project:

HECAG SMP

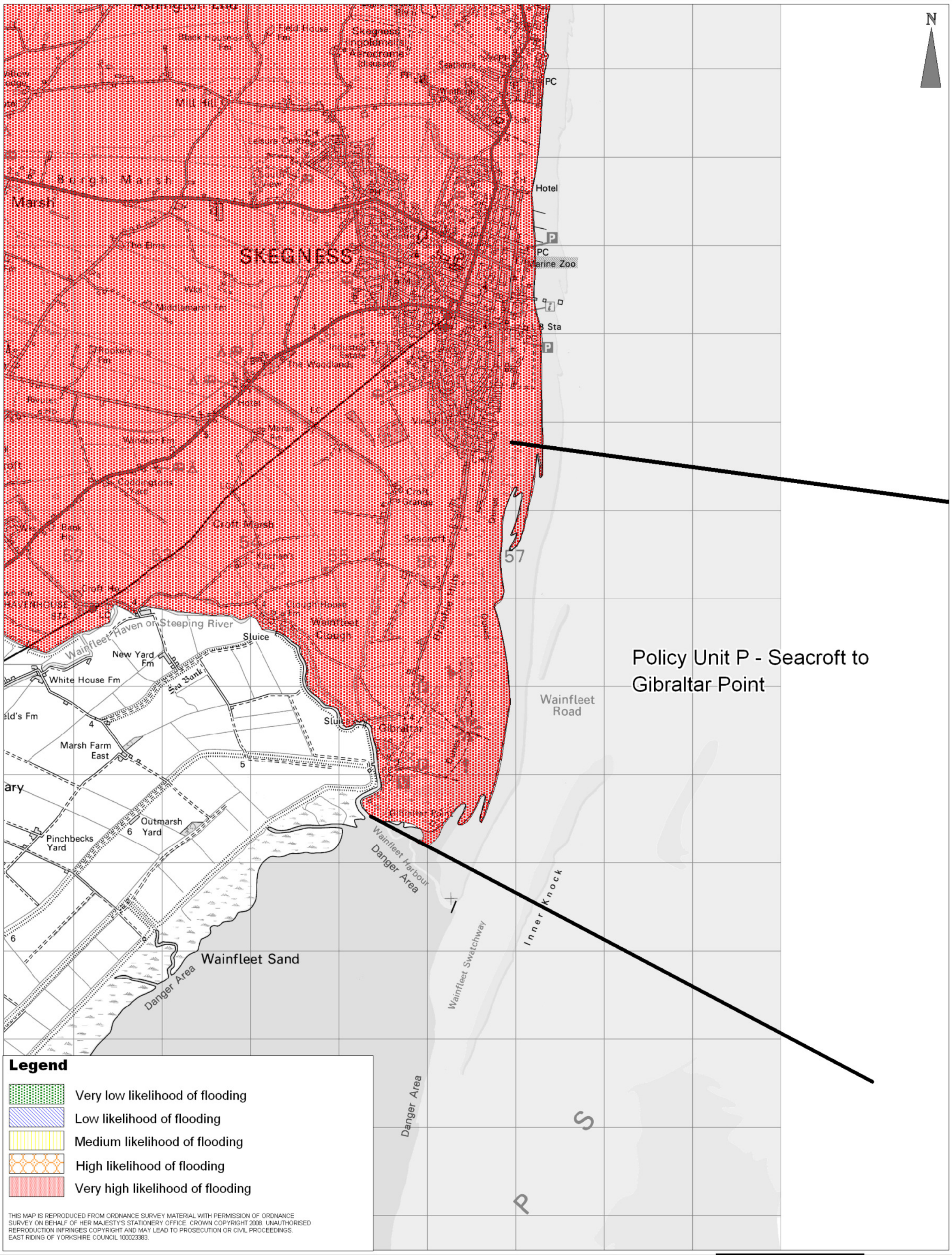
Title:

Baseline Scenario: No Active Intervention - Epoch 2

NAI PU P 2

Scale: 1:60,000

Drw	App	Chk
JS	LM	DD
Rev 1	Date Final	



Project:

HECAG SMP

Title:

Baseline Scenario: No Active Intervention - Epoch 3

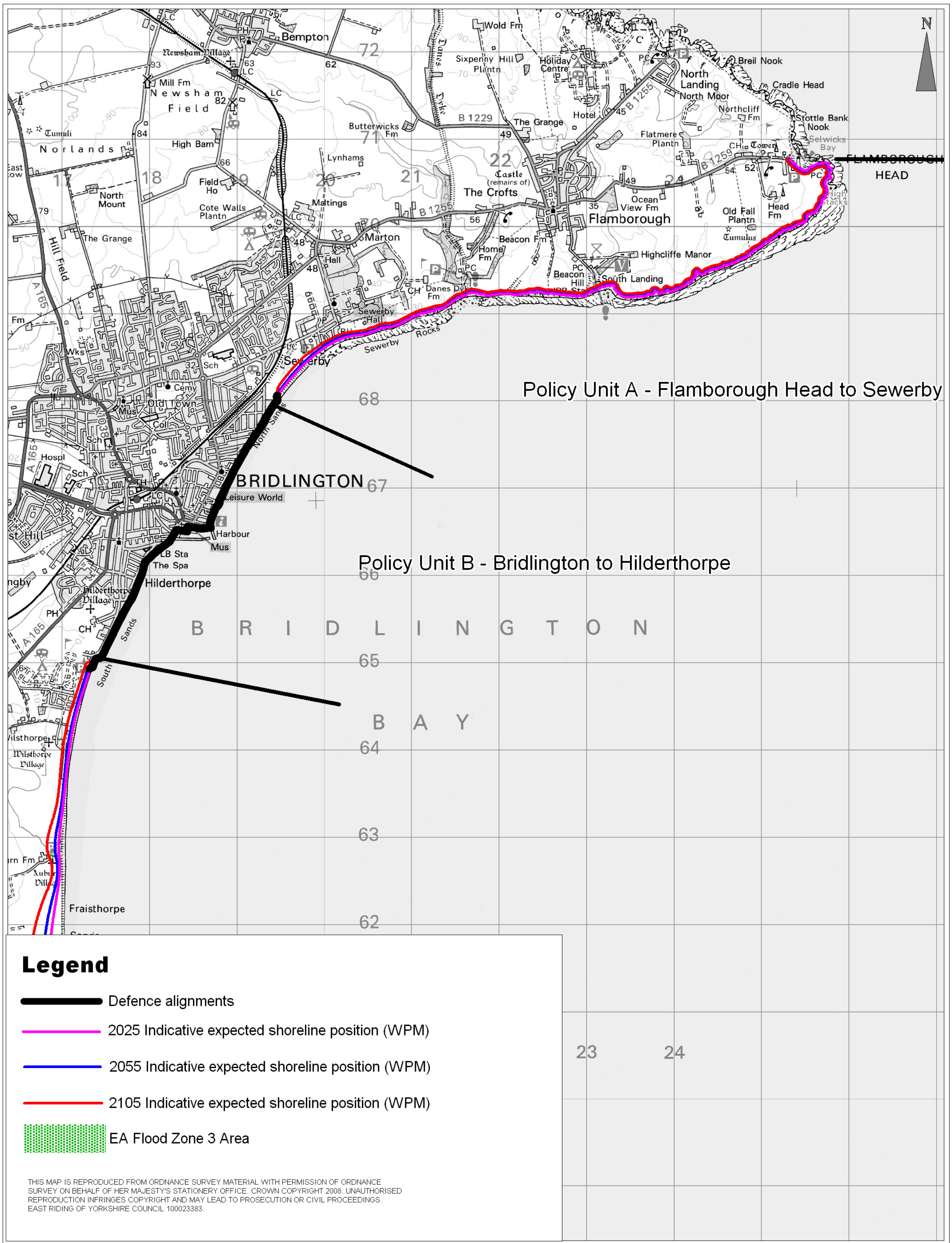
NAI PU P 3

Scale: 1:60,000

Drw	App	Chk
JS	LM	DD
Rev 1	Date Final	

C9 With Present Management Mapping

Note: Following consultation, the predicted indicative erosion lines presented here were modified and smoothed for the SMP preferred policy to represent more likely 'on the ground' cliff positions (See Main Document and Non Technical Summary). The erosion rates at Flamborough were also revised and updated following consultation review.



Project:

HECAG SMP

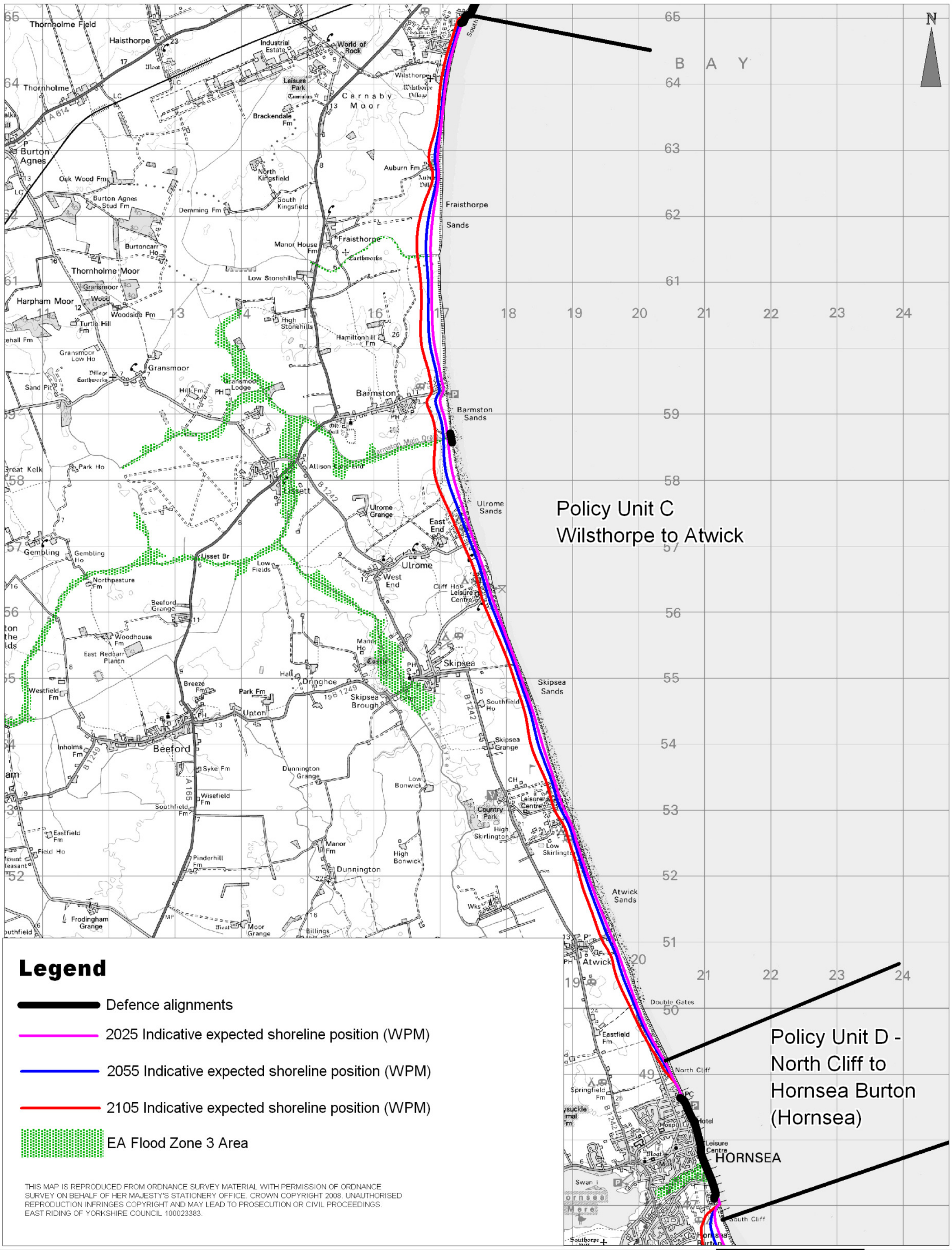
Title:

Baseline Scenario: With Present Management

WPM PU A&B

Scale: 1:60,000

Drw	App	Chk
JS	LM	DD
Rev 1	Date Final	



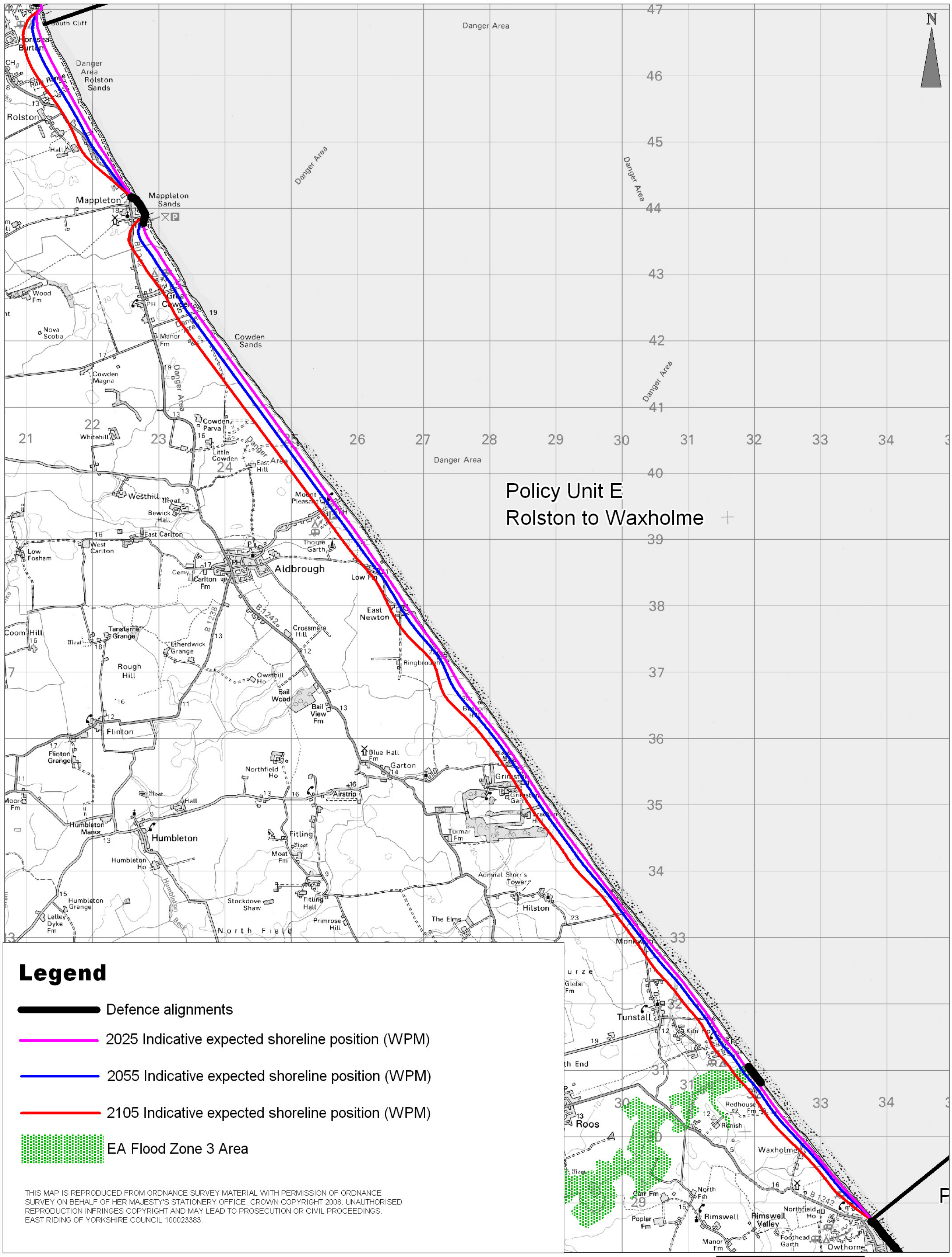
Project:

HECAG SMP

Title:

Baseline Scenario: With Present Management

WPM PU C&D		
Scale: 1:80,000		
Drw JS	App LM	Chk DD
Rev 1	Date Final	



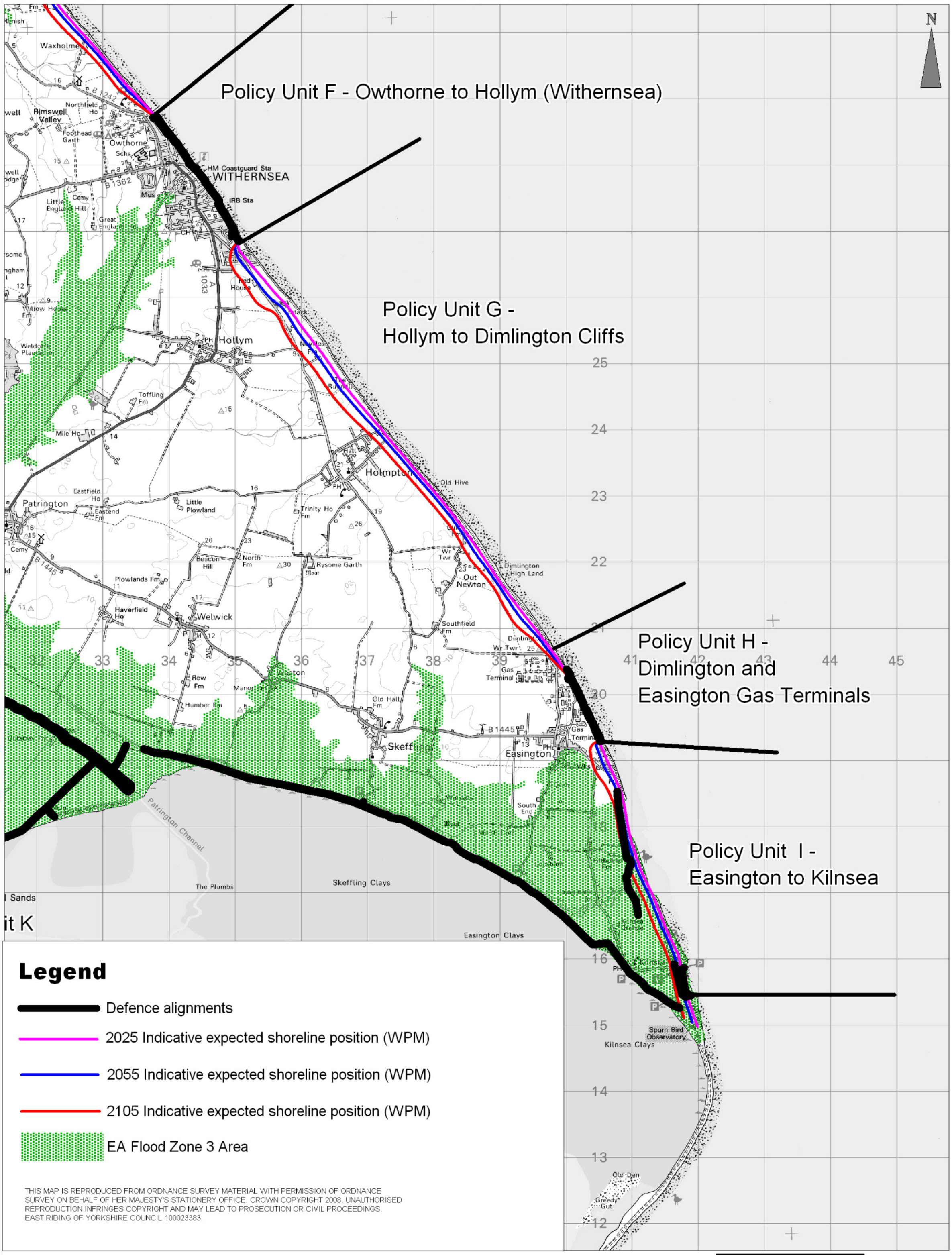
Project:
HECAG SMP

Title:
Baseline Scenario: With Present Management

WPM PU E

Scale: 1:80,000

Drw	App	Chk
JS	LM	DD
Rev 1	Date Final	



Project:

HECAG SMP

Title:

Baseline Scenario: With Present Management

WPM PU F, G, H & I		
Scale: 1:80,000		
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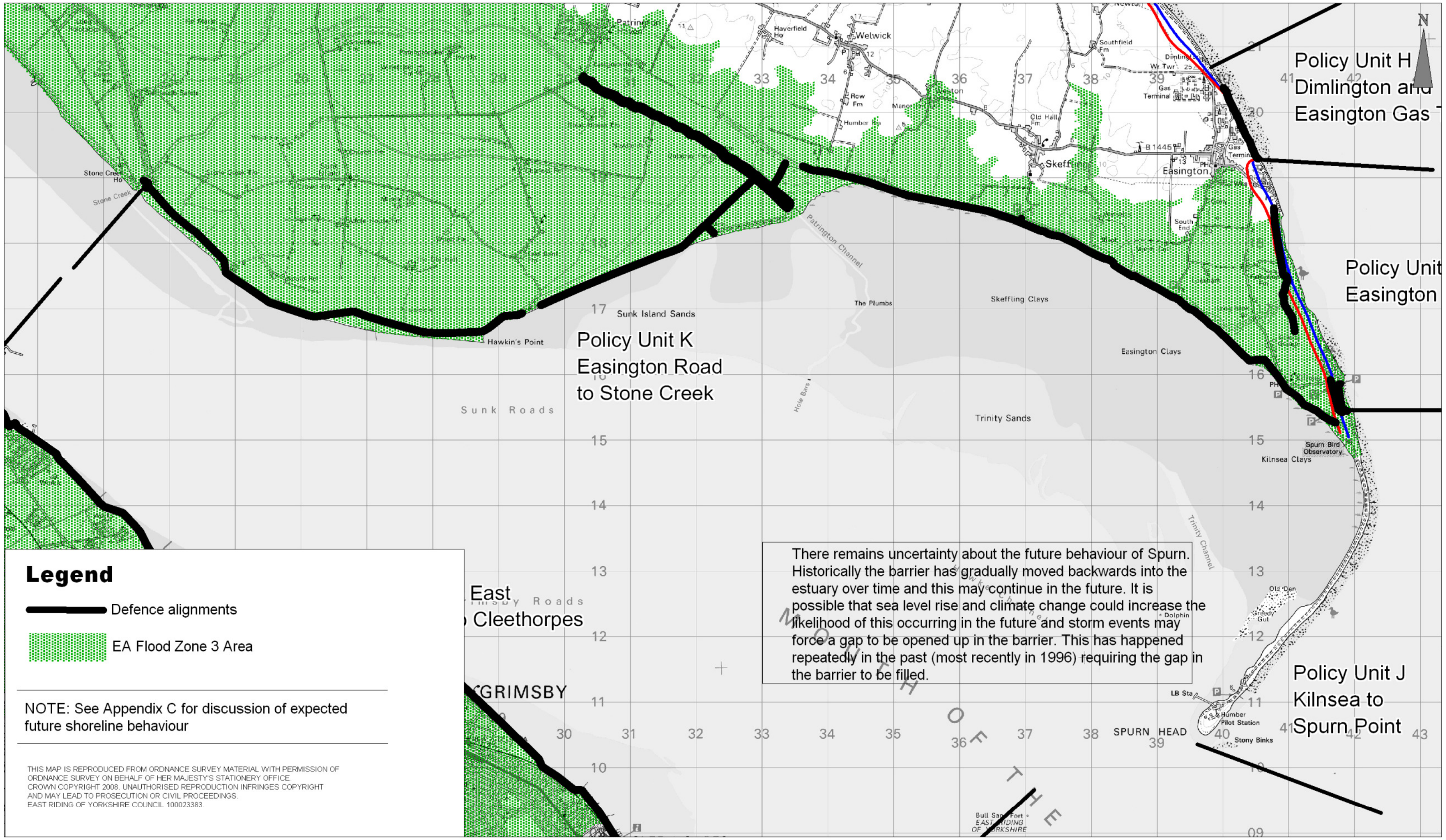
Rev **1**	Date Final	



Project:

HECAG SMP

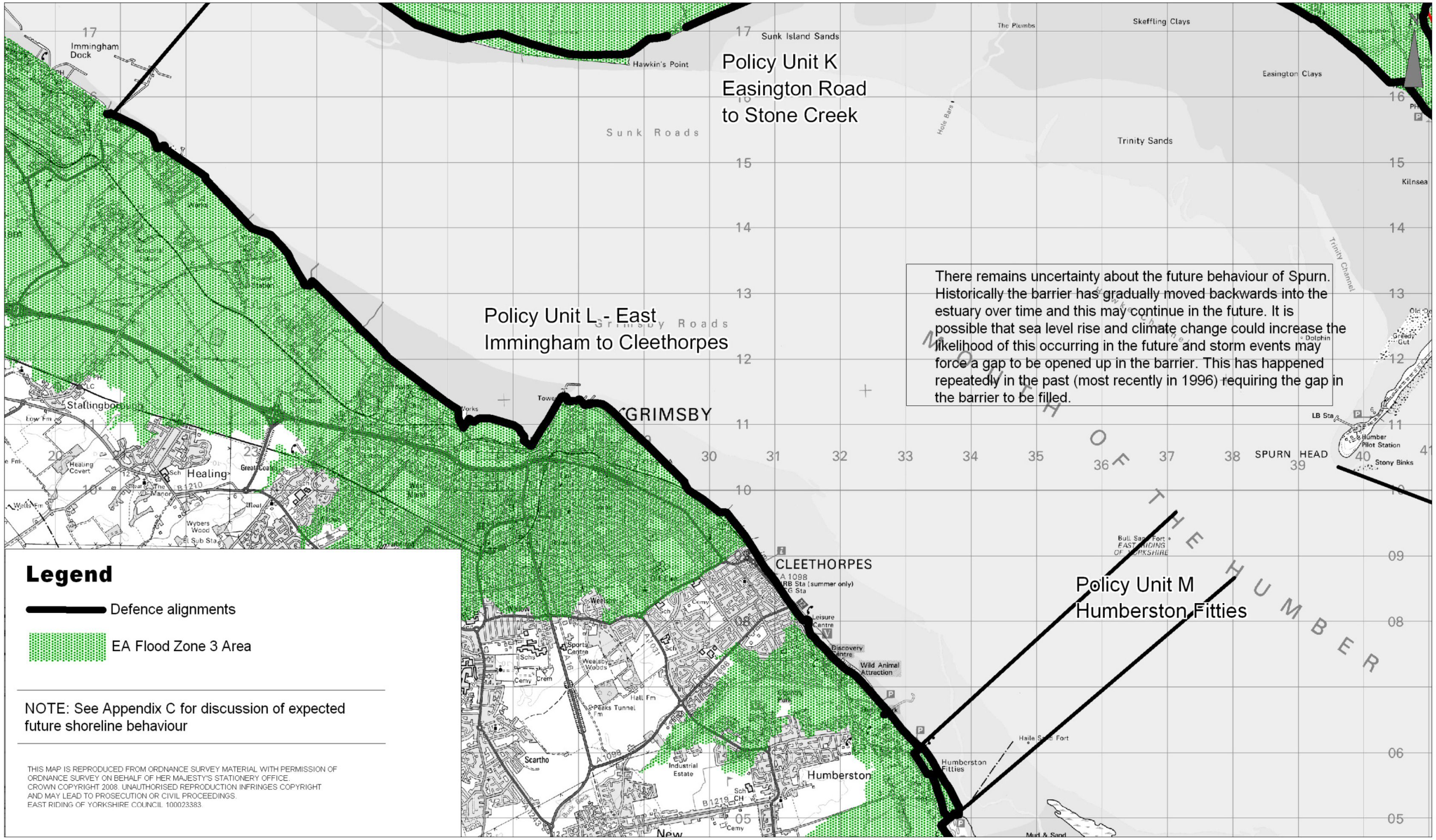
Title:

Baseline Scenario: With Present Management

WPM PU J&K

Scale: 1:80,000

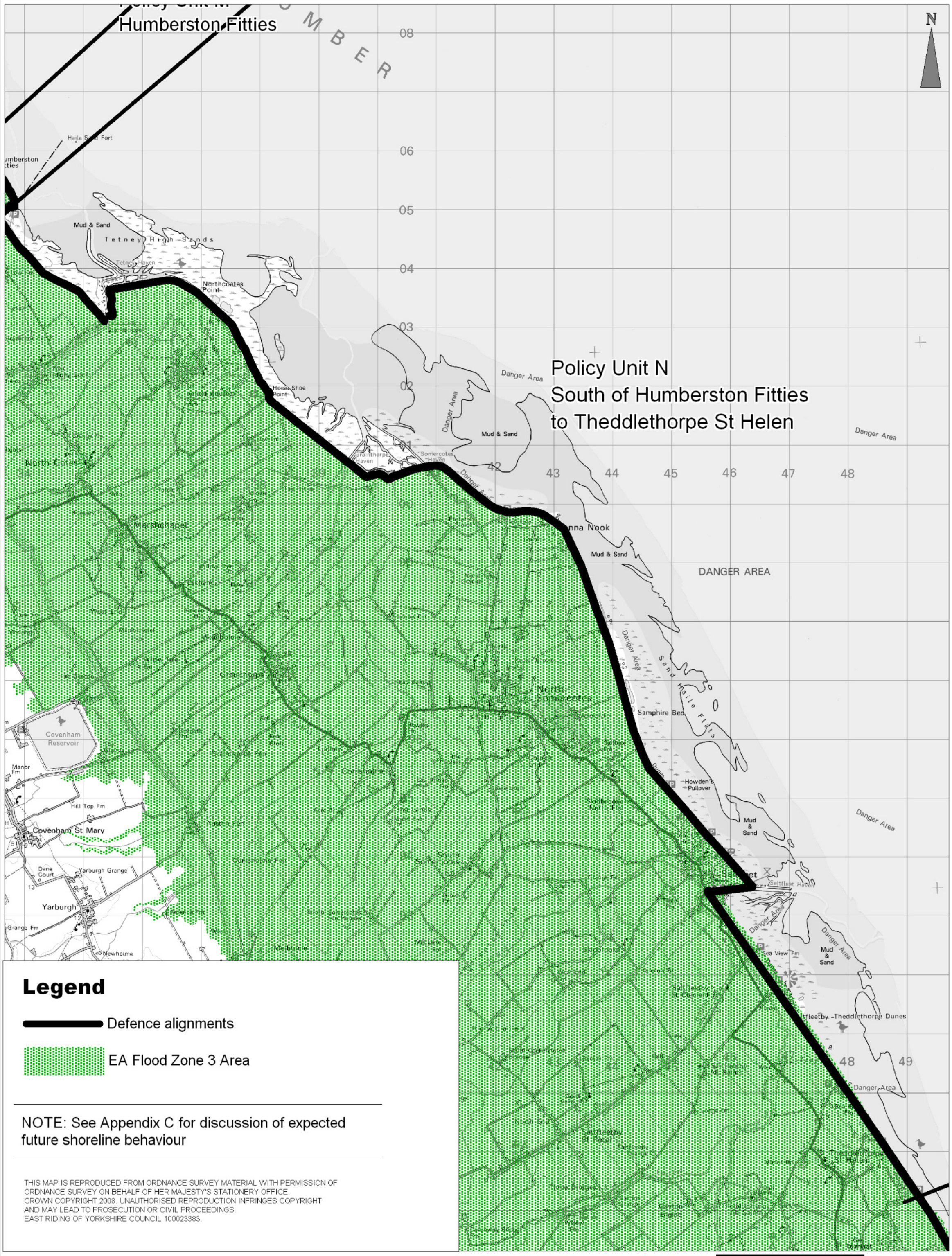
Drw	App	Chk
JS	LM	DD
Rev 1	Date Final	



Project:
HECAG SMP

Title:
Baseline Scenario: With Present Management

WPM PU L&M		
Scale: 1:80,000		
Drw JS	App LM	Chk DD
Rev 1	Date Final	



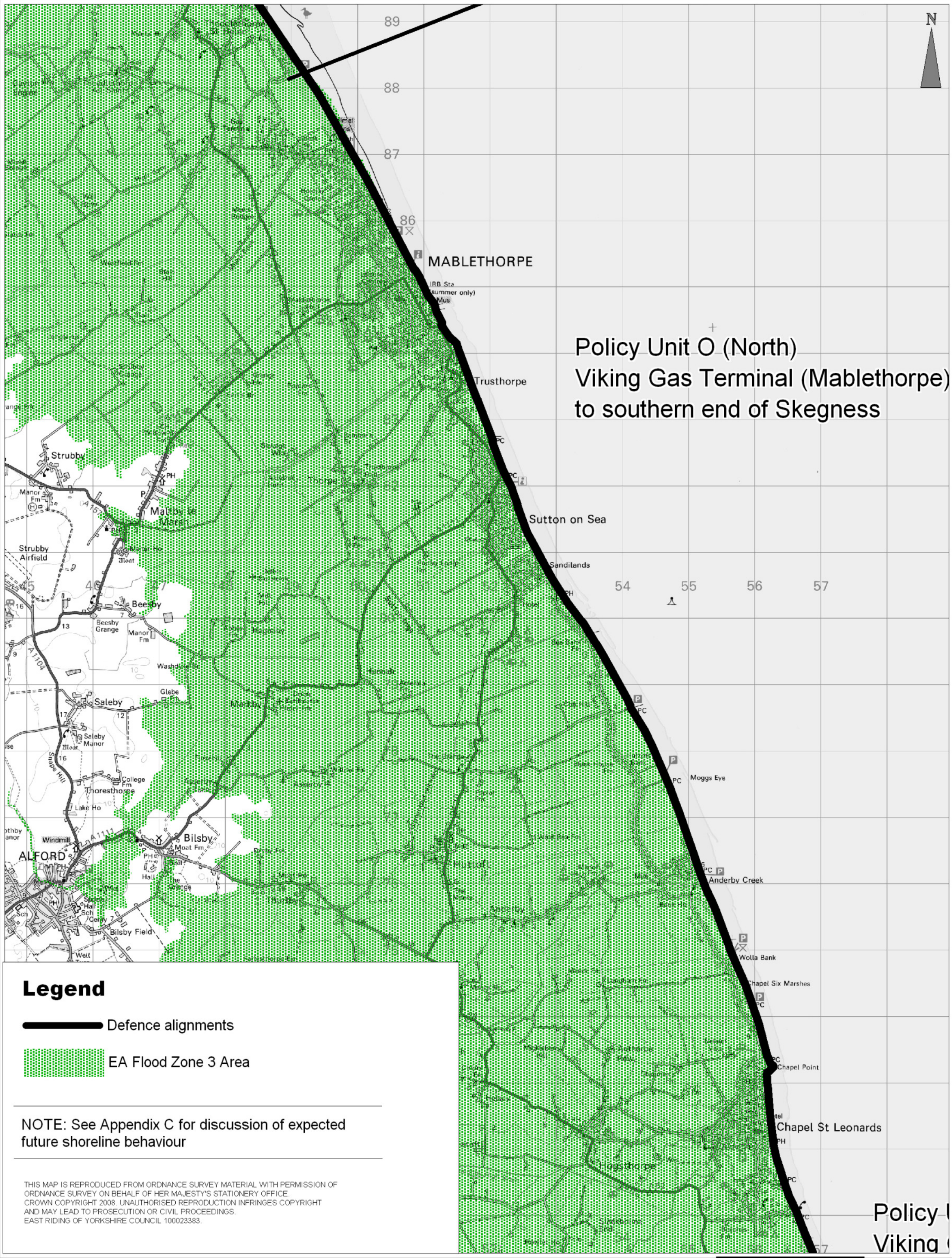
Project:
HECAG SMP

Title:
Baseline Scenario: With Present Management

WPM PU N

Scale: 1:90,000

Drw	App	Chk
JS	LM	DD
Rev 1	Date Final	



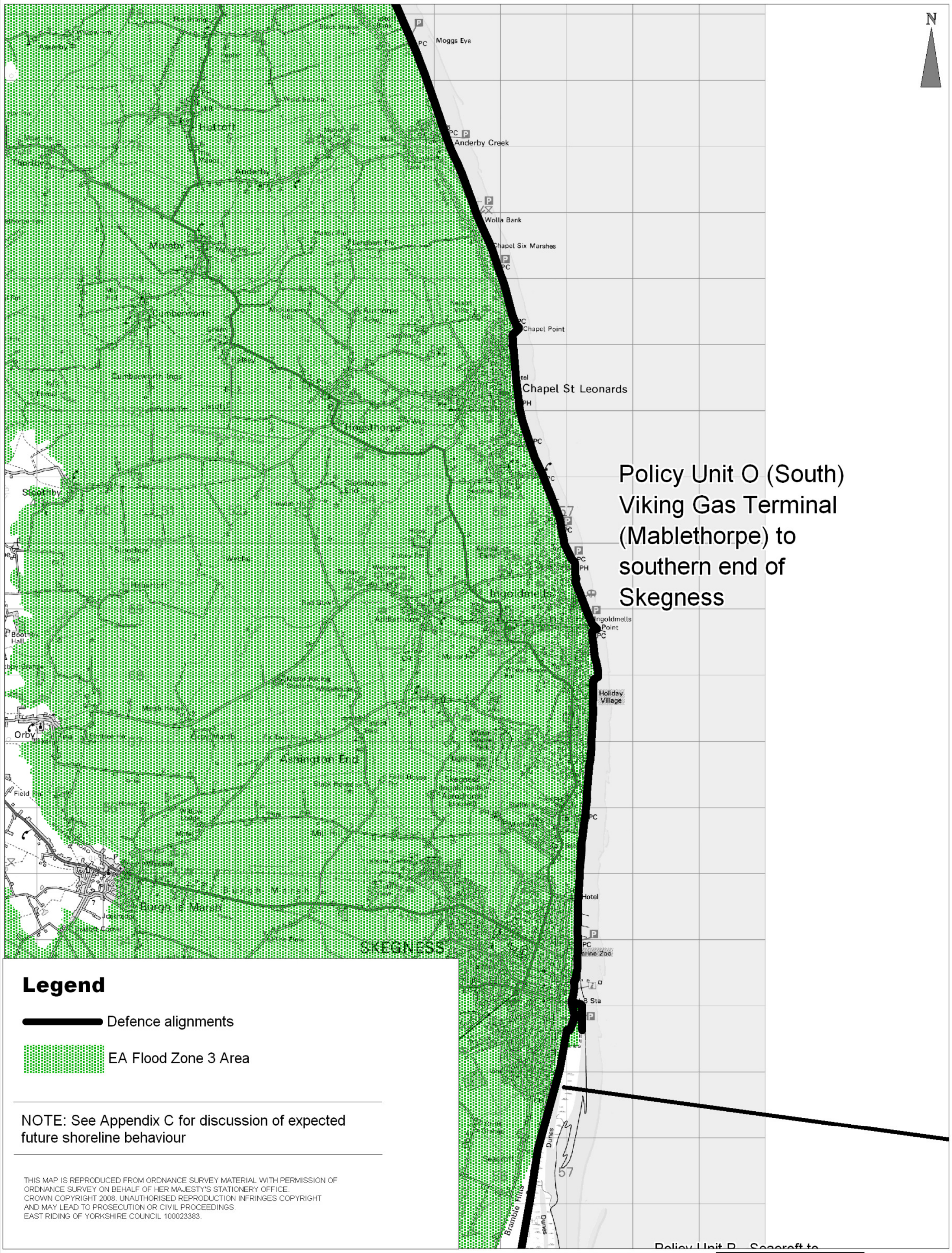
Project:

HECAG SMP

Title:

Baseline Scenario: With Present Management

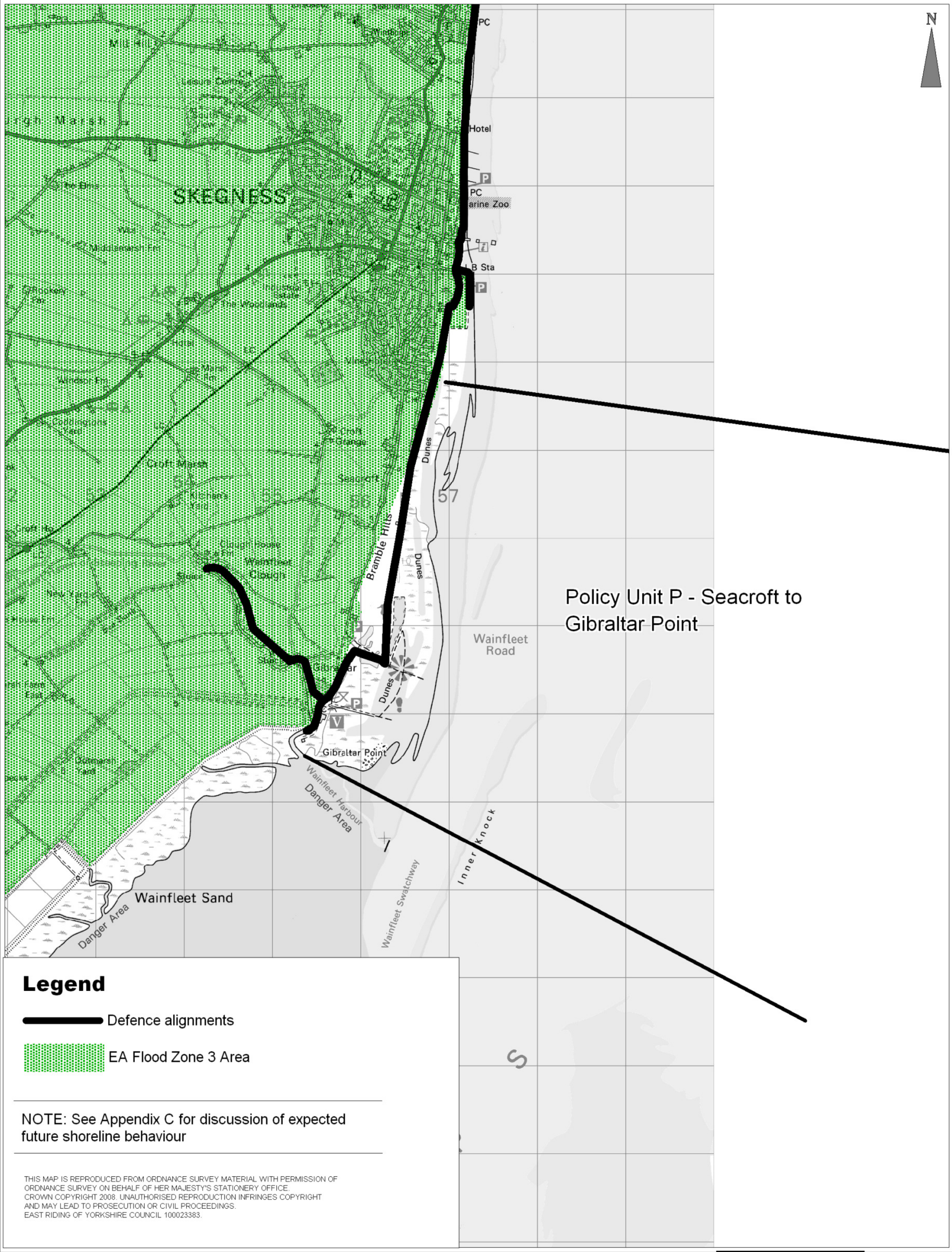
WPM PU O(1)			
Scale: 1:80,000			
Drw JS	App LM	Chk DD	
Rev 1	Date Final		



Project:
HECAG SMP

Title:
Baseline Scenario: With Present Management

WPM PU O(2)		
Scale: 1:80,000		
Drw JS	App LM	Chk DD
Rev 1	Date Final	



Project:

HECAG SMP

Title:

Baseline Scenario: With Present Management

WPM PU P

Scale: 1:60,000

Drw	App	Chk
JS	LM	DD
Rev 1	Date Final	