Taw Torridge Estuary Coastal Management Study

Pebbleridge Study

DRAFT

October 2012

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B&V project no.	109403	Client's reference no.	

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1 INTRODUCTION

1.1 Aims and objectives

Black & Veatch were commissioned by the Environment Agency and Torridge District Council to investigate options to better manage coastal erosion and flood risk along Northam Burrows, near Westward Ho!, Devon. Currently the whole area is protected from coastal flooding by a 2.5km long pebbleridge. A key aim of the study is to use the numerous existing studies to develop an overview of the processes that have and may continue to influence the development of the Westward Ho! Pebbleridge.

The overarching objective is to develop a more sustainable long-term flood risk management solution for this area, taking into account future projections of climate change.

Supporting objectives for this study are to:

- Provide a clear understanding of the coastal and hydrodynamic processes that form and influence the Pebbleridge, making use of and updating previous studies.

- Investigate the likely future morphological evolution of the Pebbleridge and assess what impact this will have on flood risk if there is no active intervention to the existing defences.

- Develop options for the Pebbleridge, taking into account future climate change scenarios, which will include:
    - Identifying the best alignment and extent of defences taking into account technical, social, economic and, environmental considerations
    - Defining the standard of protection of any realigned defences
    - Understanding the impacts of various management options, including managed realignment
    - Investigating methods for the implementation of management options
    - Assessing the potential impact on internationally designated sites
    - Investigating any mitigation measured required for the loss of any designated habitats
    - Considering the effects on the landfill site and developing solutions for its protection (covered in a separate Landfill Report, September 2012).

1.2 Approach

This review is based on the existing information available, collected as part of the Taw Torridge Estuary Coastal Management Study, (refer to the END of this document for full references). The approach adopted makes particular use of existing information such as the study by John Pethick of coastal processes, the proposals of the Shoreline Management Plan Review (SMP2) and local knowledge, in order to develop proposals for the future coastal management of the Pebbleridge and the landfill site (covered by a separate report). The study also takes into account new information arising from recent work such as installation of the Bideford wave recorder installed in 2009.

The existing data is sufficient to establish appropriate options for future management of flood risk along Northam Burrows. (see Figure 2.1) However, further investigations will be recommended to optimise the options and further reduce risk. Hence the approach undertaken is to work with the present understanding, in order to suggest solutions that are robust and sustainable in that they are unlikely to be regretted in the future should our present understanding of coastal processes or today's climate change projections prove to be incorrect.

1.3 Sources of information

This study makes use of the following data sources:

- OS mapping (MasterMap, 10k, 25k, 50k, and 250k)
- LiDAR data – (March 2003, April 2006, November 2006, February 2007, February 2008, March 2008, March 2009, Sept 2009, Oct 2010)

- Bathymetry data
- Extreme tide level data
- Wave data obtained from the Bideford wave buoy
- Geological mapping (Sheet 292 – Bideford and Lundy Island, 1977)
- Borehole data

The following existing reports and studies have been collected and reviewed:

- Shoreline Management Plans (1 and 2)
- The Taw-Torridge Estuaries: Geomorphology and Management Report to Taw-Torridge Estuary Officers Group, Feb 2007.
- Further Geomorphological Advice in respect of Westward Ho! SSSI. Oct 2005.
- Draft Taw Torridge Estuary Coastal Management Study, Consultation document
- Phase I and Phase II Site Investigation at Northam Burrows Former Landfill and Waste Recycling Site, Devon County Council, Jan 2009.
- Exeter Universities Boulder Study
- Thematic Trails Publications (see reference list for full details)

Additional supporting analysis was undertaken using new data not available to previous studies for the study area, these include:

- Historic trends analysis – to describe the morphological evolution of the Pebbleridge.
    - Analysis of LiDAR data is used to inform our understanding of short term changes along the ridge.
    - Erosion and deposition mapping.

- Hydrodynamics assessment
    - Bideford wave buoy data is used to supplement our understanding of coastal processes and hydrodynamics in Barnstaple and Bideford Bay.

- Flood risk assessment
    - Assessment of flood risk and breach vulnerability of main defences using results of modelling and LiDAR assessment.

This information has been used to assess the implications for the long-term sustainability of the Pebbleridge at Northam Burrows and to inform the development of management options for the Northam Burrows coastline.

2 BACKGROUND

2.1 Study Area

The Northam Burrows Country Park lies within an Area of Outstanding Natural Beauty and forms part of the United Nations Biosphere Reserve. The Burrows is a Site of Special Scientific Interest and provides habitat for many important species of flora and fauna. It also provides access points to the 2 mile stretch of beach at Westward Ho! which is a popular draw for tourists and locals alike. Northam Burrows is home to the oldest links golf course in England (the Royal North Devon Golf Club) and also provides common rights for grazing. There is also a historic landfill site at the northern end of Northam Burrows, see figure 2.1.

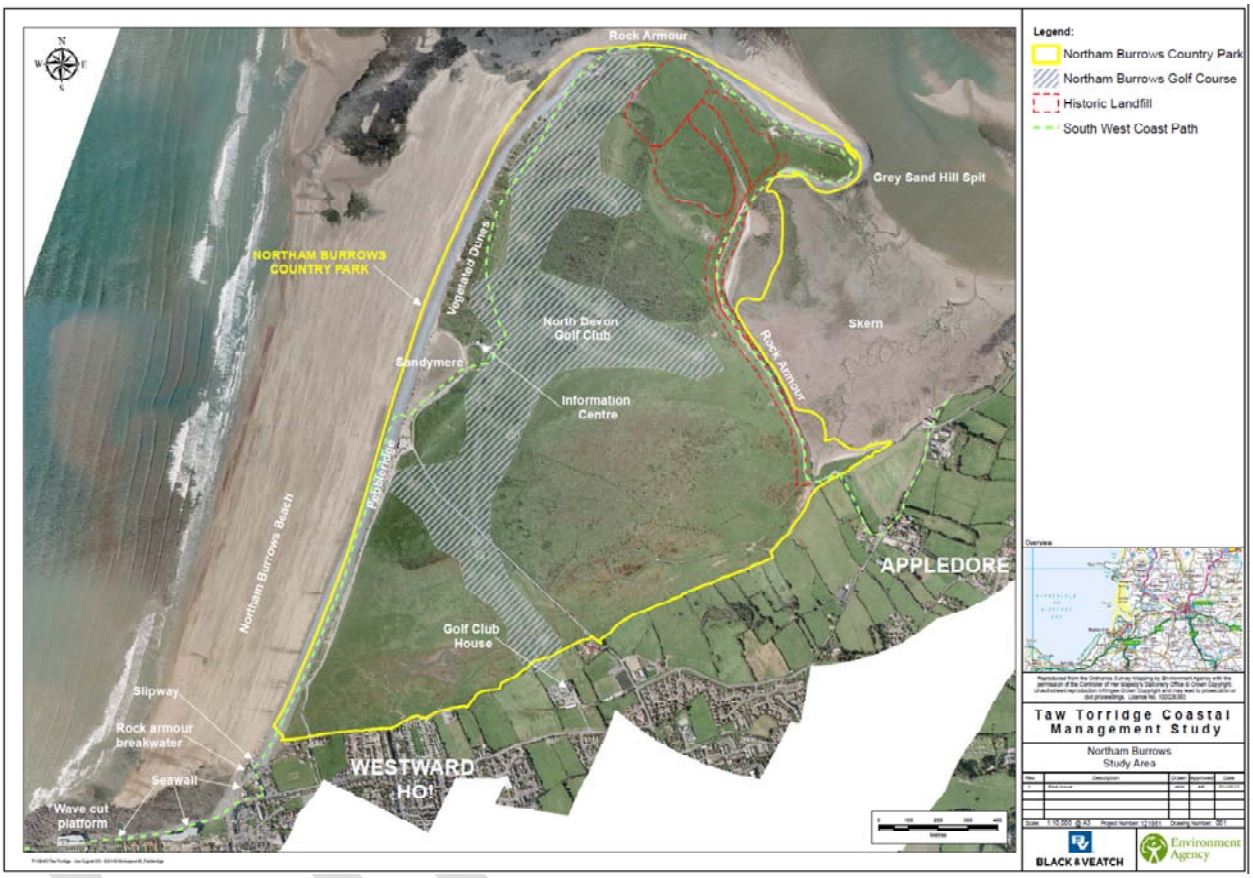


Figure 2.1: Northam Burrows Country Park.

2.2 Physical setting and geology

Northam Burrows beach is composed of a thin veneer of sand overlying clay, though it has been noted that this composition varies considerably with the seasons. At times it is sand covered, up to a depth of approximately 1 or 2m thick (P.Keene personal communication), at other times the sand is washed away and the beach is formed of the underlying 'head' and blue clay. The sand can wash away over 2 or 3 days and then reappear again just as quickly, which is particularly evident at the Westward Ho! end of the beach (P.Keene personal communication). The clay is relatively soft, though it includes stiff clay bands, which erode slowly.

The upper beach is overlain by a relatively shallow depth of pebbles, forming the Pebbleridge, which extends northwards from Westward Ho! for about 2.5km until it reaches the mouth of the estuary of the Rivers Taw and Torridge, see figure 2.1. When the sand disappears, the clay underlying the present alignment of the Pebbleridge can be seen all the way along its base.

The majority of Northam Burrows is underlain by alluvium and windblown sand deposits. However there is a sharp topographical boundary at the southern end of the common, which represents the change to underlying weathered siltstone bedrock geology of the wave cut platform on which Westward Ho! is located. The majority of properties in Westward Ho! are located on this higher platform above the Common. However, the exact location of the underlying bedrock/alluvium boundary is unknown, which has implications for the construction of any potential new defences. The wave cut platform which is exposed at the southern end of Northam Burrows extends around the coast to the west (see figure 2.1 and photo A.9 in Appendix A).

2.3 Tidal defences and existing management regime

The whole area of Northam Burrows and southern limit of Westward Ho! is protected from coastal erosion and flooding by the natural Pebbleridge, which extends in a north-south orientation away from the town. The Pebbleridge ties into a seawall, which provides protection to low lying areas of Westward Ho!, see figure 2.1 and photo A.6 in Appendix A. The seawall used to be of vertical construction which was built in 1928-32. This vertical wall eventually led to erosion of the beach in front as a result of the wave reflection. This was resolved by the addition of rock armour in front of the wall in 1982-3 to absorb more wave energy (see photo A.10 in Appendix A). The majority of this revetment was built onto the wave cut rock platform (at -2mOD), though the seaward end is reported to be beyond the end of the platform.

Historically, works to recharge vulnerable sections of the Pebbleridge were undertaken by both the local Council and local residents during an event called potwalloping. In addition, for about 20 to 25 years, recycling of cobbles from the northern end to the southern end of the Pebbleridge was practised to try and limit erosion at the southern end. This involved the transport of 1000 to 2000m^3 of material (Orford 2005) and it is understood that up to 6500m^3 may have been redistributed along the ridge in both 1996 and 2002. This management ceased about five years ago, and as a result the Pebbleridge is reported to be lower and flatter and is now less effective as a flood defence (Slade 2009).

Rock armour has also been used to provide additional coastal erosion protection to the northern end of Northam Burrows, and to the seaward side of the road out to the northern end of Northam Burrows, see figure 2.1. This rock armour protection was probably placed in 1978 and is discussed in our Landfill report.

2.4 Current management issues

A series of notes reporting concerns relating to the Pebbleridge were made during the site visit in January 2012 of the Technical Working Group for the Taw Torridge Estuary Coastal Management Study. A summary of the notes is included on figure 2.2. The primary concerns relating to the Pebbleridge are described below.

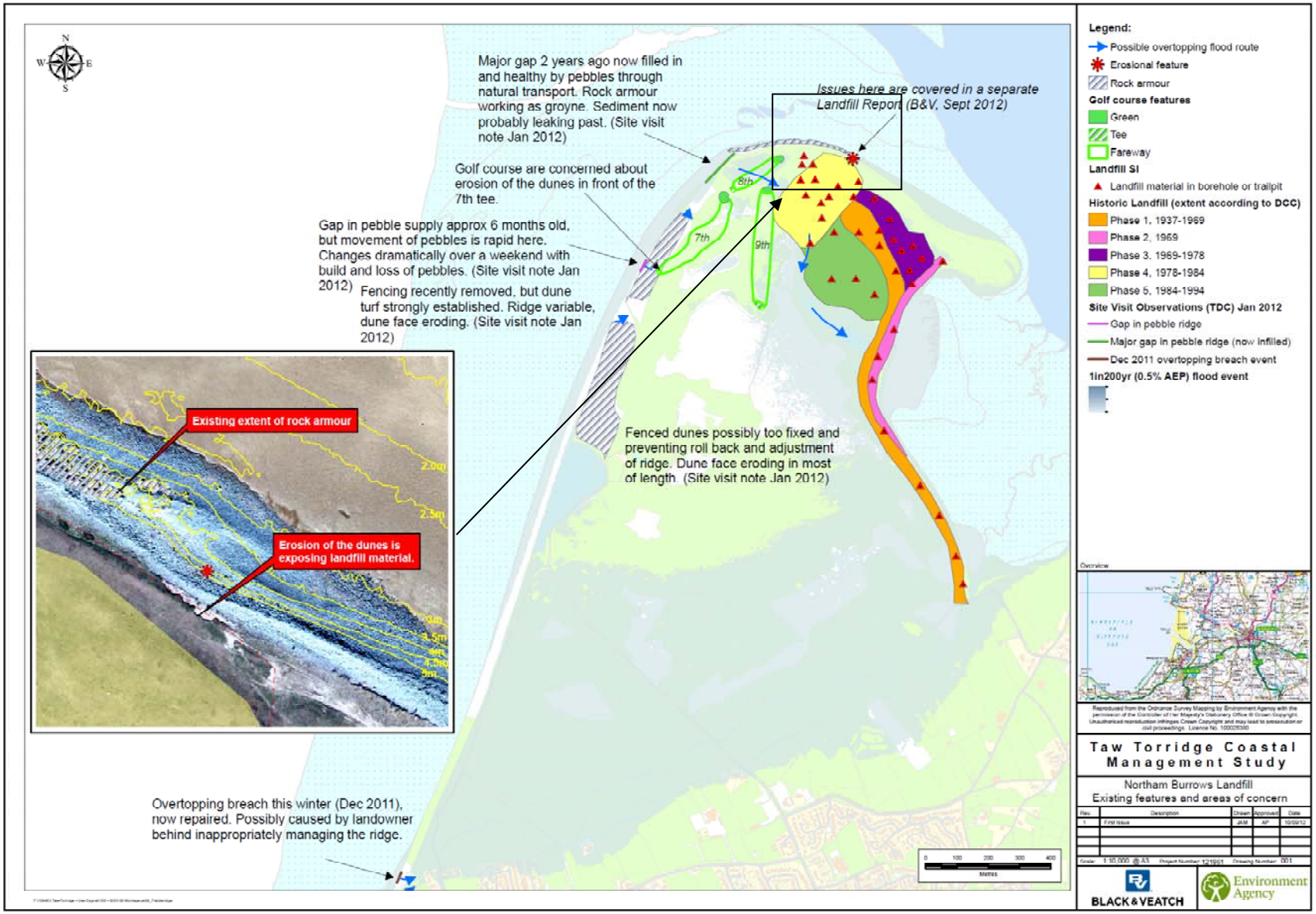


Figure 2.2: Northam Burrows – existing features and areas of concern.

2.4.1 Flooding of property and land due to breach in the defences

There is considerable concern that the Pebbleridge could overtop or breach, putting at risk lives, properties and businesses in Westward Ho! There are 21 properties located within the 1 in 200yr (0.5% AEP) tidal floodplain and approximately 107ha of agricultural land (mostly common land and the golf course). There is also an electricity sub-station and pumping station located within the tidal floodplain behind the Pebbleridge. This infrastructure is currently protected by the existing hard defences (see A.6 and A.10 in Appendix A) at the north end of Westward Ho! and the Pebbleridge. However, all are at risk if either the hard defences or Pebbleridge are breached.

The ridge is recorded to have breached during major storm events in the past. The most major breach event documented occurred in 1962, following a major storm event. The 1962 event, see figure 2.3, occurred immediately to the north of a series of newly constructed wooden groynes. The breach was believed to have been caused by restricted pebble movement and depletion of the ridge adjacent to the groynes. The breach was subsequently manually infilled and the second phase of groyne construction was never completed.

Figure 2.3: 1962 major breach event in the pebbleridge.

A breach also occurred in the 1970's. In December 2011, the ridge experienced a minor breach at its southern-most end, close to a local go-kart business in Westward Ho!. Analysis of wave and tide data for this event shows that the breach formed during a westerly storm, which occurred during a high tide and produced large swell waves, which broke onto the ridge (see appendix B for details). In addition, work had been undertaken along the Pebbleridge around the go-kart track earlier in the year to protect the track from erosion and also to improve access between the Pebbleridge and the track. It is likely that a combination of these two factors contributed to the minor breach event that occurred in December 2011, see figures 2.4 and 2.5.

Figure 2.4: Recent works undertaken along the pebbleridge around the go-kart track.

Figure 2.5: Recent works undertaken along the pebbleridge around the go-kart track. Redistribution of shingle on the ridge was one of the factors that potentially contributed to the minor breach event that occurred in December 2011. (a) prior to works, (b) post works.

2.4.1 Erosion of the historic landfill site and golf course

Further concerns relate to the northern end of the Pebbleridge on the coastal frontage adjacent to the golf course and historic landfill. It has been noted that a number of gaps have formed in the ridge, and whilst most breach areas migrate and fill in over quite short timescales, there is considerable concern about how further erosion of the ridge and dunes behind may threaten the landfill and also the sustainability of the golf course. The golf club are particularly concerned about the erosion of the dunes around the 7th tee.

The concerns relating to the northern end of the landfill are covered in a separate Landfill Report (Black & Veatch, September 2012) and are not discussed further in this study.

3 REVIEW OF PREVIOUS STUDIES AND POLICIES

3.1 Pethick (2007) Taw/Torridge Estuary Report

In 2007, Pethick developed a conceptual model of coastal processes in Bideford Bay and estuary processes in the Taw Torridge estuaries. He drew on the work of many previous authors, much of which was compiled in the SMP of 1998. The major piece of new data collected for Pethick 2007 was LiDAR and bathymetry data for the estuaries.

Pethick's chief achievement was to develop a conceptual model of the estuary which included both estuary and coastal processes. However, the model must be used with caution and care taken in interpretation as the model is only intended as a hypothesis that provides a framework to help explain the observed coastal geomorphology processes. With that caution in mind Pethick's analysis of the Taw Torridge estuary and coastal system provides a logical explanation of the dominant processes. When it comes to detailed consideration of management at individual locations or over timescales of decades as opposed to centuries, careful scrutiny of the evidence, potential risks and benefits is necessary rather than relying too heavily on the high level and long term approach that Pethick adopts.

Pethick suggests a future management approach for the Northam Burrows. This approach builds on earlier suggestions by Orford to recycle shingle to the southern end of the Northam Burrows, but feeding the back face instead of the seaward face and so encouraging the Pebbleridge to migrate and become more 'swash aligned' perpendicular to the dominant wave direction. However, he identified several risks inherent in this approach, including to the landfill.

3.2 Shoreline Management Plan Review (SMP2) Hartland Point to Anchor Head, October 2010

The SMP2 reviews previous studies of coastal processes at the Northam Burrows and appears to largely follow Pethick's findings. The SMP2 considered what would happen with 'No Active Intervention' and with a 'Continuation of Present Management Practices' and recommends a preferred plan. The key elements are summarised below. Further detail and figures are included in following sections.

- The Pebbleridge is expected to continue rotating to become more swash aligned by moving east at its southern end but remain at its current position at the northern end for around 50 years.
- As the southern end of the Pebbleridge moves east, the preferred plan is to construct an east-west bank to protect low lying property in Westward Ho!

The plan recommends the following actions for the Pebbleridge.

1. Basically do nothing to the Pebbleridge, apart from the repair of local damage if necessary. The raised access road to the landfill on the east side of Northam Burrows should be maintained.
2. The northern end around the landfill is not expected to retreat for the next 50 years due to sea level rise, but beyond then is expected to retreat by 'several hundred metres'. The SMP2 preferred strategy is to continue to take measures to maintain the landfill in situ over the next 100 years by defending it against the sea because this is likely to be less costly than trying to move it.

The SMP2 envisages that in the long term, tidal inlets may form in the Northam Burrows as the sea levels rise and the Pebbleridge breaks down especially at its southern end. A main estuary channel is not expected to form across Northam Burrows.

The suggestion has been made that whilst the road to the landfill should be held to provide access to the landfill and avoid the risk of the material used to construct the road escaping, increasing the size of the drainage channels under this road could be used to help create intertidal habitat area on the south east part of the Burrows.

4 TIDAL FLOOD RISK

4.1 Methodology

Analysis has been undertaken using LiDAR to determine the volume of water that could potentially inundate Northam Burrows and flood properties in Westward Ho! in the event of breach. This has included an analysis of the existing situation (2012 baseline) and also considered the effects of rising sea levels over time using similar epochs as used in the SMP2: 2022, 2032, 2062 and 2112.

In order to assess the absolute flood risk to properties in Westward Ho!, it has been necessary to consider the effects of a 'Do Nothing' flood risk management strategy. In this scenario, we have assumed that there will be no further maintenance of the Pebbleridge and/or improvements to other defence. This also assumes that breaches will be allowed to develop in the Pebbleridge and they will not be repaired.

4.2 Do Nothing Scenario - Exiting situation

There are 21 properties located within the 1 in 200 (0.5% AEP) tidal floodplain and approximately 107ha of common grazing land, see figure 4.1. These properties are currently defended by the Pebbleridge and the man-made defences in Westward Ho! The majority of the Pebbleridge currently provides a high standard of protection (greater than 1 in 200 0.5% AEP event). However, this estimate is based on an assessment of crest level against tide level only and does not take into account overtopping from wave action or possible breach events. Wave action does result in more frequent overtopping of the Pebbleridge, the latest event occurred on the 17th October, 2012, and flooded the Sandymere car park area (see photos A.11 and A.12 in Appendix A).

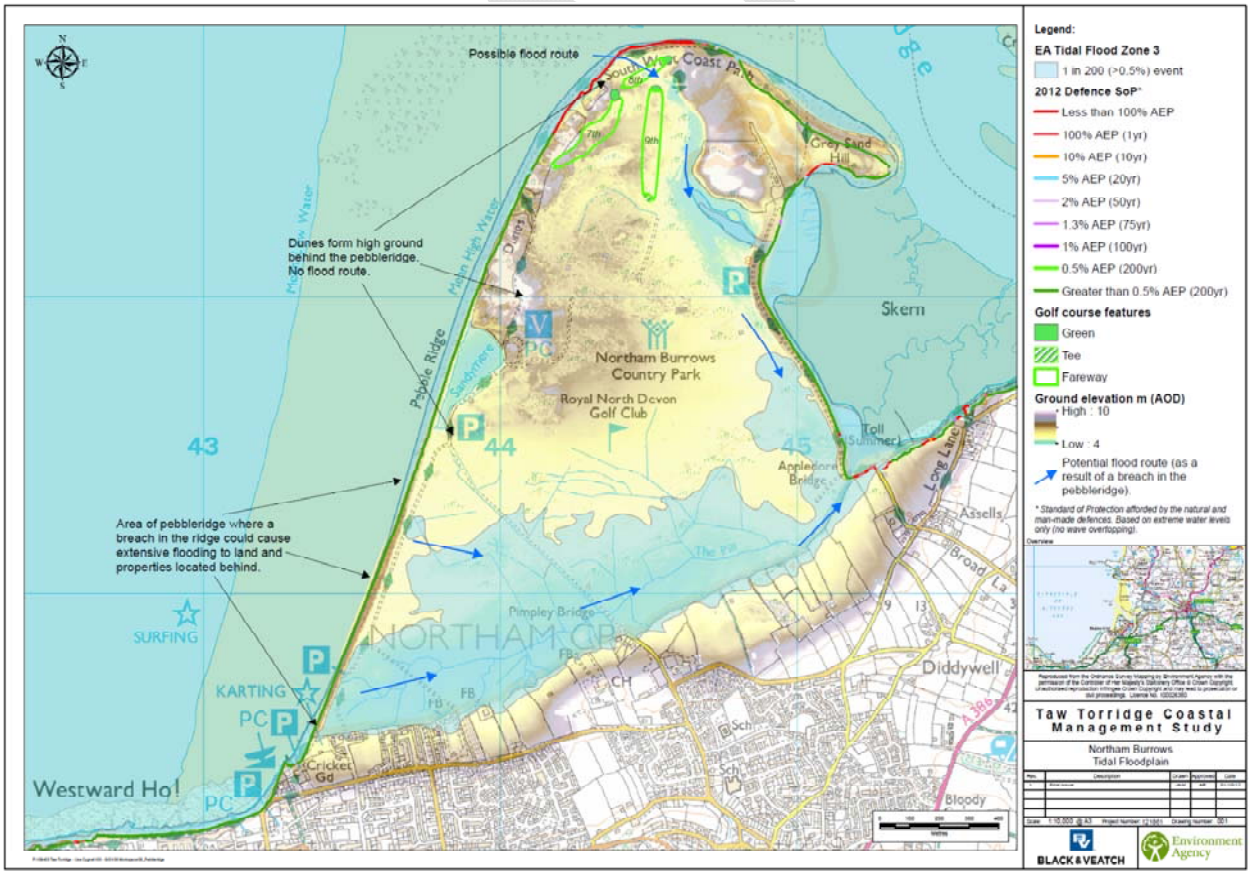


Figure 4.1:Extent of the tidal floodplain and possible flood routes across Northam Burrows.

There is considerable concern that the Pebbleridge could overtop or breach putting at risk lives, properties and businesses in Westward Ho! Analysis of LiDAR topographic data has shown that the tidal floodplain of Northam Burrows has an estimated storage volume of approximately 1.1Mm^3 before any properties are at risk of being flooded. As a result, wave overtopping on its own is unlikely to cause damage to

properties, although it could temporarily affect the golf course and car park, depending on the overtopping volume. However, if the Pebbleridge were to breach, there is the potential for a very large volume of water to inundate the floodplain behind, putting at risk properties in Westward Ho! Breaching events are known to occur more frequently than the standard of protection indicated by crest levels, as there have been at least three reported breach events in the last 50 years. It is therefore reasonable to assume that flood risk is considerably greater than 1 in 200 annual probability.

The extent of the tidal floodplain, (1 in 200 or 0.5% annual probability event) is shown in figure 4.1. The Pebbleridge is most vulnerable to breaching along its southernmost end and along a short stretch at the northern end (before the rock armour begins). The rest of the Pebbleridge is backed by dunes, which forms high ground and effectively cuts off any potential flood routes.

Potential routes for flood water are also shown on figure 4.1. There is a possible route at the northern end of the common. This area coincides with an area of low crest height, which further adds to the vulnerability of the area. Low ground extends behind this area and down the southern flank of the historic landfill site. There is therefore a risk that any substantial breach and flood event here could erode the landfill from the southern side. No properties are at risk however from a breach in this location, but littering by eroded landfill material would be a serious issue.

In terms of flooding to property, the primary risk comes from a potential breach event along the southernmost 1.2km of the Pebbleridge. Of the documented breach events that occurred in 1962 and 2011, both occurred along this stretch of the ridge. Neither event caused any flooding to properties. However many of the properties at risk today in Westward Ho! were constructed after 1962. Should this event happen today, therefore, it is very likely that some properties in Westward Ho! would flood. A large area of the common flooded during the 1962 event and (though no evidence has been obtained) this will undoubtedly have affected the golf course and grazing land.

4.3 Do Nothing Scenario - Future flood risk

Figure 4.2 shows the properties at risk in Westward Ho! from a 1 in 200 annual probability (0.5% AEP) flood event resulting from a breach in the Pebbleridge. The figure also shows the potential future scenarios based on current sea level rise projections. Recent Environment Agency advice in 2011 gives a likely increase of 0.32m in sea level over the next 50 years to 2062 and almost 0.75m over the next 100 years to 2112 (Defra advice based on the International Panel for Climate Change figures for a medium scenario, 95 percentile). There are 21 properties at risk today in Westward Ho!, but this could rise to 54 properties by 2112. In addition, many of the properties immediately behind the ridge will become vulnerable to direct wave action as the Pebbleridge flattens and rolls backwards.

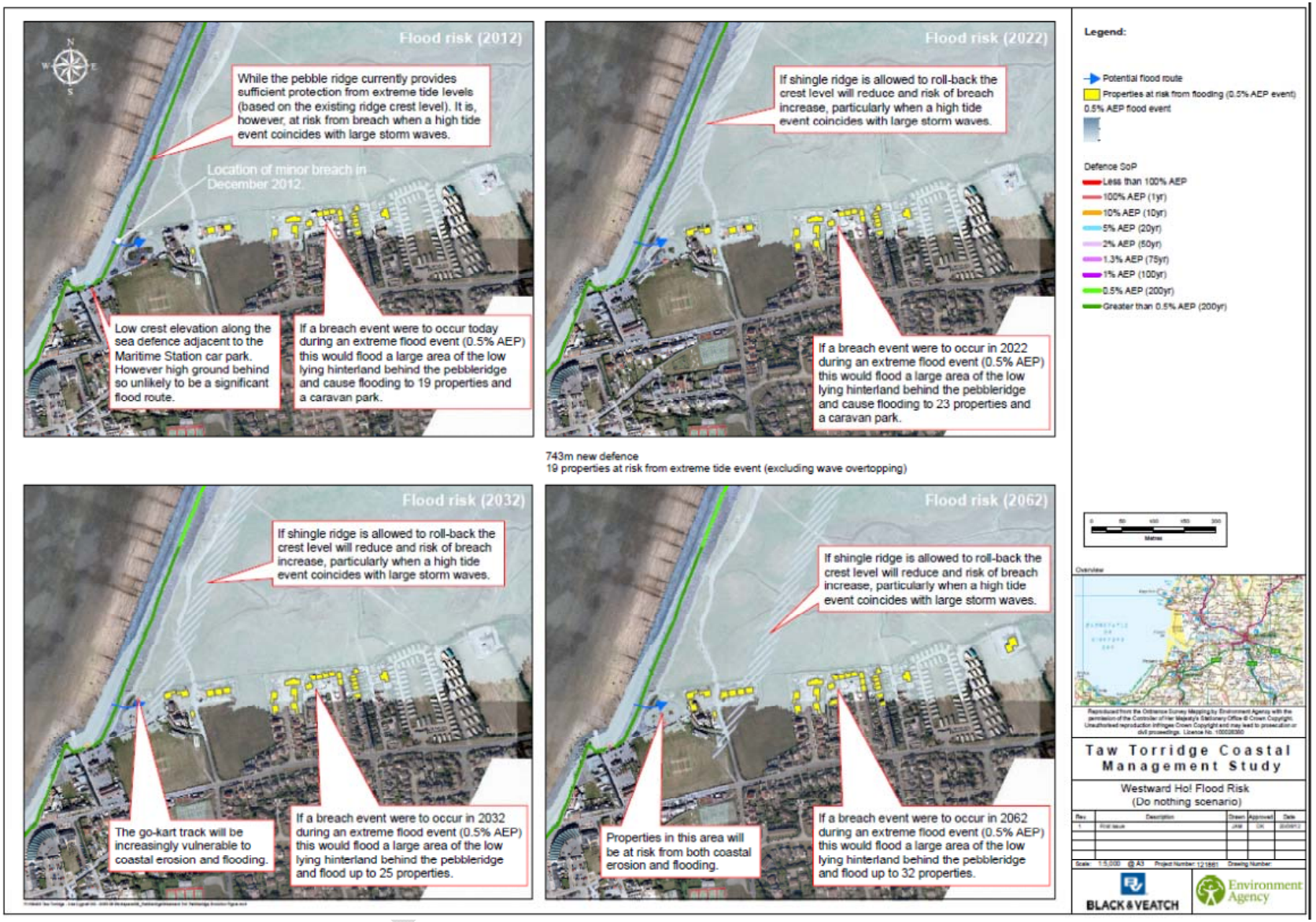


Figure 4.2: Properties at risk from flooding in Westward Ho! based on estimated 0.5% AEP flood outline.

5 COASTAL PROCESSES

5.1 Methodology

Our understanding of the dominant coastal processes and trends affecting the study area is largely based on the work of others, supplemented with targeted additional analysis where necessary. The following sub-sections provide an overview of our present understanding of the coastal processes and hydrodynamics that have led to the development of options for the Pebbleridge at Northam Burrows. A conceptual drawing is also shown in figure 5.1. Further details of the documents reviewed are included in the Appendices.

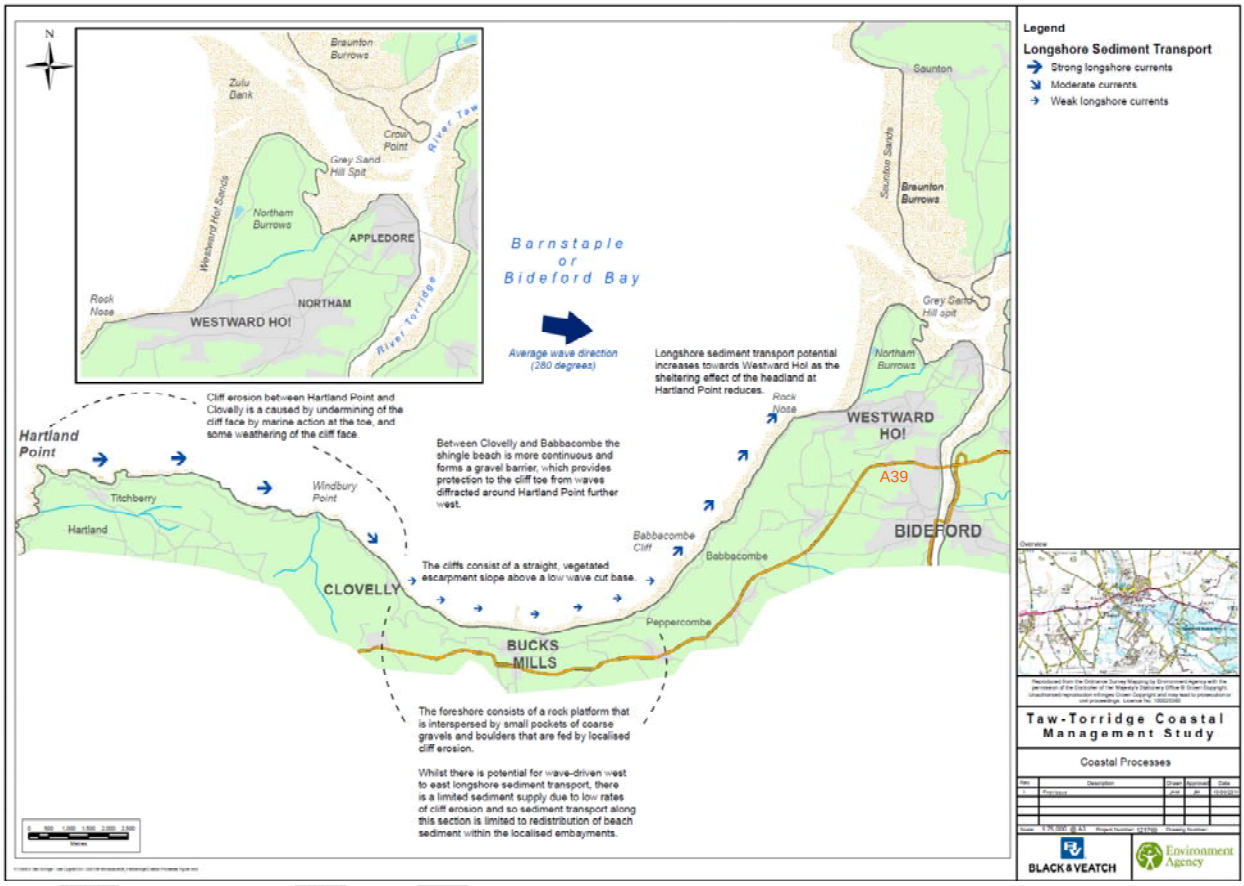


Figure 5.1: Conceptual drawing of coastal processes and trends

5.2 Hydrodynamics/wave climate

Bideford Bay experiences a large tidal range and the orientation of the coastline means that the areas within the bay (including Northam Burrows) can be attacked by extremely large waves. The 1998 SMP noted that a significant wave height of 6m has a 1 in 10 annual probability at Northam Burrows, although this may not coincide with a high tide or spring tide sequence.

New data obtained from a wave buoy in Bideford Bay shows that wave direction is very consistent, being dominantly from the west (around 280° slightly N of W). Plots of the near shore bathymetry and topography in figure 5.2 show that the lower foreshore contours are at a slightly different angle from the upper foreshore contours. The lower contours have a bearing approximately 12° or 13° east of grid north so orthogonal to an incoming wave direction of 280°. The upper foreshore is rotated around 8° east relative to the lower foreshore so orthogonal to an incoming wave direction of around 290° from grid north. This suggests the **lower part of the foreshore is already close to being swash aligned** while the upper foreshore and Pebbleridge is around 8° away from swash alignment, see figure 5.2. The reason for this is difficult to explain, but photographs show a hard substrate under the sand and of blue clay beds with tank marks still visible after 65 years may **indicate that parts of the foreshore are resistant to erosion**

The alignment of Northam Burrows beach therefore helps to dissipate the energy in the Atlantic storms which can break a considerable distance offshore, due to the nature of the shallow underlying clay layer. The impact of these storms can vary considerably depending on whether they occur at high or low water.

The north facing frontage of Westward Ho! is not directly attacked by the Atlantic swell which passes the town and is dissipated on Northam Burrows beach. The town is, however, directly exposed during north or northwest storms to more locally generated wind waves.

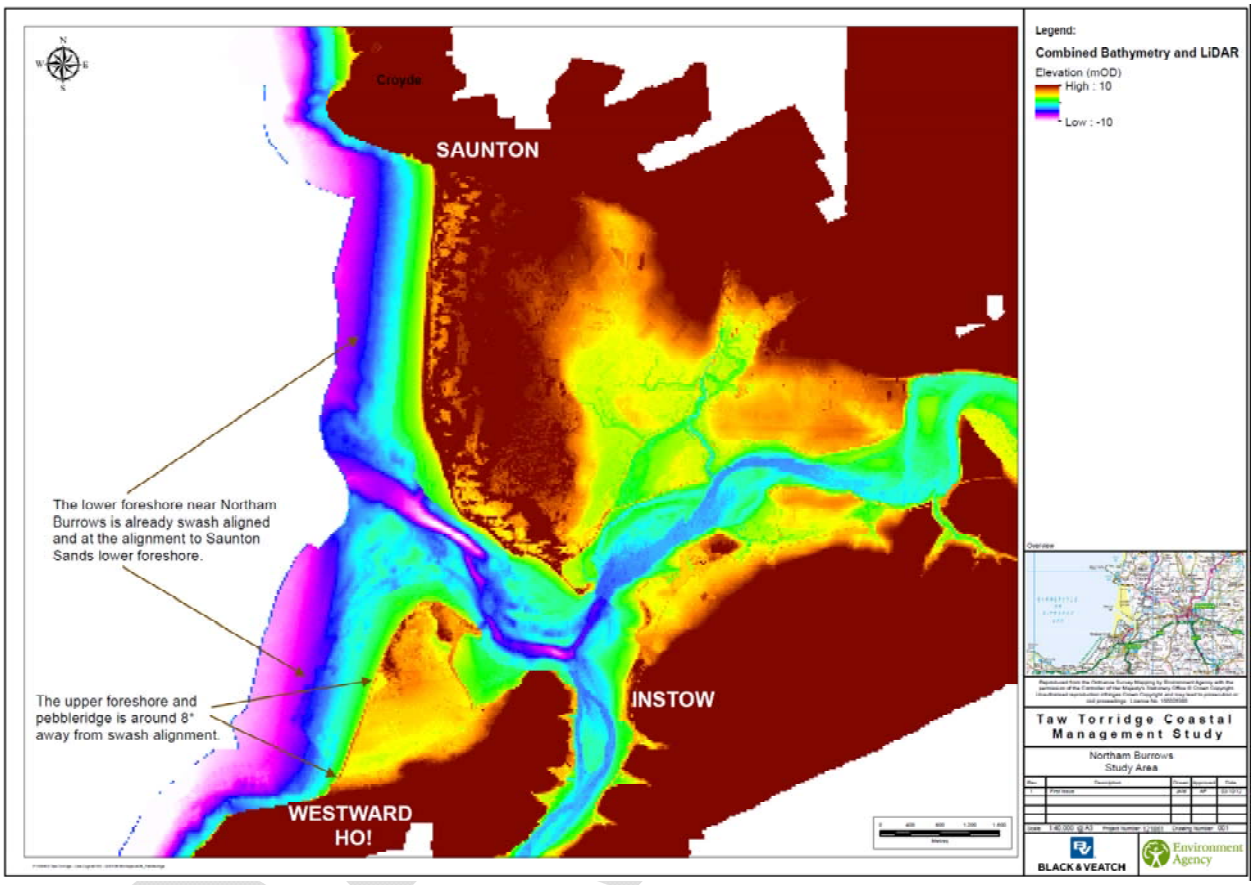


Figure 5.2: Combined Bathymetry and LiDAR data of the Taw-Torridge Estuary and Bideford Bay, showing the swash alignment of the lower foreshore.

5.3 Evolution of the Pebbleridge

The source of the sediment that forms the Northam Burrows Pebbleridge has been of some debate. The three main theories are:

- that the ridge is composed of pebbles and underlying clay deposits that are derived from glacial deposits from the past Ice Age, (Orford and Bradbury, 2008).
- That the ridge is composed of eroded cliff material.
- That the ridge was formed from an unrecorded landslip (pre 1795) near Bucks Mills (which formed the Gore), which worked its way north west towards Westward Ho! Pebbleridge (P. Keene).

It is likely that the formation is a combination of all of these sources. However the only significant long-term sustainable supply is that derived from cliff erosion. Pebble deposits at the foot of the cliffs at Rock Nose are a similar geology to the Pebbleridge. There is documented evidence that for many years there was a drift of pebbles from south of Rock Nose towards Westward Ho! and eventually to Grey Sand Hill spit in the estuary. The ridge along the west and north perimeter of Northam Burrows is therefore replenished.

Recent comparison of photos taken at different timescales of the cliffs and foreshore at Rock Nose shows that this area is largely bereft of pebbles and therefore the Pebbleridge is largely isolated from further supplies for the foreseeable future (Orford and Bradbury, 2008). There are pebbles south of Rock Nose, but most are trapped within headlands south of Cornborough Cliff at least 2 miles from Westward Ho!. As the headland erodes, the present trickle of pebbles northwards will increase. This is not believed to provide any significant supply in the short-term, but may help limit the speed of recession in the long term.(Orford and Bradbury, 2008).

Recent work by Exeter University has investigated the rate of boulder transport at the foot of the promenade in Westward Ho! Pebbles were fitted with radio transponders so that boulder movement could be monitored. Movement was measured over one month (March to April 2010) and showed that during that time 96% of the pebbles moved under moderate wave conditions. The furthest distance moved was 82m with the majority moving from west to east towards the Pebbleridge. This study confirms the easterly movement of pebbles along the coast; however the volume of supply has undoubtedly reduced over the years. In addition, structures built into the foreshore and wave-cut platform in Westward Ho! will further restrict the supply of pebbles to the ridge (by capturing the passing drift of material), see figure 5.3.

Figure 5.3 The slipway and various other features help to further cut off the supply of sediment to the Pebbleridge from any remaining supply from the west.

Pethick (2007) estimated that 5,000m^3 of coarse sediment may be lost from the ridge at its northern end with no corresponding replenishment at its southern end. However, the volumetric analysis required to prove Pethick's theory that the coarse sediments are being stored in the gravel spread at Grey Sand Hill Spit has not been carried out. An analysis could be undertaken if it is felt this would better inform management decisions rather than reacting to changes highlighted by monitoring. However, the analysis may be hampered by a lack of reliable data for calibration purposes.

The general consensus reached by Pethick and others therefore, is that as there is **no known present day feed of sediment from the south of any significance**, Northam Burrows is evolving into a more 'swash aligned' coastline that is aligned north-south to be perpendicular to the dominant wave direction. Mapping shows a significant retreat of the southern end of Northam Burrows adjacent to Westward Ho!

(1.5 to 2.6m/year), which is reported to have become narrower and lower over this period, see figure 5.4. At the same time there has been a slight advance at the northern end of Northam Burrows over the past 160 years, see figure 5.5. These two effects combine to align the coast closer to a north-south orientation. As the coast becomes more swash aligned the rate of sediment transport should decline.

This review finds no new evidence to dispute this finding in terms of long term movement and therefore this assumption has been taken into consideration during the development of management options for the Pebbleridge.

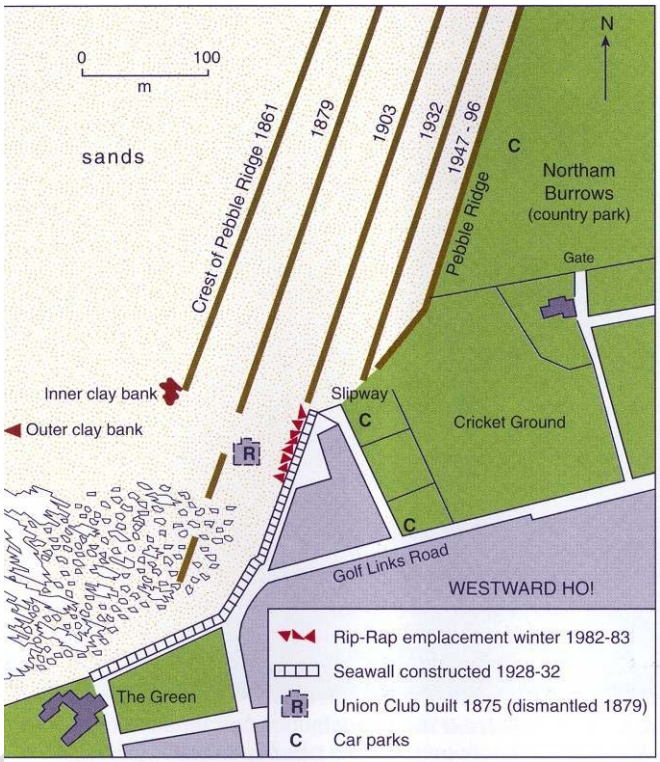


Figure 5.4: Movement of the Pebbleridge near Westward Ho 1861 – 1996. Source P. Keene.

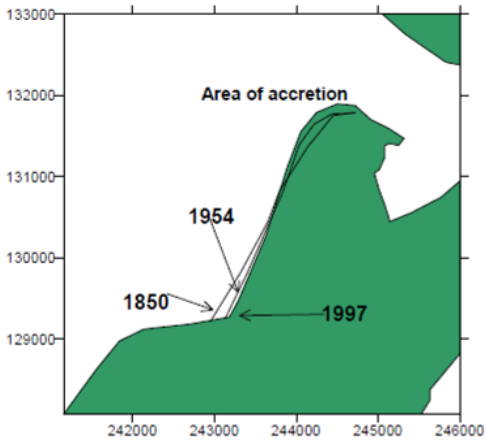


Figure 13: Movement of the pebble ridge 1850 – 1997. Data for 1850-1954 from Stuart and Hookway (1954). 1997 shore from OS 1: 25,000.

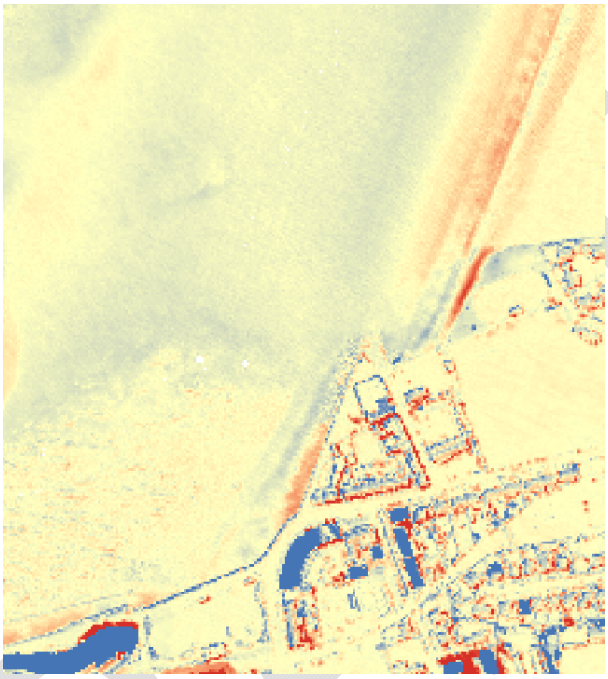
Figure 5.5: Movement of the Pebbleridge 1850 – 1997. Source P. Keene.

5.4 Recent changes along the Pebbleridge

Most of the changes along the pebbleridge occurred prior to World War II and generally over the past 50 years it has been fairly stable. However, recent instabilities have started to occur at the southern end of

the ridge (i.e. the minor breach event of Dec 2011). This observed stability in recent decades could be due to the management of the ridge and active recycling of pebbles or it may be that the main beach has been founded on a clay ridge that is more resistant to erosion than experienced during the previous 100 years. Either way, with less recycling (which may help the northern end of the ridge), or if harder material is eroded away, more rapid erosion would be likely to start again.

LiDAR surveys indicate the short term changes along the Pebbleridge over a six year period from 2003 to 2009. Comparison of the changes between these dates is shown in figure 5.6. This data shows that recent works at the southern end of the ridge have narrowed the landward side of the shingle ridge.



Red erosion; blue accretion between March 2003 and September 2009

Figure 5.6: Accretion and erosion near to Westward Ho! between 2003 and 2009 from LiDAR survey.

5.5 Implications for the development of management options for the Pebbleridge

From this review of coastal process information and new data, the following general observations have been made:

- The rate of erosion of the Pebbleridge goes in phases as it passes through clay layers that slow the processes. This means that it is not really rolling eastwards, but can be described as eroding eastwards and readjusting its alignment inland to maintain the natural profile.
- It is important to consider the whole beach as the factor controlling movement, as the movement of the Pebbleridge is dependent on the beach relative to the wave action.
- The northern end of the ridge has suffered more erosion than the southern end. However this may be due to material being used for recharge of the southern end in the past and may not now be such an issue now recharging has stopped.
- Recent works at the southern end of the ridge have narrowed the landward side of the shingle ridge.
- There is a risk that further breaches will occur at the southern end of the Pebbleridge in future years.

6 FUTURE COASTAL EVOLUTION

6.1 Basis of predictions

The SMP2 predictions (Halcrow 2010) over the next century are based on sea level rise guidance provided by Defra (2006). The predictions are also informed by the findings of UKCP09. SMP2 was published before the most recent guidance by the Environment Agency (2011) which predicted reduced rates of sea level rise after about 2055. This would not affect the findings of the SMP2 in the short term (2010-2025) and medium term (2025-2055) but could mean the predictions for the long term (2055-2105) may take longer to materialise.

The majority of SMP2 predictions are based on Pethick (2007) predictions supported by other sources such as Halcrow (2002), May (2003), Orford (2005) and Slade (2009) for the rate of retreat of the Pebbleridge.

6.2 With a no active intervention policy

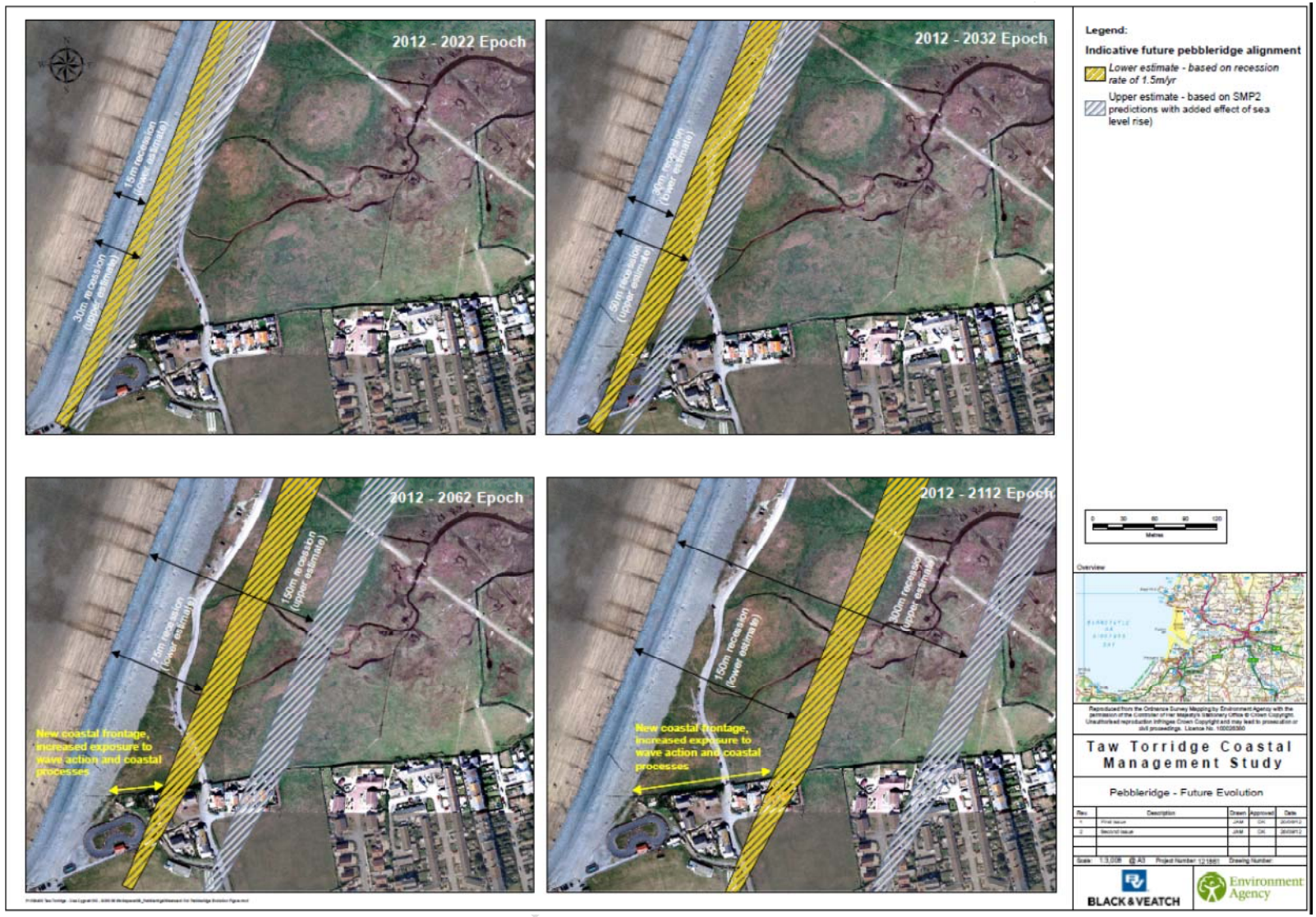


Figure 6.1: Predicted likely Pebbleridge evolution.

6.2.1 Short term (2010-2025)

The SMP2 predicts the Pebbleridge will retreat by 40 to 60m by 2025 at its southern end and to become more swash aligned. There will be an increasing risk of overtopping and possibly breaching during this epoch as its volume continues to reduce. The general expectation is that most breaches will self-heal. This retreat is shown on figure 6.1, along with a lower estimate based on a retreat rate of 1.5 m/year derived from the historic retreat of the Pebbleridge (section 5.3).

6.2.2 Medium Term (2025-2055)

Although erosion south of Westward Ho! may release more sediment into the coastal system, this is thought unlikely to provide a significant contribution to maintaining beaches. The Pebbleridge will continue to realign and its southern end is expected to retreat by 100 to 150 m by 2055, see figure 6.1. The risk of breaching of the Pebbleridge is expected to increase and self healing may no longer occur at the end of this epoch. If prolonged open breaches occur, the low lying land behind and the dunes of Northam Burrows, would be exposed to erosion and flooding. It is thought unlikely that the Taw Torridge Estuary will cut an alternative route through Northam Burrows.

6.2.3 Long Term (2055-2105)

The Pebbleridge will continue to retreat, realign and break down with greatest erosion at the southern end. The ridge may have retreated by 200 to 300 m by the end of this epoch, see figure 6.1. As breaches are unlikely to seal naturally a number of tidal inlets may form. These inlets would themselves become sediment sinks which would in the very long-term raise ground levels within Northam Burrows. There is a small possibility that a major cliff fall further south may provide a pulse of cobbles that travels along the cliff base to Westward Ho!, though there is doubt that it could reinforce the retreated and degraded Pebbleridge (Orford 2005). The estuary outfall is thought unlikely to cut through the Northam Burrows despite the anticipated gaps in the Pebbleridge and the tidal inlets.

6.3 With continuation of the present management policy

6.3.1 Short term (2010-2025)

As Northam Burrows currently receives limited maintenance, the results of continuing present management practices are likely to be very similar to pursuing a no active intervention policy. Any breaches in the Pebbleridge that did not heal naturally within a short time would be repaired using shingle or cobbles from elsewhere along the Pebbleridge.

6.3.2 Medium Term (2025-2055)

As Northam Burrows currently receives limited maintenance, the results of continuing the present management practices are likely to be very similar to pursuing a no active intervention policy. With the increasing likelihood of breaches to the Pebbleridge, the most notable difference would be that any breaches in the Pebbleridge that did not heal naturally within a short time would be repaired using shingle or cobbles from elsewhere along the Pebbleridge.

6.3.3 Long Term (2055-2105)

As Northam Burrows currently receives limited maintenance, the results of continuing present management practices are likely to be very similar to pursuing a no active intervention policy. With the increasing likelihood of breaches to the Pebbleridge, the most notable difference would be that any breaches in the Pebbleridge that did not heal naturally within a short time would be repaired using shingle or cobbles from elsewhere along the Pebbleridge. This practice could, however, be difficult to sustain with the gradual reduction in the volume of material available in the Pebbleridge. Material removed to repair breaches would weaken the ridge at the source. This might still lead to a permanent breach in the Pebbleridge and the formation of one or more tidal inlets.

7 POTENTIAL MANAGEMENT OPTIONS

7.1 Summary of SMP2 preferred management approach

The SMP2 recommends a preferred plan, involving the following actions.

1. Basically do nothing to the Pebbleridge, but repair local damage if necessary. The raised access road to the landfill on the east side of Northam Burrows should be maintained.
2. The northern end around the landfill is not expected to retreat for the next 50 years due to sea level rise, but beyond then is expected to retreat by 'several hundred metres'. The SMP2 preferred strategy is to continue to take measures to maintain the landfill in situ over the next 100 years by defending it against the sea because this is likely to be less costly than moving it.

The suggestion has been made in SMP2 that whilst the road to the landfill should be held to provide access to the landfill and avoid the risk of the material used to construct the road escaping, increasing the size of the drainage channels under this road could be used to help create an intertidal habitat area on the south east part of the Burrows.

With regard to doing nothing along the Pebbleridge, Pethick (from the 2007 report) suggested a management approach for the Northam Burrows that builds on earlier suggestions by Orford to recycle shingle along the southern end of the Northam Burrows. The recommendation was to feed the back face instead of the seaward face to encourage the Pebbleridge to migrate and become more swash aligned.

7.2 Management Options

Following on from the options considered by Pethick and in the SMP2 we have reviewed a wide range of possible flood and coastal erosion risk management options for Northam Burrows in order to develop a preferred management approach. Details of the review of options are summarised in Table 7.1.

The options considered are:

- Do nothing;
- Hold the existing line;
- Construct new linear defences or secondary defences;
- Individual property resilience and resistance;
- Soft and hard foreshore management;
- Managed realignment, and
- Monitoring

Table 7.1: Review of options for the pebbleridge at Northam Burrows.

Option	Description	Pros	Cons	Comment
Do Nothing	No works are carried out along the Pebbleridge. Risk of breach in the short, medium and long term.	1. No capital cost 2. Allows the Pebbleridge to evolve naturally 3. Maintains contribution to the wider natural coastal system, sand and shingle supply. 4. The northern end of golf course may be better protected by reduced recharge along the southern end of the ridge.	1. Unacceptable flood risk in the short term due to no action to repair breaches. 2. Does not acknowledge the safety risk or allow users to make choices to protect themselves i.e. risk to life. 3. Existing amenity uses would be affected (i.e. Golf course tee and common).As the Pebbleridge rolls back there will be increased wave exposure to some properties and businesses in Westward Ho! 4. Breach at the southern end would lead to the ingress of saline water to Units 2 and 3 of the Northam Burrows SSSI which could alter the habitat type from dune grassland to saltmarsh.	**Not recommended as does not responsibly manage risk to life**
Do Minimum	The ridge will be allowed to naturally evolve and minor or major breaches will be repaired in the short term, however in the medium and long term these will not be repaired.	1. Low capital cost 2. Allows the Pebbleridge to evolve naturally 3. Maintains contribution to the wider natural coastal system, sand and shingle supply. 4. Protects property and reduces risk to life in the short-term as breaches will be repaired. 5. The northern end of golf course may be better protected by reduced recharge along the southern end of the ridge.	1. Only acceptable if considered in conjunction with additional works to reduce flood risk in the medium and long-term. 2. Existing amenity uses would be affected as the Pebbleridge rolls back (i.e. Golf course tee and common), however there may be space to relocate the most affected tees. 3. Some businesses and properties may be affected by allowing the Pebbleridge to roll landward. 4. Breach at the southern end would lead to the ingress of saline water to Units 2 and 3 of the Northam Burrows SSSI which could alter the habitat type from dune grassland to saltmarsh however; there is already a potential source of water from the estuary to the area from a ditch running from the Skern.	**This is considered to be a potential option** in conjunction with other options to protect property within Westward Ho!

Option	Description	Pros	Cons	Comment
Hold the existing line	Maintain the Pebbleridge along its existing alignment. Continue annual maintenance. Repair any minor or major breaches as they occur.	1. Will continue to protect property in Westward Ho! from flooding and coastal erosion 2. Will continue to protect the hinterland and amenity interests within Northam Burrows (i.e. Golf course and common land). 3. Will maintain the current SSSI habitats	1. Both capital and maintenance costs will increase over time as shingle supply diminishes. 2. Not sustainable in the medium or long-term due to a continuing reduction in sediment supply from which to maintain and repair breaches and also will be increasingly difficult to maintain a sufficient crest level to protect from rising sea levels. 3. Will not prevent the continuing reduction in the level of the main beach which will increase the exposure of the Pebbleridge to wave attack. 4. Maintaining the ridge reduces the natural supply at the northern end and wider system. Further erosion along the northern end, near the landfill is likely to occur. 5. Breach at the southern end would lead to the ingress of saline water to Units 2 and 3 of the Northam Burrows SSSI which could alter the habitat type from dune grassland to saltmarsh however; there is already a potential source of water from the estuary to the area from a ditch running from the Skern.	**This is considered to be a potential option in the short term,** however in the long term it will become increasingly difficult to hold the line without considerable capital investment.
New linear defence / secondary defence	Construct landward located new defences to manage flood and coastal risk along the primary structure (the Pebbleridge). This may include earth embankments, revetments, rock armouring, wave re-curve walls, concrete/masonry walls and ground raising. This can be used to split flood cells, or control flood risk more effectively.	1. Will provide coastal erosion and flood risk protection to properties and businesses in Westward Ho!. 2. Will reduce the length of defence that needs to be maintained into the future by allowing the Pebbleridge to naturally evolve. 3. Will maintain the current SSSI habitats	1. High capital cost and ongoing maintenance costs, though along a much reduced asset defence line. 2. The new defence to protect Westward Ho! could involve works within the Go-Kart Track and cricket ground.	**This is considered to be a potential option** in conjunction with allowing the Pebbleridge to naturally evolve as in the 'Do Minimum' option.
Individual property resilience and resistance	Works on or around specific properties to manage flood and coastal risk.	1. Protects property from flooding and coastal erosion. 2. Potentially could reduce the length of new linear defence required to protect all property in Westward Ho!	1. Due to the number of properties at risk of flooding this option is unlikely to be economically viable. 2. Breach at the southern end would lead to the ingress of saline water to Units 2 and 3 of the Northam Burrows SSSI which could alter the habitat type from dune grassland to saltmarsh however; there is already a potential source of water from the estuary to the area from a ditch running from the Skern.	There are a number of properties located on the outskirts of Westward Ho! which may benefit from this option. **This is considered to be a potential option for these locations.**

Option	Description	Pros	Cons	Comment
Soft foreshore management	Maintain the Pebbleridge and beach using sediment recharge, recycling, and structures made from vegetation (polders, mattresses)	1. Would help to maintain the Pebbleridge and natural supply at the northern end and wider system. 4. Will maintain the current SSSI habitats	1. High capital costs and ongoing maintenance costs associated with this option. 2. Soft techniques such as polders are unlikely to be effective in maintaining the Pebbleridge as the natural supply of material is depleted. 3. Recharge is potentially viable but would have to be undertaken annually, significant costs associated with transporting material to recharge on the beach. 4. Recycling pebbles from the northern end to the southern end will increase erosion along the northern end of Northam burrows, increasing risk of erosion of the important sand dune system behind.	Replacing the Pebbleridge with soft defences is not an economically or environmentally viable option. **It is therefore not recommended**
Hard foreshore management	Maintain the Pebbleridge and beach using techniques including groynes, breakwaters and toe protection.	1. The existing alignment of Northam Burrows would be protected and maintained into the future. 2. No loss of land or amenity within Northam Burrows. 3. Properties protected within Westward Ho!	1. High capital costs. 2. Groynes have been used previously along the foreshore and were not effective in maintaining the ridge due to restricting sediment supply further along the ridge. 3. Maintaining the Pebbleridge with hard defences (such as rock armour) would be detrimental to the whole natural system and would severely restrict shingle supply to the northern end and wider system. Increased erosion in these areas may be expected as a result. 4. Hard defences could also lead to accelerated erosion of the clay foreshore.	Replacing the pebbleridge with hard defences is not an economically or environmentally viable option. **It is therefore not recommended**
Managed realignment	Changes to the existing asset position driven by habitat creation opportunities.	1. Creation of new intertidal habitat within Northam Burrows.	1. Does not address or reduce flood risk to properties within Westward Ho! 2. Existing amenity uses would be effected (i.e. Golf course tee and common),	This is not a flood risk management option in its own right. There would be remaining risks to life and property behind the Pebbleridge defence.
Monitoring	Use of remote or in-field monitoring to survey the Pebbleridge to assess response of the system for FCRM. This may include LiDAR, CASI, topographic survey, hydrometric survey, etc.	1. Low cost 2. Can be used to determine the rate of change along the Pebbleridge.	1. Does not reduce the risk to properties and other interests on Northam Burrows from coastal erosion and flooding.	Not a long-term management option. Many previous studies confirm the future of the Pebbleridge. **Awaiting the results of further monitoring before taking action will just delay work with resulting residual risks which may be unacceptable. However, monitoring will be required to inform the medium and long term options which are dependent on the movement of the Pebbleridge.**

7.3 Overview of Preferred Plan Recommendations

The preferred approach is to follow the SMP2 recommendation of 'No Active Intervention' apart from local maintenance following breaches (our 'Do Minimum' option). This will allow the Pebbleridge to evolve naturally whilst continuing to repair any breaches as far as practical and to encourage migration by recharging the back of the ridge, see figure 7.1. Monitoring of the Pebbleridge should be continued to determine in particular how realignment changes, whether it matches the current predictions and if not, whether the options need to be reviewed.

A 'New Linear Defence' is recommended to maintain protection to property in Westward Ho! as the Pebbleridge evolves, although there is currently no programme of funding to do this. The landfill and its access track could also be protected, see figure 7.1.

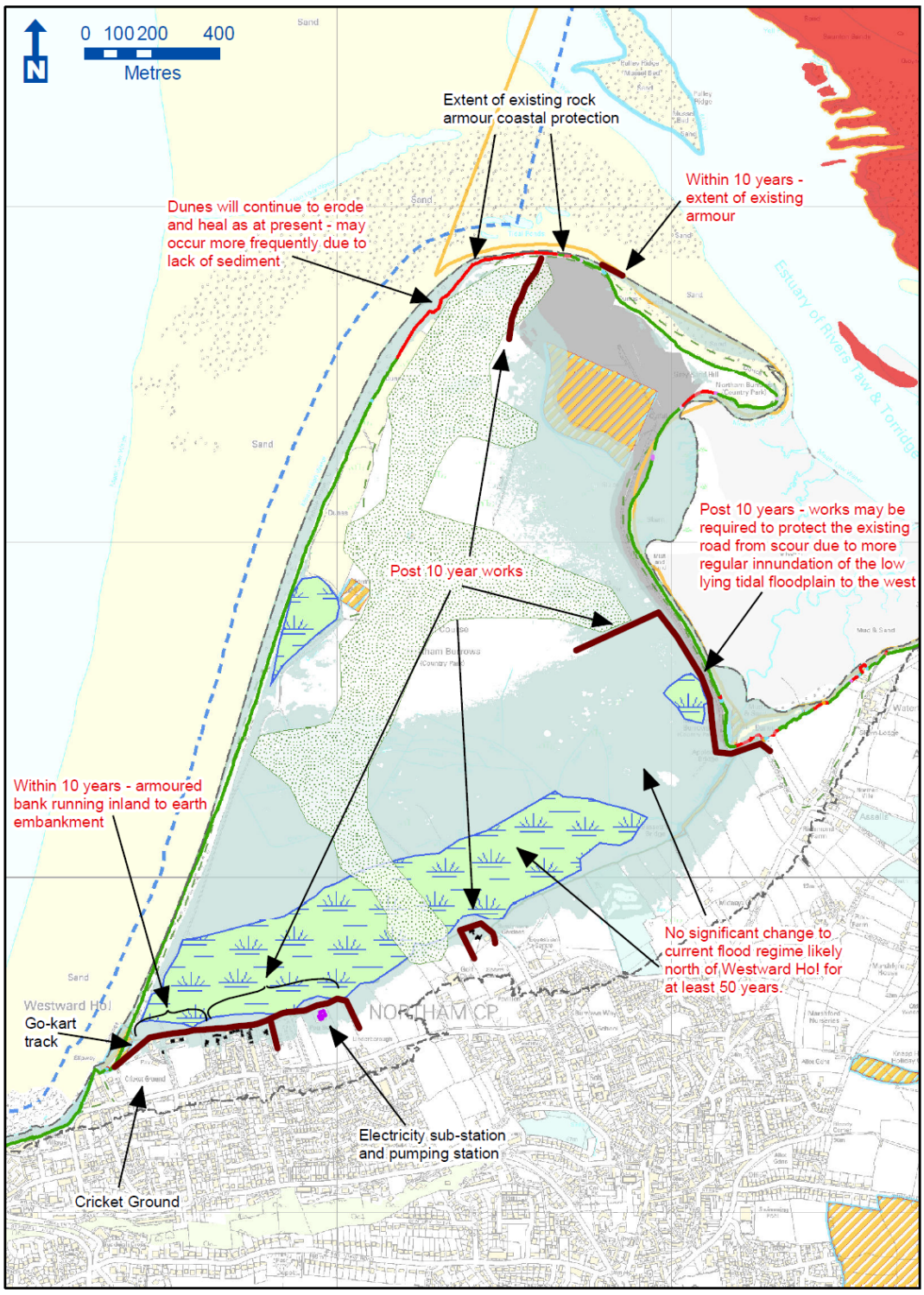


Figure 7.1: Preferred management options for Northam Burrows. (Note: Key is included in Appendix E)

7.3.1 Short term

- Maintain the Pebbleridge where breaches occur as far as practical.
- Maintain the existing sea defences at Westward Ho! to protect from any further reduction in foreshore level.
- Extend the rock armour erosion protection at the northern end of Northam Burrows to protect the landfill from erosion.
- If funding can be raised, promote a scheme to protect properties at Westward Ho! at risk of erosion and tidal flooding if the Pebbleridge moves or breaches.

The key issue is to make sure that any scheme is built on the wave platform. If not it will require increasing toe protection as the foreshore falls, which will dramatically increase cost and would affect its economic viability.

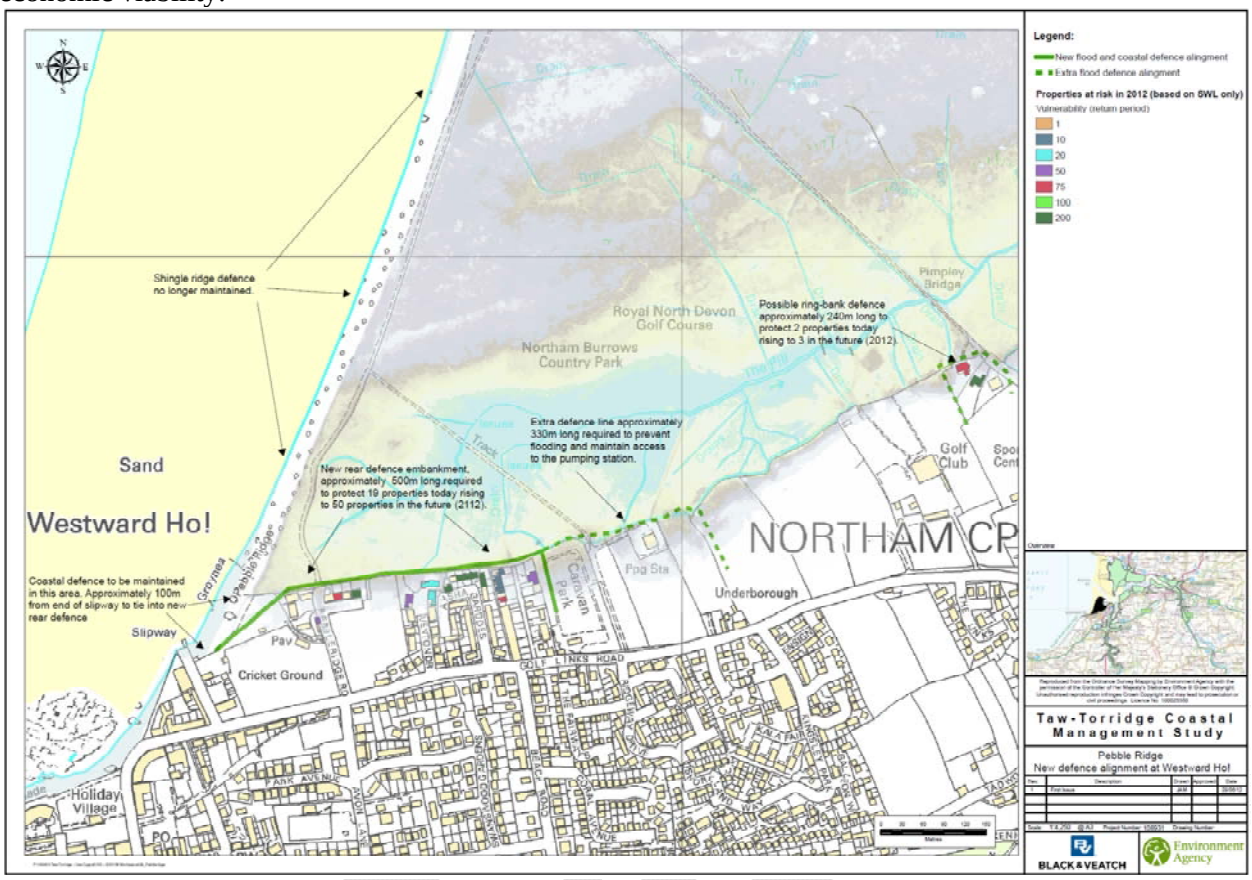


Figure 7.2: Short term potential management options for Westward Ho! coastal frontage.

7.3.1 Medium and long term

Continue short term policies. Depending on the movement of the Pebbleridge, extend the embankment along the northern edge of Westward Ho! to avoid outflanking and continue protection to developed area. Previously constructed sections of this embankment that are expected to be seaward of the Pebbleridge as it retreats should be armoured to resist wave attack,

Construct embankments to protect the south west flank of the closed landfill site and hold the line along the southern part of the access road to prevent erosion from its west side due to more regular inundation of the Northam Burrows. This may be accompanied by construction of larger culverts under the access road to allow the water inundating Northam Burrows to drain more easily.

8 POTENTIAL NEW COASTAL DEFENCE ALIGNMENT

The potential new coastal defence alignment is shown in figure 8.1 below. It is noted however, that this currently cuts across the go-kart track. It is important for any defence to be founded on the bedrock, and the line that is shown follows the assumed boundary between the bedrock and alluvium. The exact location of this boundary is unknown between the point where the rock is visible as a wave cut platform and the ridge that is apparent to the north of the Westward Ho! properties. Therefore the alignment at the westerly end may be subject to change following further site investigation.

Whatever the exact alignment, it is important that the proposed defence runs behind the back of the Pebbleridge and ties into the existing sea wall, whilst at the same time limiting any disturbance to the existing properties.

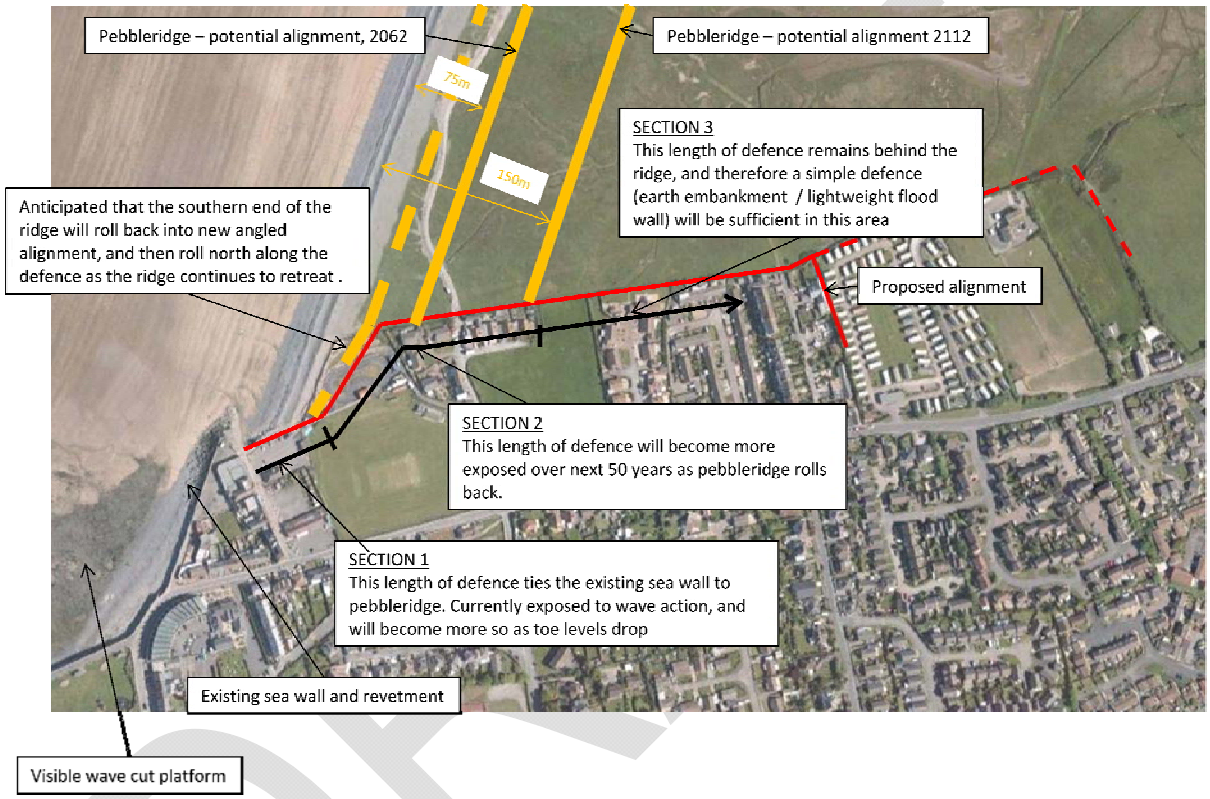


Figure 8.1: Potential new defence alignment to continue to protect properties in Westward Ho! but enable the pebbleridge to naturally evolve.
(Note: The Pebbleridge alignment shown is the lower estimate of movement).

8.1 Defence Form

The new defence can be considered in three different sections.

8.1.1 Section 1

This is the section at the most westerly end of the defence, and is currently exposed to wave action. As the Pebbleridge retreats it is anticipated that the foreshore levels will drop, and therefore the defence will come under increasing attack from wave action. A robust sea wall, which ties into the existing seawall, is therefore required in this area. The toe level could be founded on the bedrock to prevent the structure being undermined as the foreshore levels drop, and the crest level of this defence will need to be high enough to limit overtopping due to wave attack.

8.1.2 Section 2

This length of defence will become exposed if the Pebbleridge continues to retreat as anticipated. As the ridge rolls eastward the foreshore levels will drop, and the defence will overtime become the front line and be vulnerable to direct wave action. A substantial defence founded on the bedrock is likely to be required to protect properties behind.

8.1.3 Section 3

This length of defence is to the east of the likely alignment of the Pebbleridge in 100 years time, and therefore will not be exposed to wave attack. The purpose of the defence in this area is to provide protection against flooding in the event of a breach. It is unlikely that the ground levels in this area will drop.

8.2 Issues for consideration

The boundary between the more robust Section 2 construction (which will be required to resist increasing wave action) and the more lightweight Section 3 (which will purely act as a barrier against flood water) will need to be determined once there is more certainty in the rate of retreat of the Pebbleridge from the ongoing monitoring.

The investment decision will need to be made considering the construction cost estimates and the availability of funds. The priority will be to provide a defence at the western end that will provide protection against wave action as the foreshore levels drop in the near future. Towards the eastern end of Section 2 it may be preferable to provide a cheaper defence initially (as per Section 3). If it becomes apparent that the ridge is continuing to retreat, this section of defence could be armoured before the Pebbleridge reaches it.

Further details of the design criteria used to inform the form of the defences presented here are described in Appendix D. Final decisions about the form of the defences will have to take into account the specific site requirements, geology, cost and effect on the people and properties in the area.

9 ENVIRONMENTAL CONSTRAINTS, OPPORTUNITIES AND MITIGATION

9.1 Existing environmental baseline

Northam Burrows lies at the mouth of the Taw-Torridge Estuary and is designated as a Site of Special Scientific Interest (SSSI). The SSSI is split into units which are all in unfavourable condition. To the north of Northam Burrows is Braunton Burrows which is a Special Area of Conservation (SAC) designated for its dune features. Northam Burrows is within the North Devon Area of Outstanding Beauty (AONB) and UNESCO Biosphere Reserve. The Taw Torridge Estuary is recommended to become a Marine Conservation Zone and is also a SSSI.

The site is used for recreation and hosts the Royal North Devon Golf Course, Go Kart Track and other facilities used by visitors to the area from the popular tourist destinations of Appledore and Westward Ho!.

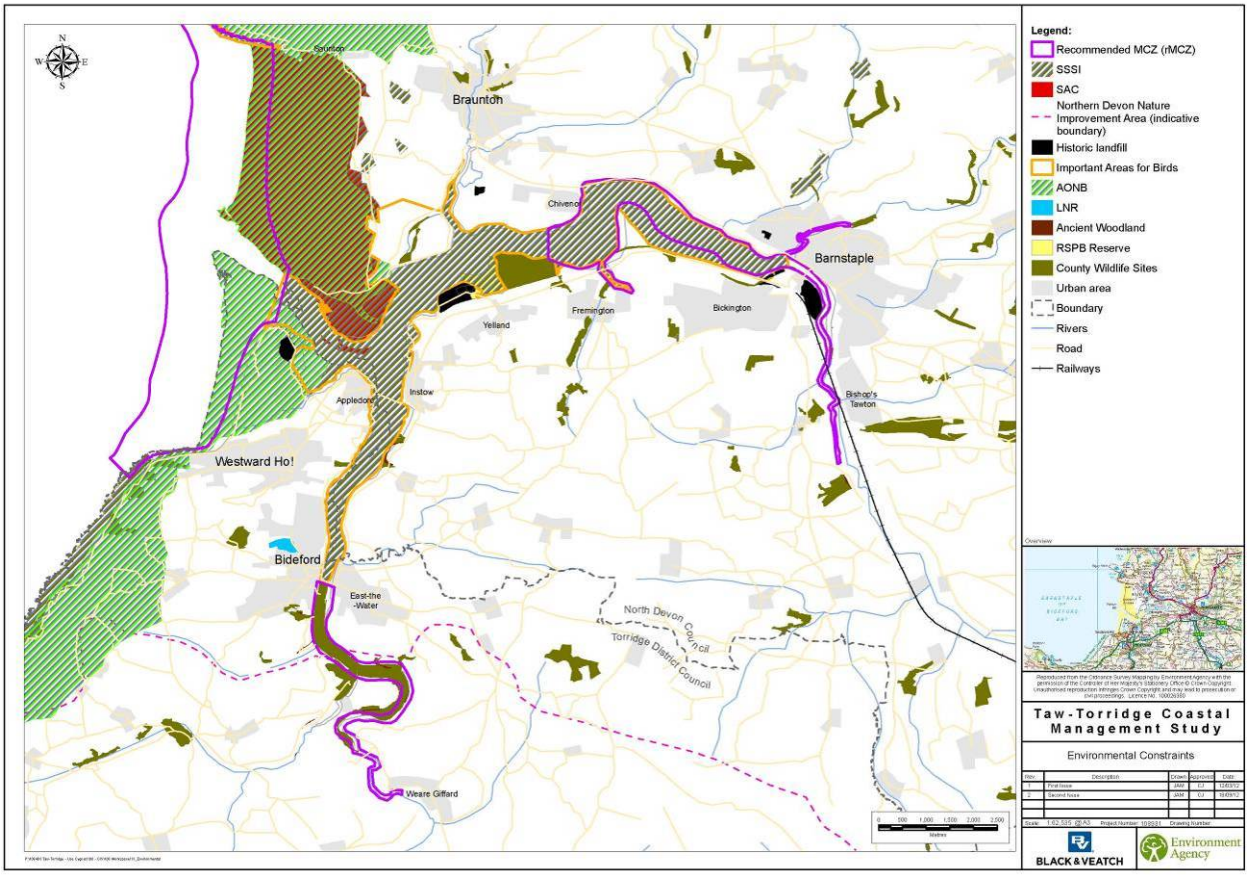


Figure 9.1: Environmental constraints plan, showing the important designations across Northam Burrows and wider context.

9.2 Impacts of the preferred option

A golf course tee off would be affected as a result of allowing the ridge to naturally evolve as sea level rise. However, there is space to relocate the tee and maintaining the ridge will mean that the tee in its present position will be protected in the short term. In addition, by allowing the ridge to naturally evolve, material will migrate along the ridge towards the northern end, which will improve the condition of the Pebbleridge and reduce the risk of breaches occurring at that location. This will be to the benefit of the golf tees located behind.

The proposed new defence to protect Westward Ho! could involve works within the Go-Kart Track and cricket ground. These businesses and clubs will need to be consulted about the proposals.

The SAC is located outside of the study area but could potentially be affected by any major works which impact on the wider coastal system. The preferred approach will allow the Pebbleridge to naturally evolve and therefore there will be no adverse impacts on internationally designated sites. The maintenance of the rock armour around the historic landfill site will be unlikely to have a significant effect on the mouth of the estuary.

The character of the AONB and UNESCO Biosphere Reserve will be unchanged. Any visual effects from the small defences will not affect the character and can be reduced by good design.

The coastal waterbody Bideford Bay (Waterbody Reference: GB610807240000) is adjacent to the Pebbleridge. It is currently classified as Moderate Status with a predicted status of Good Status by 2027. The reason cited in the South West RBMP for its moderate status is because the levels of phytoplankton do not achieve the good status boundary values, however, there is low confidence of failure and therefore the deadline has been extended to allow investigations to explore what pressures are causing the failure and what mitigation is required. The proposals are unlikely to affect phytoplankton levels as it is allowing natural geomorphological process to occur.

Allowing the southern end of the Pebbleridge to breach will allow ingress of tidal water into the Northam Burrows SSSI, however, there is already a link from the Skern area (refer to figure 2.1) through to the area to be affected at the south of the site. The area to be affected is within the SSSI units 2 and 3. Unit 2 is described as unfavourable, declining due to under grazing. Unit 3 is described as semi-fixed and fixed dune grassland but it is described during the latest assessment in 2011 as being more of a transitional site towards a wet grassland habitat, not a dune slack. The ingress of saline water from breaches within the Pebbleridge could create brackish channels within the grassland which could potentially change the ecology in the area. The influence of a channel which has already formed from the saltmarsh habitat around the Skern is not known although this could give an indication of the significance of the impact of further channels.

According to the latest assessment of the Taw Torridge Estuary SSSI Unit 101 in 2011, the road is interrupting the transition from fixed dune grassland to dune slack and pseudo-saltmarsh habitats. This will still occur under the preferred option because the access road to the historic landfill site will remain.

9.3 Environmental Opportunities and Mitigation Measures

Saltmarsh is already forming to the north east of the site at Northam Burrows and it is reported in the latest condition assessment for the Northam Burrows Unit 4 that when the culverts under the access road to the landfill site were opened during the winter of 2010/11, pioneering saltmarsh species were able to establish in low lying areas. There is an opportunity to maximise saltmarsh habitat in the area by leaving the culverts open in the long term although this will need to monitored for potential negative impacts on the landfill in the short term and appropriate action taken if required.

10 CONCLUSIONS AND RECOMENDATIONS

Property in Westward Ho! is vulnerable to tidal flooding and coastal erosion as a result of wave overtopping, foreshore erosion, movement and breach of the Pebbleridge. The ridge is slowly moving east and the volume of new pebbles from the west is thought to be diminishing due to reduced long-term supply.. In future, with sea level rise, the risk of breach is expected to increase.
The preferred approach recommended by this study, is to allow the Pebbleridge to evolve naturally, whilst continuing to repair any breaches as far as practical and to encourage migration by recharging the back of the ridge. A new defence is recommended to maintain protection to property in Westward Ho! as the Pebbleridge evolves, although there is currently no programme of funding to do this. The landfill and its access track should continue to be protected.

It is considered that the following works are required to enhance the existing defences and provide increased protection for the properties of Westward Ho!

1. Allow the Pebbleridge to evolve naturally but continue to repair breaches (particularly in the short term) as required. Any repairs should occur along the back face instead of the seaward face to encourage the Pebbleridge to migrate and become more swash aligned.

2. Maintain the existing sea wall at Westward Ho! to protect from any potential reduction in foreshore level in the short term.

3. As soon as is expedient, extend the rock armour erosion protection at the northern end of Northam Burrows to protect the landfill from erosion.

4. Within the next 10 years, construct a new defence to tie into the existing sea wall and revetment at the southern end of the Pebbleridge (Section 1 of the defence). Extend beyond the current Pebbleridge location to ensure continuity of defence as the ridge retreats eastward in the short term

5. Within the next 10 years, consider constructing a new defence on an alignment across the go-kart track and then on an east-west alignment to the rear of the most northerly Westward Ho! properties (Section 2 of the defence). This will define the coastline, and will “train” the Pebbleridge so that it rolls northwards as it retreats inland. This will protect the land behind from coastal erosion and provide protection to the properties from flooding due to tidal inundation and wave action.

6. Within the next 10-25years continue the flood defence to protect properties located further east. This will provide continued protection against flooding due to possible breaches in the Pebbleridge. (Section 3 of the defence). Also consider extending set back defences to avoid outflanking from other flood routes and continue protection to the landfill site and access road.

Recommendations to progress this as a project are:

- Ground investigation to confirm the depth of bedrock in the vicinity of any proposed works and to inform the detailed design.
- Investigate the form of the current sea wall and revetment, to determine whether any works will be required to ensure that this defence remains stable as foreshore levels drop and wave action increases.

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Slade 2009 A report on coastal erosion at Westward Ho!

APPENDIX

Appendix A: Photographs

Appendix B: Past Breach Events

Appendix C: Geology

Appendix D: Outline Design Details

Appendix E: Management Unit 1 Legend

Appendix A: Photographs

Figure A.1: The pebbleridge. View looking south towards Westward Ho!

Figure A.2: The pebbleridge. View looking north towards Braunton Burrows in the distance.

Figure A.3: View looking south along the pebbleridge towards Westward Ho!

Figure A.4: View looking north along the pebbleridge adjacent to Sandymere car park.

Figure A.5: View looking south behind the pebbleridge.

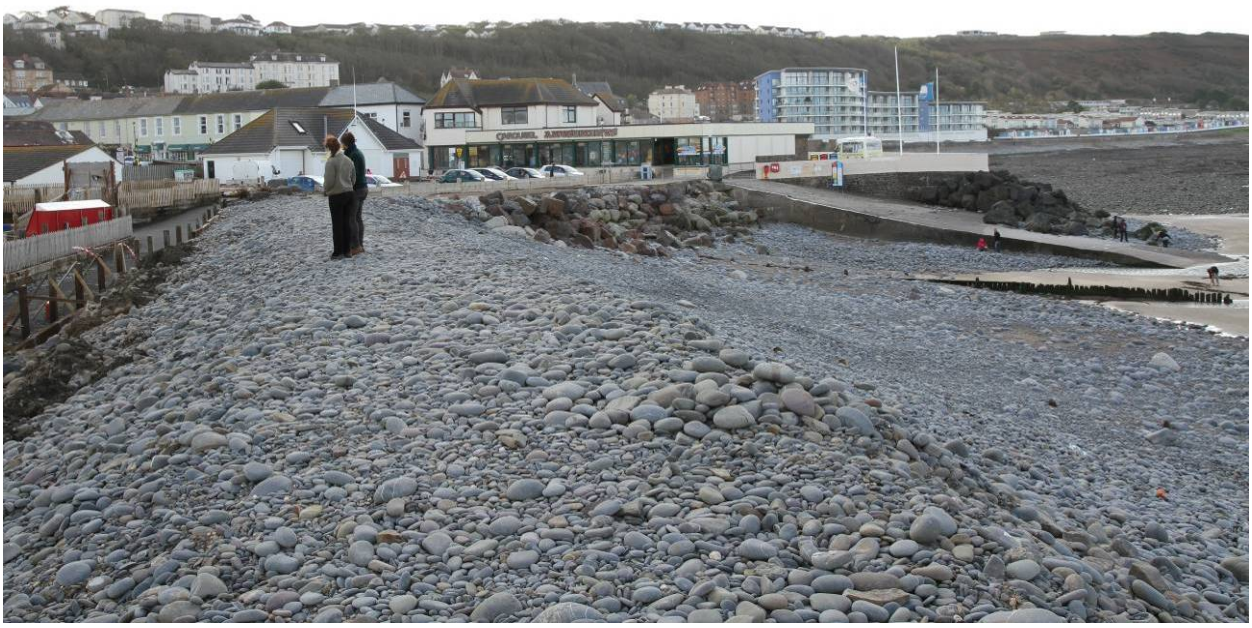


Figure A.6: The southern end of the pebbleridge where it ties into the hard defences at Westward Ho!

Figure A.7: Go-kart track and properties located behind the existing pebbleridge.

Figure A.8: Wooden groynes have been used in the past to reduce pebble loss near to Westward Ho!

Figure A.9: The wave cut platform is exposed along the foreshore in Westward Ho!

Figure A.10: Existing seawall and rock armour defences which are used to protect property in Westward Ho!

Figure A.11: Flooding of the Sandymere area caused by wave overtopping during a storm event on 17th October, 2012.

Figure A.12: Wave overtopping along the northern end of the Pebbleridge during the storm event of the 17th October, 2012.

Appendix B: Past Breach Events

1962 Breach Event

A major storm in 1962 breached the ridge (see figure 1). This occurred just beyond the last groyne (see figure 2) near the Westward Ho! end of the Pebbleridge. The breach was blamed on down drift starvation caused by the construction of the groynes. The 1962 breach gorged a deep trench through the ridge into the underlying clay. This was subsequently infilled with dragon's teeth tank traps (see figure 3). This type of deep breach is similar to that which occurred in the Porlock shingle ridge. However, that breach was not repaired and new saltmarsh habitat has been created in the tidal floodplain.

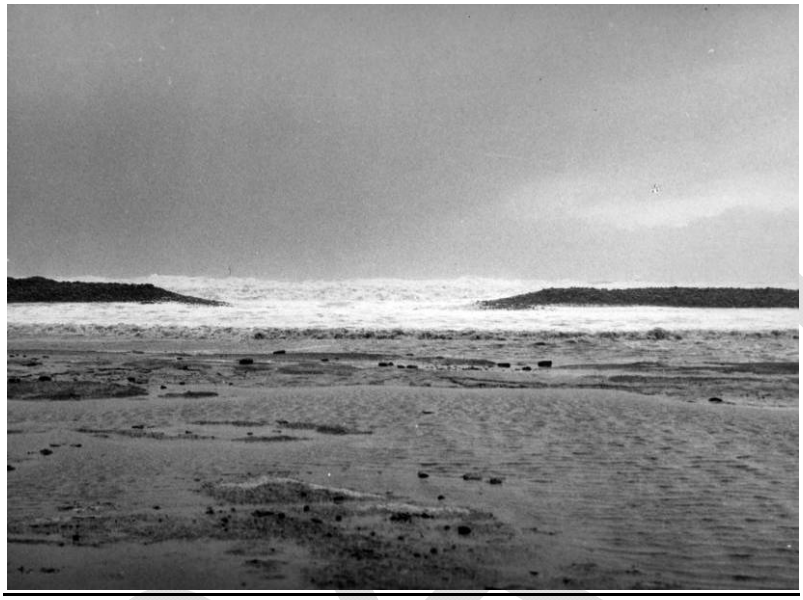


Fig 1: Location of 1962 breach event.
Source: P. Keene.

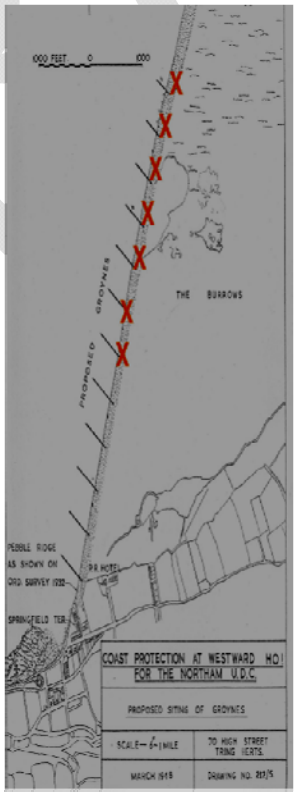


Fig 2: Five wooden groynes were constructed in 1948 to prevent transfer of pebbles further north. The crossed out groynes shown were never built. *Source: P. Keene.*

Fig 3: Repair of the 1962 breach in the ridge which was infilled with dragon's teeth tank traps.
Source: P. Keene.

6th December 2011 Breach Event

A minor breach in the Pebbleridge occurred on 6 December 2011. This was described in an e-mail from Tara Sanders, Torridge District Council - *"I have this morning inspected a minor breach on the Pebbleridge which will require some works to prevent flooding (approx location as per attached plan). The breach is located at the Westward Ho! end of the ridge, outside of the Burrows & the SSSI.."*

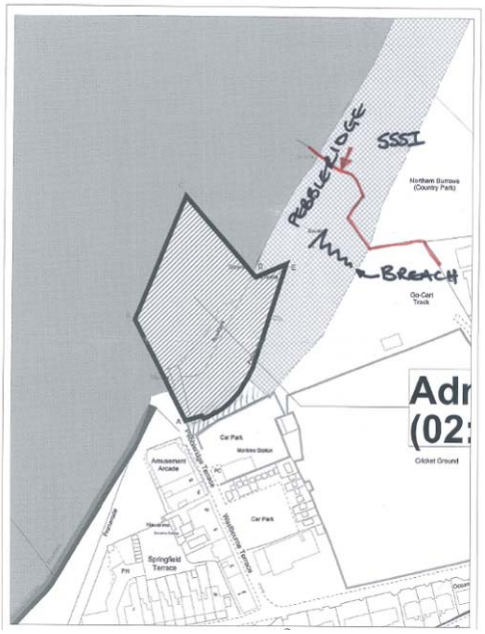


Fig 4: Location of December 2011 breach event.
Source: Torridge District Council.

Fig 5: Minor breach in the ridge which occurred on 6th December 2011.

The tide gauge for Ilfracombe shows that the breach occurred at the end of the neap tidal cycle; see figure 6 and Table 1.

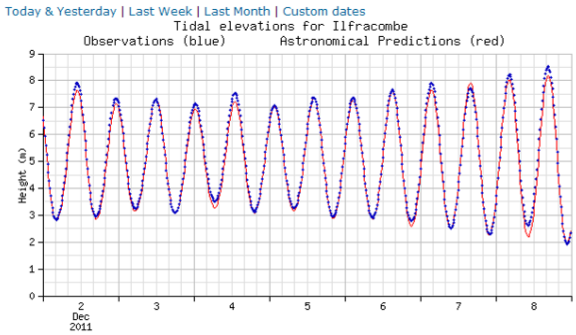


Fig 6: Tidal data recorded from tide buoy at Ilfracombe.

Table 1: HAT data for secondary ports in the Taw-Torridge study area.

Location	HAT (m)	
	(m CD)	(m OD)
Ilfracombe	10.3	5.5
Clovelly	9.2	4.8
Appledore	8.7	5.52
Bideford	7.0	5.62

The WaveRider buoy in Barnstaple Bay recorded wave conditions on the day of the breach event. See figure 7.

- Significant wave height (hs) at around high tide on the 5th December (between 1200 and 1600) remained between 2.4 to 2.7m for the duration of the high tide.
- Significant wave height (hs) at around high tide on the 6th December (between 0100 and 0400) remained between 2.1 to 2.4m for the duration of the high tide.
- H (max) exceeded the 4m storm threshold during both the 5th and 6th December high tide events.
- It is likely that the events on the 5th December caused the breach in the Pebbleridge.

Date	Time	Hs	Hmax	Tz	Comments
04/12/2011	0100	1.79	2.96	5.1	
	1300	1.94	2.74	5.1	

05/12/2011	0230	2.57	4.47	5.6	Period of greatest swell waves
	1430	2.45	4.2	5.5	
06/12/2011	0300	2.35	3.57	5.4	
	1500	1.89	3.09	5.0	Breach occurred before this time

Table 4: Wave conditions prior to the breach event.

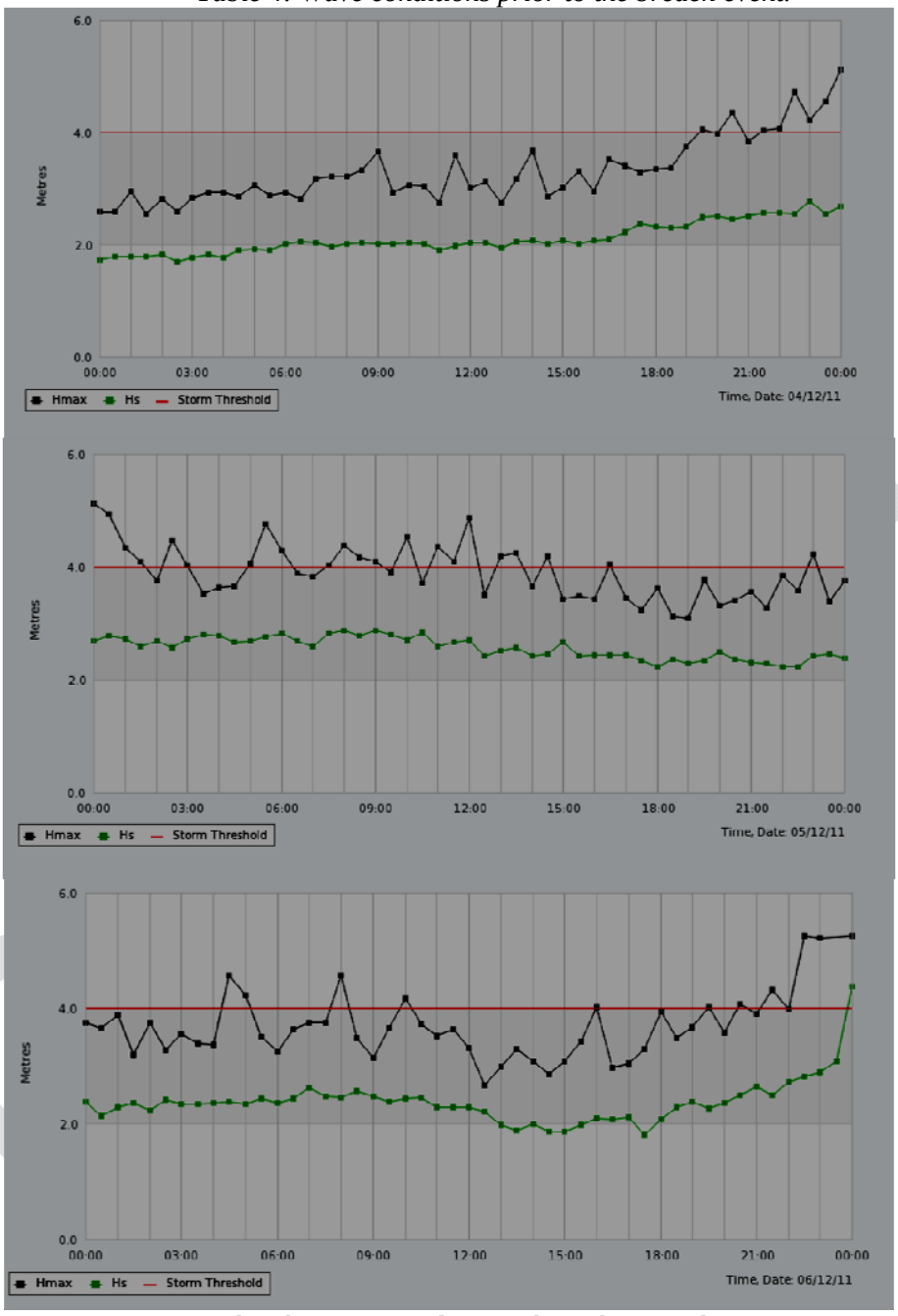


Fig 7: Wave height: Monitored over 4th – 6th December 2011.

Summary conclusions:

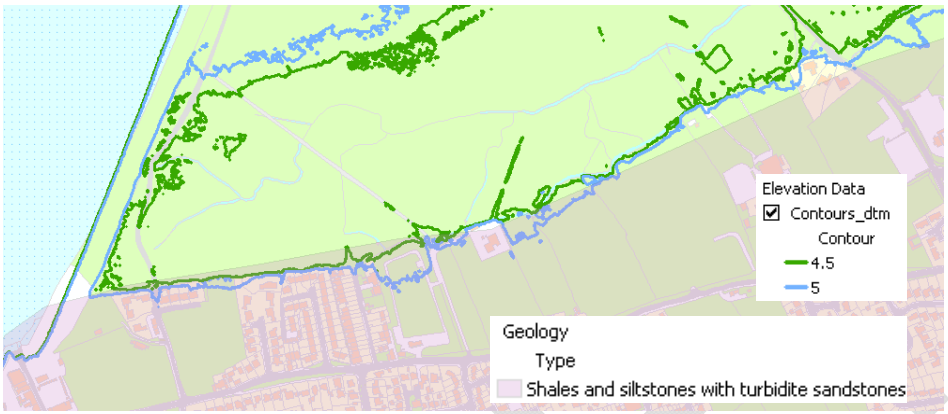
- The breach was observed in the morning on 6th December 2011 after being reported to the council.
- This follows two tides on 5 Dec that coincided with relatively high significant wave conditions and high wave period/swell, see table 4.
- It is likely that the breach occurred during one of the high tide events on the 5th December.

- In practice the combination of the two/three tides (the am tide on 5 Dec had highest Hs although lower level) with large waves is probably significant and helped cause the breach, as it allows two/three times the number of waves to attack the Pebbleridge.
- Significant wave height was slightly elevated during these events but was still well below the 4m storm threshold. Only Hmax exceeded the storm threshold (see figure 7).

Appendix C: Geology

Geology

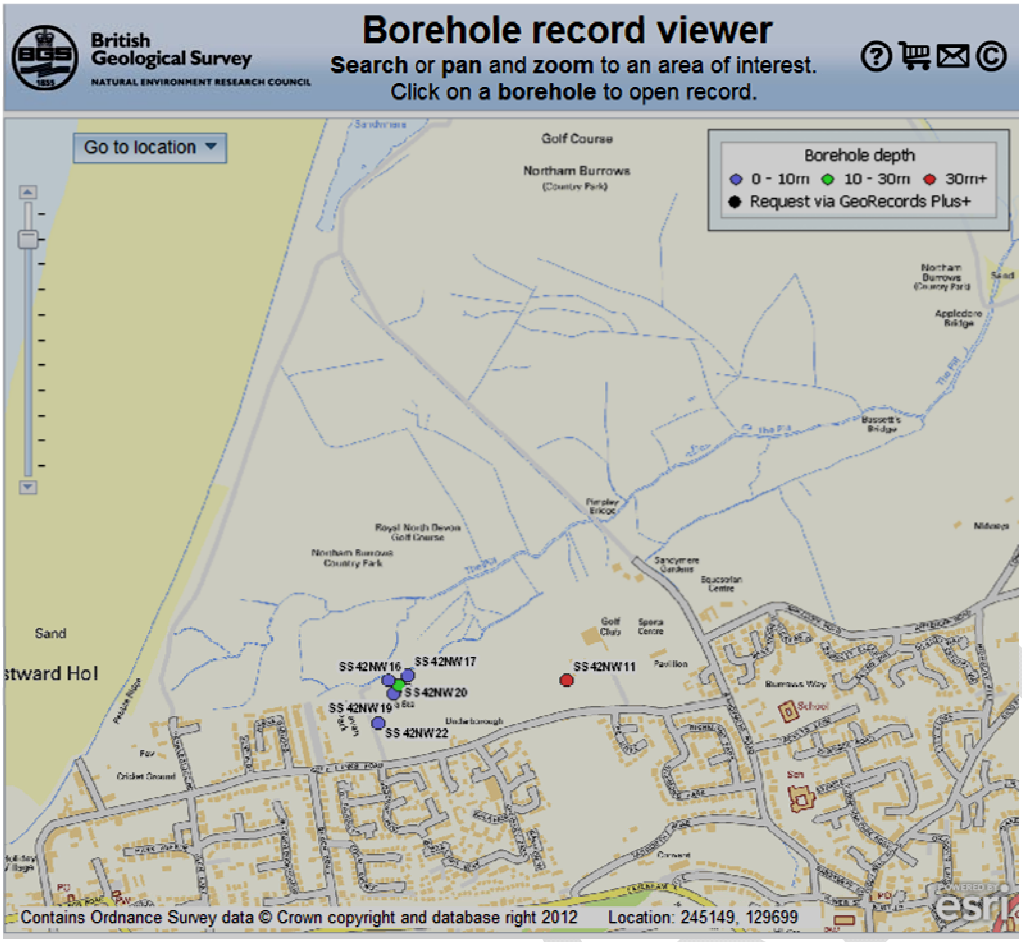
Northam Burrows is mainly underlain by alluvium, which forms a sharp boundary with the hard underlying geology of the Ashton Mudstone Member and Crackington Formation (mudstone and siltstone) which underlies the majority of the town of Westward Ho!. This boundary appears to occur around the 4-5m AOD ground level change (see figure below). Anything below 4.5m is likely to be underlain by alluvium, while above 4.5m is likely to be underlain by weathered silt and shale bedrock.

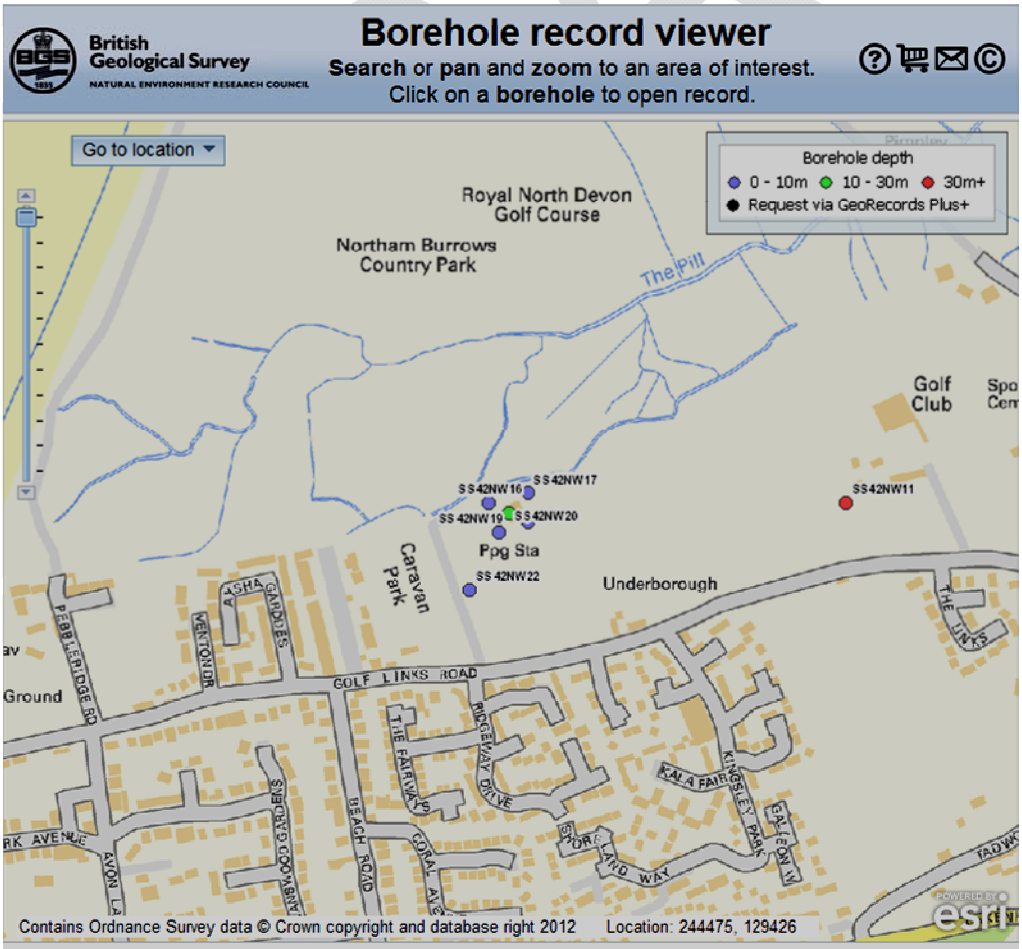


Borehole Data

Seven borehole logs, available from the BGS online database, were analysed to determine the depth to bedrock in and around Westward Ho!. See the table and figure below for details.

Borehole Log No.	Depth (m)	Date of BH	Superficial Geology	Bedrock Geology	Depth to bedrock (m)	Depth of water table (m)
SS42NW/16	0-10	18/10/1983	Clay with pockets of gravel	Weathered siltstone	2.9	2.9
SS42NW/17	0-10	19/10/1983	Clay with pockets of gravel	Weathered siltstone	3.0	3.0
SS42NW/18	0-10	20/10/1983	Clay with pockets of gravel	Weathered siltstone	2.7	2.7
SS42NW/19	0-10	20/10/1983	Clay with pockets of gravel and silt	Weathered siltstone	3.6	3.0
SS42NW/20	10-30	29/10/1983	Clay with pockets of gravel	Weathered siltstone	2.9	3.0
SS42NW/22	0-10	19/20 January 1978	Made ground (ash, glass and shale fill)	Weathered slate	6	3.9
SS42NW/11	+30m	29/8/1987	Backfill over sand	Shale Weathered siltstone	12.8 23.8	4.6


British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL
Borehole record viewer
Search or pan and zoom to an area of interest.
Click on a borehole to open record.
Go to location
Borehole depth
0 - 10m
10 - 30m
30m+
Request via GeoRecords Plus+
Golf Course
Northam Burrows
Sand
SS 42NW16
SS 42NW17
SS 42NW20
SS 42NW19
SS 42NW22
SS 42NW11
Contains Ordnance Survey data © Crown copyright and database right 2012
Location: 245149, 129699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Borehole depth
0 - 10m
10 - 30m
30m+
Request via GeoRecords Plus+
Royal North Devon
Golf Course
Northam Burrows
Country Park
The Pill
Golf
Club
SS 42NW16
SS 42NW17
SS 42NW19
SS 42NW20
SS 42NW22
SS 42NW11
Ppg Sta
Caravan
Park
Underborough
GOLF LINKS ROAD
Contains Ordnance Survey data © Crown copyright and database right 2012
Location: 244475, 129426

Appendix D: Outline Design Details

D.1 Proposed alignment

The proposed line of the defence is shown in the figure below. It is noted that this cuts across the Go-Kart track. It is important, ideally for any defence to be founded on the bedrock, and the line that is shown follows the assumed boundary between the bedrock and alluvium. The exact location of this boundary is unknown at present between the point where the rock is visible as a wave cut platform and the ridge that is apparent to the north of the Westward Ho! properties. Therefore, the alignment at the westerly end may be subject to change, following further site investigations.

Whatever the exact alignment, it is important that the proposed defence runs behind the back of the Pebbleridge and ties into the existing sea wall, whilst at the same time limiting any disturbance to the existing properties.

D.2 Defence form

The defence will be considered in three different sections.

Section 1: This is the section at the most westerly end of the defence, and is currently exposed to wave action. As the Pebbleridge retreats it is anticipated that the foreshore levels will drop, and therefore the defence will come under increasing attack from wave action. A robust sea wall, which ties into the existing, is therefore required in this area. The toe level could be founded on the bedrock to prevent the structure being undermined as the foreshore levels drop, and the crest level of this defence will need to be at such a level to limit overtopping due to wave attack.

Section 2: This length of defence will become exposed if the pebbleridge continues to retreat as anticipated. As the ridge rolls eastward the foreshore levels will drop, and the defence will overtime become the front line and be vulnerable to direct wave action. A substantial defence founded on the bed rock is likely to be required to protect the properties behind.

Section 3: This length of defence is to the east of the likely alignment of the pebbleridge in 100 years time, and therefore will not be exposed to wave attack. The purpose of the defence in this area is to provide protection against flooding in the event of a breach. It is unlikely that the ground levels in this area will drop.

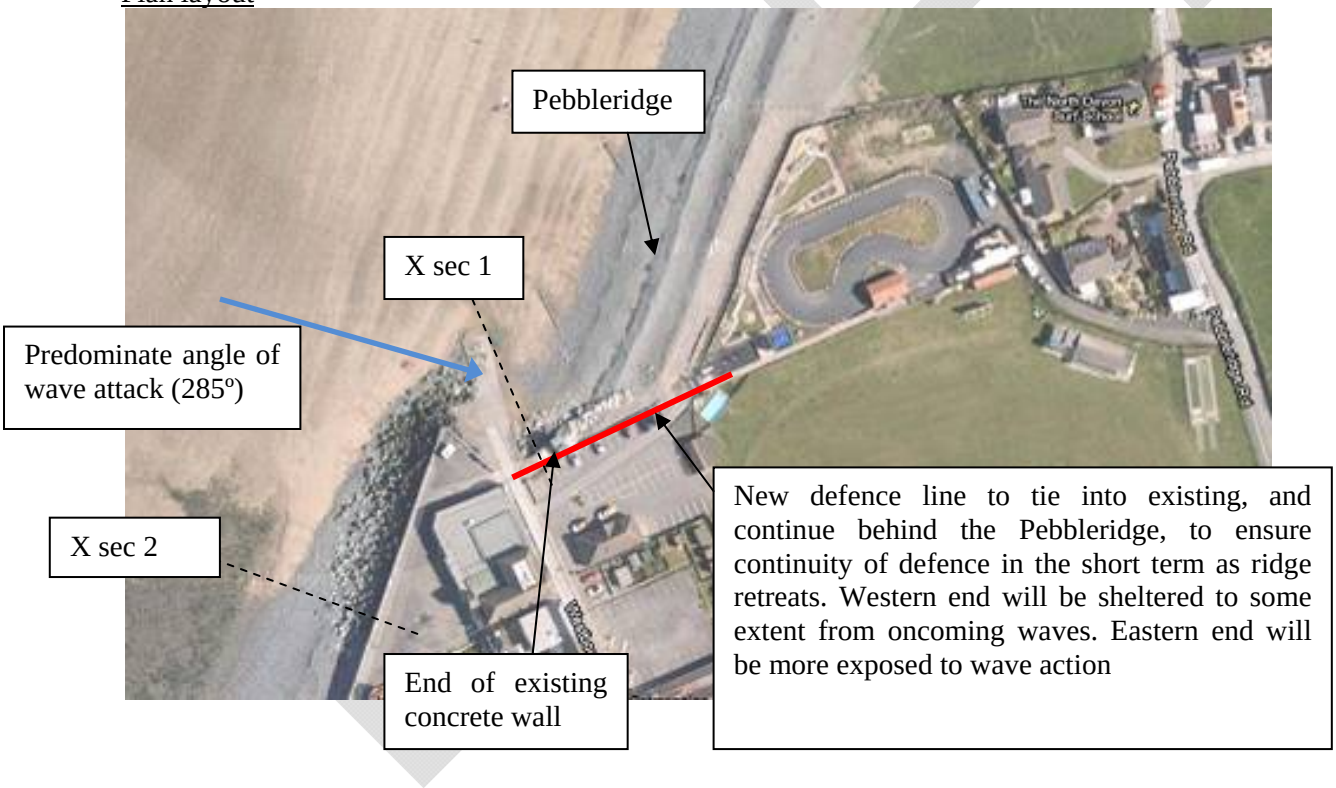
It is difficult to judge exactly where the boundary between the more robust Section 2 construction (which will be required to resist increasing wave action) and the more lightweight Section 3 (which will purely act as a barrier against flood water) should be, as the exact rate of retreat of the pebbleridge is uncertain.

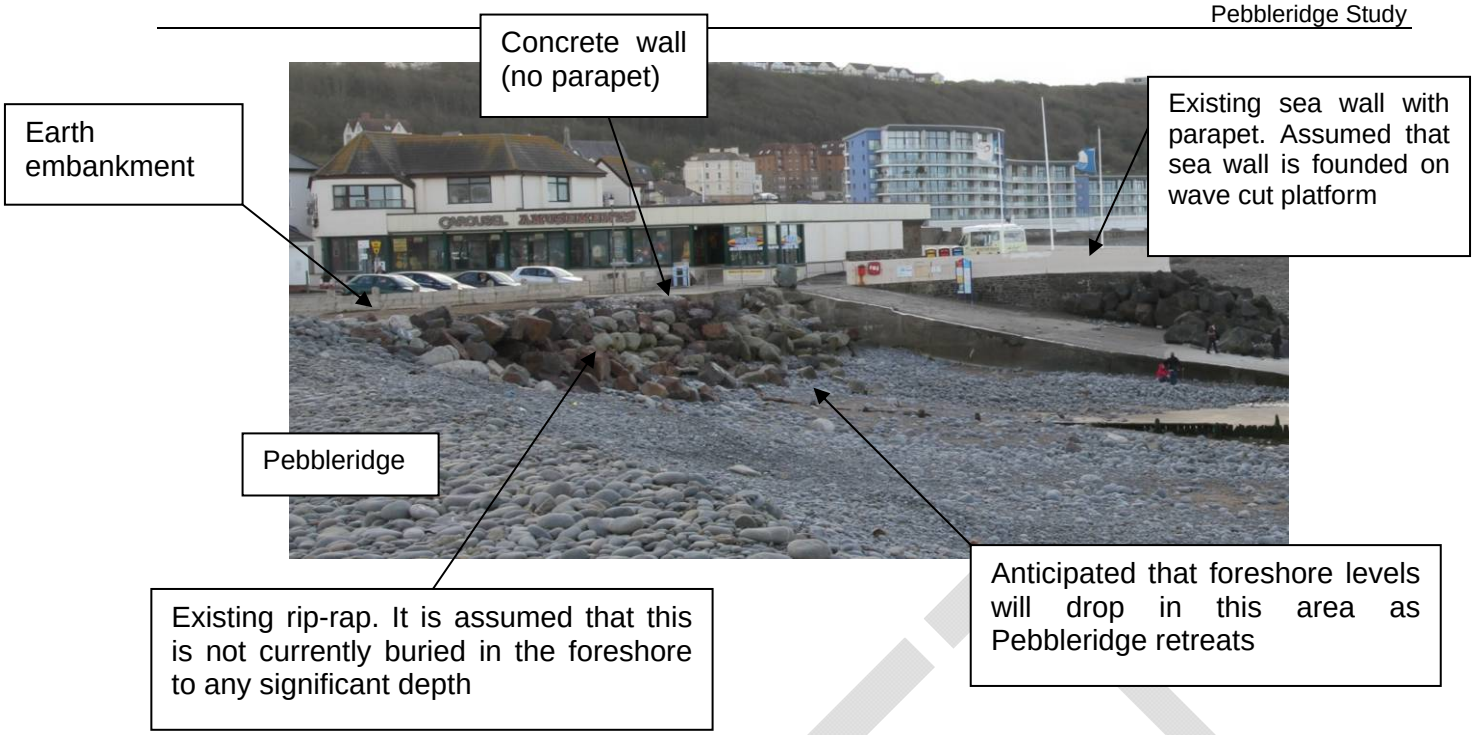
The decision will likely be a question of construction cost and available funds. The priority will be to provide a defence at the western area that will provide protection against wave action as the foreshore levels drop in the near future. Towards the eastern end of Section 2 it may be preferable to provide a cheaper defence (as per Section 3), with the aim of adapting it if it becomes apparent that the ridge is continuing to retreat.

D.3 Section 1 Potential Defence Alignment

The aerial view and photograph show the current layout of the land. The figures are annotated to highlight what work may be required to reinforce the defence in this area as the Pebbleridge retreats. The cross sections indicated on the diagram are for calculation purposes and are shown for later reference post study.

Plan layout





Evolution of the foreshore

It is assumed that as the Pebbleridge rolls eastwards, the foreshore level also drops. A basic assessment has been carried out assuming that the level of the old Union club in 1879 was similar to land behind the Pebbleridge. This indicates that foreshore levels have dropped 0.04m/yr over the last 139 years. Assuming that this trend continues, over a design life of 100 years, foreshore levels in front of the new defences could lower by up to 4m. The current foreshore levels at the base of the Pebbleridge and existing defences are approximately 2mOD, meaning that levels could drop to -2mOD over the next 100 years if there was no change in underlying geology with depth.

Exposure to wave action

The wave recorder in Bideford bay (in place since 2009) shows that the predominant peak wave period for waves approaching the shore are between 7 and 13.5 seconds.

The wave heights will be depth limited, and therefore wave heights at the defence will increase as the foreshore level drops.

For the purposes of outline design the wave height at the defence will be taken as 0.8 x water depth at the toe. This wave height will be combined with wave periods of between 7secs and 15 secs.

Water levels

The extreme design water levels will be based on the water levels at the Mouth of Taw which are as follows (current water levels) based on the current Environment Agency guidance on extreme sea levels:

EWL Value (mAOD)	Mouth of Taw (National Chainage 224)
1-Year	5.02
2-Year	5.08
5-Year	5.17
10-Year	5.25
20-Year	5.32
50-Year	5.41
75-Year	5.46
100-Year	5.49
150-Year	5.53
200-Year	5.56
500-Year	5.63
1000-Year	5.68

Sea level rise is estimated to be 0.32m in the next 50 years and 0.75m over the next 100 years.

Required crest levels to limit overtopping

The current crest level as shown on cross section 1, east of the boat ramp, is around 7mOD, however cross sections through other defences further west and the Pebbleridge show a level of approximately 8mOD.

A very simple assessment of overtopping indicates that a level of 7mOD with the current toe level of 2m is around 100l/s/m for the 1 in 100 year return period water level (with no allowance for climate change), increasing to 500l/m/s if the toe level drops to 0.5mOD, which is not considered to be acceptable. With a crest level of 8mOD, overtopping is only around 12l/s/m for a current toe level of 2mOD, increasing to 100l/m/s if the toe level drops to 0.5mOD. These values are considered to be more reasonable, and therefore a crest level of 8mOD should be considered for outline design.

These overtopping values assume that rip rap is placed in front of the wall to a level of 7mOD as the calculations show that overtopping rates are lower for a rubble mound slope than for a vertical wall, especially for the longer period waves. It may be more economical to provide a higher crest, with a lesser amount of rip rap, but this can be investigated further during more detailed design and optioneering stages.

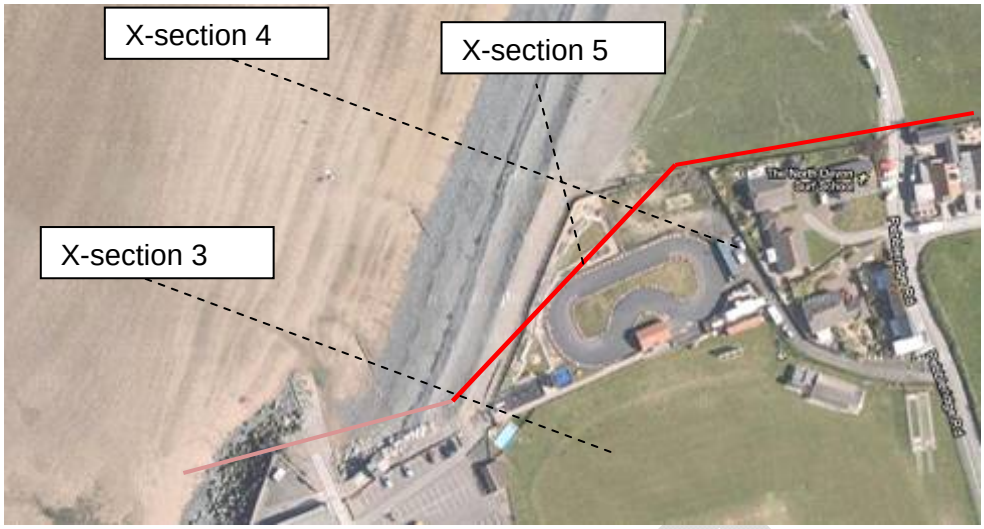
D.4 Section 2 Potential Defence Alignment

The indicative alignment for section 2 is shown on the plan below. The benefit of providing a hard line of defence along this line, before the Pebbleridge migrates further, is that it protects the land behind from erosive processes, and defines the position of the coastal frontage, effectively “training” the ridge to follow a chosen path, rather than allowing the current retreat trend to continue (whereby significant portions and land, and potentially properties are lost to the sea as the shoreline moves eastwards). It is also a proactive method for managing the effect of increased flooding due to the recession and degradation of the ridge, rather than resorting to continuous small scale emergency measures as storm and flood events occur.

The westerly portion of this section (on a SW to NE alignment) will potentially become the front line defence and exposed to wave action over the next 40-50 years. Although the alignment shown cuts across the go-kart track, there are no other properties in the area, and therefore construction in this area is not likely to be too disruptive (provided that the land can be purchased or some agreement can be reached with the owner of the track).

The easterly section of this defence (running along a nearly W-E alignment to the rear of the properties shown on the plan) may become exposed over the next 50-100 years if the ridge continues to retreat as shown. Construction in this area will therefore have to be managed carefully to avoid damage to the buildings and to limit disruption to the residents. As it is likely to be some way into the future before this section becomes a front line defence, it may be preferable to provide a simple barrier against flood waters in case of breach of the ridge. It will then be possible to reassess in the future to determine whether more substantial construction is required as the rate of Pebbleridge recession continues to be monitored over coming decades.

Plan layout



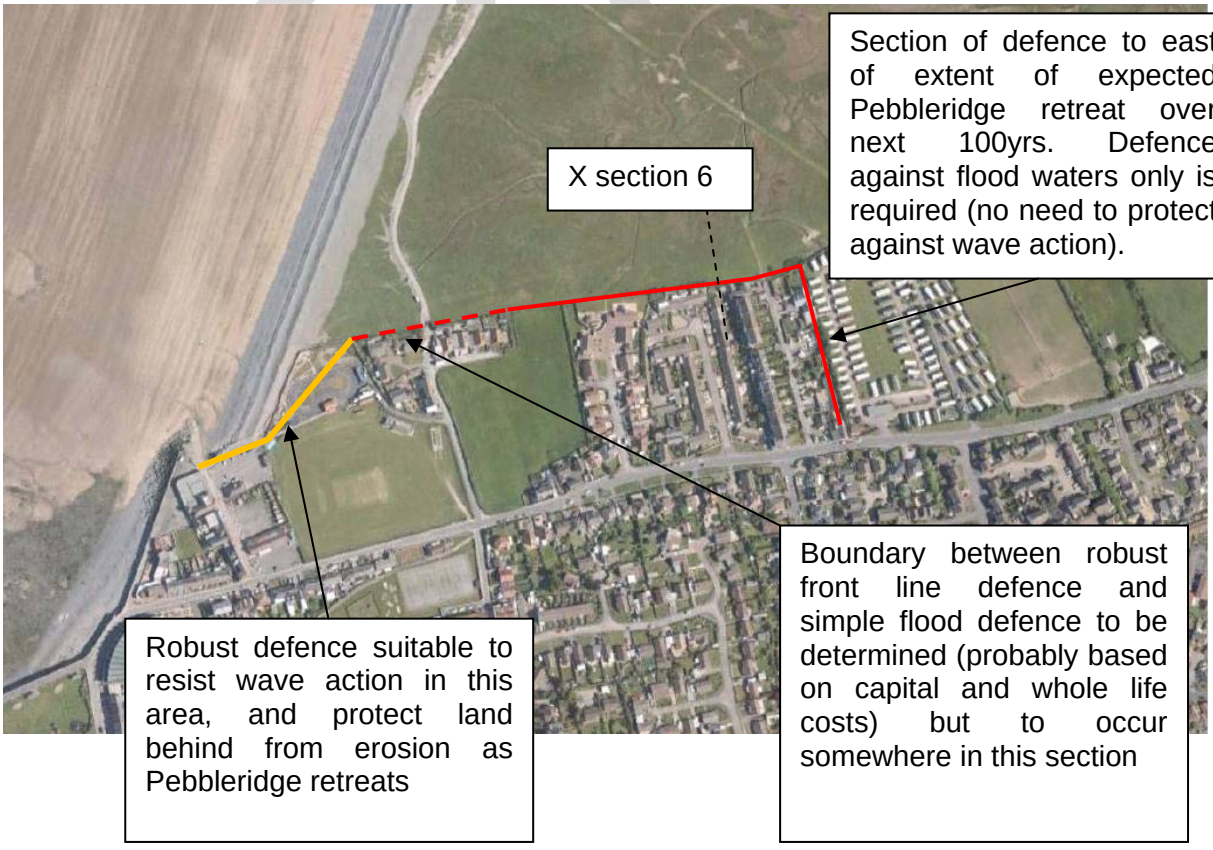
Cross Sections

The current ground level at the point of the proposed defence is approximately 5.5 to 6mOD. Therefore providing a defence with a crest level of 8mOD or higher (which would be required to limit overtopping due to wave action as the defence became the front line) would result in a wall 2 to 3m higher than the surrounding ground. This may not be a preferable option from an aesthetic point of view, so it may be appropriate to raise the ground level behind the defence so that it is possible to see over the top.

D.5 Section 3 Potential Defence Alignment

This section is to the east of the expected extent of the Pebbleridge retreat, and therefore the defence will not be subject to wave action and it is unlikely that the ground levels will drop in this area.

The defence is therefore only required to provide a barrier against flooding that may occur if the Pebbleridge breaches.



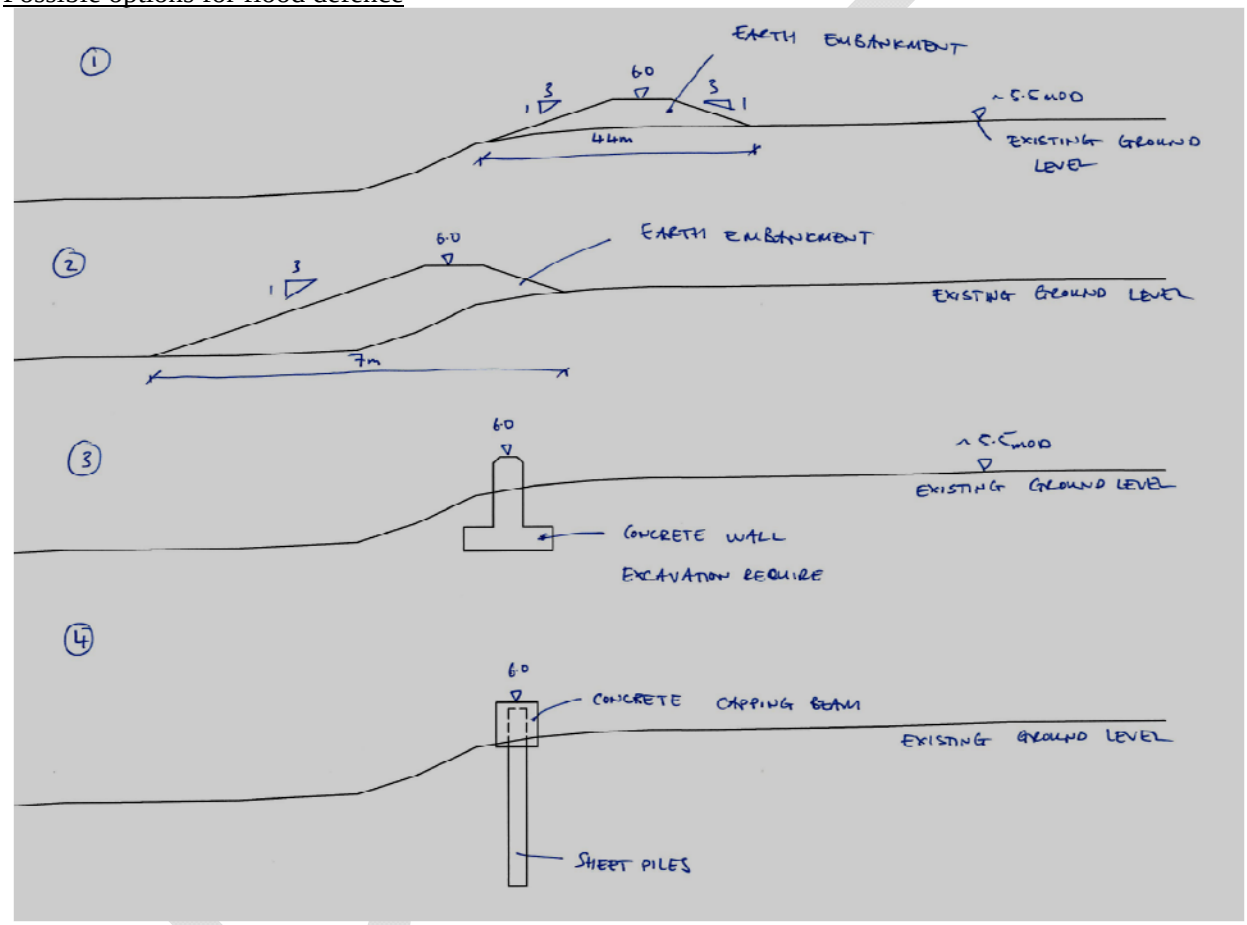
Required crest levels

The recommended defence level is one that provides protection against the 1 in 200 year flood (the 0.05% event). The current 1 in 200 year flood level is 5.56mOD, increasing to 5.88mOD after 50 year of climate change and 6.31mOD after 100 years of climate change.

The provisional recommended crest level is 6.0mOD, which gives a freeboard of 440mm over current levels and 120mm freeboard over expected levels in 50 years. Although this level would not provide protection against the 0.05% event in 100 years time; but as climate change allowances are only an estimate it is not considered appropriate to include that allowance in the current design.

Different forms for the defence could include earth embankments or low rise concrete walls. The exact type will depend on cost, site access constraints and minimising disruption to local residents.

Possible options for flood defence



The sketches in the figure above show different options for the flood defences.

1) Shows an earth embankment founded on the higher ground to the east of the ridge. This limits the amount of material required, but may encroach onto people's property lines, as the aerial photographs appear to show the gardens of the residential properties in this area backing up to the proposed defence line.
2) Shows and earth embankment founded mainly on the lower ground to the west of the ridge. This requires more material but is likely to encroach less onto people's property.
3) This shows a low concrete wall founded beneath the existing ground level. This option has a smaller footprint than the earth embankment, but requires excavation.
4) This shows a sheet pile wall with a concrete cap. This has a small footprint and doesn't require much excavation, but does require piling equipment.

Final decisions about the form of the defence will have to take into account the specific site requirements, cost and effect on the people and properties in the area.

D.6 Existing sea wall immediately to the south of the pebbleridge

As the Ppebbleridge retreats and foreshore levels drop it will be important to maintain the sea wall and revetment to the south of the Ppebbleridge, as this provides the front line defence for Westward Ho! The exact form of this defence is currently unknown. It may not be founded on bedrock, with the rip rap in front providing protection to the wall foundations. It is possible that the rip rap that is currently in place in front of the wall may need rearranging or supplementing as the wall is subject to increasing wave action if the levels drop further before encountering bedrock.

D.7 Summary and recommendations

It is considered that the following works are required to enhance the existing defences and provide increased protection for the properties of Westward Ho!

- Investigate form of current sea wall and revetment to determine whether any works will be required to ensure that this defence remains stable as foreshore levels drop and wave action increases
- Construct robust defence to tie the existing sea wall and revetment to the southern end of the Pebbleridge (Section 1 of the defence as discussed above). Extend beyond current Pebbleridge location to ensure continuity of defence as ridge retreats eastward in the short term
- Consider constructing robust defence on an alignment across the go kart track and then on an EW alignment to the rear of the most northerly Westward Ho! properties (Section 2 of the defence as discussed above). This will define the coastline, and will “train” the Pebbleridge so that it rolls northwards as it retreats inland. This will protect the land behind from coastal erosion and provide protection to the properties from flooding due to tidal inundation and wave action.
- Continue the flood defence along the rear of the Westward Ho! properties to provide continuing protection against flooding due to possible breaches in the Pebbleridge. (Section 3 of the defence as discussed above).

Appendix E: Legend

Key for Figure 7.1