Baseline Coastal Processes Study

Appendix E2.1

Robin Hoods Bay Coastal Strategy

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Produced for
Scarborough Borough Council

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Contents

Glossary of Terms

Term	Definition
Accretion	The addition of newly deposited sediment vertically or horizontally.
Aeolian	The erosion, transport and deposition of material due to the action of wind at or near the earth's surface.
Amphidromic point	The centre of an **amphidromic system**; a nodal point around which a standing-wave crest rotates once each tidal period.
Backshore	A morphological term for the area of beach that lies between mean high water and the landward limit of marine (storm wave) activity.
Bathymetry	Topography of the sea floor.
Beach	A deposit of non-cohesive material (e.g. sand, gravel) situated on the interface between dry land and the sea (or other large expanse of water) and actively "worked" by present-day hydrodynamic processes (i.e. waves, tides and currents) and sometimes by winds.
CD	Chart Datum – a datum or plane to which depths or heights are referred. (Also see **OD**).
Coarse sediment	Generally refers to sediment of grain size greater than fine sand.
Coastal processes	Collective term covering the action of natural forces on the shoreline and nearshore seabed.
Coastline	The shape, outline, or boundary of a coast, that marks the area between the seaward limit of terrestrial influence and the landward limit of marine influence.
Convergence zone	The 'meeting' of the named variable (e.g. drift) at a certain location. (Also see **drift convergence**).
Divergence zone	The 'separation' of the named variable (e.g. drift) at a certain location. (Also see **drift divergence**).
Drift convergence	A boundary at which the direction of two differing littoral drift patterns meet, often producing a zone of sediment accretion.
Drift divergence	A boundary at which the direction of two differing littoral drift patterns part, often producing a zone of sediment erosion. Also known as drift divide.
Drift reversal	A switch of an indigenous direction of littoral transport.
Dune	A landform produced by the action of wind on unconsolidated material, normally sand, to produce ridges or mounds of loose sediment.
Dynamic equilibrium	A state of balance between environmental conditions acting on a landscape and the resisting earth material which themselves fluctuate around an average that is itself gradually changing.
Ebb	A period when the tide is falling.

Ebb tide	The falling tide, immediately following the period of high water and preceding the **flood tide**.
Embayment	A concave shoreline plan shape between rocky headlands, sometimes with only a narrow entrance.
Episodic	Composed of a series of episodes rather than as a continual process.
Erosion	The movement of soil and rock material by such agents as running water, waves, wind, moving ice and gravitational creep. The landward retreat of a shoreline due to this process.
Flood	A period when the tide is rising or alternatively, inundation of the land normally above highest tide levels.
Flood tide	The rising tide, immediately following the period of low water and preceding the **ebb tide**.
Foreshore	A morphological term for the lower shore zone/area on the beach that lies between mean low and high water.
Geology	Geological structure and lithological variability.
Geomorphological	Landforms or earth processes pertaining to geomorphology.
Geomorphology	The study of the physical features of the earth's surface and their relation to its geological structure.
Glaciation	The covering of a landscape or larger region by ice; an ice age.
Glacial	Products of, or deposited by, or derived from a glacier.
Hinterland	The land directly adjacent to and inland from a coast, extending landward from the upper limit of extreme wave and tidal energy.
Hydrodynamic	The process and science associated with the flow and motion in water produced by applied forces.
Landslides	The large-scale mass movement of sub-aerial material down-slope, or its vertical movement down a cliff face.
Large-scale	Spatial distance of 100 km +.
Littoral drift	See **longshore drift**.
Longshore drift	Transport of sediment along the shore by the combined effect of swash and backwash set up by wave driven currents. Currents produced in the surf zone are caused by waves breaking at an angle and the current running roughly parallel with the shore. (Also see **drift-aligned**, **drift convergence**, **drift divergence**, **drift reversal**).
MLWS	Mean Low Water Springs
MHWS	Mean High Water Springs
Nearshore	The zone, which extends from the swash zone to the position marking the start of the **offshore** zone, typically at water depths of the order of 20m.

OD	Ordnance Datum – a datum or plane to which depths or heights are referred to. (Also see **CD**).
Offshore	The zone beyond the **nearshore** zone where sediment motion induced by waves alone effectively ceases and where the influence of the seabed on wave action is small in comparison with the effect of wind.
Raised beaches	Beaches formed when relative sea-level was higher, and which are now found above the level of the present shoreline.
Realignment	Movement of the shoreline toward a more natural state or position, e.g. following the removal of coastal defences which would have previously maintained the shoreline in an artificial state.
Recession	Movement of the shoreline to landward.
Relative sea-level	Mean sea-level relative to the land, taking account of both **isostatic** and **eustatic** components.
Rock platform	Gently seaward sloping, intertidal bench cut into the land mass by the action of waves and also known as a **wave-cut platform**.
Sedimentary	Rock containing, resembling, or derived from sediment formed under the process of deposition. Sedimentation begins with the supply of sediment, followed by its reworking and modification by physical, chemical and biological processes all before final deposition.
Shingle	Gravel-sized beach material, normally well rounded as a result of abrasion.
Storm Surge	A rise in water level in the open coast due to the action of wind stress as well as a decrease in atmospheric pressure on the sea surface. A surge typically has a duration of a few hours.
Surge	Changes in water level as a result of meteorological forcing (wind, high or low barometric pressure) causing a difference between the recorded water level and that predicted using harmonic analysis, may be positive or negative.
Till	Poorly-sorted, non-stratified and unconsolidated sediment carried or deposited by a glacier.
Wave climate	The seasonable and annual distribution of wave height, period and direction.
Wave-cut platform	A near horizontal layer of solid rock stretching seaward from the toe of a beach. Also see **rock platform**.

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1 Introduction

1.1 Study background, purpose and scope

This study will provide a baseline understanding of coastal processes, behaviour and dynamics. The study will also focus on the key information that will underpin decisions on future management of the coast over the Coastal Strategy Study CSS timescale of 100 years and ensure that policy choices are technically-sound and sustainable in terms of coastal processes.

A detailed assessment of the baseline processes is undertaken on the section of coast between Whitby and Hundale Point to understand the wider scale interaction with the policy units set out in the North East Shoreline Management Plan 2. The coastal process baseline scenario assessments will be undertaken within the CSS development as a result of this study and will be used to identify risks and test the response and implications of different management policy scenarios over different timescales.

1.2 Location

The study area lies along the north eastern shores of North Yorkshire, covering approximately 23 km (see Figure 1).

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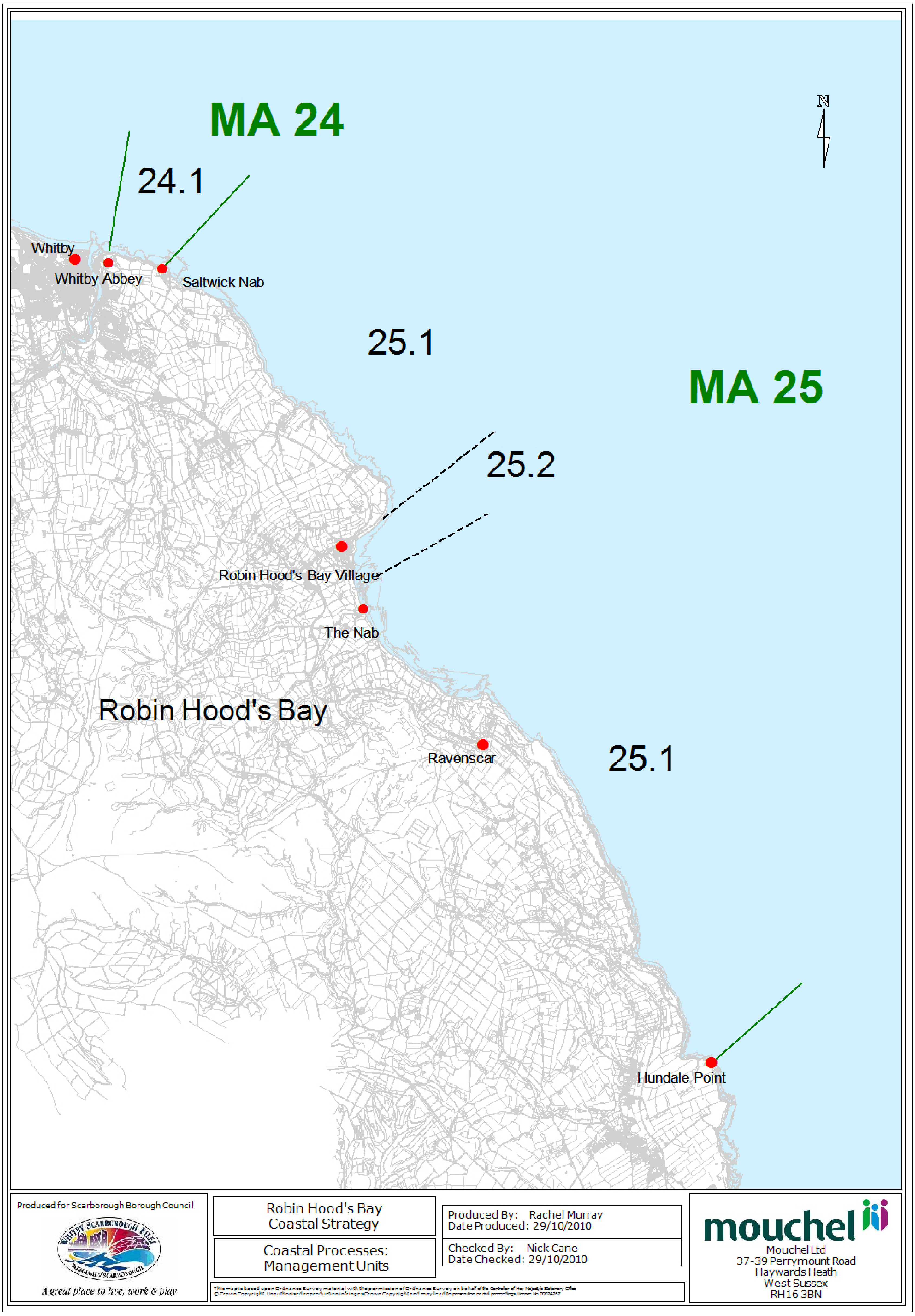

Figure 1: Study Area Map of Management Area –MA24 and MA25 and individual Policy Units.

2 Developing an Understanding of Baseline Coastal Processes

This chapter provides a background and approach for this study. This section also discusses the development of the baseline coastal process understanding; outlines the key information used and the general approach adopted. It also details key information regarding climate change and sea level rise.

2.1 Shoreline Management Plans

The first rounds of Shoreline Management Plans were based upon littoral cell boundaries, which had previously been defined as zones of longshore sediment transport convergence and divergence. Whilst the littoral cell concept has been an accepted approach, it is only one aspect of coastal system behaviour and other factors need to be considered when assessing future shoreline evolution, therefore is not adequate for making holistic longer-term predictions.

The SMP Guidance (Defra, 2006) now recommends a 'Behavioural Systems' approach, which involves the identification of the different elements that make up the coastal system and development of an understanding of the relationships and interactions between these various elements, on a range of both temporal and spatial scales.

2.2 Implementation of Futurecoast

The Futurecoast (Defra/Halcrow, 2002) project was originally commissioned by Defra 'to improve the understanding of coastal evolution for the open coast of England and Wales'. It provides an understanding of coastal dynamics and shoreline evolution around the coastline of England and Wales and provides a long term vision of the coast 100 years from now.

The Futurecoast project was also intended to build on the first round (and intended to inform the second round) of SMPs and is therefore a key source of information required for this study.

The project was designed to understand coastal behaviour and involved the identification of large scale units, termed Coastal Behavioural Systems (CBS) from assessment of:

- Shoreline and offshore geology
- Offshore features and their interactions with the shoreline
- Hydrodynamic and sediment processes
- Holocene evolution
- Historical trends

Within each CBS, are smaller units named Shoreline Behaviour Units (SBUs) which are described as discrete stretches of coast where plan-form evolution appears to be governed by these controls and influences, through a combination of different linkages. Each SBU comprises of a number of geomorphological elements along its length, such as:

- beaches
- barriers
- coastal dunes
- cliffs
- tidal flats
- marshes/shore platform

Predictions of future tendency were based on the geomorphological interpretation of the critical elements, behaviour and sensitivity at the SBU scale, and identifying potential areas of increasing, decreasing, continuing, ceasing or commencing pressure. This understanding of changing pressures, combined with a generic understanding of how individual elements of the coast respond to such changes, enabled predictions to be made of the likely future shoreline response. The predictions also considered cumulative impacts and knock-on effects. Once descriptions of future tendency were made for the natural response scenario (i.e. without present engineered intervention), a trend was identified by comparing predicted future with observed past rates or tendencies of evolution (both plan form shape and cross-shore response) and using professional judgement to identify whether there was the likelihood for:

- Continuation of past rates;
- Acceleration of past rates;
- Deceleration of past rates;
- Cessation of past rates;
- Re-commencement of past rates; and/or
- Complete change in morphological type

2.3 Approach Adopted for this Study

The baseline process assessments carried out for this study and to ultimately inform the CDS have adopted the ‘Behavioural Systems’ approach detailed in the above section.

An overview of the current understanding in terms of coastal processes and the wider area is required to describe the large scale movements and interactions. Initially, a wide scale assessment of the East Coast of England is undertaken, and then a more focussed assessment of the coast using Futurecoast (Defra, 2002).

The SBU’s defined by Futurecoast (Defra, 2002) have been reviewed and the information applied where necessary. Information from previous studies has been applied such as the first round SMPs, in particular Huntcliffe (Saltburn) to Flamborough Head Shoreline Management Plan and the second round River Tyne to Flamborough Head Shoreline Management Plan Review (SMP2).

The SBU has been adopted for this study as the smaller scale units and stated in the SMP2 as Coastal Process Units; these smaller units have been defined through considering geomorphology, coastal processes and coastal features.

The Futurecoast local-scale statements include more detail for shorter sections of coast. These statements consider:

- **Interactions** –includes key geomorphological features, sediment linkages, mechanisms of sediment transport, local sediment budgets and interactions and potential feedbacks with adjacent stretches of coast.

- **Movement** –focuses on available data on trends and rates of beach and backshore changes, the type of change and mechanisms of change.

- **Existing predictions of shoreline evolution** – existing predictions and the assumptions made in making these predictions. A key source of data has been Futurecoast, but other information has been sourced, where available.

2.4 Key data sources used in the baseline understanding

The baseline process understanding has been compiled from a desk study of available data, reports and peer-reviewed literature, and the interpretation of this information in the context of the CSS. The following key data sources have been used to inform the coastal processes study.

2.4.1 Huntcliffe (Saltburn) to Flamborough Head Shoreline Management Plan – Sub cell 1d (1997)

The first round Shoreline Management Plan for the North East – Sub cell 1d, as discussed in the previous section, was based upon littoral cell boundaries, which had previously been defined as zones of longshore sediment transport convergence and divergence.

2.4.2 River Tyne to Flamborough Head Shoreline Management Plan 2 (SMP2)

Baseline Process Understanding within the SMP2 includes a baseline coastal process report, defence assessment, No Active Intervention (NAI) and With Present Management (WPM) assessments and summarises data used in assessments.

2.4.3 Futurecoast

As described above, Futurecoast is an essential source for coastal process baseline understanding.

2.4.4 National Coastal Erosion Risk Map (NCERM)

NCERM will be reviewed and applied were necessary when the final document becomes available.

2.4.5 United Kingdom Climate Impact Programme (UKCIP)

UKCIP provides scenarios that show how our climate in the UK might change and co-ordinates research on dealing with our future climate.

2.4.6 Planning Policy Statement 25 (PPS25)

Planning Policy Statement 25 sets out the Government's national policies on different aspects of land use planning in England.

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3 Defence Assessment

The Defence Assessment table provides a summary of the existing defences along the MA24 and MA25 frontage together with an assessment the interactions with coastal processes. The asset information in this section has been taken from the NECAG Coast Protection Assets and Coastal Slope Condition Analysis (2009) produced by Halcrow and Royal Haskoning. Other information has been extracted from assessments and reports which have been undertaken along the MA24 and MA25 frontage. The Defence Assessment is used to inform the baseline processes. It primarily provides information to enable us to understand how defences and management practices affect coastal behaviour.

Table 2.4-1: Table showing engineered defences within MA24 and MA25 and the interaction with coastal processes.

NFCDD reference	Location	Engineered Asset Type	Interaction with Coastal Processes
1221D901D0803C05	Cliffs east of Whitby Harbour	Rock armour	The armour rock appears to be stabilising the cliff toe therefore limiting sediment input to the nearshore, although weathering to the upper cliff is still occurring.
1221D901D1003C01	Robin Hoods Bay	Sea wall and rock armour	The sea wall and armour rock appears to be stabilising the cliff toe therefore limiting sediment input to the nearshore.
1221D901D1003C02	Robin Hoods Bay	Large vertical sea wall	The sea wall is retaining the cliff therefore limiting sediment input to the nearshore. It is not considered a control point at present however this depends on future management of the areas flanking the structure.

1221D901D1003C04	Robin Hoods Bay	Sea wall	The sea wall is retaining the lower cliff and foundations of a property therefore limiting sediment input to the nearshore. It is not considered a control point at present.
1221D901D1003C07	Cowling Scar	Rock armour	The rock armour at present is well integrated to the cliff contours and does not appear to be holding significant levels of sediment. Future erosion of the southern flank will expose this rock and will possibly act as a control point.
1221D901D1003C09	Robin Hoods Bay	Sea wall and rock armour	The sea wall and armour rock appears to be integrated and stabilising the cliff toe therefore limiting sediment input to the nearshore. It is not thought that this structure will act as a control point however this is dependent on future management practices of adjacent sea defence structures.

The information shown in Table 2.4-1 gives an indication that although sediment is limited by certain structures in terms of sediment supply to the net and variable drift direction, it is not likely that the current engineered defence structures will create control points for sediment transport. However, the retreat of the undefended sections of coast could create control points at the defending structures, increasing the potential to 'starve' coastal areas further along the sediment drift direction. Future coastal management would need to consider action plans to mitigate against any potential sediment starving and interdependency between defending structures.

4 Overview of Current Understanding

It is important to gain a solid understanding of wider scale coastal processes to inform the local scale assessment. This section describes the large scale geology and coastal processes along the North East Coast of England coast with reference to local areas from Futurecoast (Defra, 2002) and includes a series of short summary statements describing the current understanding of coastal behaviour for the smaller sections of the coastline. Unless otherwise stated, information provided in Section 4 is taken directly from Futurecoast (Defra, 2002).

4.1 East Coast of England Coastal Processes

4.1.1 General

The North Sea provides the driving force for many of the processes, which act upon the East Coast. There are two open-sea entrances to the North Sea (see also Figure 2):

- the wide northern entrance between Scotland and Norway; and

- the much narrower entrance through the Dover Straits at the eastern end of the English Channel.

Figure 2: Map of the North Sea entrances (Source: Graphic Maps)

The North Sea is typically less than 40 m water depth. In addition, the Southern North Sea is typically shallower than the northern. This means that during the Holocene sea level rise the southern region was inundated after the northern region and, as such, may still be adjusting to the hydrodynamic forces.

The North Sea can be subdivided on the basis of difference in bathymetry and process regimes. The effect of these regimes, in combination with the summer heat input to the surface waters, leads to a stratified water column within the central North Sea and a mixed water column in the coastal region and in the Southern Bight. Further division of the North Sea has been made, by including the water mass characteristics such as nutrient levels and turbidity. Details of the hydrodynamic and sedimentological regime of this region are given in the following sections.

4.1.2 Tides

Tidal propagation

The Atlantic tidal wave enters the North Sea i) between Scotland and Norway; and ii) through the Dover Straits. The timing of the tidal wave propagation along the East and South coasts is such that the High Water (HW) of both coincides at the Dover Straits. However, the East Coast's tidal wave reaches the Straits one tidal period ahead of that of the South Coast. It should also be noted that the Dover Straits is the location of some of the highest tidal velocities observed in the English Channel and coincides with a zone of sediment transport convergence. The tidal wave exits the North Sea through the Baltic Sea and along the western coast of Norway. The result of this tidal propagation is an anticlockwise circulatory pattern of water movement within the North Sea. The inflow rate is greater through the northern entrance to the North Sea than the southern. There are three amphidromic points (for the M2 component) in the North Sea (see Figure 2):

- Between the Anglian and Holland coasts;
- Offshore from Esbjerg, Denmark; and
- Offshore from Stavenger, Norway.

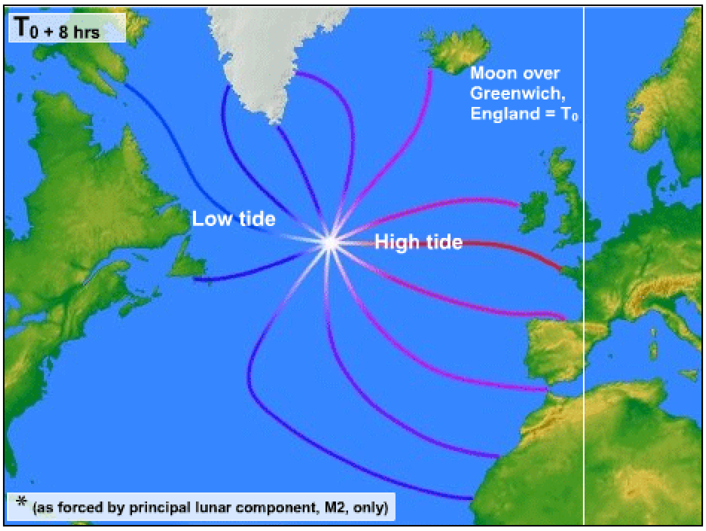

Figure 3: Map showing M2 tidal constituent for the Atlantic. (Source MetEd)

Tidal range

The tidal ranges are between 1.5 and 5 m along the open coast. The highest tidal range along the East Coast is located between the River Humber and the Wash embayment. In the Wash, a mean spring range of 6 m and a mean neap range of 3m occurs due to resonance and shallow water coastal bathymetry.

Tidal currents

Maximum depth-averaged M2 tidal currents are found:

- within the Dover Straits, extending to North Foreland (> 1 m/s);
- to the north-east of Anglia (0.8 -0.9 m/s); and
- at the mouth of the Humber (0.7 -0.8 m/s).

The maximum depth-averaged S2 tidal currents are found:

- within the Dover Straits (0.3 -0.4 m/s);
- to the north-east of Anglia (0.25 -0.3 m/s); and
- from Flamborough Point to the Wash (0.2 -0.3 m/s).

Therefore, taking into account the M2 and S2 tidal currents, the maximum depth-averaged tidal currents can be found:

- within the Dover Straits, extending to North Foreland (> 1 m/s); and
- to the north-east of Anglia (0.8 -0.9 m/s).

The tidal ellipses show a distinct change offshore, where they become more circular due to the absence of coastal boundary effects.

4.1.3 Waves

The direction of wave approach varies from the northern North Sea (north-east and north-north-east) to the southern North Sea (east-north-east to south-east). In the north of the region, the hydrodynamic climate contains a significant swell component with the predominant waves originating from the northeast and north-north-east, arising from the North Atlantic. Under certain conditions, swell can also propagate into the southern North Sea. Offshore extreme wave heights in the North Sea show a significant decrease from the north to south. Based upon the 10 year return period, the offshore extreme wave height varies from 16m, in the northern limits, to 7m, in the southern limits of the North Sea. This large difference results from a number of factors:

- Depth limitation effects;

- Extreme mean wind speed variation; and

- Breaking/refraction processes.

Such changes in the wave climate will lead to significant variations in the sea bed processes, such as boundary layer thickness and turbulence, which impact on sediment transport processes. There is presently some uncertainty regarding whether or not the hydrodynamic climate around the UK is showing temporal change. Any trend is complicated further by the degree of variation within the wave climate, which masks the underlying trend; "what is clear is that the North Sea and north-east Atlantic region is liable to bigger variation of its climate than have hitherto been appreciated" (Futurecoast 2002). Data obtained from the north-east Atlantic has been used to show that, between 1962 and 1984, significant wave heights have increased. This trend would imply that there has been a gradual increase in storminess over this period. However, the most recent research into this trend shows that, although there has been an increase in wave height and storminess since 1962, the recorded values of the last two decades are comparable to those obtained from the beginning of the 20th century.

4.1.4 Storm Surges

Extreme water levels along the East Coast are dominated by surges, which act to increase the water levels by > 2 m. The surge effect increases from north to south, due to the funnelling effect of the North Sea. The North Sea is highly susceptible to storm surges, in response to a number of characteristic features:

- shallow water depth in the south;

- large area over which the wind stress can build up; and

- a northern opening, which lies in the track of many atmospheric depressions passing between Iceland and Scotland.

The storm surges of the North Sea can be divided into two types:

- external; and

- internal.

External surges originate from the shelf seas off northern Scotland and propagate into the North Sea, with only small changes in amplitude. It has been suggested, although not proven, that another source of external surges could be deep ocean disturbances generated in the Atlantic, which propagate into the shallow Scottish shelf waters. The internal surges result from wind action over the North Sea and can be generated either in localised areas, or over the whole area. Low pressure systems could also be important for internal surges. It should be noted that the non-local internal surges are typically combined with external surge characteristics.

Probably the most well known storm surge is the disastrous event of 1953. A deep depression passed to the north of Scotland, before veering south-eastwards into the North Sea, causing a shift in the wind direction. This movement resulted in very severe north-westerly gales over the majority of the North Sea and as a result water piled up creating a surge, which raised the sea level by more than 2.4 m in places.

Although North Sea storm surges have the potential to be disastrous, there are a number of factors which act to reduce the frequency occurrence of these events:

(1) the time of high water (HW) and (2) Inflow/outflow through the Dover Straits for an outflow through the Straits can suppress surge residuals by up to 1 m.

Short-lived storm surges tend to be confined to the rising tide, rather than HW. The explanation for this is that: 'the long duration of a positive surge relative to the semi-diurnal tide, results in an effective increase in the mean water depth on which the tidal wave is superimposed. Hence the tidal wave travels faster than expected, resulting in a tide whose high point reaches a given point earlier than predicted. When the predicted tidal curve is subtracted from the resulting time-displaced tidal curve, the resulting maximum positive residual occurs on the rising tide. This then combines with the surge to produce a surge maximum; at the predicted time of HW the tide-surge interaction residual will be negative, thus lowering the total residual caused by the surge' (Defra, 2002).

Note that future changes in storm surge levels may be important in future shoreline evolution since present evidence suggests that these surge levels have increased over the past 100 years (OSPAR Report, 2000).

4.2 Saltburn to Flamborough Head

4.2.1 Physical Characteristics and internal constraints

This coastline is composed of eroding cliff and beach units. The mobile sea bed sediments are predominately sand although, in the offshore region, the material also has gravel content. The 20 and 40 m contours run parallel to the coast, and at Flamborough Head the 10 and 20 m contours become attached to the land.

Water levels

The table below shows existing water levels at the Whitby Harbour entrance taken directly from the Admiralty Tide Tables (2009).

Table 4.2-1: Water levels determined for Whitby using the River Tees as the standard port. Levels are to Ordnance Datum Newlyn. Chart Datum is approximately 3.0m below Ordnance Datum. Source (tidal levels): Admiralty Tide Tables (2009) for main and secondary ports, with other values interpolated. Future levels are based on PPS25.

MLWS	MHWS	HAT	2025	2055	2085	2115
0.80 m AOD	5.60 m AOD	6.30 m AOD	6.34 m AOD	6.55 m AOD	6.85 m AOD	7.24 m AOD

Future water levels based on United Kingdom Climate Projections (UKCP) follow a similar increase to PPS25 (Table 4.2-1) on a 95 per cent frequency and medium CO2 emissions scenario (central estimate) for the section of coast at Robin Hoods Bay as shown in Figure 2 (predictions are to 2100). For example, the difference between the current highest astronomical tide (HAT) (6.3m AOD) and the 2085 PPS25 predicted HAT (m AOD) is 0.55 m, where as UKCP have predicted a relative sea level rise of 0.58 m for a 95 per cent frequency for the same year.

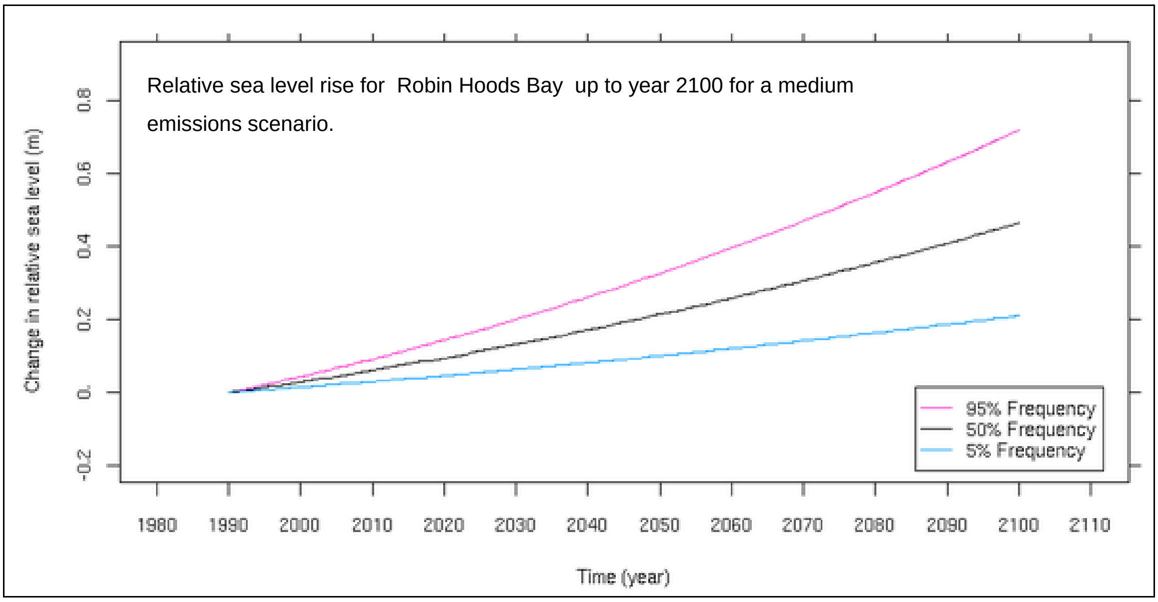

Figure 4: Graph showing relative sea level rise at Robin Hoods Bay. Source UKCP

Wave climate

The wave climate data from the SMP2 (Royal Haskoning, 2007) has been used to provide information for the return periods stated in Table 4-2. Figure 4 also shows Cefas wave data from the Tyne/Tees wave buoy taken between August 2007 and August 2009.

Table 4.2-2: Wave Climate for Whitby at 8m OD contour. Source: Royal Haskoning, 2007. River Tyne to Flamborough Head Shoreline Management Plan Review.

Return Period (years)	Wave Height Hs (m)
1:0.10	3.71
1:1	4.79
1:10	5.79
1:100	6.73
1:200	7.39

Return Period (years)	Wave Height Hs (m)
1:500	7.81

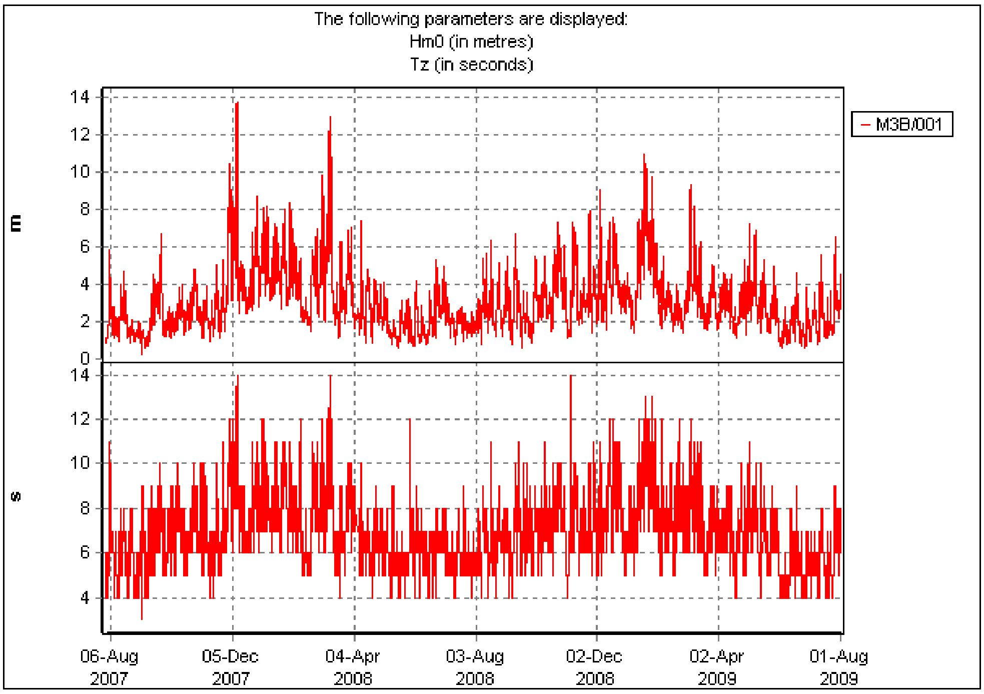

Figure 5: Cefas wave data from the Tyne/Tees wave buoy taken between August 2007 and August 2009.

Baseline Erosion Rates

The table below shows baseline erosion rates for the section of coast between Saltwick Nab and North of Hundale Point. The rates shown here reflect the figures stated in the SMP2 (Royal Haskoning, 2007). The erosion rates, according to the SMP2 (Royal Haskoning, 2007), are based on existing evidence and are likely to increase with sea level rise, therefore a factor of 2.5 has been used to allow for this over 100 years. The SMP2 (Royal Haskoning, 2007) goes on to mention that 'where defences exist it is generally assumed that if they fail erosion rates would initially be greater, subject to other control features in the area'.

Table 4.2-3: Baseline Erosion Rates for Saltwick Nab to Hundale Point. Source: Royal Haskoning, 2007. River Tyne to Flamborough Head Shoreline Management Plan Review.

Coastline	Baseline rate (m/year)	Added 2.5 factor (m/year)
The Scar (Abbey	0.04	0.1

Coastline	Baseline rate (m/year)	Added 2.5 factor (m/year)
cliffs)		
Saltwick Nab	0.28	0.7
Northern Coast	0.04	0.1
North Cheek	0.04	0.1
Robin Hoods Bay Village	0.12	0.3
Robin Hoods Bay	0.12	0.3
Ravenscar	0.08	0.2
Beast Cliff	0.04	0.1
North of Hundale Point	0.04	0.1

4.2.2 External forcing

The dominant wave direction is from the north-northeast, has a large swell component and is not fetch-limited. The annual 10% exceedance significant wave height is 1.5 to 2.0 m.

Tidal currents have a southerly residual (Motyka and Brampton, 1993), although they are subject to reversal in the vicinity of estuaries. Tidal current speeds increase in a southerly direction from Saltburn-on-the-Sea to Flamborough Head:

- 0.36m/s between Saltburn-on-the-Sea and Robin Hood's Bay;
- 0.39 m/s between Robin Hood's Bay and Filey Brigg;
- 0.5 m/s in Filey between the Brigg and Speeton;
- 0.64 m/s around the northern coast of Flamborough Head; and
- 0.77 m/s at Flamborough Head.

The tidal range is fairly constant within this stretch of the coastline with the mean spring tidal range at Scarborough being 4.8 m.

The tidal currents around Flamborough Head have several unique characteristics:

- There is no slack water;

- There are typically slower tidal currents during the autumn and winter months; and

- During spring tides there is a northwards residual of 0.11 m/s, whilst during neap tides there is a southerly residual flow of 0.09 m/s. This enables sediment movement to take place from Smithic Sands (Bridlington Bay) into Filey Bay at certain tidal states.

4.2.3 Sediment transport

Net littoral transport is in a southerly direction, except during certain states of the tide (see above) when material is transported northwards around Flamborough Head. However, it is also considered that there is little small-scale interaction between embayments, due to the isolated nature of the beaches (Motyka and Brampton, 1993).

Current studies of the SBC coast do not provide sufficient evidence for an offshore-onshore sediment transport link. Although there is likely to be an extensive thin veneer of mobile sand, resting on bedrock, between the coast and the 20 m bathymetric contour, the movement of this sediment has not been determined. However, a link can be inferred from sediment budget estimates and the longshore morphology of the coast .

4.2.4 Esk Estuary Assessment

This is a small Type 3b Ria without spits. It is short, with a small river catchment. The mouth has jetties on both sides, and there has been build up of a reasonable beach on the west side. Within the mouth there are harbour walls and defences that protect the town of Whitby. The harbour largely empties of water at low tide exposing sandflats.

It is known that there is a tidal intrusion front occurring during the early flood tide. This signifies the onset of plume formation at higher river flows.

The cross sectional area is rather high for the volume and the mouth width is small for the channel length. However, these are probably a function of the harbour mouth dimensions. The intertidal area ratio is fairly low at 0.64, so that some further deposition may occur. The maximum flow ratio is close to unity, and a plume is likely on the ebb tide.

The estuary is small and is likely to be a weak source for muddy sediment.

4.3 Futurecoast Shoreline Behaviour Statements

The Futurecoast Shoreline Behaviour Statements (Defra, 2002) for the frontages linked to the study area including Robin Hoods Bay are presented in full in the following sections. Within each of the Shoreline Behaviour Statements there are a number of Local Shoreline Response Statements (LSRS) for the following frontages as defined by Futurecoast (Defra, 2002):

- Saltburn to Ravenscar Shoreline Behaviour Statement
    - Saltburn to Sandsend (excluding Runswick Bay) and Whitby to Robin Hood's Bay LSRS

    - Sandsend to Whitby West Pier LSRS

    - Robin Hood's Bay LSRS

- Ravenscar to Scalby Ness Shoreline Behaviour Statement

    - Peak Steel to Scalby LSRS

This presents a localised background to the coastal processes, on which the more detailed discussion is carried in Section 5. Figure 6 shows the LSRS in relation to the study area. The LSRS boundaries are presented as they are set out in the Futurecoast study (Defra, 2002).

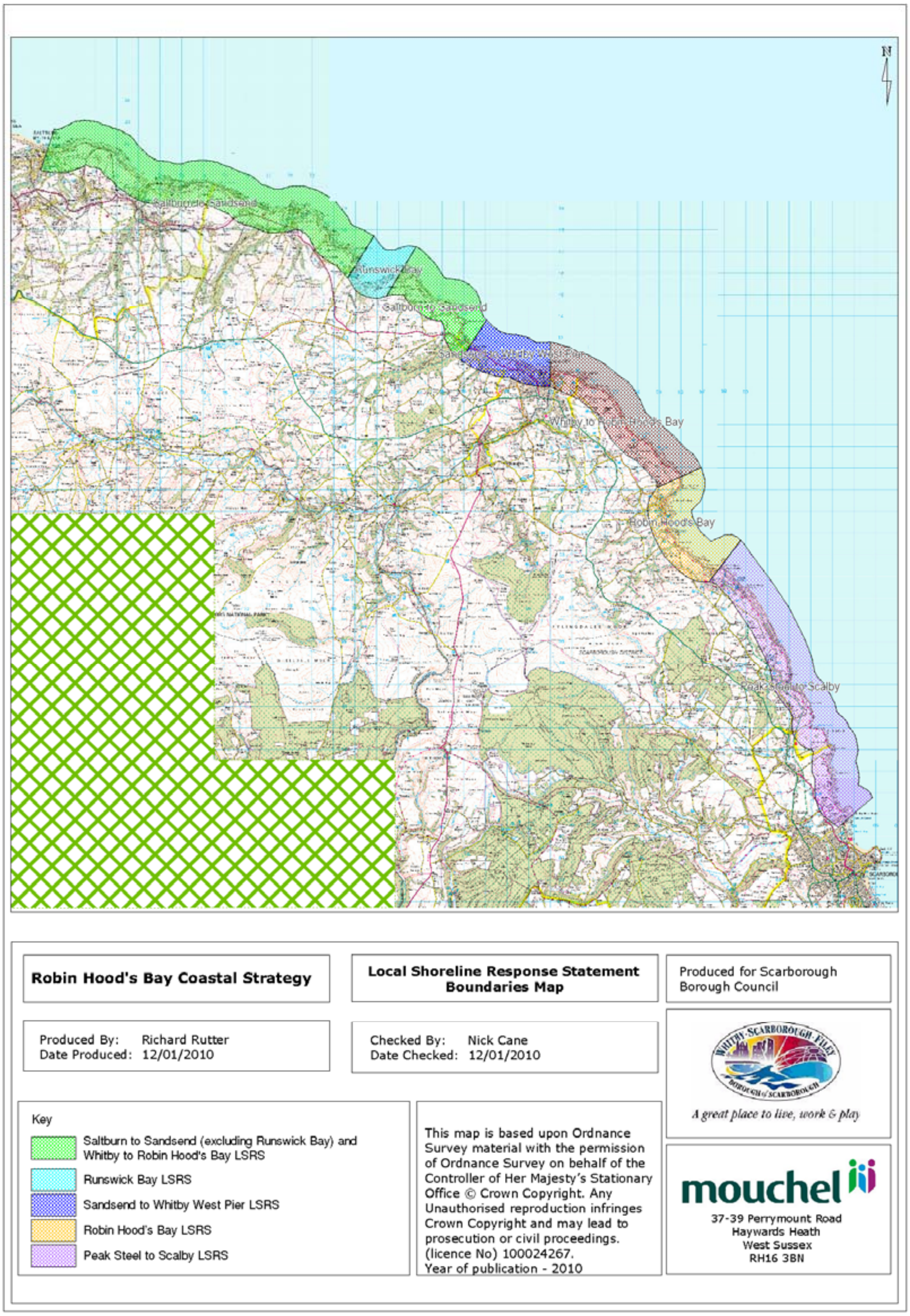

Figure 6: Futurecoast Local-Scale Shoreline Response Statement Units

LOCAL-SCALE SHORELINE RESPONSE:

Saltburn to Sandsend (excluding Runswick Bay) and Whitby to Robin Hood's Bay

Assessment of Characteristics and Behaviour

Components

This frontage contains high and near vertical sea cliffs composed of Jurassic mudstones and sandstones, overlain by till and fronted by a wave cut platform. Lias mudstones occur in the lower cliff sections and are prone to marine erosion. Harder sandstone layers occur higher in the cliffs and are subject to occasional rockfalls. The upper cliffs are capped by till, which is prone to frequent slippage and has a much lower slope profile. Rock platforms strewn with boulders and, in some locations, narrow sand beaches, are exposed at low tide.

Present management practices

Concrete and stone seawalls have been built protecting most of the coastal villages and towns including: Old Saltburn; Staithes where the breakwaters are reinforced by block armour; the stone jetties and artificial harbour at Port Mulgrove, where the breakwaters are now in poor condition; a seawall and apron at Sandsend; aprons and rock armour along the Whitby frontage, and two breakwaters at Whitby harbour.

Historic trends

Cliff retreat affects the entire frontage, at a rate dictated by the erodibility of the Lias mudstones in the lower part of the cliffs. The overlying more resistant sandstone beds do not slow erosion to any significant degree, because they are eventually susceptible to rock falls when undercut by the removal of the underlying Lias.

Shale quarries to extract alum have left the cliff line with lowered, irregular, profiles at Sandsend, Saltwick and Kettleness. Extensive spoil heaps occur on the cliffs at these localities.

The wave cut platform along this frontage is remarkably smooth; a factor which has been attributed to erosion, following repeated cycles of wetting and drying in the intertidal zone. The Lias mudstones are particularly prone to cracking, especially during the summer. The progressive erosion of the wave cut platform facilitates the erosion of the cliffs by increasing the exposure to wave attack at the cliff base.

Wider scale interactions:

Small amounts of sand and gravel are supplied to the nearshore sand belt from cliff erosion, primarily from glacial till.

<u>Assessment of Future Geomorphic Evolution</u>

Potential tendency (unconstrained)

The shore platform would continue to erode at slow rates, in turn facilitating cliff erosion. Lias mudstone cliffs would be prone to higher rates of erosion than the harder sandstones exposed higher in the cliffs between Staithes and Robin Hood's Bay.

Predicted behaviour with present management practices

Cliffs composed of Lias mudstones with overlying till will continue to retreat at a rate commensurate with the erosion of the Lias. The soft till upper cliff sections will remain subject to slippage even on protected sections of coastline.

Uncertainty classification

Potential tendency for unconstrained scenario: low uncertainty.

Predicted behaviour with present management practices: low uncertainty.

LOCAL-SCALE SHORELINE RESPONSE:

Sandsend to Whitby West Pier

Assessment of Characteristics and Behaviour

Components

This frontage contains a long sand and shingle beach backed by sea cliffs comprised largely of soft till, with hard Jurassic rocks at West Cliff. Sand occurs on the seabed immediately offshore. The cliffs behind Upgang Beach are now the main source of new sand and gravel for the beach.

Present management practices

There exists a seawall and apron at Sandsend, and aprons and rock armour along the Whitby West Cliff frontage together with the west breakwater at Whitby harbour. Cliff stabilisation measures have been carried out along West Cliff at Whitby. The cliffs behind Upgang Beach are not defended. Groynes help to retain beach sand along the foreshore below West Cliff.

Historic trends

Over the past century there has been a net loss of beach sand along this part of the coastline. Development of the sea defences has reduced the supply of sediment to the beaches fed from local cliff erosion. The route of a disused railway line that now crosses the current cliff position behind Upgang Beach indicates that considerable recession has occurred over the past century.

Wider scale interactions

Some beach sand is lost offshore and moves east by longshore drift. The outflow of the River Esk at Whitby may alter coastal currents locally, carrying some sand further offshore.

Assessment of Future Geomorphic Evolution

Potential tendency (unconstrained)

Sandsend to Whitby would develop into an embayment without the constraints of coastal defences. A spit is likely to grow across the mouth of the River Esk at Whitby from the northern side. Foreshore steepening and narrowing would continue due to ongoing sea level rise and the potentially insufficient supply of sand from local cliff recession to balance this.

Predicted behaviour with present management practices

The cliff behind Upgang Beach will continue to retreat. The soft till cliffs behind defended sections of this frontage will continue to be affected by periodic landslides, with the possibility of some material being shed onto the beach over the top of the existing seawalls.

Uncertainty classification

Potential tendency for unconstrained scenario: medium uncertainty.

Predicted behaviour with present management practices: medium uncertainty.

LOCAL-SCALE SHORELINE RESPONSE:

Robin Hood's Bay

Assessment of Characteristics and Behaviour

Components

Cliffs formed of Lias shale overlain by glacial till surround the bay. The till is thickest in the centre of the bay, and in some places the solid geology can only be seen on the wave cut platform. Northeast of Robin Hood's Bay village the cliff is almost entirely composed of Lias mudstone. Rock cliffs form the southern boundary of this frontage. Wave cut platforms dominate the foreshore.

Present management practices

A concrete seawall with steel piling protects Robin Hood's Bay old village. Due to landslides on the steep slope below the upper village during the 1990s, slope remedial works and the construction of new sea defences were undertaken in 2000. The new defences comprise a new concrete wall at beach level below West Scar. This new wall has been backfilled with gravel and its front is also protected by rock armour. The slope above the seawall has also been regraded. Rock armour also extends 200m south of the old village to help reduce landslide movements. There are no defences elsewhere in the bay.

Historic trends

Landslides within the glacial till have caused cliff retreat, particularly in the centre of the bay, followed by marine erosion of the slipped sediment. Severe erosion of the unprotected cliff occurs beyond the southern end of the sea defences.

Wider scale interactions:

There is a general southward drift of sediment in the nearshore zone between Saltburn and Ravenscar, and sand derived from erosion of the till may provide a very small contribution to the nearshore sand belt south of the bay.

Assessment of Future Geomorphic Evolution

Potential tendency (unconstrained)

The central part of Robin Hood's Bay would recede more quickly than at the adjacent headlands due to lithological and structural controls, resulting in a progressively deepened embayment. Average erosion rates of the thick glacial till occurring in the centre of the bay are quadruple those of medium strength Lias shales. Robin Hood's Bay has a natural tendency to become more incised. Small amounts of sand released from erosion of till would be added to the foreshore, but insufficient amounts to prevent slight lowering of the foreshore platform.

Predicted behaviour with present management practices

The village of Robin-Hood's Bay in the north-west of the bay will be protected from marine erosion, although instability of the cliff above the sea defences could still pose a potential problem for some housing in the village. The central and southern parts of the bay will continue to retreat.

Uncertainty classification

Potential tendency for unconstrained scenario: low uncertainty.

Predicted behaviour with present management practices: low uncertainty.

4.4 Cliff Behaviour Assessment

4.4.1 Cliff Characteristics

In terms of assessing coastal processes, it is important to review the cliff characteristics within the study area and also in areas adjacent to provide an understanding of geomorphology and interactions. Table 4.4-1 details the cliff characteristics for the study area as well as adjacent frontages.

Table 4.4-1: Cliff characteristics and behaviour between Whitby and Burniston, adapted from Futurecoast (DEFRA, 2002).

Location	Behaviour	Max Height (m OD)	Engineering Works	Materials	Failure Mechanism	Sediment Supply Grade	Sediment Supply Potential	Activity
Whitby	Simple landslides	20	None	Weak superficial deposits	erosion, slides, mudslide	medium	high	Very active
Whitby	Simple landslides	35	Cliff stabilisation, Toe protection	Weak superficial deposits over jointed weak rock	Erosion, falls, slides, mudslide	medium	low	Marginally stable
West Cliff, Whitby (*)	Simple landslides	35	None	Weak superficial deposits over jointed weak rock	erosion, falls, slides, mudslide	medium	high	Very active
East Cliff, Whitby	Composite cliffs	35	None	Weak superficial deposits over jointed weak rock	erosion, falls, slides, mudslide	medium	medium	Active
Saltwick Nab	Complex cliffs	50	None	Stiff clays overlain by hard caprock	erosion, slides, multi rotational	medium	high	Marginally stable
Saltwick Bay	Simple cliffs	60	None	Stiff clays overlain by hard caprock	erosion, falls, slides, debris	medium	medium	Active
High Whitby	Composite cliffs	90	None	Stiff clays overlain by hard caprock	erosion, falls, slides, debris	coarse	high	Active
Hawsker Cliffs	Simple cliffs	60	None	Jointed weak rock	erosion, falls, slides, debris	medium	medium	Active

Location	Behaviour	Max Height (m OD)	Engineering Works	Materials	Failure Mechanism	Sediment Supply Grade	Sediment Supply Potential	Activity
Hawsker Bottoms	Simple cliffs	35	Cliff stabilisation Toe protection	Jointed weak rock	erosion, slides	medium	low	Marginally stable
Robin Hood's Bay (*)	Simple cliffs	35	None	Jointed weak rock	erosion, slides	medium	medium	Active
Cowfield Hill, Robin Hood's Bay	Composite cliffs	30	None	Weak superficial deposits over jointed weak rock	erosion, slides, mudslide	medium	high	Active
Stuope Cliffs	Composite cliffs	60	None	Weak superficial deposits over jointed weak rock	erosion, slides, mudslide	medium	medium	Active
Ravenscar to Beast Cliff	Complex cliffs	130	None	Weak superficial deposits over jointed weak rock	erosion, falls, slides	coarse	high	Active
Hayburn	Simple cliffs	70	None	Jointed weak rock	erosion, falls, slides, debris	coarse	medium	Active
Hayburn Wyke	Complex cliffs	80	None	Jointed weak rock	erosion, falls, slides	coarse	high	Marginally stable
Cloughton Wyke	Simple cliffs	50	None	Jointed weak rock	erosion, falls, slides, debris	coarse	high	Active

Location	Behaviour	Max Height (m OD)	Engineering Works	Materials	Failure Mechanism	Sediment Supply Grade	Sediment Supply Potential	Activity
Burniston	Composite cliffs	40	None	Weak superficial deposits over jointed weak rock	erosion, falls, slides, mudslide	medium	medium	Active

4.4.2 Future potential change

To understand how the study area and coast might evolve in the future, the table below details the elements that could affect future coastline change. This information is used to inform the detailed coastal processes and ultimately the any future management for MA24 and MA25.

Table 4.4-2: Future potential change

Location	Recession Potential	Recession potential (single landslide event)	Recession (event) frequency	Sensitivity to Climate Change	Uncertainty
Whitby	Very low <0.1m/yr	Medium 10-50m (0.2-1ha)	<1 year (erosion), 10-100 years	Medium	Moderate
Whitby (*)	Medium 0.5-1m/yr	Medium 10-50m (0.2-1ha)	<1 year (erosion), 1-10 years	High	Low
East Cliff, Whitby	Low 0.1-0.5m/yr	Low <10m (<0.2ha)	<1 year (erosion), 1-10 years	Medium	High
Saltwick Nab	Low 0.1-0.5m/yr	High >50m (>1ha)	<1 year (erosion), 250-1000+ years	Medium	Moderate
Saltwick Bay	Low 0.1-0.5m/yr	Medium 10-50m (0.2-1ha)	<1 year (erosion), 10-100 years	Medium	Moderate
High Whitby	Very low <0.1m/yr	Low <10m (<0.2ha)	<1 year (erosion), 1-10 years	Medium	High
Hawsker Bottoms	Low 0.1-0.5m/yr	Low <10m (<0.2ha)	<1 year (erosion), 1-10 years	Medium	High
Robin Hood's Bay	Very low <0.1m/yr	Low <10m (<0.2ha)	<1 year (erosion), 10-100 years	Low	Moderate
Robin Hood's Bay (*)	Low 0.1-0.5m/yr	Low <10m (<0.2ha)	<1 year (erosion), 1-10 years	Medium	Low
Cowfield Hill, Robin Hood's Bay	Medium 0.5-1m/yr	Medium 10-50m (0.2-1ha)	<1 year (erosion), 10-100 years	High	High
Stuope Cliffs	Low 0.1-0.5m/yr	Medium 10-50m (0.2-1ha)	<1 year (erosion), 10-100 years	Medium	High
Ravenscar to Beast Cliff	Low 0.1-0.5m/yr	High >50m (>1ha	<1 year (erosion), 100-250 years	Medium	High
Hayburn	Low 0.1-0.5m/yr	Low <10m (<0.2ha)	<1 year (erosion), 1-10 years	Medium	High
Hayburn Wyke	Very low <0.1m/yr	High >50m (>1ha)	<1 year (erosion), 250-1000+ years	Medium	High

Location	Recession Potential	Recession potential (single landslide event)	Recession (event) frequency	Sensitivity to Climate Change	Uncertainty
Cloughton Wyke	Low 0.1-0.5m/yr	Low <10m (<0.2ha)	<1 year (erosion), 1-10 years	Medium	High
Burniston	Low 0.1-0.5m/yr	Medium 10-50m (0.2-1ha)	<1 year (erosion), 1-10 years	Medium	High

* Definitions based on DEFRA's Soft Cliffs Study: prediction of recession rates and erosion control techniques.

** Sub-division of mechanisms based on GSL landslide classification (GSL, 1986).

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5 Discussion of Coastal Processes

This chapter builds upon the information from the SMP2 (Royal Haskoning, 2007) and the Futurecoast information provided in Section 4 and gives a detailed assessment of the coastal processes using existing data. For consistency, the Coastal Process Units, as detailed in the SMP2 (Royal Haskoning, 2007) are defined in terms of the following boundaries (see also Figure 4):

- **Coastal Process Unit 33** – is from the Whitby West/East Pier to the northern limit of Robin Hoods Bay.
- **Coastal Process Unit 34** – is Robin Hoods Bay.
- **Coastal Process Unit 35** - is set between the southern limit of Robin Hoods Bay to Scalby Ness.

For each of the coastal process units, interactions, movements and behaviours are discussed, along with the following specific elements:

- sediment input
- sediment transport
- sediment sinks
- Control and sensitive points

Figure 7 shows the coastal process and the associated elements between Whitby and Scalby Ness. Information for the following coastal process elements in Figure 7 have been taken from the Futurecoast mapping tool (Defra, 2002).

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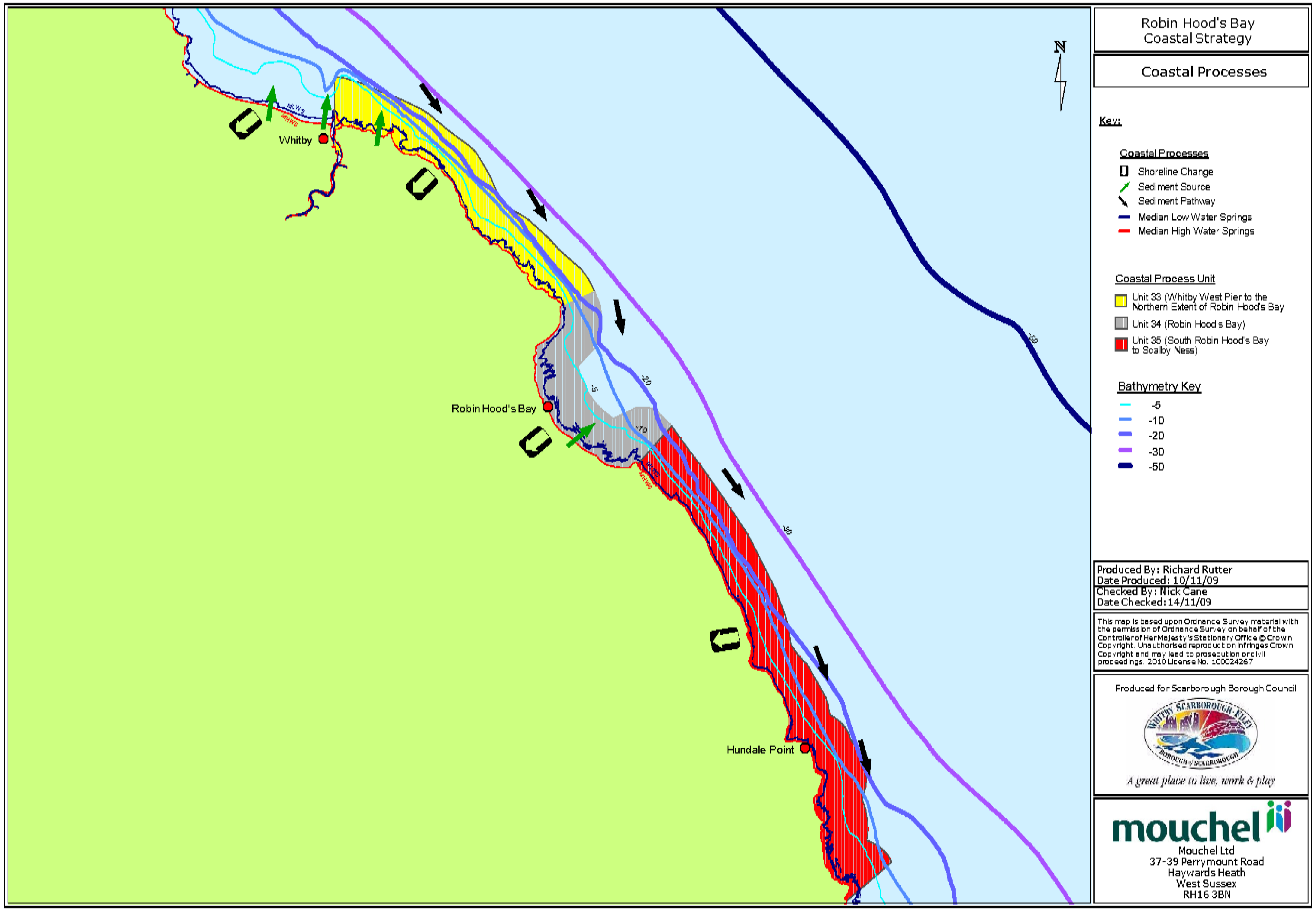

Figure 7: Coastal Processes between Whitby and Hundale Point

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5.1.1 Coastal Process Unit 33 - Whitby West/East Pier to the northern limit of Robin Hoods Bay

This frontage contains high and near vertical sea cliffs composed of Jurassic mudstones and sandstones, overlain by till and fronted by a wave cut platform with a visible layer of larger sediment. As the frontage nears the northern limit of Robin Hoods Bay, the Staithes Sandstone and Cleveland Ironstone becomes visible as it is exposed at the cliff face (British Geological Survey, 1998b; Royal Haskoning, 2007).

Sediment input to the nearshore sand belt is likely to be small amounts of gravel from cliff erosion, primarily glacial till. Historically, the cliffs have retreated at a rate dictated by the erodibility of the Lias mudstone in the lower toe layers of the cliffs. The long term cliff erosion rate is stated in the SMP2 (Royal Haskoning, 2007) as being 0.19m/y which is consistent with Futurecoast which states in the Cliff Classification a low erosion rate of between 0.1-0.5m/yr. The characteristics of the Whitby east cliffs show sediment input to the nearshore is relatively low, however occasional single slip events could increase the sediment input. According to Futurecoast (Defra, 2002), between Saltwick Nab and Hawsker Cliffs there is medium to high potential for sediment input from cliff erosion.

When considering coastal processes for the frontage between Whitby West/East Pier to the northern limit of Robin Hoods Bay, any inclusive or nearby estuaries and the associated behaviours should be included. The Esk Estuary lies between the Whitby west and east piers and is a small Type 3b Ria without spits. It is regarded as being short, with a small river catchment, compared to the Tees and Humber estuaries along the wider coastline. There is not thought to be any significant input of muddy sediment to the net littoral drift from the Esk (Defra, 2002).

Net littoral transport is to the south east and evidence of a build up of a reasonable beach on the west side of the western pier would suggest this. However, during certain states of the tide, material is transported northwards (Defra, 2002). It is also thought that there is small-scale interaction between embayments, due to the isolated nature of the beaches (Motyka and Brampton, 1993). With the net littoral transport to the south east, it is conceivable to conclude that the Esk Estuary and Whitby West/East Piers are interrupting the nearshore processes and ultimately restricting sediment input to the cliff frontages to the south east.

5.1.2 Coastal Process Unit 34 - Robin Hoods Bay

Robin Hoods Bay contains mostly cliffs formed of Lias shale overlain by glacial till which is thickest in the centre of the bay, and in some places the solid geology can only be seen on the wave cut platform. To the north of Robin Hood’s Bay Village the cliff is composed almost entirely of Lias mudstone (Defra, 2002). Rock cliffs form the southern boundary of this frontage. Wave cut platforms dominate the foreshore.

The upper slopes towards the northern limits of Robin Hoods Bay are composed of soft material and support some vegetation cover with evidence of slumping and sliding in places. The lower slopes are near vertical with no vegetation cover and are stained by the material eroded from the upper slopes. Sliding and marine undercutting is also occurring (NECAG, 2008).

A concrete seawall with steel piling protects Robin Hood’s Bay old village and limits any sediment input to the nearshore. Due to landslides on the steep slope below the upper village during the 1990s, slope remedial works and the construction of new sea defences were undertaken in 2000. The new defences include the new concrete wall at beach level just below West Scar. This new wall is backfilled with gravel and its front is also protected by rock armour. The slope above the seawall has also been regraded and again perhaps limiting sediment input. Rock armour also extends 200m south of the old village to help reduce landslide movements. There are no anthropogenic defences elsewhere in the bay.

The general south easterly drift of sediment again indicates that the Esk Estuary and Whitby West/East Piers are interrupting the nearshore processes and ultimately restricting sediment input to Robin Hoods Bay to the south east. There will be more information when The Esk and Coastal Streams Catchment Flood Management Plan (which is currently under development) becomes available. According to Futurecoast (Defra, 2002) Whitby east cliffs and Saltwick Nab are considered to be significant sediment sources; however it is not known exactly how much of this sediment makes its way to the nearshore zone at Robin Hoods Bay.

In terms of sediment supply to the nearshore from the local cliffs, the Futurecoast (Defra, 2002) cliff behaviour assessment indicates Robin Hoods Bay as being active with a medium level of sediment supply, however the erosion of the till cliffs does not appear to be contributing to any contained beach material within the bay. Cliff activity was documented in the NECAG (2008) report as having no change in activity between 2005 and 2008. The NECAG report indicates the cliffs located at Robin Hoods Bay are either partly active or dormant.

The physical control points on the northern and southern limits of Robin Hoods Bay would suggest that some sediment is trapped, however Royal Haskoning (2007) state that there appears to be little evidence of longshore sediment transport in the bay. Documented erosion rates within the bay have been estimated to be up to 0.6 m/yr between 1973 and 1996 (High-Point Rendell, 1997 pg. 4). The erosion rates are generally consistent with figures stated in Futurecoast (2002) (see Table 4.4-2) which gives an average erosion rate within the bay of between 0.1 and 0.5 m/yr. The erosion of the local till cliffs and sediment input from other sources does not appear to be sufficient to maintain any permanent beaches within Robin Hoods Bay.

5.1.3 Coastal Process Unit 35 - southern limit of Robin Hoods Bay to Scalby Ness

The stretch of coast between the southern limit of Robin Hoods Bay and Scalby Ness measures approximately 15 km and is dominated by vertical cliffs of varying height. The cliffs at the southern limits of Robin Hoods Bay reveal Whitby Mudstones and Blea Whyke Sandstone at the base. The cliffs further south are mostly composed of Ravenscar sandstones and mudstones with a foreshore of cobbles, pebbles and rock shore platforms (Royal Haskoning, 2007).

The cliffs between Robin Hoods Bay and Scalby Ness are classified as being active and have a medium to high potential for supplying sediment to the nearshore (see Table 4.4-1). Cliff erosion for the entire coastal process unit is stated in Futurecoast (Defra, 2002) as being between 0.1 and 0.5 m/yr (also see Table 4.4-2). The rates stated in Futurecoast (2002) are consistent with figures stated in by High-Point Rendel (2002a) of 0.13 m/yr for the rock cliffs over 100 years (average c. 0.1 m/yr). The North East SMP2 has calculated that the till cliffs south of Cloughton Whyke are estimated to provide 1700m³/yr. The coarser components of the till cliff sediment are retained where they form narrow fringing and pocket beaches and it is only when the frontage reaches the small sheltered areas immediately north of Scalby Ness, the coastal waters are calm enough to hold sediment (Royal Haskoning, 2007). As mentioned previously the Net littoral transport is in a south easterly direction, except during certain states of the tide when material is transported northwards. However, it is also considered that there is not a significant amount of small-scale interaction between embayments, due to the isolated nature of the beaches (Motyka and Brampton, 1993).

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6 Summary

This study determines the main coastal forces acting upon the policy units between Whitby and Hundale Point and, in particular, the existing natural and man made coastal defences along the frontage. The results of this study help to determine future changes to the coastline as a result of coastal forces, and to assess how various options for future coastal defence will work under present and future conditions. The information detailed in this baseline study of coastal processes for the Whitby to Hundale Point frontage will ultimately inform the policy decisions recommended in the wider CSS.

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