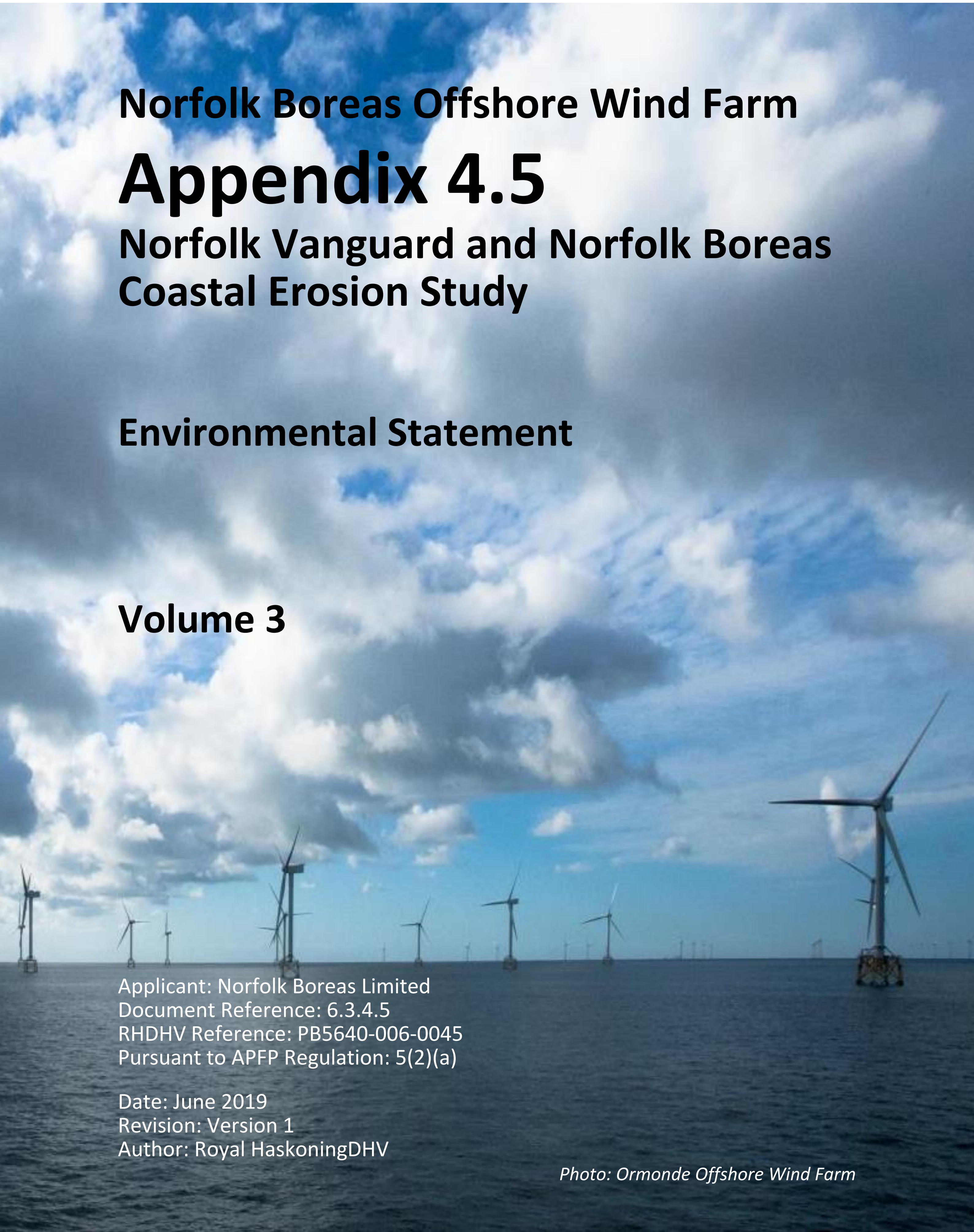
Norfolk Boreas Offshore Wind Farm

Appendix 4.5

Norfolk Vanguard and Norfolk Boreas Coastal Erosion Study

Environmental Statement

Volume 3



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REPORT

Norfolk Vanguard and Norfolk Boreas Coastal Erosion Study

Client: Norfolk Boreas Limited

Reference: WATPB4476R001F0.1

Revision: 0.1/Final

Date: 17 May 2017

Royal HaskoningDHV

Enhancing Society Together

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1 Introduction

Vattenfall Wind Power Limited (VWPL) is currently assessing potential landfall locations for Horizontal Directional Drilling (HDD) for the Norfolk Vanguard and Norfolk Boreas Offshore Wind Farm export cables. Following the engineering feasibility study, VWPL has identified three landfall sites where the offshore cables could be brought ashore and jointed to the onshore cables. The three sites identified are at Bacton Green, Walcott Gap and Happisburgh South as presented in Figure 1-1.

Royal HaskoningDHV was requested by Norfolk Vanguard and Norfolk Boreas Limited (subsidiary companies of VWPL) to produce a technical report assessing the coastal erosion and geomorphological environment at the potential landfall locations.

1.1 Landfall sites

The area for this study is the 7km-long stretch of coast between the Bacton Gas Terminal in the North West and Eccles-on-Sea in the south east (Figure 1-1). Site 1 Bacton Green is located immediately south of the Bacton Gas Terminal; Site 2 Walcott Gap is approximately 1.8km south of Bacton Green, and Site 3 Happisburgh South is located approximately 5km south of Walcott Gap.

Figure 1-1: Potential landfall locations for the Norfolk Vanguard and Norfolk Boreas offshore wind farm export cables.

The two northern sites of Bacton Green and Walcott Gap have an opportunity to site related onshore infrastructure (including the cable relay station) close to the existing Bacton Gas Terminal, which has the potential to reduce landscape impacts given the industrial nature of the area. However, these two sites would require offshore cabling through the Marine Conservation Zone (Figure 1-2). The southern site at Happisburgh South has the opportunity to accommodate the landfalls of both Norfolk Vanguard and Norfolk Boreas and the export cables would approach the coast from outside of the Marine Conservation Zone. However, this site has other associated risks due to known and unknown archaeology in this area.

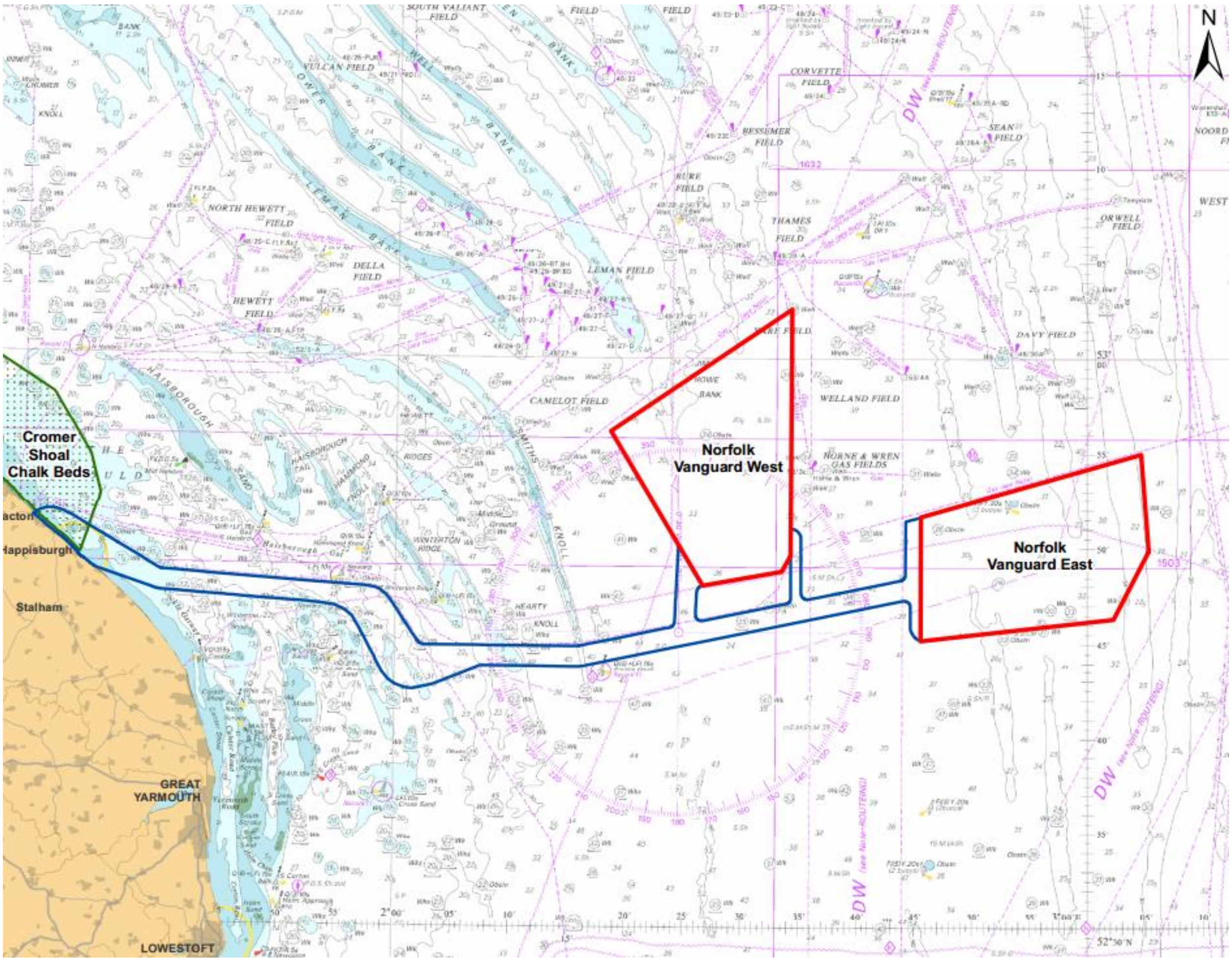


Figure 1-2: Marine Conservation Zone in relation to the Landfall sites.

1.2 Appraisal criteria

Coastal processes and coastal management along the north east Norfolk coast could influence Norfolk Vanguard and Norfolk Boreas Limited's decision in a number of ways:

- Cliff erosion: the transition pits have to be placed at an inland area where the risk of ongoing erosion affecting the site during the functional life is acceptable.
- Beach erosion: the depth, trajectory and exit point of the HDD have to be designed so that the risk of foreshore and seabed lowering affecting the cable is acceptable. In addition to risk of exposure, the general variability of beach levels is also important, as this would determine structural design of the cable.
- Coastal processes effects: the presence of the cable exit and its effects on coastal processes would need to be assessed to ensure that any potential impact locally or elsewhere along the coast are minimised.

- Coastal management schemes: existing and ongoing defence schemes could influence risk and costs of landfall construction.

1.3 Study objectives

The overall aim of this study is to assess the coastal geomorphology and coastal management policies along the Bacton Gas Terminal to Eccles-on-Sea frontage in order to inform landfall selection and design.

This study will provide a coastal processes and coastal management evidence base that could influence or be influenced by the landfall. The baseline evidence is then used to appraise the three landfall options and, for each location, the choice between 'short' and 'long' HDD.

The HDD will either exit on the beach (above the level of mean low water spring), classified as a 'short HDD' approximately 150m in drill length, or at an offshore location up to 1000m in drill length, classified as a 'long HDD'. The short HDD would minimise offshore works associated with the HDD, however requires suitable access to the beach for excavators and associated equipment. Temporary beach closures would be required during drilling exit and duct installation.

1.4 Structure of report

This report is structured as follows:

- Section 2: Baseline Understanding – this section covers geomorphology and coastal processes, hydrodynamics, Shoreline Management Plan, existing coastal defences, and monitored recent / ongoing changes.
- Section 3: Potential Changes – this section covers the following management scenarios; No Active Intervention, SMP 6 Policy management and With Present Management.
- Section 4: Appraisal.
- Section 5: Conclusions and Recommendations.

2 Baseline Understanding

2.1 Geomorphology and Coastal Processes

The coast of north east Norfolk between Cromer (to the north of Bacton) and Happisburgh in the south is an almost continuous line of glacial till cliffs with an average height of approximately 20 metres. They reach a maximum height of approximately 60 metres at Trimingham and east Cromer. To the south of Happisburgh the backshore gradually changes from cliffs to sand dunes. Figure 2-1 presents photographs along the study area.

Figure 2-1: Site Photographs – Bacton Gas Terminal to Happisburgh. Source: Royal HaskoningDHV.

The coastline is exposed to waves generated in the North Sea and is therefore very dynamic. The undefended parts of the cliffs are subject to recession, which has been ongoing for about the last 5,000 years when sea level rose to within a metre or two of its present position (Kelling to Lowestoft Ness SMP, 2012).

Foreshore lowering is also an issue throughout this region along with temporary steepening following a storm event. When the beach is stripped away during storms the platform beneath becomes exposed and eroded causing foreshore lowering. This erosion is irreversible and when the beach returns during calmer conditions, it does so over a lowered surface.

Along the north east Norfolk coastline, net sediment transport is to the south east and the potential for transport increases with distance south as the coastline curves from a west / east alignment to a north / south alignment (Kelling to Lowestoft Ness SMP, 2012). During storm surges, large waves predominantly approaching from the north and north-east combine with strong nearshore tidal currents to transport large volumes of sediment offshore and alongshore. As outlined in the Overstrand to Walcott Strategy Study, Littoral Sediment Processes HR Wallingford Report EX 4692, 2003, net longshore transport rates along the study area have been estimated several times in the past, with a wide range of predictions. An early study by Vincent (1979) estimates a potential net drift of 148,000 cubic metres per year at Happisburgh and this was revised to 260,000 cubic metres per year in 1983. Vincent, McCave and Clayton (1983) also estimated a rate of 100,000 cubic metres per year passing through Overstrand towards Bacton. Clayton also estimates 180,000 cubic metres per year of transport passing through Trimmingham (north of Bacton), decreasing to 160,000 cubic metres per year at Happisburgh. This reduction was thought to be a function of sand being lost offshore. All of these estimates have assumed that the coastline was still in a natural state with no defences in place.

The nearshore and offshore zones are characterised by shoals and sand banks, which influence coastal exposure and wave patterns. This results in complex sediment transport interactions between the offshore, nearshore and beach zones which have an impact on alongshore transport. Peak sediment transport rates take place at approximately 150m offshore reducing seaward but with a further increase at approximately 300 to 400m offshore (Kelling to Lowestoft Ness SMP2, 2012). This may vary along the frontage and is influenced by the specific profile at different locations.

2.1.1 Mundesley to Walcott

The coastline between Mundesley and Walcott forms a small shallow embayment. This embayment has in part been created between historic coastal protection at Mundesley and Walcott, which constitute bounding headlands. Other factors, such as local variation in bathymetry and the change in the underlying geology of the shoreline have influenced the development of the embayment. The beach in front of the cliffs at the Bacton Gas Terminal is therefore slightly set back and slightly wider than along the shoreline to the south and this additional width helps dissipate the energy at the cliff line.

2.1.2 Mundesley to the Bacton Gas Terminal

There is a net southwards alongshore movement of sediment between Mundesley and Bacton with transport rates varying in magnitude, often linked to the cliff erosion. The rate of sediment transport increases to the south meaning that more sediment is leaving this zone than is entering from the North West (Kelling to Lowestoft Ness SMP, 2012).

The cliffs at Mundesley are sandier and better drained compared to the cliffs to the north. Erosion of the cliffs is generally a gradual process, but with small scale recession events resulting in 1 to 5 metres of erosion per event. The cliff top evolution between Mundesley and Bacton between 1900 and 2016 is presented in Figure 2-2. This has been derived by Royal HaskoningDHV by plotting cliff top lines from historical mapping sourced from National Library of Scotland. Annual cliff top retreat between Mundesley and Bacton has been estimated at approximately 1.1 - 4.5 metres per year for 1900-1937. For 1937 to 2016 retreat has been estimated at approximately 0.65 – 1.2 metres per year.

Figure 2-2: Cliff Top evolution between Mundesley and Bacton
Map Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

2.1.3 Bacton to Walcott

The coastline between Bacton and Walcott is characterised by soft cliffs of varying height comprised of clays and fine sands. Given their position within the shallow embayment, the beaches in front of the cliffs at the Bacton Gas Terminal and Bacton Green are slightly set back and wider than along the shoreline to the south at Walcott. This additional width helps to dissipate the wave energy at the cliff toe.

Despite the beach width, sediment supply to the foreshore is limited due to the presence of coastal defences up drift. The Bacton to Walcott coast therefore relies on sediment input from both cliff and beach erosion further up the longshore sediment transport pathway. As a result of sediment supply shortages, cliff erosion has progressed rapidly over recent years. The impacts of this were evident following the November 9th 2007 and December 5th 2013 storm surges, and also in January 2017 where the cliff line eroded. Cliff instability is now threatening the Bacton Gas Terminal infrastructure, a problem which is also evident at the Castaways Caravan Park adjacent to Bacton Green.

The evolution of the cliff top between Bacton and Walcott has been mapped at three distinct dates; 1900 which predates the construction of the sea defences and that of the Gas Terminal, 1937 and 2016 as presented in Figure 2-3. This has been derived by Royal HaskoningDHV by plotting cliff top lines from historical mapping sourced from the National Library of Scotland. Annual cliff top retreat along Bacton has been estimated at 0.5 – 1.35 metres per year for 1900-1937. For 1937 to 2016 retreat has been estimated at approximately 1.3 – 1.7 metres per year. Annual cliff top retreat along Walcott has been estimated at approximately 3.1 – 3.8 metres per year for 1900-1937. For 1937 to 2016 retreat has been estimated at 1.0 – 1.2 metres per year.

Figure 2-3: Cliff top evolution between Bacton and Walcott
Map Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 2-3 shows that the cliff top between Bacton and Walcott has receded since 1900. It also shows that most of the erosion occurred by around 1937 prior to the seawall being constructed in the 1950s. Following the December 5th 2013 storm surge the cliffs along the Bacton Gas Terminal frontage have retreated further indicating the vulnerability of the coastline at Bacton Green.

2.1.4 Walcott to Eccles-on-Sea

From Walcott to Happisburgh sediment transport rates have been estimated at just over 500,000 cubic metres per year between 1979 and 1994 (Kelling to Lowestoft Ness SMP, 2012). The rate of transport at Happisburgh is thought to be the highest along the coastline and more sediment is leaving from the south than is entering from the North West, due in part to the coastal defences up drift and the orientation of the coastline. The cliffs between Walcott and Happisburgh consist of fine sediment, containing a mixture of silt/clay and fine sand, and therefore contribute only small volumes of sediment to the beach system. The foreshore along this stretch of coast primarily relies on supply of sediment from the north west, albeit limited.

Figure 2-4 presents the shoreline evolution along Happisburgh (This has been derived by Royal HaskoningDHV by plotting cliff top lines from historical mapping sourced from the National Library of Scotland) and Figure 2-5 presents aerial photography of recent cliff erosion events from 2001, 2010 and 2014 reflecting the cliff retreat following the failure of the defences. The cliffs at Happisburgh are retreating primarily in response to wave undercutting. The shoreline has shown a history of net retreat and predefence maps (1900 – 1937) show the average erosion rate varied between 0.4 – 2.1 metres per year. An analysis of post-defence erosion rates (1937 – 1999) concluded that erosion rates varied between 0.4 (north of the landfall site) – 0.8 metres per year. Since 1999 the shoreline has shown a higher rate of erosion along the landfall site in response to the failure of existing defences with erosion of up to 10 metres per year. Cliff top analysis for year 2017 shows a negligible change in cliff top retreat, however this cannot be taken as a sign for retreat rates slowing down, but more that retreat is variable.

Figure 2-4: Cliff erosion between Happisburgh and Cart Gap
Map Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 2-5: Cliff erosion along Happisburgh– 2001, 2010 and 2014.
Source: Eastern Daily Press, 2014.

2.2 Hydrodynamics

2.2.1 Water levels

Tide levels for the study area are presented in Table 2-1 sourced from the Environment Agency's Coastal Flood Boundary Conditions for UK Mainland and Islands (2011). The tidal range varies along the north Norfolk coastline and along the study area the spring tidal range is approximately 3.5mAOD. The area can be subject to significant surge activity which may raise water levels above those of the predicted tide. The average annual extreme water levels can exceed predicted levels by 1 metre. The extreme 1:100 year water level is around 2 metres higher than normal mean high water springs.

Table 2-1: Astronomical Tides, Present Day (base year 2008) sea levels and future 2065 extreme sea levels.

Site	LAT	MLWS	MLWN	MSL	MHWN	MHWS	HAT
Lowestoft	-1.40	-1.00	-0.50	0.20	0.60	0.90	1.40
Winterton-on-Sea	-1.72	-1.22	-0.62	-0.01	0.78	1.38	2.38
Bacton	***-2.55***	***-1.58***	***-0.75***	***0.11***	***1.05***	***1.88***	***2.71***
Cromer	-2.25	-1.85	-0.85	0.20	1.25	2.25	2.95

Site	**1 year**	**10 year**	**50 year**	**100 year**	**200 year**	**1,000 year**	**10,000 year**
Bacton (present day)	2.86	3.28	3.64	3.79	3.96	4.39	5.08
Bacton (2065)	3.28	3.70	4.06	4.21	4.38	4.81	5.50

The meaning of the acronyms used in the table is as follows:

- LAT: Lowest Astronomical Tide;
- MLWS: Mean Low Water Springs;
- MLWN: Mean Low Water Neaps;
- MSL: Mean Sea Level;
- MHWN: Mean High Water Neaps;
- MHWS: Mean High Water Springs; and
- HAT: Highest Astronomical Tide.

The allowance for sea-level rise due to climate change up to 2065 is estimated as 0.42 metres. This is based on the recent update of the Environment Agency's guidance for climate change allowances (Environment Agency, 2016). Table 2-2 provides a summary of the predicted sea-level rise to 2065 using the range of published allowances and scenarios in UK Climate Projections 2009 (UKCP09). This illustrates that 0.42 metres is at the high end of the predictions, but also shows that there is a possibility that sea-level rise could be nearly double that value, at 0.77 metres. This indicates that the sensitivity of design solutions to take into consideration climate change predictions should be taken into account.

Table 2-2: Sea level rise to 2065 using different published allowances and scenarios

Guidance/study	Scenario	Total sea level rise to 2065 (from 2008 in m)
UKCP09	Medium emissions, 50%ile	0.23
	Medium emissions, 95%ile	0.34
	High emissions, 50%ile	0.27
	High emissions, 95%ile	0.42
	H++ (unlikely but plausible)	0.77
Environment Agency (2016) – "Flood Risk Assessments – Climate Change Allowances	N/A	0.41

2.2.2 Tidal currents

As a result of the variation in tidal range along the shore, strong tidal streams are generated, with relatively strong flows occurring around and just after high water and low water. Maximum currents flowing southeast occur around high water, continuing over the early part of the ebb tide. The maximum northerly flood-tide flows occur about one hour after low water. The tidal current velocities are sufficient to mobilise and transport large quantities of seabed sediment. As strong tidal flows occur around the time of the highest water levels, under storm conditions, the large waves at the shoreline are likely to occur at the same time as strong tidal currents, this increases the potential for sediment transport.

2.2.3 Waves

Storm waves typically approach the shoreline from the north through to the east with the dominant sector being from the north-north east through to the north east. The net wave energy is slightly out of alignment with the orientation of the shoreline, resulting in net sediment transport to the southeast. It should however be noted that given the spread of wave energy, transport to the northwest also occurs. Table 2-3 and Figure 2-6 presents predicted nearshore waves from Royal HaskoningDHV's recent work on the Bacton Gas Terminal Coastal Protection project.

Table 2-3: Derived inshore wave conditions

Return period (1 in X year)	Point 7004		Point 7001		Point 7003	
	Significant wave height Hs (m)	Peak wave period Tp (s)	Significant wave height Hs (m)	Peak wave period Tp (s)	Significant wave height Hs (m)	Peak wave period Tp (s)
1	2.46	9.6	2.54	9.6	2.42	9.5
2	2.89	10.4	3.01	10.4	2.82	10.3
5	3.11	10.9	3.24	10.9	3.02	10.7
10	3.25	11.1	3.39	11.1	3.15	10.9
20	3.38	11.4	3.54	11.4	3.27	11.2
50	3.56	11.7	3.73	11.8	3.43	11.5
100	3.69	12.0	3.87	12.0	3.55	11.7
200	3.82	12.2	4.01	12.3	3.67	11.9
1,000	4.12	12.8	4.34	12.9	3.95	12.5
10,000	4.55	13.6	4.81	13.8	4.35	13.3

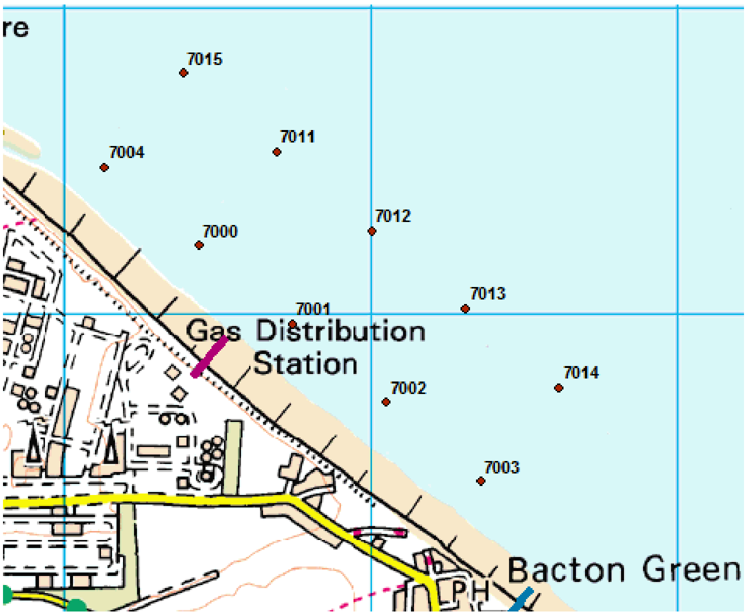


Figure 2-6: Location of Modelling Output Points

2.3 Shoreline Management Plan

The Kelling to Lowestoft Shoreline Management Plan No.6 (Kelling to Lowestoft Ness SMP2, 2012), published and adopted in 2012, sets out the high level coastal management policies for the north Norfolk coastline over the next 100 years. The SMP recommends management policy for three 'epochs': the short term (0-20 years), medium term (21-50 years) and long term (51-100 years) (Table 2-4). The SMP, coastline is divided into 13 policy units and these have each been assigned one of the following policies for each 'epoch':

- **Hold the Line:** to build or maintain artificial defences so that the position of the shoreline remains. Sometimes, the type or method of defence may change to achieve this result.
- **Managed Realignment:** allowing the shoreline to move naturally, but managing the process to direct it in certain areas. This is usually achieved in low-lying areas, but may occasionally apply to cliffs.
- **No Active Intervention:** there is no planned investment in defending against flooding or erosion, whether or not an artificial defence has existed previously.

It is important to note that these policies are in fact 'only' an intent of management. They are based on an integrated and long term assessment with involvement from all partners and stakeholders, and they aim to reflect realistic funding levels. However, the policies are not a guarantee: if it turns out that funding for interventions can't be secured, then in practice a lower level of management may materialise.

Table 2-4: Shoreline Management policy per frontage.

SMP6 Policy Unit	Short term (0-20 years)	Medium term (21-50 years)	Long term (51 – 100 years)
6.05 Cromer to Overstrand	Managed Realignment	No Active Intervention	No Active Intervention
6.06 Overstrand	Hold the Line	Managed Realignment	Managed Realignment
6.07 Overstrand to Mundesley	Managed Realignment	No Active Intervention	No Active Intervention

SMP6 Policy Unit	Short term (0-20 years)	Medium term (21-50 years)	Long term (51 – 100 years)
6.08 Mundesley	Hold the Line	Hold the Line	Managed Realignment
6.09 Mundesley to Bacton Gas Terminal	Managed Realignment	No Active Intervention	No Active Intervention
6.10 Bacton Gas Terminal	Hold the Line	Hold the Line	Hold the Line
6.11 Bacton Walcott and Ostend*	Hold the Line	Managed Realignment	Managed Realignment
6.12 Ostend to Eccles*	Managed Realignment	Managed Realignment	Managed Realignment
6.13 Eccles to Winterton	Hold the Line	Hold the Line	Hold the line (conditional)

* indicates the SMP policy unit the landfall sites fall within.

For the study area, the highlighted policy units 6.10, 6.11 and 6.12 are directly relevant; the others are shown for context. The SMP policy varies along the study area. At the Bacton Gas Terminal (SMP Policy Unit 6.10) the policy over the next 100 years is Hold the Line because the SMP recognises the national importance of this infrastructure and that there is considerable justification for maintaining this site. The accompanying text in the SMP provides two important points of nuance: the duration of the Hold the Line policy is limited by the economic life of the Terminal, which may be shorter than 100 years; and holding the line is only acceptable if any negative impacts on coastal processes are mitigated. The currently planned Sandscaping scheme (see Section 2.4) is being designed to meet these conditions.

SMP Policy Unit 6.11 contains both Bacton Green and Walcott Gap landfall sites. Here the policy is Hold the Line over the next 20 years meaning that there is the intention for defences to be maintained in the short term to reduce risk to property. However, over the medium term (nominally year 20 to year 50) the policy changes to Managed Realignment such that cliff erosion will be allowed to occur but with the intention to manage this process. The main reason for this change is that continuation of Hold the Line is not seen as economically viable (comparing the costs of intervention with the benefits of preventing erosion) or sustainable (as it would further starve the wider coast of sediment, and over the long term it won’t be possible to stop the erosion). It is important to note that the currently planned Sandscaping scheme is expected to delay the onset of erosion, see Section 2.4).

Along the Ostend to Eccles coast (Policy Unit 6.12), containing the Happisburgh South landfall site, the policy is Managed Realignment over the next 100 years meaning that beach and cliff erosion will be allowed to occur but in a controlled manner. Critically, as seen in Figures 2.4 and 2.5, as the old timber revetment started to fail, a light rock toe has been put in place, providing a degree of protection to the village. This is typical of actions taken in managing and implementing the policy of Managed Realignment.

It should be noted that policy units are defined quite loosely recognising the interaction between sections of the coast and the need to manage this section of the coast as a complete management area. Policy units are defined in relation to the assessment of risk as set out in the text contained within the SMP2.

2.4 Existing and planned coastal defences

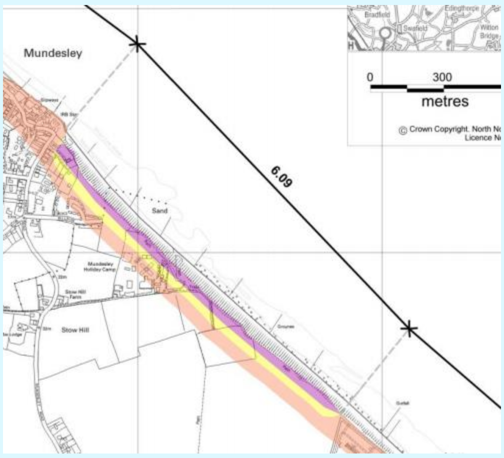
The existing coastal defences of the study area include a mixture of timber groynes, timber revetments and concrete sea walls along with stretches which remain undefended. Table 2-5 presents a summary of the defence history, existing coastal defences, their estimated residual life (based upon the Kelling to Lowestoft Ness SMP, 2012 and the Cromer to Winterton Coastal Study, 2012) and potential / planned coastal defences known over the next 50 years.

The most relevant planned coastal defence scheme is the intended Sandscaping scheme at Bacton Gas Terminal. This consists of a mega beach nourishment that aims to provide a high level of cliff erosion protection for the Bacton Gas Terminal, while also gradually supplying sediment to the currently eroding beaches in front of the villages of Bacton, Walcott and Ostend; this is expected to slow down beach erosion, and may even lead to temporary accretion. This is relevant for the Bacton Green and Walcott landfall sites. It is possible that the scheme will also include direct placement of some sediment on the stretch of beach just to the south-east of the terminal.

The scheme is currently going through detailed design and Environmental Impact Assessment, and is planned to be implemented in the Summer of 2018. The nourishment is being designed to provide the required erosion protection for 10-20 years; the beneficial effect on the beaches downdrift is likely to last some time longer. After this initial scheme there may be a renourishment, to be determined by the Bacton Gas Terminal Companies, depending on the economic life of the Gas Terminal. It is uncertain whether a renourishment would again be designed to supply sand to the downdrift beaches; this depends on availability of funding for the additional sediment required.

There is a chance that the scheme will not be implemented, but this is very small. It is very unlikely that the Gas Terminal will remain unprotected. Any alternative to a Sandscaping scheme would probably be designed for the same level of cliff erosion protection. Its positive impact downdrift would be smaller, but any negative impacts compared to the current situation would have to be mitigated.

Table 2-5: Existing coastal defences from Bacton through to Eccles-on-Sea.

Mundesley to Bacton Gas Terminal – SMP Policy Unit 6.09 **Defence History** 1964: Timber breastwork constructed. 1966: groyne field constructed along section. **Present Day Defences** The entire length is fronted by a timber revetment, which is semi-buried, which serves to reduce rather than halt erosion. There are also timber groynes throughout this length. **Residual Life:** Timber revetment: 0-10yrs Groynes: 0-8yrs **Natural Features** Low, unconsolidated cliffs, between 5-10m high, which generally fail through land sliding but which are presently stable. **Planned Coastal Defence Work** Norfolk Council is developing a business case to hold the current defences in line with the Hold the Line SMP management policy along this frontage in the short and medium term, which is likely to be implemented in the coming years. No planned work between Mundesley and Bacton Gas Terminal as this frontage heads towards the medium term SMP management policy of No Active Intervention.	

Bacton Gas Terminal – SMP Policy Unit 6.10

Defence History
1960s: Timber breastwork and groynes constructed at northern end.

Present Day Defences
The length north of Tulsa Way is fronted by a timber revetment, which is semi buried, and serves to reduce erosion. Timber groynes are present throughout this length spaced at approximately 180m.

Defences and local management, such as landslide remedial measures at Bacton Gas Terminal, have held the shoreline position however mean low water has retreated at an approximate 1 – 2 metre a year rate resulting in beach narrowing in locations where hard defences are in place.

Residual Life:
Timber revetment: 0-10yrs
Groynes: 0-8yrs

Natural Features
Low, unconsolidated cliffs, between 5-10m high

Planned Coastal Defence Work It is likely that in 2018 a mega-nourishment scheme (referred to as Sandscaping) will be implemented, which will minimise the chance of erosion up to the end of the Terminal's economic life. Temporary erosion protection works are currently being constructed to bridge the period until implementation of the Sandscaping solution.

Bacton, Walcott and Ostend – SMP Policy Unit 6.11

Defence History
1954: Concrete wall and apron with steel piled toe constructed along much of section. Timber groynes also constructed along section.
1991: Timber revetment at southern end of Ostend wall.

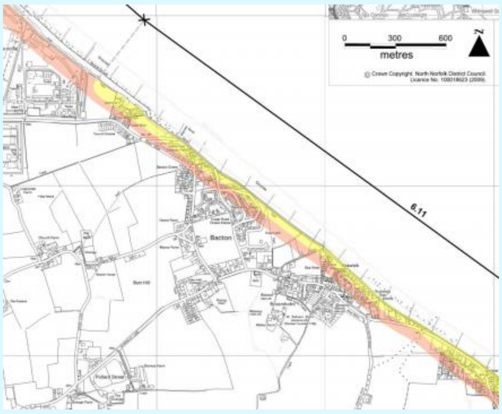
Present Day Defences
Immediately south of Bacton Gas Terminal the coastline is protected by a length of steel sheet piles together with rock armour connected to the Bacton Gas Terminal frontage. There is also a length of steel sheet piles and a length of timber revetment together with rubble.

South-east of the Castaways Caravan Park frontage, the timber breastwork continues along the whole of the frontage between Bacton Green and Walcott before returning to the cliff line just after the start of a concrete seawall. The concrete seawall, apron and steel piled toe extends southward a considerable distance towards Walcott. Along Walcott the timber revetment continues. Timber groynes are present throughout this section.

Residual Life:
Timber revetment: 0-5yrs
Groynes: 0-5yrs
Seawall: 0-10yrs
The Sandscaping scheme is expected to increase these residual lives significantly.

Natural Features
Unconsolidated till cliffs which drop down to beach level at Walcott, creating a short gap in the line of cliffs that run from Cromer to Happisburgh.

There is very little permanent backshore along this shoreline, and in places no backshore is present. The beach rests on a clay platform and occasionally this is exposed and subject to marine erosion.



Planned Coastal Defence Work The Sandscaping mega-nourishment, likely to be implemented at the Bacton Terminal in 2018, may involve direct placement of sediment on the Bacton Green frontage, and would lead to natural sediment supply over time to the Bacton Green and Walcott frontages, reducing the exposure and increasing the residual life of the defences.	
Ostend to Eccles-on-Sea – SMP Policy Unit 6.12 **Defence History** 1958 – 1959: Small section of timber and steel revetment built in front of Happisburgh. 1961: Timber revetment and groynes constructed along frontage. 1970: Small section of concrete wall north of timber revetment. 2003: Line of rocks placed at cliff toe along Happisburgh village frontage. **Present Day Defences** The whole length of shoreline is protected by a timber revetment, which reduces erosion rather than halts it, along with timber groynes. Some sections of the revetment are in the process of failing and the timber revetment and groynes fronting Happisburgh were identified as largely failed in 2013 and redundant. A line of rock armour presently provides protection, although this serves only to reduce rather than halt erosion. There are no defences to the cliffs south of the village. **Residual Life:** Timber revetment: 0yrs Groynes: 0yrs Rock Barrier at Happisburgh: 0-2yrs **Natural Features** Unconsolidated cliffs which increase in height towards Happisburgh. Beaches are predominantly sand with shingle occasionally exposed in low runnel features. The sand forms a thin layer over the clay platform and this is occasionally exposed, particularly during storm events. **Planned Coastal Defence Work** There is potential for the current rock fronting the cliff line to be rolled back in response to cliff retreat, however there may not be funding in place for this.	

2.5 Recent / ongoing changes from monitoring

This section summarises analysis of beach profile change between 1991 and 2016. Analysis has been provided on the variation in beach volumes from 1991 to 2016, with volumes above and below Mean Sea Level (MSL) being distinguished. The change in upper beach volume has then been translated to the average vertical erosion of the beach, by dividing volume change over beach width.

2.5.1 Bacton

The profiles of interest along Bacton are N071, N072 and N073 as presented in Figure 2-7.

Figure 2-7: Location of known beach profiles surveyed along Bacton to Walcott

Figure 2-8 presents the analysis of profile N071 and shows that beach volumes along the Bacton Gas Terminal frontage have generally increased from 1991 to 2003 when they reached maximum volume, despite a number of inter-annual fluctuations. Beach volumes above MSL have dropped significantly since 2003 until present day, at an annual rate of 11m^3/m/year. This results in typical vertical erosion of the beach above MSL of approximately 0.15m/year since 2003.

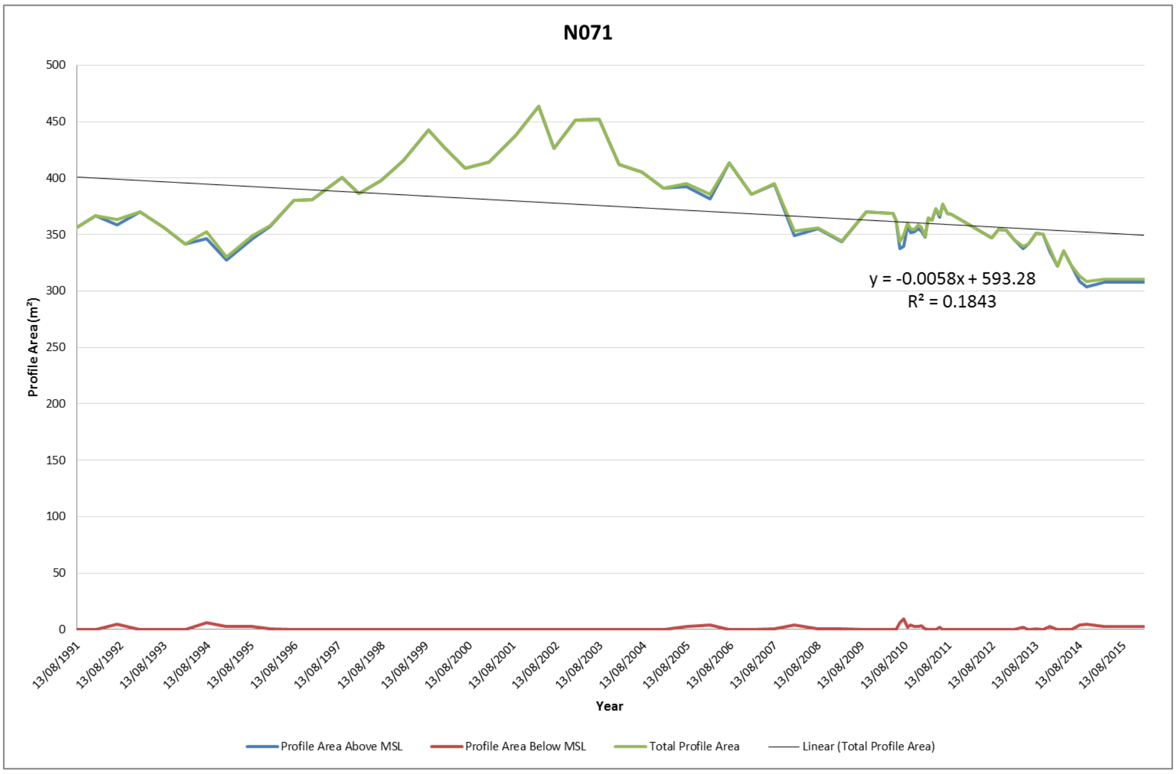


Figure 2-8: Evolution of beach volumes at Bacton Gas Terminal.

Figure 2-9 presents the analysis of profile N072 and shows that beach volumes along the Bacton Green frontage have generally increased from 1991 to 2002 similar to Profile N071; however volumes reached maximum in 2002. Since 2002 beach volumes above MSL have dropped at an annual rate of 4m^3/m/year and despite some fluctuations they have not recovered to the present day. This results in typical vertical erosion of the beach above MSL of approximately 0.25m/year since 2002.

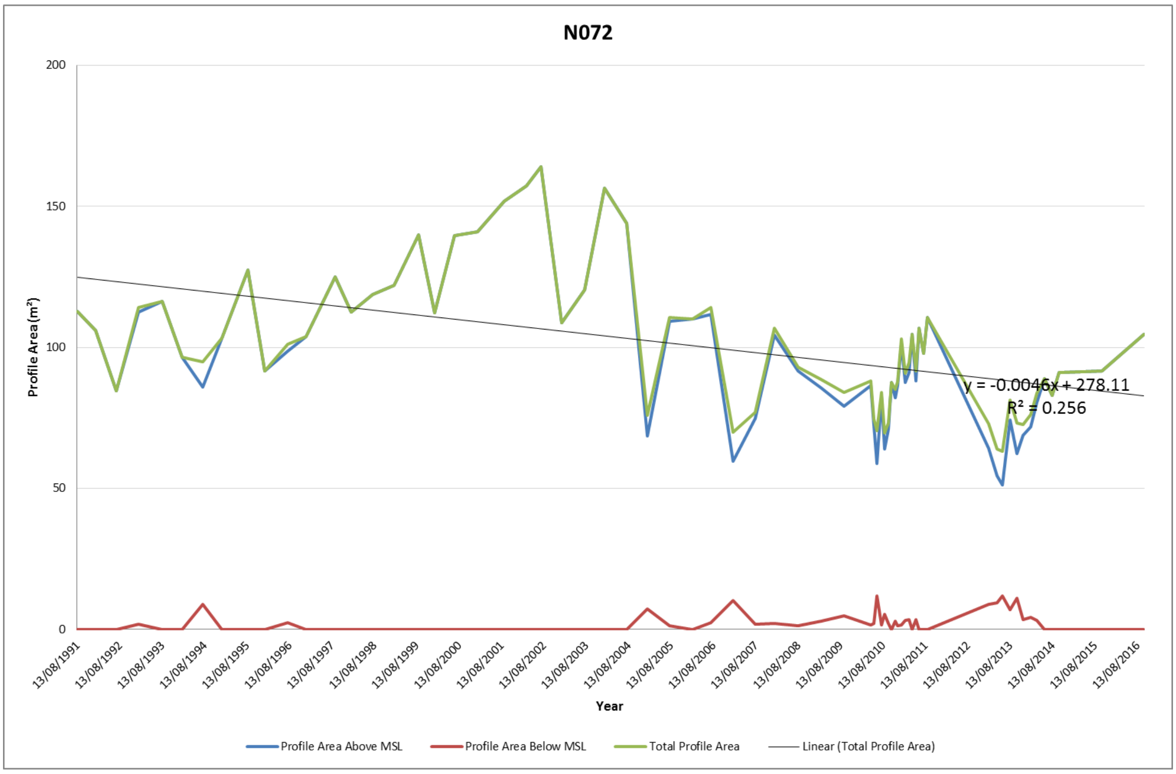


Figure 2-9: Evolution of beach volumes at Bacton Green.

Figure 2-10 presents the analysis of profile N073 which shows that the beach levels along the eastern Bacton frontage have generally accreted slightly between 1991 and 2004, with a number of inter-annual fluctuations. Since 2002 beach volumes have been falling steadily and quite rapidly at an annual rate of 7m^3/m/year. This results in typical vertical erosion of the beach above MSL of approximately 0.4m/year since 2002.

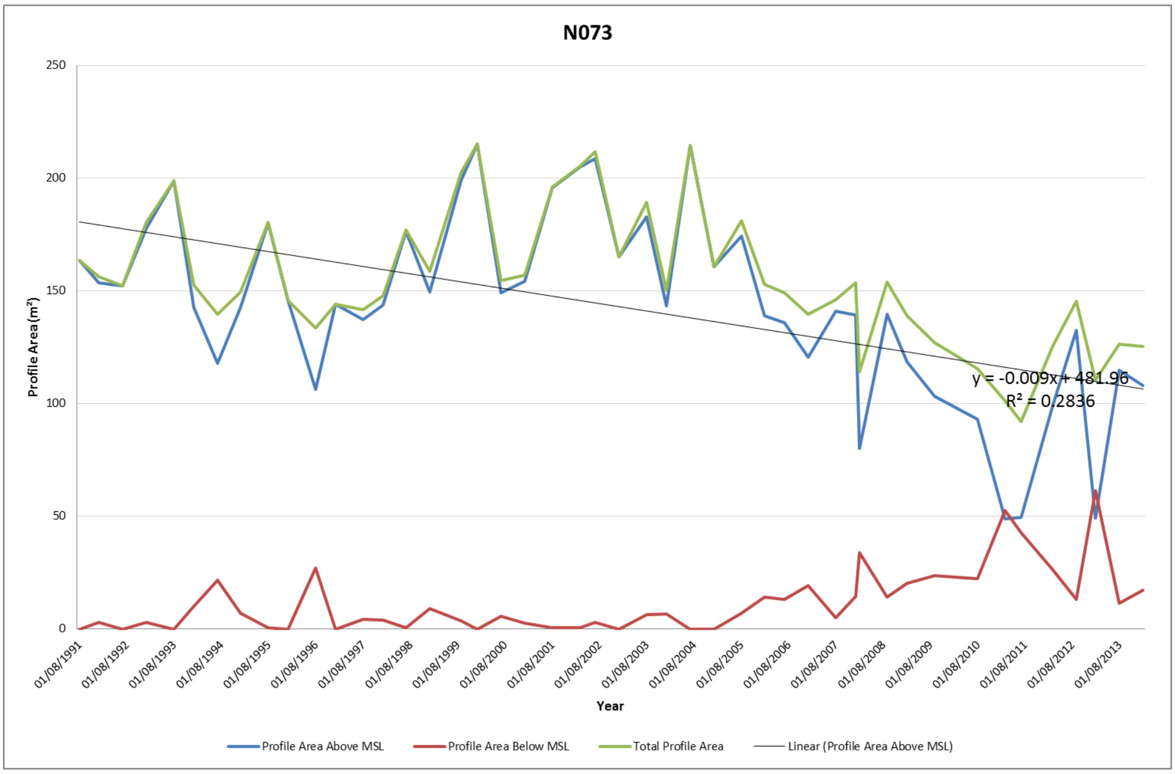


Figure 2-10: Evolution of beach volumes at Bacton.

In summary, the average beach erosion closest to the candidate landfall site (N072) has been approximately 0.25m/yr, while the erosion on the neighbouring frontages has been in the range of 0.1 to 0.4 m/yr.

2.5.2 Walcott

The profiles of interest along Walcott are N074 and N075 as presented in Figure 2-11.

Figure 2-11: Location of known beach profiles surveyed along Bacton to Walcott

Profile N074 illustrated in Figure 2-12 (directly in front of Walcott) has been relatively stable over the years with some fluctuations and a minor trend of beach levels dropping at a rate of $0.6m^3$/m/year since 1991. This results in typical vertical erosion of the beach above MSL of approximately 0.05m/year since 1991. The low profile area reflects the narrow beach along this frontage which is controlled by the presence of the sea wall. The most noticeable fluctuation is in 2013 where beach levels above MSL dropped significantly. This is thought to be due to the winter storms in 2013/2014 temporarily eroding the beach. Beach levels following this appear to be recovering.

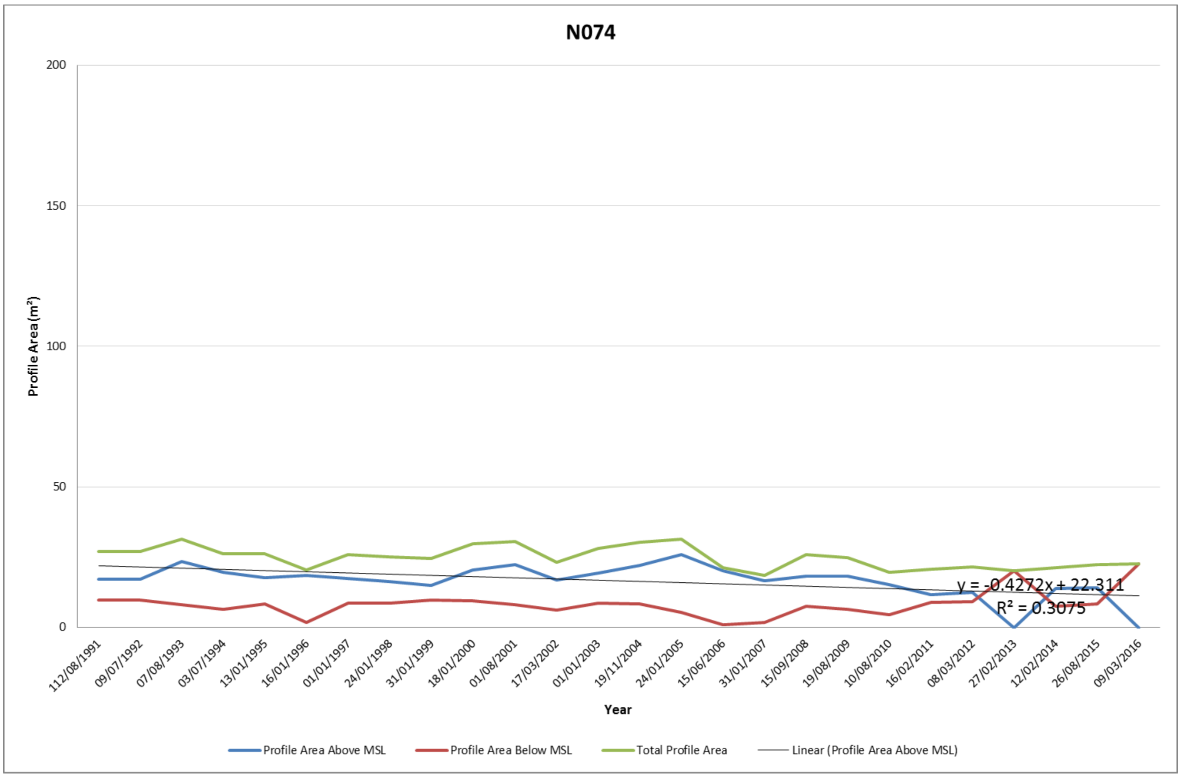


Figure 2-12: Evolution of beach volumes at Walcott.

Figure 2-13 presents the analysis of profile N075 and shows that the beach south of Walcott experiences annual fluctuations but with a marginal trend of beach levels reducing 2m³/m/year since 1991. This results in typical vertical erosion of the beach above MSL of approximately 0.05m/year since 1991.

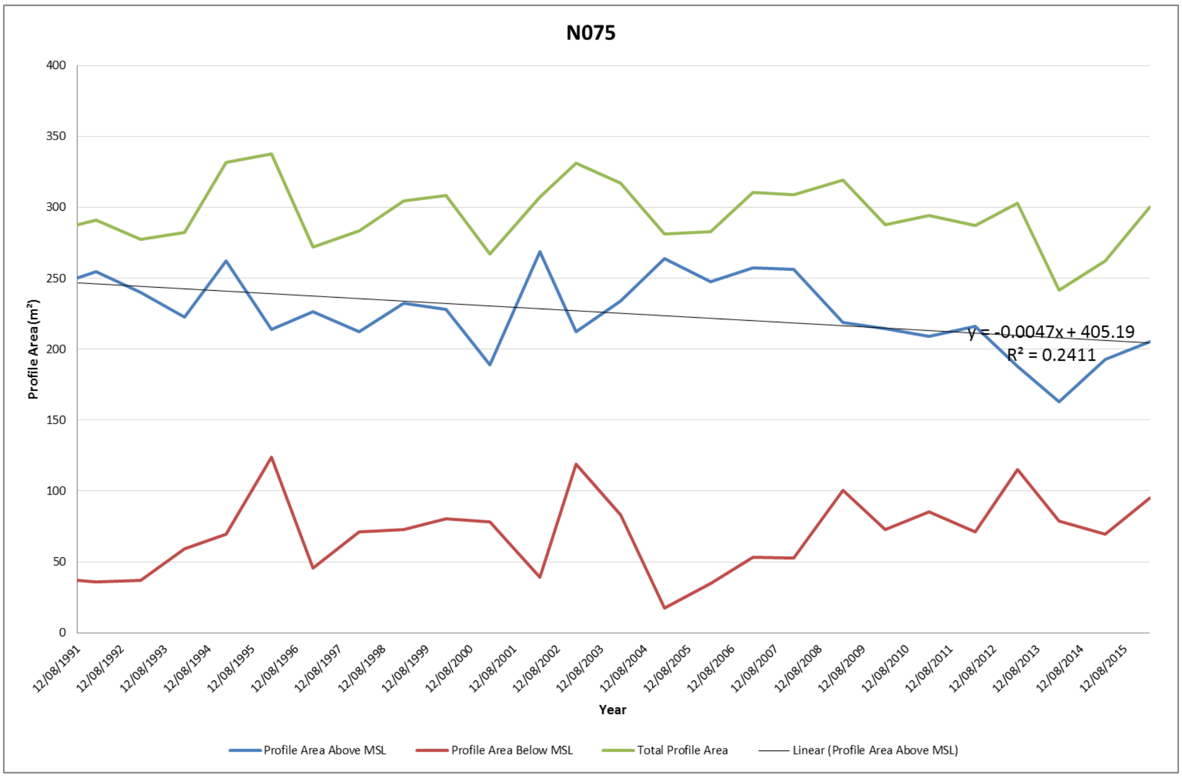


Figure 2-13: Evolution of beach volumes at Walcott.

In summary, the average beach erosion of the Walcott frontage has been approximately 0.05m/yr at both monitoring locations.

2.5.3 Happisburgh to Cart Gap

The profiles of interest along Happisburgh to Cart Gap are N077 (Happisburgh) and N078 (Cart Gap) as presented in Figure 2-14.

Figure 2-14: Location of known beach profiles surveyed along Happisburgh to Cart Gap.

Figure 2-16 presents the analysis of profile N078 and shows that beach levels along Cart Gap have stayed relatively stable since 1992 with some periodic fluctuations. Overall, beach volume above MSL and average upper beach level are practically unchanged since 1992. This is thought to be attributed to the coastal defences along this section which have prevented the MSL from naturally migrating as beach levels drop and sea levels rise. In recent years beach volumes below MSL have tended to increase and this is thought to be due to the accelerated erosion along Happisburgh to the north supplying the beaches here and the reduction in volume above Mean Sea Level.

Figure 2-16 presents the analysis of profile N077 at Happisburgh and shows that beach levels have generally decreased from 1991 – 2011 by approximately 9m³/m/year above MSL. This results in typical vertical erosion of the beach above MSL of approximately 0.6m/year since 1991. Since 2011 levels have fluctuated but been broadly stable with a periodic increase in 2012. From 2012 onwards there is an obvious trend of the upper beach volume dropping to a point where there is no beach above MSL. This evidence supports the ongoing but episodic (rather than continuous) erosion experienced at Happisburgh in recent years.

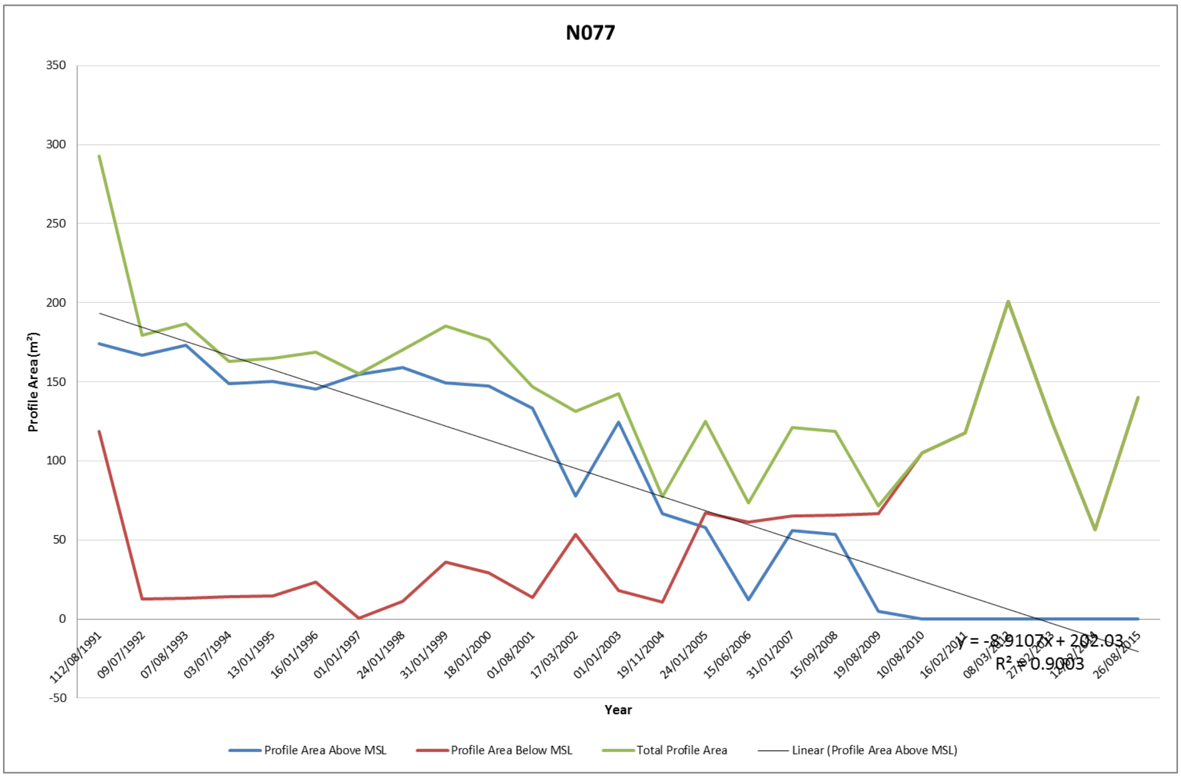


Figure 2-15: Evolution of beach volumes at Happisburgh.

Figure 2-16 presents the analysis of profile N078 and shows that beach levels along Cart Gap have stayed relatively stable since 1992 with some periodic fluctuations. Overall, beach volume above MSL and average upper beach level are practically unchanged since 1992. This is thought to be attributed to the coastal defences along this section which have prevented the MSL from naturally migrating as beach levels drop and sea levels rise. In recent years beach volumes below MSL have tended to increase and this is thought to be due to the accelerated erosion along Happisburgh to the north supplying the beaches here and the reduction in volume above Mean Sea Level.

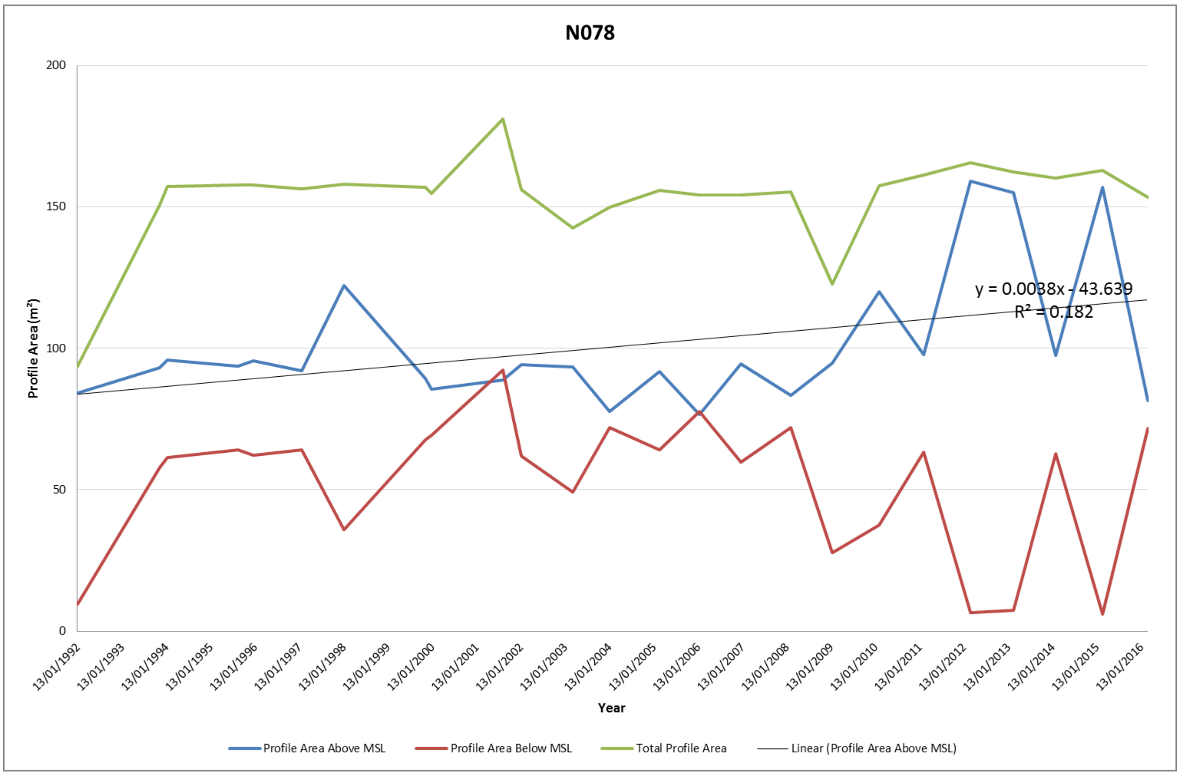


Figure 2-16: Evolution of beach volumes at Cart Gap.

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3 Expected changes to the coast

3.1 Introduction

This section assesses potential future changes of the position and shape of the coastline over the expected life of the landfalls (20 to 50 years). The assessment uses scenarios for the two key determining factors; future shoreline management and the magnitude of future climate change. The Shoreline Management Plan and the Cromer to Winterton Ness Coastal Management Study (2013) are important sources for this assessment, but their findings have had to be amended with more recent insights where relevant, in particular related to the impacts of the intended Sandscaping scheme.

This 'most likely management scenario' and the best estimate of climate change form the basis for the assessment. The impact of other management scenarios (No Active Intervention or a continuation of present management) is included as a sensitivity test.

Relative sea level is predicted to rise between 0.10 to 0.18 metres over the next 20 years and 0.27 to 0.77 metres over the next 50 years (ref: Table 2-2). This rise, coupled with anticipated increase in storminess around the UK, may lead to increased erosion along the undefended coastline. This has been taken into account in the assessment.

3.2 Mundesley to the Bacton Gas Terminal

3.2.1 Most likely scenario

This unit is north-westerly (updrift) from the landfall locations, but is included in this section for context.

The long-term policy along this frontage is retreat as there are few socio-economic benefits for defending the cliff. The short-term SMP policy is Managed Realignment followed by No Active Intervention over the medium to long term. Over time this policy should promote a naturally functioning coastline which will provide both sediment to the beaches and allow it to transport naturally south. The intended Sandscaping scheme is likely to slow down beach erosion and delay failure of structures in the short and possibly medium term.

Short Term: 0-20 years
In the short term the policy allows natural processes to take place. The existing timber revetments and groynes will not be maintained and once failed will be removed; hence the policy for the short term is Managed Realignment to allow for the removal of failed defences. The positive influence of the intended Sandscaping scheme will delay this failure (more so at this frontage's south-east end), possibly even into the medium term. Some cliff erosion may still occur, but this is likely to be less than 10 metres.

Medium Term: 20-50 years
The SMP policy in the medium term is No Active Intervention, but due to the likely positive impact of the intended Sandscaping scheme the defences may still be in place. They could start to fail in this period, followed by cliff erosion. If so, erosion of the cliff line is expected to be rapid initially as the cliff line is allowed to naturally erode without any management.

The figures below are based on the SMP policy, but do not take account of the likely positive impact of the Sandscaping scheme, so they can be seen as conservative. With a sandscaping scheme in place, the erosion extents in the figures are likely to be reached later. Figure 3-1 presents the SMP's indicative erosion zones up to 2025, 2055 and 2105 for Mundesley to Bacton Gas Terminal based on the SMP management scenario. Figure 3-2 presents the indicative erosion zones for year 0 – 20, 21 – 50 and 51 – 100 based on the existing SMP management scenario from the Cromer to Winterton Ness Coastal Management Study (2013).

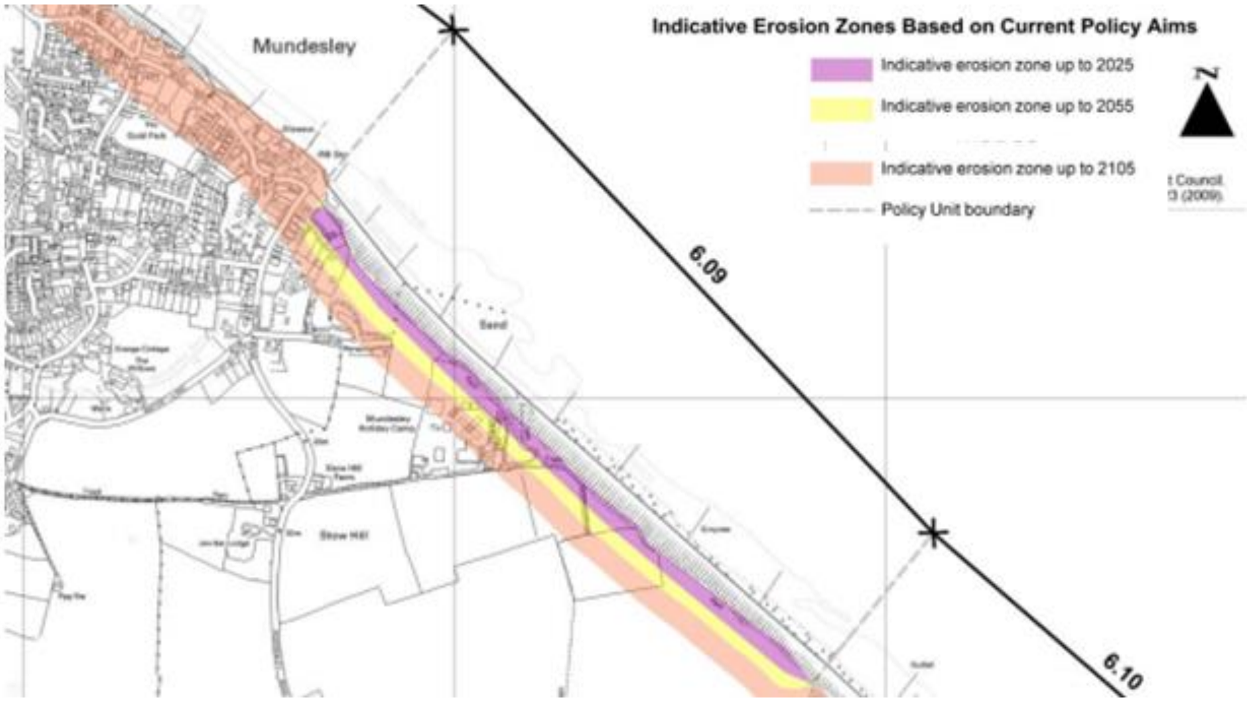

Figure 3-1: Mundesley to Bacton Gas Terminal Indicative Erosion Zones from the Kelling to Lowestoft Ness SMP (2012) - SMP Policy 6 Management

Figure 3-2: Mundesley to Bacton Gas Terminal Indicative Erosion Zones from the Cromer to Winterton Ness Coastal Management Study - SMP Policy 6 Management

3.2.2 Other scenarios

In a No Active Intervention scenario, defences would fail in the short term. Cliff erosion would be 15-45m up to year 20, and 50-90 metres until year 50.

If present management with timber revetments and groynes would be continued, there would be continued cliff erosion, initially at the current slow rates and then speeding up due to sea level rise. Throughout this process the beach will initially retain its current form, although in a retreated position. In the medium term it will start to narrow.

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3.3 Bacton Gas Terminal

3.3.1 Most likely scenario

The Bacton Gas Terminal is a nationally important feature and there is justification for maintaining this site. The Policy throughout the SMP is Hold the Line

Short Term: 0-20 years
The policy is to protect Bacton Gas Terminal through Hold the Line. The SMP notes that this may be achieved through maintaining the existing timber revetments, although it is possible that new structures will be required to strengthen the defence as beach levels reduce over time and existing defences fail.

The Bacton to Walcott Sandscaping scheme which is expected to go ahead in 2018 will place a large volume of sediment on the beach and thereby strongly reduce the chance of cliff erosion. This is likely to afford protection for at least 20 years, but possibly up to 50 years and beyond.

Medium Term: 20-50 years
The policy remains as Hold the Line based on the assumption that the terminal will still be operational for up to 50 years. If the Sandscaping scheme goes ahead then after 20 years the need for further recharge would be considered. If no further action were taken, after a number of years the beach will have eroded back to currently existing levels, and cliff erosion will resume, likely at an accelerated rate.

3.3.2 Other scenarios

A scenario without a new cliff erosion protection scheme, lasting at least 20 years, is very unlikely. Alternatives to Sandscaping could be a more traditional nourishment (smaller scale, higher frequency of renourishment), which would lead to very similar coastal change within this frontage. Another alternative could be a hard structure, which would have to be combined with an element of beach nourishment to mitigate negative impacts downdrift. At the Terminal frontage this is likely to lead to lowering and steepening of the beach, and therefore more rapid return to cliff erosion after the end of the structure's life.

3.4 Bacton, Walcott and Ostend

3.4.1 Most likely scenario

The long-term plan for Bacton to Walcott is to allow the current defences to reach the end of their effective life and then allow the shoreline to retreat. Loss of the groynes would allow some sediment to be transported more effectively south through the system towards Happisburgh. The properties along this coastline do not generate sufficient economic justification to continue to hold the current position of the cliff and as such will be lost in time. The intended Sandscaping scheme is likely to delay this process significantly, as part of its objectives.

Short Term: 0 – 20 years
In the short term a Hold the Line management policy is in place; however the residual life of some of the seawalls is less than 20 years, and it is not guaranteed that funding will be available for repairs when they fail, in which case erosion could start within the first 20 years. However, the intended Sandscaping scheme is being designed to reduce beach erosion or even generate beach accretion, with the aim of delaying seawall failure beyond year 20.

In the unlikely but possible scenario that a different Terminal protection scheme is implemented, cliff erosion is likely to start before year 20.

Medium Term: 20 – 50 years

The medium term SMP policy was based on the assumption that the defences will have reached the end of their life before year 20, after which cliff line retreat would be allowed to occur, although localised intervention measures may be put in place to temporarily slow erosion (where technically and economically feasible). However, the intended Sandscaping scheme is likely to delay this process significantly, even if it only remains in place for 20 years (a conservative assumption).

Generally speaking, the positive impact of the Sandscaping scheme is expected to last some time beyond the end of the scheme (as there will still be a significant sediment volume in front of the Terminal available to feed the downdrift frontage). The positive impact would gradually reduce and then reverse to erosion, initially more rapid than currently as the coast catches up. When beach levels reach critical depths, or their structural condition deteriorates further, the seawalls will fail. For now it is assumed that the seawalls would not be repaired in that scenario, so cliff erosion would start from that point.

This positive impact will start earlier and be larger just downdrift from the Terminal. The details of this, and how it varies along the frontage, are as yet uncertain, as it will depend on the detailed design which is currently being developed. Judgement-based assessments for the landfall sites at Bacton Green and Walcott are provided in Section 4.

In the unlikely but possible scenario that a different Terminal protection scheme is implemented, cliff erosion will have started before year 20 and could reach up to 100 metres by 2065 (estimated based on SMP erosion predictions for 2055 and 2105).

The figures below are based on the SMP policy, but do not take account of the likely positive impact of the Sandscaping scheme, so they can be seen as conservative. With a Sandscaping scheme in place, the erosion extents in the figures are likely to be reached significantly later, and this influence will reduce from north-west to south-east. Figure 3-3 presents the SMP's indicative erosion zones up to 2025, 2055 and 2105 for Bacton to Walcott based on the SMP management scenario. Figure 3-4 presents the indicative erosion zones for year 0 – 20, 21 – 50 and 51 – 100 based on the existing SMP management scenario from the Cromer to Winterton Ness Coastal Management Study (2013).

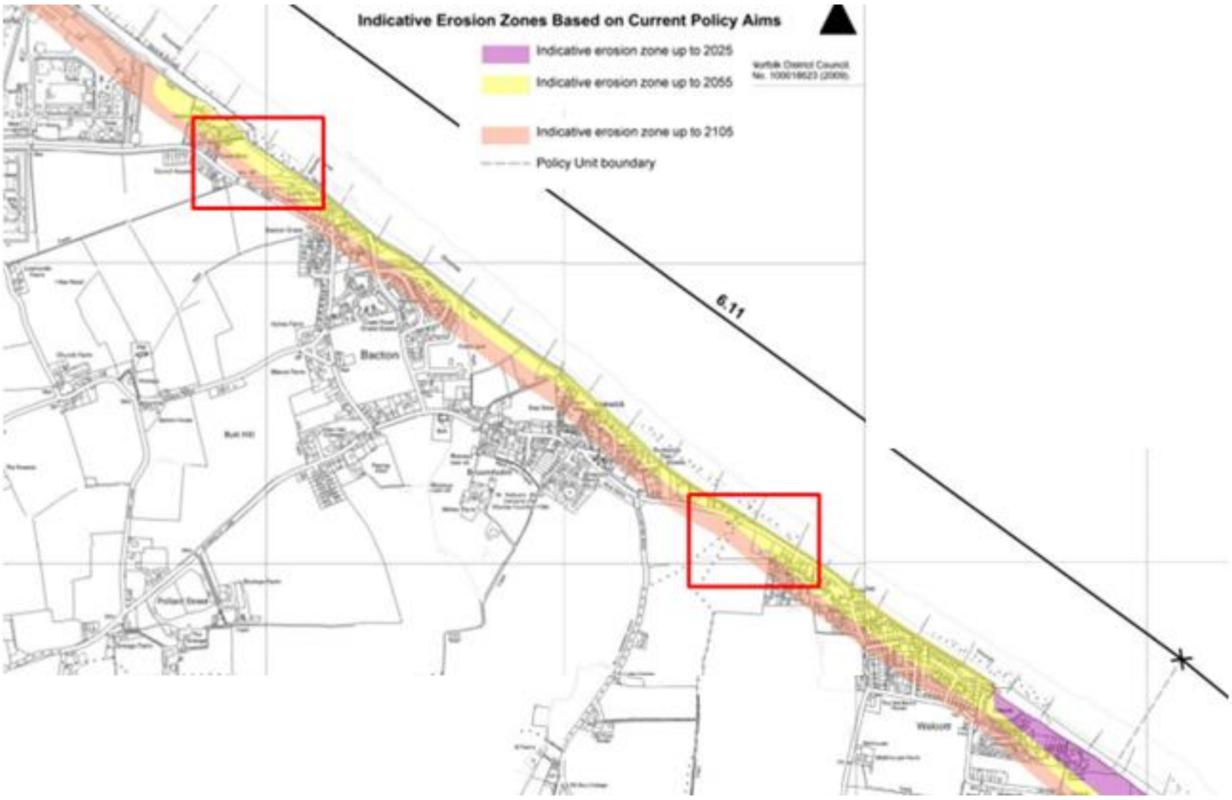

Figure 3-3: Bacton and Walcott Indicative Erosion Zones from the Kelling to Lowestoft Ness SMP (2012) - SMP Policy 6 Management

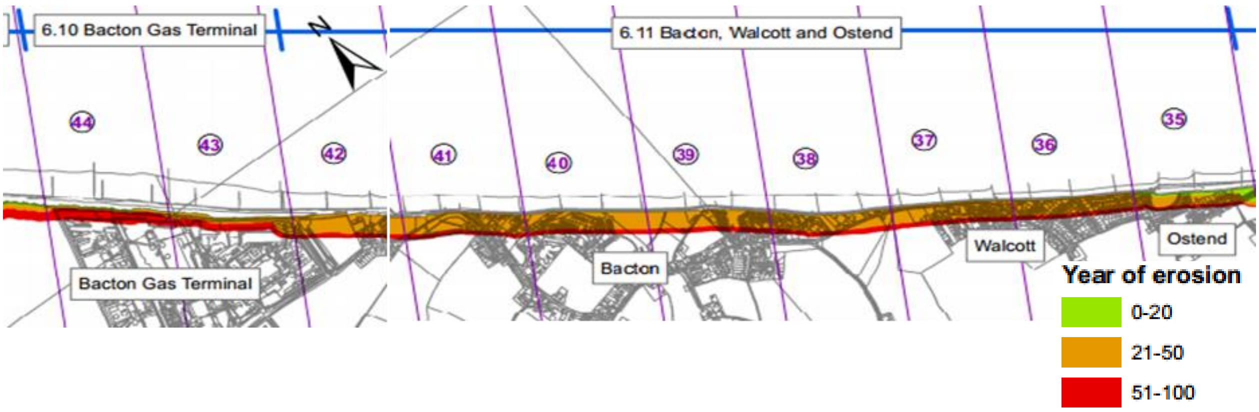

Figure 3-4: Bacton and Walcott Indicative Erosion Zones from the Cromer to Winterton Ness Coastal Management Study - SMP Policy 6 Management

3.4.2 Other scenarios

In a No Active Intervention scenario, defences would fail in the short term. Cliff erosion at Bacton village would be 15-45m up to year 20, and 45-95 metres until year 50. At Walcott, the seawall has a longer predicted residual life, so cliff erosion would be lower initially, but then catch up to similar values as at Bacton.

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If present management with seawalls and groynes would be continued, cliff erosion would be prevented but the beaches would gradually be depleted, which would lead to a requirement for ever more extensive structures.

3.5 Happisburgh

3.5.1 Most likely scenario

In the short and medium term Happisburgh will not be protected from erosion as it is both technically difficult to sustain and would impact significantly on alongshore sediment transport. The long-term plan therefore is to allow natural functioning of the coast through Managed Realignment. However, in the short term, the Local Authority will make every effort to minimise the rate of coastal erosion at this location. This approach is being applied using appropriate temporary measures such as maintenance of the existing rock with a view to allowing time for people to adapt to the changes.

Short Term: 0 – 20 years
Allowing the coastline to naturally retreat with a No Active Intervention policy could result in significant immediate impacts on the community such as loss of properties. Therefore, the management policy in the short term is Managed Realignment which allows for the existing line of defence to be held but recognising that this will not be extended or substantially rebuilt. The intent here is not to protect the coastline but to manage the retreat to allow time for people to adapt and prevent sudden significant impacts. According to North Norfolk District Council it is unlikely that funding will be available for any major schemes to slow down erosion. The Shoreline Management Plan estimates an approximate retreat of 60 – 70 metres between 2005 and 2025, with an additional 20 metres by 2035. This suggests that the expected erosion from 2016 to 2035 according to the SMP is approximately 50 metres.

There are however more recent indications that erosion south of the village has reached a point where it is likely to slow down significantly; the main area of erosion (and impact on properties) is now likely to be the main village and the area to its north-west, at the caravan park. The headland acts as a control and a shelter for the undefended beach. As the headland continues to erode, the undefended area will follow, but more slowly as the ‘depth’ of the local bay shape reduces. This seems to be confirmed by the monitoring data analysis (see Section 2.5.3) which suggests that the rapid continuous erosion from the past is being replaced by episodic erosion. This is also in line with the analysis of the Cromer to Winterton Ness Coastal Management Study (2013). According to this interpretation, the expected erosion from 2016 to 2035 is approximately 25 metres. On balance, this study suggests that this lower estimate is more likely than the 50 metres based on the SMP.

Medium Term: 20 – 50 years
The medium-term management policy is also Managed Realignment so that the cliff reaches a more natural position. There will be loss of properties during this time which will need to be managed. As time goes on there will be an increase in sediment from direct cliff erosion and up drift as the management policy along Bacton and Walcott changes to Managed Realignment; this policy transition is likely to be delayed as a result of the intended Sandscaping scheme, but it is possible that this scheme will also lead to some increase in sediment supply to Happisburgh. The Shoreline Management Plan estimates an approximate further retreat of 40 – 60 metres between year 20 and year 50; the total expected erosion from 2016 to 2065 is therefore approximately 110 metres.

The Cromer to Winterton Ness Coastal Management Study predicts that by this time the Happisburgh headland will have been largely eroded; however further erosion is predicted to be limited as a result of expected increase of sediment supply from the north-west. The Coastal Study suggests there would be hardly any further erosion.

Overall, it would be prudent to take into account some further erosion due to uncertainty in the coastal processes and management approaches: not as much as predicted in the SMP, but more than in the Coastal Study. The total expected erosion from 2016 to 2065 is therefore estimated conservatively at approximately 50 metres.

Figure 3-5 presents the indicative erosion zones up to 2025, 2055 and 2105 for Ostend to Eccles-on-Sea (which includes Happisburgh) based on the existing SMP management scenario from the Kelling to Lowestoft Ness SMP (2012). Figure 3-6 shows the existing SMP management scenario from the Cromer to Winterton Ness Coastal Management Study (2013).

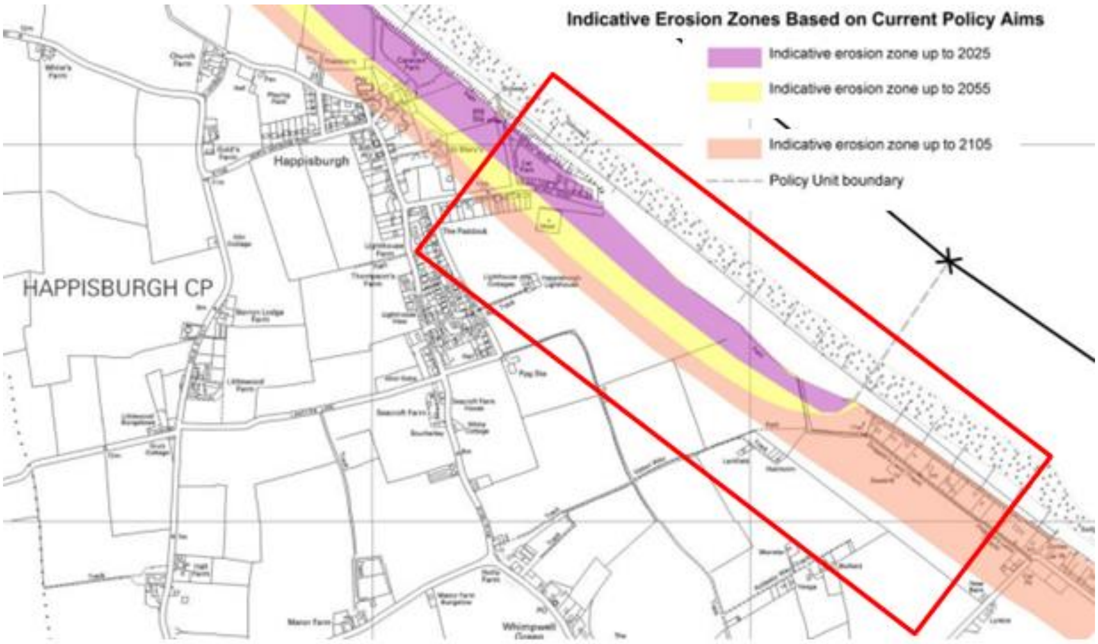

Figure 3-5: Happisburgh Indicative Erosion Zones from the Kelling to Lowestoft Ness SMP (2012) - SMP Policy 6 Management

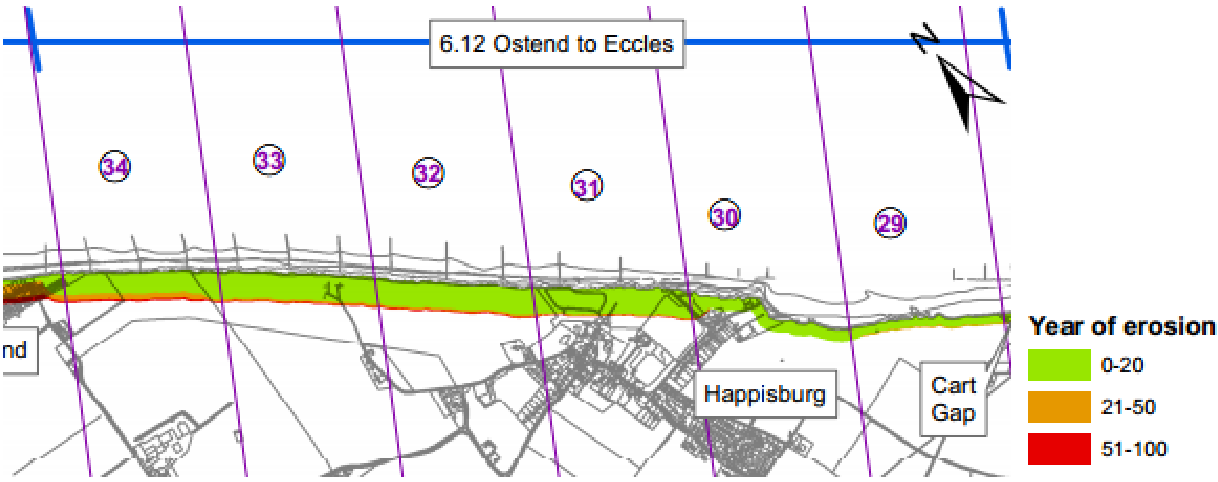

Figure 3-6: Happisburgh Indicative Erosion Zones from the Cromer to Winterton Ness Coastal Management Study - SMP Policy 6 Management

3.5.2 Other scenarios

The No Active Intervention scenario is very similar to the most likely scenario, with more rapid cliff erosion in the short term, but a relative slow down as the coastline reaches an equilibrium.

If the existing defences were to be maintained, cliff erosion would continue at similar rates as currently, and the structures would have to be moved landward regularly in response to the erosion.

3.6 Cart Gap

3.6.1 Most likely scenario

The coastline to the South of Happisburgh differs from the majority of the study areas and surrounding coastline as there is a risk of flooding, as well as erosion. The majority of the coastline is protected by a series of groynes along with a concrete sea wall and apron which holds the coastline in position. The coastline is very exposed which means in the long term it could be technically and economically difficult to maintain the current defence line. If the coastline to the north continues to erode then the coastline to the south of Happisburgh will become more prominent. This in turn will reduce any sediment from the north, reaching areas to the south.

Short Term: 0 – 20 years
In the short term a Hold the Line management policy is in place; primarily due to the residential properties at risk and the uncertainty of how the coastline could evolve. The sea wall is likely to be maintained, with groynes being replaced and beaches nourished as necessary. With this approach beaches will be maintained as well as a supply of sediment to down drift areas.

Medium Term: 20 – 50 years
In the medium term a Hold the Line management policy continues. The SMP2 recommends investigations to assess sustainability of this policy and to investigate possible managed realignment options for the long term.

Figure 3-7: Happisburgh Indicative Erosion Zones from the Kelling to Lowestoft Ness SMP (2012) - SMP Policy 6 Management

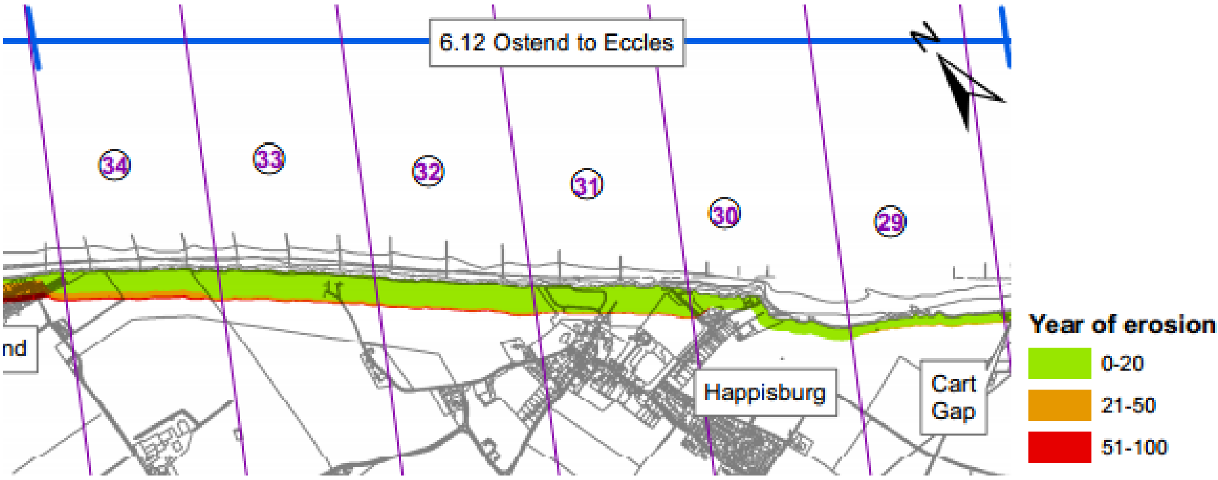

Figure 3-8: Happisburgh Indicative Erosion Zones from the Cromer to Winterton Ness Coastal Management Study - SMP Policy 6 Management

3.6.2 Other scenarios

In a No Active Intervention scenario, the defences are likely to remain in the short term and hold the coastline in position. Beaches will also be maintained naturally via sediment feed from the north. There is however a greater risk of defence failure along Cart Gap due to the retreat of cliffs to the north cutting behind the defence line. In the medium term, despite sediment feed from the north, the beach would be too far seaward in comparison to the eroding cliffs along Happisburgh, which would result in increased exposure and therefore sediment transport, rather than retention, through this area. As a result beach levels will lower and defences will breach.

4 Appraisal

4.1 Introduction

The following section provides an initial appraisal based upon the four criteria that will inform Norfolk Vanguard and Norfolk Boreas Limited's decision, as outlined in Section 1.2:

- Cliff erosion
- Beach erosion
- Coastal processes effects
- Existing and ongoing schemes

The resulting assessment for each criterion is summarised in a table, illustrated with a traffic light colour code. The table also includes an assessment and explanation of the level of confidence.

4.2 Cliff erosion

For this criterion the assessment is based on the most likely shoreline management approach as described in Section 3; the consequences of a different approach are provided for information only. The assessment is based on the upper estimate of erosion rate for the most likely management approach. The uncertainty provided concerns the likelihood that total erosion will be smaller. Cliff erosion is expressed as the horizontal landward movement of the cliff edge.

4.2.1 Bacton Green

It is expected that the Bacton to Walcott Sandscaping scheme will reduce the ongoing beach erosion at Bacton Green immediately after placement (expected in 2018), and there may even be local beach level increase. This would significantly reduce the chance of seawall failure. Assuming the minimum expected functional life of 20 years for the Sandscaping scheme, beach erosion is likely to resume after approximately 25 years, possibly initially at an accelerated rate. The beach levels would erode down to current levels by approximately year 35, and then the seawalls are likely to fail in 5 years (year 40), followed by accelerated cliff erosion. Based on this, the predicted total erosion up to 2065 is judged to be up to 25 metres, based on interpretation of the SMP6 erosion predictions for the situation with Sandscaping.

This would of course depend critically on the on-going management of the Bacton Terminal frontage: if a different scheme is implemented, then erosion is already likely to have started by year 20, and could be up to 100m by 2065.

Overall, it is likely that the transition pits on the landward side of the landfall site would have to be located at least 25 metres from the current cliff / defence line, if the Sandscaping scheme is implemented. If not, then a margin of at least 100m is required.

4.2.2 Walcott

A similar scenario as described for Bacton Green will be experienced at Walcott, although the likely positive impact of the Sandscaping scheme will be smaller and will not start until a few years after implementation, because the Walcott site is further down the sand transport pathway. Assuming the minimum expected functional life of 20 years for the Sandscaping scheme, it is expected that beach levels would erode down to current levels by year 30, and then the seawalls are likely to fail in 5 years (year 35), followed by accelerated cliff erosion. Based on this, the predicted total erosion up to 2065 is judged to be up to 35 metres, based on interpretation of the SMP6 erosion predictions for the situation with Sandscaping.

If a different Terminal Protection scheme is implemented, then erosion is already likely to have started by year 20, and could be up to 100m by 2065.

Overall, it is likely that the transition pits on the landward side of the landfall site would have to be located at least 35 metres from the current cliff line, if the Sandscaping scheme is implemented. If not, then a margin of at least 100m is required.

4.2.3 Happisburgh to Cart Gap

As presented in Section 3.5, a reasonably conservative estimate of future cliff erosion at Happisburgh is 25 metres by 2035 and 50 metres by 2065. This is based on the assumption that the 'bay' at Happisburgh has reached a dynamic equilibrium, which means it is controlled and relatively sheltered by the Happisburgh headland. It also assumes an increase of sediment supply from the northwest in the medium term, which would be the likely consequence of the intended management approach.

Along the Cart Gap frontage, the policy intent is to prevent cliff erosion at least for the short term; for the medium term (year 20 to 50) this may change if the frontage is under pressure. The frontage is currently defended by a concrete sea wall and timber groynes, the condition of the defences, in particular the concrete sea wall, is good and it is unlikely to fail in the short term. In addition, the inclusion of rock at the north western end of the wall reduces the risk of outflanking caused by cliff top erosion. If the cliffs continue to retreat the coastline will become more exposed and will become more prominent and at risk of erosion and outflanking of the sea wall. In conclusion, the expected cliff erosion here is 0, but after year 20 there is a chance that erosion will start, and this is then likely to catch up rapidly with the undefended frontage.

4.2.4 Resulting assessment

Site	Maximum cliff erosion [m], horizontal	Uncertainty
Bacton Green	25	Medium, but critically dependent on management to the north.
Walcott	35	Medium, but critically dependent on management to the north.
Happisburgh	50	High, due to dependence on processes and management elsewhere.

4.3 Beach erosion and variability

Expected beach level is important for determining depth, trajectory and exit point. General beach level variability over time is important as this determines geotechnical loading on the cable housing, which could influence design. Note that beach levels in the area all have a significant natural variation: on a seasonal / annual basis they vary in the order of 1-2m, and in addition there is short-term scour during storms in the same order of magnitude. Beach erosion is expressed as the vertical downward movement of the average beach surface level.

4.3.1 Bacton Green

The beach is currently gradually eroding, at an average rate of approximately 0.25m per year vertically, and without intervention this is expected to continue in the short term. The Bacton to Walcott Sandscaping scheme is expected to reduce the ongoing erosion, and could even initially cause level increase, possibly even through direct placement. Assuming the minimum expected functional life of 20 years for the Sandscaping scheme, beach erosion is likely to resume after approximately 25 years, possibly initially at an accelerated rate. The beach levels would erode down to current levels by approximately year 35, and then continue to erode down to approximately 2m below current levels, until seawall failure, expected around year 40. As the seawalls fail, this would lead to re-profiling of the beach and potentially slow further beach degradation.

The potential significant beach loss in the medium term could be a risk to a short HDD solution as the distance between mean low water spring and the defence line narrows and the depth of drilling may have to increase. Over the longer term, burial of the cable to a depth of 3m (based on existing beach levels), may mean that the cable would only be buried to a depth of 1m. Based on this minimum burial depth, the cable could become vulnerable to exposure under storm conditions, when temporary and localised scour occurs.

Overall, it is likely that beach lowering by up to 2m could occur at some point in the next 50 years.

The Sandscaping scheme will influence beach level variation if the scheme includes initial placement at Bacton Green. This would introduce a higher initial level, possibly up to 4m higher, followed by more rapid beach level erosion. Seasonal beach level variation is likely to be reduced in this scenario.

4.3.2 Walcott

A similar scenario as described above will be experienced at Walcott with beaches gradually eroding at an average rate of approximately 0.05m per year vertically. Without intervention the beaches are likely to be squeezed more strongly due to the presence of the sea wall. The Sandscaping scheme will have a positive impact, but this is smaller and will start 1-2 years later, because the Walcott site is further away. Beach erosion slowdown is expected, but beach level increase is unlikely. Assuming the minimum expected functional life of 20 years for the Sandscaping scheme, it is expected that beach levels would erode down to current levels by year 30, and then continue to erode down to approximately 2m below current levels, until seawall failure, expected around year 35.

As the seawalls fail, this would lead to re-profiling of the beach and potentially slow further beach degradation.

Overall, it is likely that beach lowering by up to 2m will occur at some point in the next 50 years.

The Sandscaping scheme will influence beach level variation if the scheme includes initial placement at Walcott. This would introduce a higher initial level, possibly up to 3m higher, followed by more rapid beach level erosion. Seasonal beach level variation is likely to be reduced in this scenario.

4.3.3 Happisburgh to Cart Gap

Sediment supply to Happisburgh will continue to be trapped by the groynes to the north and south of the landfall site. Despite this, in the long term it is expected that the beach along the retreating cliff face at the landfall site will generally be maintained as the cliff line is allowed to retreat, which will supply sediment to the beach. This, however, assumes a general set back of the whole beach profile. Monitoring results (see Section 2.5.3) illustrate this episodic erosional trend by the fluctuating but broadly stable beach volume in recent years. As the medium term management policies updrift change to Managed Realignment, possibly supported by sediment supply from the Sandscaping scheme, and the Happisburgh cliffs continue to erode (with management), the sediment supply is likely to improve from updrift and the beach along the landfall site is likely to remain healthy.

Although beaches will remain healthy, it is important to note that as the cliff line retreats the mean low water spring will also retreat. The potential erosion at any point down the beach profile will, therefore, depend on the retreat of the cliff line and the slope of the beach profile. Based on the typically existing beach profiles in the area, the vertical erosion at the line of the present cliff face could be up to 4m to 5m as the profile moves inland. Over the main mid-water level area of the existing beach vertical erosion could be between 2.5m to 3.5m. This assessment is conservative because actual vertical change is determined by the underlying platform, which is likely to be steeper but currently unknown.

Along the defended Cart Gap frontage, sediment supply from updrift and the eroding cliffs at Happisburgh will continue to be trapped by the groynes and beach profile analysis suggests that this would continue in the medium term at least. Despite this, future beach levels will be largely dependent upon the rate of cliff line retreat at Happisburgh. If the cliffs continue to retreat then it is likely that in the short term beach levels will continue to accrete or remain stable, however the coastline is very exposed and if the Happisburgh cliffs continue to erode then the coastline will become more prominent and sediment may no longer reach the defended frontage. Overall, beach erosion is likely to be smaller than on the undefended frontage.

It is known that there is significant vertical movement of the beach in this area, with potential lowering during storm events of up to 2m, particularly over the upper beach face. Over the longer term burial of the cable to a depth of 3m (based on existing beach levels), may mean that the cable would only be buried to a depth of 1m. Based on this minimum burial depth, the cable could become vulnerable to exposure under storm conditions.

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4.3.4 Resulting assessment

Site	Maximum beach erosion [m] vertical	Uncertainty	Beach level variability [m] vertical
Bacton Green	None in short term, up to 2m in medium term	Medium but critically dependent on management to the north.	2-3m natural seasonal Sandscaping may increase long term variation
Walcott	None in short term, up to 2m medium term	Medium but critically dependent on management to the north.	2-3m natural seasonal Sandscaping may increase long term variation
Happisburgh	2.5m to 3.5m	High, due to varying assessment of expected retreat rates.	2-3m natural seasonal

4.4 Influence of cable exit on coastal processes

Any temporary (construction phase) works associated with the HDD which may affect longshore (and cross-shore) sediment transport would need to be managed and impacts mitigated.

It is understood that the burial depth of the cable will be between 3 – 10 metres below sea bed level to protect the cable from wave action. It is expected that the exit of the HDD, whether short or long, would have a minimal impact on sediment transport. The short HDD exit is in a location where it could create localised scour, but this would have negligible impacts, smaller than the effects of existing groynes and pipelines in the area. If the cable requires protection (such as rock or a concrete mattress) then this could affect sediment transport.

Due to the limited expected consequences for coastal processes, this criterion is assessed to be non-distinctive for the selection of the landfall site.

Please note that the judgement-based assessment in this section is not intended to replace the formal assessment to be carried out as part of the Environmental Impact Assessment.

4.5 Influence of Coastal management schemes

4.5.1 Bacton Green

The current defences comprise of a timber revetment and groynes along with a concrete sea wall at the toe of the cliff. It is possible that there will be limited works to sustain these defences, as part of the SMP's Hold the Line policy for the short term, but any major structural works are unlikely. The HDD will have to avoid impacts on the coastal defences and there would be a need to drill beneath the existing coastal defences. Installation using the short HDD method could have an impact on defences and access to mean low water springs.

There is a possibility that the intended Sandscaping scheme could extend southward down to the Bacton Green site, possibly involving direct placement of sediment on the beach there. If this is the case, it would probably concern the south-easterly tail of the nourishment rather than its main body. If Bacton Green is taken forward, close collaboration with North Norfolk District Council and the Bacton Terminal Companies would allow any potential risks to be managed and maximise opportunity for collaboration.

4.5.2 Walcott

The current coastal defences comprise of timber groynes and a concrete sea wall. It is possible that there will be limited works to sustain these defences, as part of the SMP's Hold the Line policy for the short term, but any major structural works are unlikely. The HDD, whether short or long, would have to go beneath the existing defence and Walcott Road, thereby avoiding impacts to the coastal defences at Walcott.

The intended Sandscaping scheme is less likely to involve direct placement of sediment in this location, but there is a possibility. Possible direct and indirect effects are discussed under the previous criteria.

4.5.3 Happisburgh to Cart Gap

The cliff line along Happisburgh will continue to retreat under a Managed Realignment policy. This may involve minor works, but any major schemes are unlikely. Depending on the location, the HDD, whether short or long, would have to go beneath the existing defence, thereby avoiding impacts to the coastal defences at Happisburgh.

It is likely that any works along the Cart Gap frontage will also be minor, and without significant impacts on the landfall.

4.5.4 Resulting assessment

Site	Likely Impact [m]	Uncertainty
Bacton Green	Medium*	Low
Walcott	Low	Low
Happisburgh	Low	Low

*Note that the interaction with the Sandscaping scheme could also present opportunities

4.6 Summary of the appraisal

Site	Cliff Erosion	Beach Erosion	Impact on coastal Processes	Influence of Coastal Management Schemes
Bacton Green	25m	None in short term, up to 2m in medium term	Low	Medium - Note that the interaction with the Sandscaping scheme could also present opportunities
Walcott	35m	None in short term, up to 2m medium term	Low	Low
Happisburgh	50m	2.5m to 3.5m	Low	Low

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5 Conclusions and recommendations

The three potential landfall sites for the Norfolk Vanguard and Norfolk Boreas Offshore Wind Farms are located on the east Norfolk coastline, which has been eroding for a long time. Many coastal defences in the area constructed in the 20th century are reaching the end of their life. Broadly, the intent of management for the long term is to return to a more naturally functioning (and therefore eroding) coastline, but some areas are going through a gradual transition. Therefore coastal processes and management are key considerations in the selection of the landfall site.

The headline conclusion, purely from the perspective of coastal processes, is that the Bacton Green and Walcott sites are expected to experience less erosion, and there is a narrower uncertainty band, compared with the Happisburgh site.

Overall, if the Sandscaping scheme is implemented as intended, expected erosion at Bacton Green is very limited, and there could be opportunities for joint implementation (if risks of parallel schemes are managed properly). Expected erosion at Walcott is slightly greater, but still limited. For Happisburgh the expected erosion is again slightly greater, but this has a larger uncertainty band; for the defended section south of Happisburgh there is an intent to Hold the Line, at least for the short term.

If the Sandscaping scheme is implemented, beach level variability could be much greater at Bacton Green, and possibly to an extent also at Walcott Gap. Note that the beach level varies naturally throughout the year in the order of 2-3 metres.

For each site, there is significant uncertainty about future changes. For the Bacton Green and Walcott site, this uncertainty mainly concerns the intended Sandscaping scheme at Bacton Gas Terminal. This is very likely to be implemented, but if a different scheme is implemented, then the expected changes in the coming 50 years are much greater. For the Happisburgh site, the uncertainty concerns coastal processes in the undefended section, as this is a very dynamic location that strongly depends on developments in the neighbouring frontage to the north-west. The defended section south of Happisburgh is less uncertain.

A judgement-based assessment suggests that the location of the HDD, whether short or long, would have a minimal impact on sediment transport, which makes this criterion non-distinctive for the selection of the landfall site.

5.1 Recommendations

If either the Bacton Green and Walcott landfall options are programmed, then close liaison with the Bacton to Walcott scheme (NNDC, Bacton Terminal Companies) will be required to minimise risk and maximise opportunity.

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